ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-MOPA70

FILM DOSIMETRY CHARACTERIZATION OF THE RESEARCH LINAC AT THE UNIVERSITY OF MARYLAND

A.S. Johnson,† L.T. Gilde, M.K. Hottinger, T.W. Koeth
University of Maryland, College Park, MD, USA

Abstract

A heavily modified Varian linac was installed as part of the University of Maryland Radiation Facilities in the early 1980s. The electron linac was initially used for materials testing and pulse radiolysis. Overtime, diagnostics such as spectrometer magnets and scintillator screens have been removed, limiting the ability to describe the electron beam. The beamline is currently configured with a thin titanium window to allow the electrons to escape the vacuum region and interact with samples in air. A calibrated film dosimetry system was used to characterize the transverse beam dimensions and uniformity in air. The results of these experimental measurements will be described in this paper.

INTRODUCTION

The University of Maryland Radiation Facilities consists of a 250 kW TRIGA research reactor, a panoramic Co-60 irradiator, and an electron linac. The electron linac is a modified Varian V7715 installed at the facility in the 1980s [1]. The linac is separated into 2 shielded vaults. The accelerating vault contains the thermionic electron source, RF system, and the accelerating structure within one vault as shown in Fig. 1. After being accelerated, the beam travels through an evacuated beamline equipped with focusing and steering magnets into the other vault. There, it passes through a thin titanium window into the air; samples may be placed in this beam for irradiation experiments. The linac produces a polyenergetic beam with a fixed pulse width of 3µs, and a pulse rate variable between 10 and 200 pulses per second. The peak beam current during each pulse is approximately 100 mA. Currently, the UMD linac is configured with minimal diagnostic capabilities, therefore, a campaign of external beam measurements was undertaken to better understand the beam characteristics.

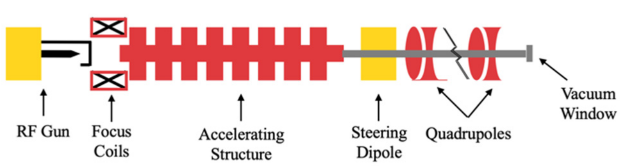

Figure 1: UMD Linac system diagram.

EXPERIMENTAL SETUP

A radiochromic film system from Far West Technology, Inc was obtained as a balance between cost and ease of use [2]. FWT-60 Radiochromic Film Dosimeters with a dose range of 0.5-200 kGy were used for all of the measurements [3]. Film dosimeters were either 1 x 1 cm sheets for routine dosimetry or 15 x 15 cm sheets for larger beam images. All 1 x 1 cm samples were read out with a FWT-92D Radiochromic Film Reader in a temperature and humidity controlled room, while larger sheets were processed on an Epson Perfection V600 flatbed scanner [4]. UV filters are used on the light fixtures in the film processing room in order to prevent discoloration of the films from UV exposure. While being handled or irradiated outside of the film processing room UV proof bags were used to protect the film.

Film Calibration

Prior to use in the electron beam, the film was calibrated using the University of Maryland Co-60 Irradiator and a calibrated ion chamber. The Co-60 source is a large, panoramic source of gamma radiation with a highly uniform dose region that is ideal for calibrating films. For the initial low dose runs, a calibrated Exradin A19 ion chamber from Standard Imaging was placed in the same location as 5 films, and the dose rate was read with a Standard Imaging SuperMAX Electrometer. By increasing the irradiation time, and extrapolating based on dose rate measured by the ion chamber, it was possible to expose the films to doses ranging from 0-200 kGy. Figure 2 shows the color change resulting from these exposures.

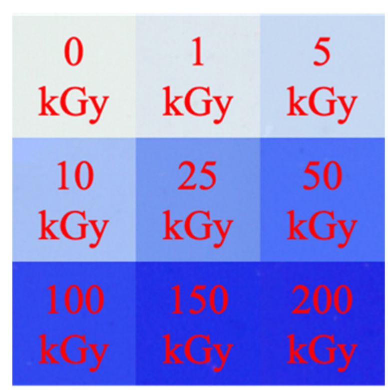

Figure 2: Representative color change of FWT-60 radiochromic films following irradiation to various doses.

Following the irradiations, the films were left to cure for 24 hours before the change in optical density (OD) was measured using either the FWT-92D Radiochromic Film Reader or the Epson Perfection V600. A calibration curve was developed by measuring the OD vs. recorded dose [5].

