

Validity of the Analysis of Radiochromic Film Using Matlab Code

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Introduction

Radiochromic film is typically used in experiments as a diagnostic to determine the energies of protons leaving the target during laser-target interactions. Upon interaction of the laser, the electrons within the target are accelerated. This creates a strong electric field which pulls the protons through the target with a broad range of energies. This mechanism is known as target normal sheath acceleration (TNSA) ^[1].

As a proton progresses through matter, it interacts with orbital electrons within atoms via transfer of energy. As the proton loses energy, it slows and the ionization increases to a maximum (known as a Bragg peak). At this point the proton picks up electrons and becomes neutral, losing its ability to ionise further material ^[2]. The RCF is built into a stack with enough material to completely stop the highest energy protons from passing through without become neutral.

RCF is composed of an active layer which reacts when ionising radiation loses energy while travelling through it. The ionisation of the active layer causes a change in colour relative to the dosage received. The active layer is added to polyester in different variations based on the type of RCF. The first, HDV2 is composed of an 8 micron active layer followed by a 97 micron layer of polyester and features a dynamic dose range of 10 to 1000Gy. The second is EBT3, which is composed of a 30 micron active layer between two pieces of 125 micron polyester. EBT3 is much more sensitive, with a dynamic range between 1cGy to 40Gy.

Two pieces of Matlab code, accompanied by graphical user interfaces (GUI's) have been written to analyse the energy deposited in the RCF layers by proton beams during laser-target interactions within the Vulcan facility. The first GUI uses a single type of RCF exposed to different known dosages to create a calibration file. The calibration file created will vary depending on the type of

scanner used to digitalise the RCF. The user is prompted to load scanned images into the interface, select the exposed part of the layer and enter the known dosage. This input data is converted to a plot of pixel value against $\log_{10}(\text{dose})$ saved to a file to be read by the previously written second GUI. The second code inputs an experimental stack of RCF and compares against the calibration file to create two plots. The first is total energy deposited within the active layer against active layer number. The second uses a previously generated response curve, an energy spectra of protons, to create a plot of Protons per MeV against initial proton Energy.

The aim of this report is to test the validity of the code; the proton energy and spectra curves compared to calculated values.

Method

The types of RCF were exposed to a range of dosages at the Birmingham cyclotron ⁽²⁾ in July 2014. Several stack designs were exposed to both single proton energies ($29 \pm 0.58 \text{ MeV}$) and through a modulation wheel (MW) ^[3] designed to expose the stack to a discrete energies of protons over a range of several MeV. This system is designed to widen the Bragg peak for applications in proton therapy and provides a potential opportunity to test the codes ability and limits in calculating proton spectra.

Six RCF stacks with different designs exposed to different dosages were provided. They will be referred to as stacks C, D, E, F, G and H as stacks A and B are exposed to various dosages and A used to create calibration files. The designs are created with aluminium filters to slow the protons and have attempted to catch the Bragg peak within an active layer of the RCF. Stacks A and B contained each type of RCF and each layer exposed to a different discrete dosage of proton. Stacks C – H are built to different specifications and exposed to

different dosages of protons. Table 1 contains the information on the dosages and initial proton energies.

Label	RCF type	Initial Proton Energy (MeV)	Dosage (Gy)
C	HDV2	29	500.69
D	HDV2	29	500.55
E	HDV2	28.2	500.55
F	EBT3	29	30.02
G	EBT3	29 – 21 (MW)	30.05
H	HDV2	28.2 – 18.5 (MW)	501.43

Table 1 - table displaying the differences between stacks C to H. Stacks G and H contain a range of initial proton energies due to use of the modulation wheel. Each stack contained 22 layers of RCF labelled 1 to 22.

To determine the accuracy of the code, the energy deposited within each layer was calculated using the Stopping Range of Ions in Matter (SRIM) software. Stacks C - F were run with a single energy to simulate the single energy exposed stacks and stacks G and H with a variety of energies to simulate the effect of the modulation wheel. SRIM software creates an energy loss against target depth plot which allows the energy deposited in each RCF active layer to be calculated.

