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THIN FILM MAPPING OF ELECTRON ACCELERATORS

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Summary

A method for mapping electron accelerator beams employing a thin film dosimeter(TFD) is discussed. The preparation, handling, exposure and reading of the TFD is elaborated. Examples are given of areal maps and depth dose measurements. An instrument for reading the film is discussed.

Introduction

The locations, distribution, and intensity of accelerator beams are all parameters critical to proper experimental analysis. Many techniques such as Faraday cups, oscillating reeds, and witness plates have been used to determine these parameters. This paper reports on the application of a thin film dosimeter (TFD) which has proved to be useful in this regard.

The blue cellophane TFD 195 CMS Blue, manufactured by FMC Corp., has long been known to be a good dose measurement film.[1] When combined with the proper reading system, it can be an effective tool for accelerator beam mapping. All that the technique involves is placing a sheet of the blue cellophane in the region of the beam which is of interest. The film is then exposed for a sufficient duration to yield a dose in the megarad region. After this, the film is scanned with an optical densitometer to determine the change in percent light transmission. This immediately yields beam location and distribution data. In order to get absolute intensity data, the film must be calibrated. This can be done in terms of dose or current density.

The Blue Cellophane TFD

Physical and Chemical Characteristics

The blue cellophane TFD is a sandwich structure with a core of regenerated cellulose dyed with the sodium salt of dimethoxy diphenyl diago bis (8 amino, 1 napthol, 5, 7 disulfonic acid). The dye is administered while the cellulose is in a plasticized wet state. Once dyed, the sheet is coated with a nitrocellulose base lacquer. Moisture content runs about 6 - 7%.

The film is 0.01 in. $\pm$ 5% thick and has structural striations running through the cellophane core. These structural non uniformities can affect optical density readings, thus it is generally advisable to make readings in which scans run along the striations. This tends to make readings more reproducible.

The fact that the film is very thin and pliable facilitates its use. It is very easy to place in constricted areas such as beam transport tubes or small scattering chambers.

The radiation chemistry which takes place when the film is bleached is not well understood. The hypothesis is that the radiation produces radicals via ionizing interactions with the cellophane. These radicals, along with intermediate radical states, then chemically react with the dye producing the bleaching effect. Obviously this process is sensitive to both the radiation and chemical environment in which the TFD is placed.

Calibrating Blue Cellophane TFD's

In order to calibrate the TFD it is generally desirable to expose it to some uniform well characterized radiation source. Often this can be a well understood accelerator beam configuration. By simultaneously exposing the TFD and reading some standard diagnostic such as an ionization chamber, calorimeter, or Faraday cup--it is possible to directly calibrate the film in terms of dose or current density. Spacial variations in the beam will be easily detected in the film read out. These can be averaged out over the area subtended by the standard diagnostic instrument and then correlated with the signal from this instrument.

Figure 1 shows a typical calibration (upper curve) done with a linac. Note that the curve is fairly linear but that it does show one distinctly non linear region. This so called "hockey stick" shape is quite characteristic of many chemical dosimeters. (It is attributed to a depletion of radical chemical constituents.) This calibration was made at a dose rate in the range of about 10^5 rads/sec. At higher dose rates, the calibration curve will tend to fall below this one. (This is thought to be the effect of radical radical interactions.) The lower curve was obtained with a pulsed electron beam machine where the dose rate was as high as 10^{15} rads/sec. Note that over 10 orders of magnitude in dose rate the change in calibration is not very significant. There are some other effects such as those due to temperature and humidity which can cause slight changes in calibration[2] but these are minor and need not be assessed except for cases where high accuracy absolute value dosimetry is desired. As long as the experimental environment is reasonably close to the calibration environment, readings should be accurate to about 10 or 15%

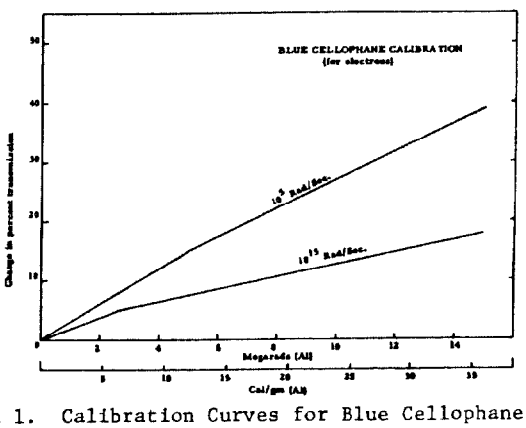

Figure 1. Calibration Curves for Blue Cellophane TFD

Reading the TFD

In order to read the change in dye density with any degree of precision, a rather sensitive instrument is required. In the past, most researchers have used optical densitometers, but we have developed an instrument whose precision and ease of use we feel is a significant improvement over what has been possible before. The monochromatic light source for this instrument is a He-Ne laser with a characteristic wave length of 6328 Å. The maximum optical density for the blue cellophane dye occurs at about this wave length. Thus the laser is well matched to the TFD for the purpose of measuring change in optical transmission.