† ajohns37@umd.edu

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-MOPA70

The relationship between dose and optical density was determined to be:

$$D = [61.45(A_f - A_0)]^{1.256} \quad (1)$$

D is dose in kGy
A_f is the optical density post-irradiation
A_0 is the optical density pre-irradiation

Transverse Profile Measurements

Films were placed at 5 cm intervals along a 120 cm long strip of polypropylene to obtain transverse profile information. The strip was then oriented either horizontally or vertically at 20 cm, 63 cm, 100 cm distances from the vacuum window. The film was then exposed to 10,000 pulses. In addition to the strips of film, large sheets of films were used to capture the entire beam spot. The sheets were placed in UV protective bags and centered around the vacuum window at distances of 0 cm, 5 cm, 10 cm, 15 cm, and 20 cm. The film was then exposed to 5,000 pulses.

Beam Energy Measurements

The energy of the linac beam was determined by measuring the dose vs. depth relationship of the beam interacting with an absorber; the dose vs. depth curve can then be used to determine the effective electron energy of a polyenergetic beam. The absorber was made from 7.5 x 7.5 cm sheets of 0.16 cm thick polypropylene with 4 films attached to the center of each to measure the dose. 24 sheets were stacked to make up a total thickness of 3.8 cm based upon an expected 5 MeV beam energy as shown in Fig. 3 [6]. The assembled block was then placed in a UV-proof bag to prevent film darkening. The entire package was then placed 63 cm from the vacuum window and exposed to 20,000 pulses.

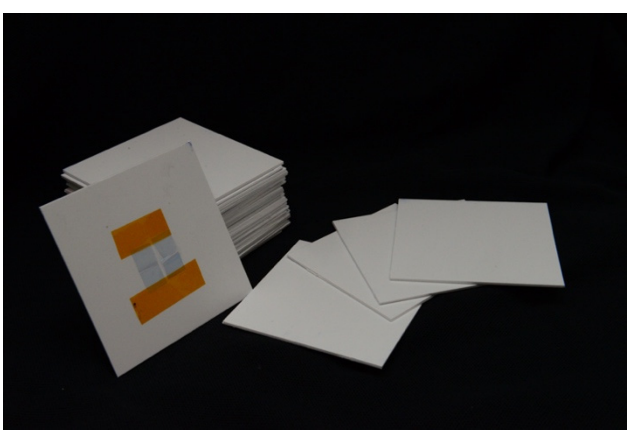

Figure 3: Polypropylene sheets and radiochromic films used for generating the depth-dose curve.

RESULTS

Transverse Beam

The results of both the large film sheets and strips of dosimeters are shown in Fig. 4. The transverse size shows the expected growth in both horizontal and vertical dimensions, with the average sigma at 10 cm from the window being 1.0 cm. The beam sigma then grows to about 7.6 cm 100 cm from the vacuum window. These measurements confirm a circular gaussian beam is produced. Fig. 5 shows the uniformity of the spot at a distance of 10 cm from the vacuum window. Projections and Gaussians fits are shown along the borders. This data is useful to determine sample coverage as a function of distance from the window.

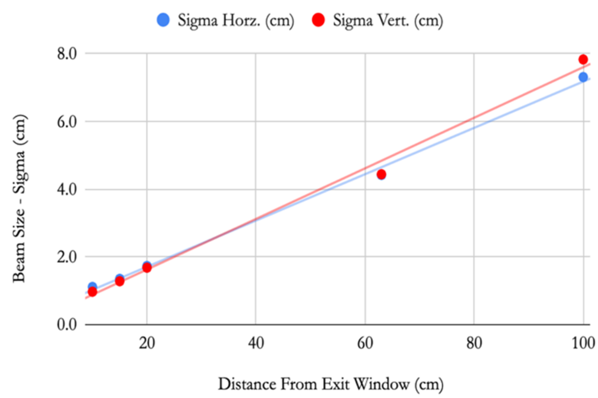

Figure 4: Measured beam spot size as a function of distance from the vacuum window.

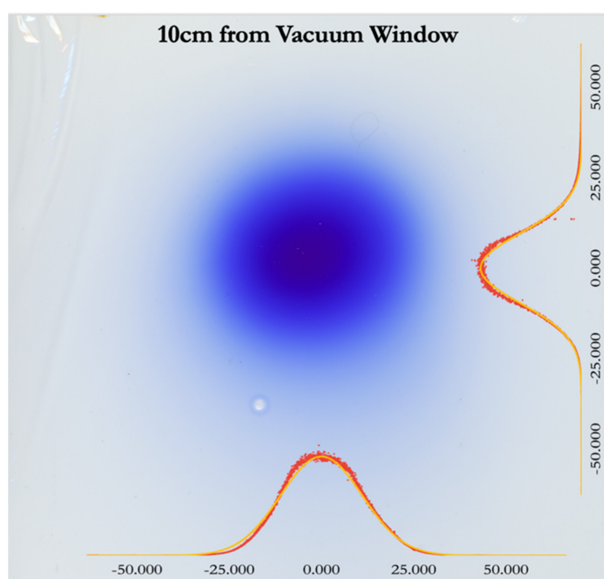

Figure 5: A scan of a 15 x 15 cm radiochromic film with an overlaid dose profiles (scales are in mm).