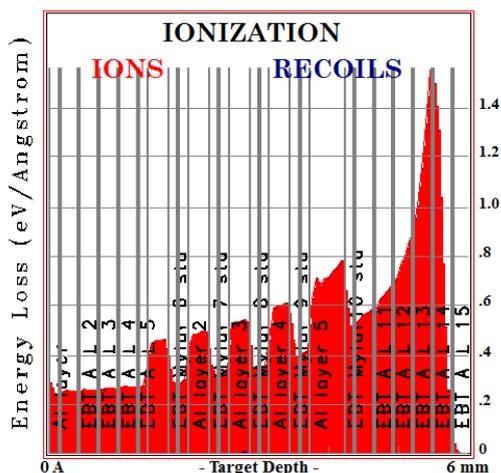


Figure 1 - example of SRIM output. Energy loss (eV/Angstrom) against target depth (mm). The energy loss within the aluminium layers is greater due to the increased density and hence increased ionisation rate. The stack is designed such that the Bragg peak contains an active layer of RCF.

Results and Discussion

The following figures show the total energy deposited by the proton beams within the layers of RCF for both the monoenergetic and polyenergetic beams.

The deposited energy shown in figures 2 and 3 show the curve's shape matches well for the HDV2 monoenergetic stacks although the values do not match up. The Bragg peaks fall relatively close to the calculated value and any deviation can be explained by the 1-2% error in the beam energy quoted at the Birmingham cyclotron which is discussed later in the text. The energy deposited values output by the Matlab analysis software tend to be slightly overstated by approximately a factor of 2. Figure 3 shows that the calculated energy deposited in the Bragg peak for the EBT3 stack is far greater than the value given by the Matlab code. This may be due to a poorly generated calibration file from inaccurate selections of the exposed area, the codes inability to analyse certain conditions, saturation of the EBT3 within the film itself, or by the scanning process as the scanner is unable to discriminate between small colour changes in the film.

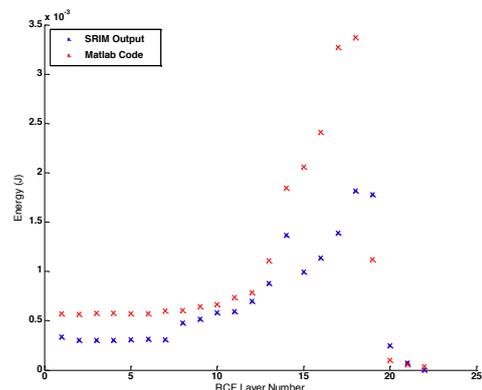


Figure 2 - Total energy deposited (J) against RCF active layer number for HDV2 (Stack E). The red displays the data output by the Matlab code and the blue displays the data output from SRIM. The initial proton energy is 28.2MeV.

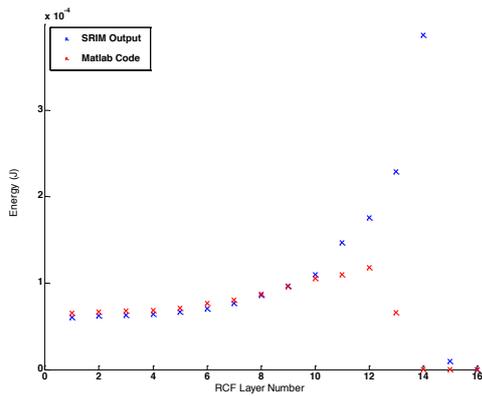


Figure 3 - Total energy deposited (J) against RCF active layer number for EBT3 (Stack F). The red displays the data output by the Matlab code and the blue displays the data output from SRIM. The initial proton energy is 29MeV.

The manually calculated data in SRIM often contains a small peak before the Bragg peak. The spike in the summed data around layer 10 in the stack G and layer 12 in F are due to the increased rate of ionisation from the aluminium layer being counted in the active layer due to the low resolution read outs. As standard, SRIM prints the read out file with 100 steps. For example, for a stack of 6mm width, the first energy loss read out will be at 0 microns, and the next at 60 microns. This complication means that to find the energy loss at either side of the active layer, the points have to be interpolated; for flat parts of the Bragg curve this causes little problem. For parts of the curve with a steep gradient, this causes a large error in the measurement. One such point is at the boundary between aluminium and an active layer, where the density drops from 2.702g/cm³ to 1.08g/cm³ and the ionisation drops significantly. This effect can give the impression that the rate of loss within the active layer is much higher than the real value when interpolating across this boundary. Figure 4 illustrates the problem.