A schematic of the TFD reader system is shown in Figure 2.

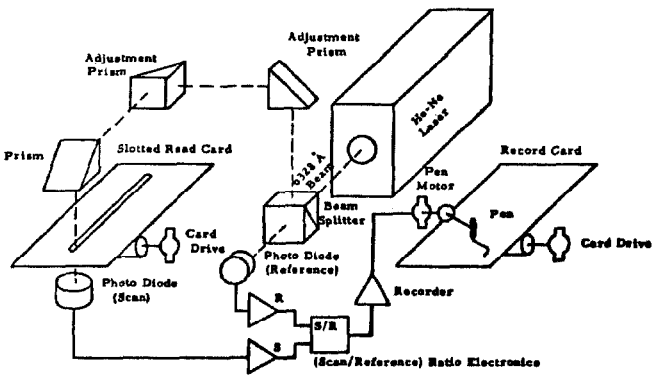

Figure 2. Schematic of the TFD Reader

The beam from the laser is split by a beam splitter with the transmitted portion directed to a reference photo diode. The other half of the beam is directed through an optical system of three prisms and then through a piece of TFD which is mounted on a slotted 5" x 8" index card. These index cards are punched so that they may be traversed through the beam by a toothed roller driven by an electric motor. Thus precise rectilinear scans can be made. The beam continues through the TFD and strikes another photo diode. These photo diodes were chosen for their high response to the laser beam wave length.

The current signals from the photo diodes go through amplifying circuits to an electronic comparator circuit where their ratio is generated. The ratio signal goes to a recorder module similar to the one which traverses the TFD through the laser beam. Here a pen records the ratio signal on an index card ruled with a zero to 100 range. The system is calibrated to show 100% transmission with the pen at full scale and 0% transmission on 0 scale. There is an offset feature which allows one to offset the unexposed transmission value. Thus by knowing the transmission of unexposed blue cellophane (approximately 15%) one can offset this value and read the change in percent transmission directly. One need merely consult a calibration curve to determine dose once the change in percent light transmission has been determined.

Figure 3 shows the actual TFD system.

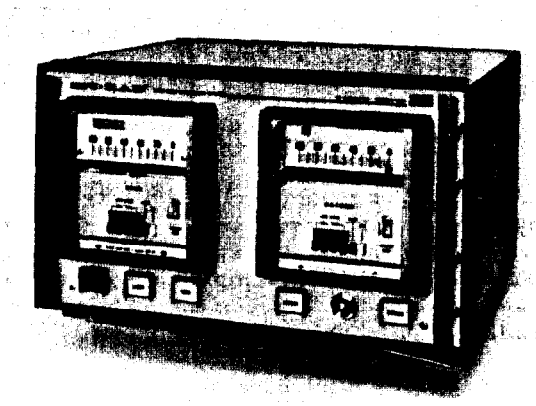

Figure 3. The Thin Film Dosimeter System

For convenience it has been made possible to expand or compress the scan read outs. This feature coupled with focusing lenses in the laser beam make it possible to determine dose values in regions a fraction of a millimeter square. In addition the gain of the system may be adjusted over more than two orders of magnitude. This makes ir possible to read doses down in the hundreds of kilorads range. (It should also be noted that there are other TFD's which have different ranges of sensitivity some of which also have their optical attenuation maximum near 6328 Å.)

The card system for mounting the TFD and reading out the data also provides a convenient key-hole index system for filing and retrieving data. This is an important feature as it amplifies the value of the nondestructive readout nature of the TFD.

Beam Mapping

The procedure for making a spacial map with the TFD is quite simple. A piece of TFD of sufficient area is selected using a visual check to insure that there are no marked defects in the film. If a very low dose is to be measured, it is often advisable to pre-scan the film as the variation in the unexposed film is $\pm$ 0.5% transmission which corresponds to about 100 kilorads. With prescanning this can be reduced to about $\pm$ 0.2% transmission.

Care should be taken in handling the film in order to avoid fingerprints, creases, scratches, dirt, and other alterations to the light attenuation of the film. It is often convenient to cut the film sample with one edge parallel to the striations in the cellophane and another orthogonal to these. This makes it easy to scan along the striations at adjacent points on the cellophane.

The TFD can be taped in place for exposure to the electron beam if one is careful not to place tape over areas which will be of interest in the readout. It is sometimes possible to remove tape and still read the film under it, but this is not a recommended practice. The film should be keyed to its orientation in the chamber for later reference. This can be done with notches or other marks in the film or by writing on the tape used to mount the film.

As a general rule of thumb an exposure of a second to a beam of a few micro amps/cm^2 of MeV type electrons should produce about 1 megarad of dose in the TFD. Below and above the few MeV range, the stopping power of the film is higher and adjustments in exposure should be made accordingly. The film is about 3.5 mgm/cm^2 thick and thus begins to appear thick to electrons of energy below a few hundred KeV. Below this energy one must consider the depth dose profile in the film when trying to assess the beam intensity.