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-MOPA70

Beam Energy

The dose vs. depth curve had the expected profile, with the beam penetrating through approximately 3.2 cm (3.4 g/cm^2) of polypropylene. Analysis of the curve (Fig. 6) yields an optimum thickness of 2.3 g/cm^2, a half value depth of 2.7 g/cm^2, a half-entrance depth of 2.8 g/cm^2, and a practical electron range of 3.3 g/cm^2. Optimum thickness is the depth at which the absorbed dose equals its value at the entrance surface of the material, half value depth is the depth at which the absorbed dose has decreased to 50 % of its maximum value, half-entrance depth is the depth at which the dose has decreased to 50% of what it is at the front face, and the practical electron range is the point at which the extrapolated linear portion of the curve intersects with the x-ray background.

Utilizing the method described in ISO/ASTM 51649:2015(E) to convert these data points into energies yields an effective beam energy of 6.2±0.2 MeV.

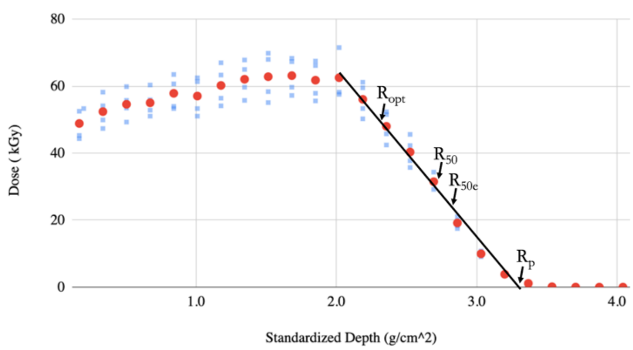

Figure 6: The measured dose vs. depth curve in polypropylene with the various parameters used for determining beam energy called out.

This measurement was roughly confirmed with the NIST ESTAR database; a 6 MeV electron has a range of 2.95 g/cm^2 in polypropylene and a 7 MeV electron has a range of 3.43 g/cm^2 [7]. As the UMD linac beam appears to have a range of 3.3 g/cm^2, its energy should be between 6 and 7 MeV. This plot indicates the presence of a beam with a large energy spread [8]. A limitation of the film is that it does not distinguish between the various energy components of the beam.

CONCLUSION

Measurements with radiochromic films have successfully been used to measure characteristics of the UMD linac beam in air. The results showed that the beam is uniformly distributed with no major hotspots, and the beam energy has been determined with greater accuracy than was previously possible. Table 1 lists the beam parameters of the UMD linac including the measurements made in this study.

Table 1: UMD Linac Parameters

Peak Energy	6.2 MeV
Pulse Width	3 µs
Peak Beam Current	100 mA
Rep Rate	10-200 PPS
Average Beam Current	60 µA (max)
Beam Power	370 W
Spot Size	10.4 cm (FWHM @ 63 cm)
Dose per Pulse	2 Gy
Frequency	2.99 MHz

REFERENCES

[1] V. Adams and W. Chappas, “Electron Omni-directional Irradiator System for Space Package Testing”, in *Proc. 19th Space Simulation Conf. – Cost Effective Testing for the 21st Century,* Baltimore, MD, USA, Oct. 1996, pp. 421-428.

[2] P. Casolaro, “Radiochromic Films for the Two-Dimensional Dose Distribution Assessment,” *Applied Sciences*, vol. 11, no. 5, p. 2132, Feb. 2021. doi:10.3390/app11052132

[3] Far West Technology, Inc., FWT-60 Series Radiachromic Dosimeters, https://www.fwt.com/racm/fwt60ds.htm

[4] H. Alnawaf, P. K. N. Yu, and M. Butson, “Comparison of epson scanner quality for Radiochromic Film Evaluation,” *J. Appl. Clin. Med. Phys*., vol. 13, no. 5, pp. 314–321, 2012. https://doi.org/10.1120/jacmp.v13i5.3957

[5] Far West Technology, Using Radiachromic Dosimeters, https://www.fwt.com/racm/support/PAL1.PDF

[6] ISO/ASTM Standard 51649, 2015, “Standard Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 300 keV and 25 MeV,” ASTM International, 2015

[7] National Institute of Standards and Technology, Physical Meas. Laboratory, ESTAR, https://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

[8] Z. P. Zagorski, “Dependence of depth-dose curves on the energy spectrum of 5 to 13 MeV electron beams, *Radiat. Phys. Chem.*, vol. 22, nos. 3-5, pp 409–418, 1983. https://doi.org/10.1016/0146-5724(83)90046-8