Figure 4 shows a single scan through the Air Force Cambridge Research Laboratory linac beam. Figure 5 is an isodose contour map of this beam showing single point data from several scans. Figures 6 and 7 are photos of three dimensional displays made from cut outs of single scans of beam intensity over the full area of the beams. Figure 6 is from the Rensallaer Polytechnic Institute 60 MeV linac beam while Figure 7 is a special high intensity "doughnut" beam at the Naval Research Laboratory. The fact that such beam visualizations can be acquired quickly and accurately, makes beam shaping a much simpler chore.

Depth Dose Measurements

Figure 8 shows another important use of TFD's in electron beam diagnostics. This is a plot of dose versus depth in a stack of attenuators. By stacking the blue cellophane TFD's between layers of material such as aluminum, one can measure the dose distribution into the material. The extrapolated range of the electrons can thus be obtained and compared with other beam energy diagnostics. This technique can also be used in situations such as post attenuator beam energy degradation measurements.

References

1. Henley, E. J., Richman, D., Analytical Chemistry 28, 1580 (1956).
2. Oswald, R. B. Jr., Eisen, H. A., and Conrad, E. E., Transactions of IEEE Conference on Nuclear and Space Radiation Effects, July 18-22, 1966.

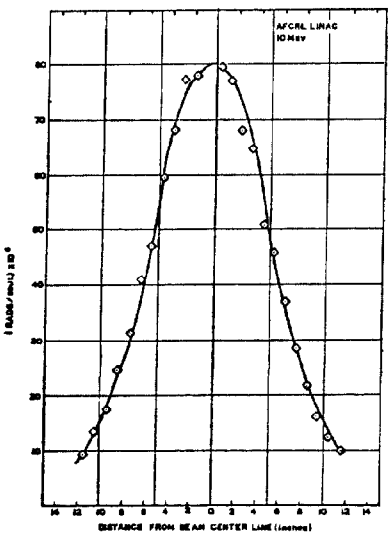

Figure 4. Beam Map of AFCRL Linac

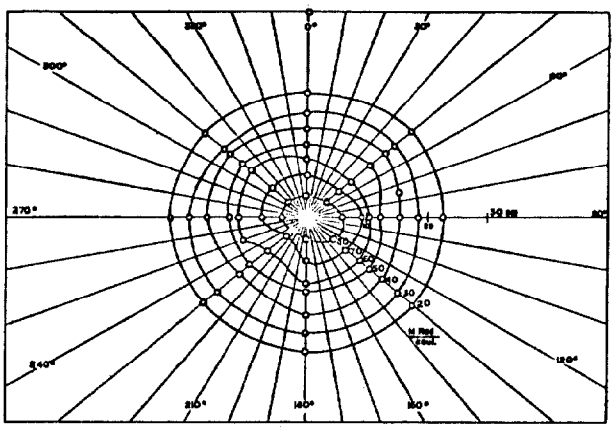

Figure 5. Isodose Contour of AFCRL Linac Beam

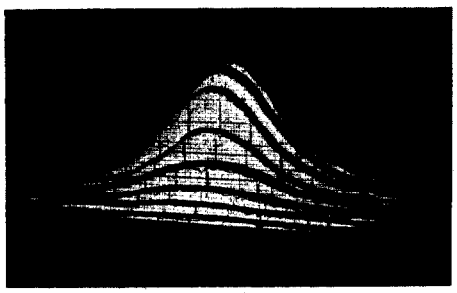

Figure 6. 3-D Cutout Display of RPI Linac Beam

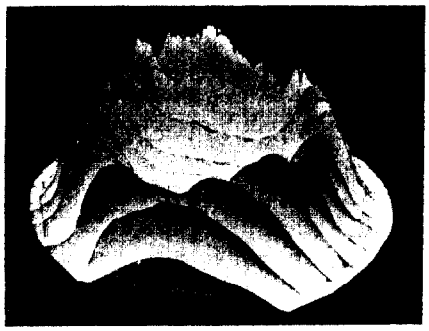

Figure 7. Experimental Doughnut Electron Beam at NRL

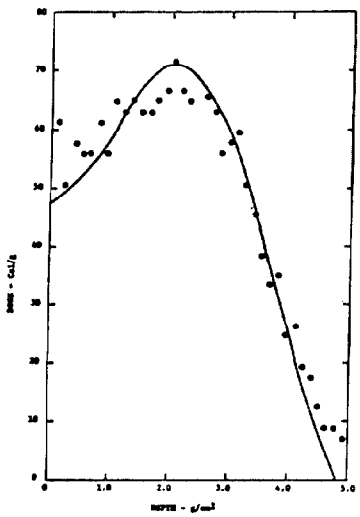

Figure 8. AFCRL Depth Dose and Transport Calculation