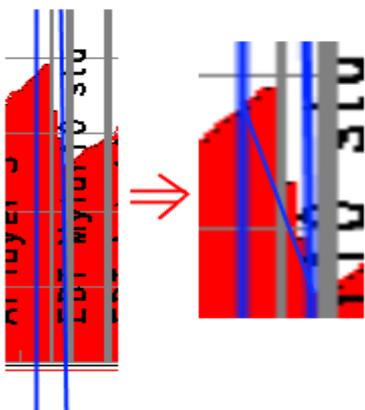


Figure 4 - Zoom from figure 1. The blue lines represent the points at which the read outs are taken. The grey lines represent the boundaries between the active layers in the stack and the red indicates the energy loss in eV/Angstrom. The image on the right displays the linear

line in blue used to interpolate where the active layer is positioned.

The following curve displays the proton spectra for the polyenergetic beam G. The monoenergetic beams do not contain multiple proton energies and therefore the program cannot output spectra. The input energies through the modulation wheel are calculated and plotted along with the experimental results output by Matlab.

The second major source of error within these simulations is the stated proton energy by the Birmingham cyclotron. For the monoenergetic stacks, the proton energy is stated as 29±0.58MeV. Most of the monoenergetic stacks were run through SRIM at 29MeV as the Bragg peaks fitted the data well. Stack E, however, was run at 28.2MeV to attempt to fit the Bragg peak to the RCF stack; this is outside the stated error of 1-2%.

The third source of error in the calculated data from SRIM comes from the calculations converting dose and mass into energy using the following equation:

$$D_A = \frac{E}{m} \quad (1)$$

Where D_A is absorbed dose in Grays, E is deposited energy in Joules and m is mass in kg. The mass was approximated by assuming a 1cm diameter circle of exposed material and the area of the circle was multiplied by the thickness to give the volume. The density of the material was used to calculate the mass of each exposed area, and this value was multiplied by the dosage to give the total energy deposited. The error is greatest at the last layer exposed as it is impossible to determine how deep the ionising protons penetrated and hence the mass of exposed material.

The greatest problem seen within many of the energy against layer graphs is the overstatement of energy output by the Matlab analysis software which occurs most prominently in the stacks built with HDV2; EBT3 appears to fit better. The energies within the HDV2 stacks output are around a factor of two greater than those calculated from SRIM. The initial layers of stack F are worth noting as the fit is nearly perfect although the energy deposited in the Bragg peak calculated by SRIM is far greater than the values output by Matlab. This may be due to the pixel values within the Bragg peak falling outside of the valid range included in the calibration file or a contribution between errors in the input energy which causes the Bragg peak to fall between active layers. This effect would cause only the start and finish of the Bragg peak to be recorded.

Figure 5 demonstrates the inability of the analyse software to generate a proton spectra due to the modulation wheel. The wheel allows a range of discrete energies and aims to create an elongated Bragg peak to span a few MeV (this effect is shown in red). The

analysis code is written to predict an exponential fall off of protons per MeV.

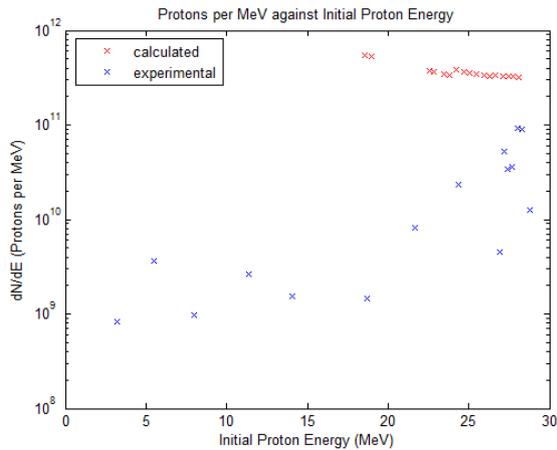


Figure 5 - Protons per MeV against Initial Proton Energy in MeV for stack G. The stack had the modulator wheel (MW) in place so provided a range of stack energies. The SRIM values are in red and the Matlab values are in blue.

Conclusion

A Matlab GUI has been created to create a calibration for a pre-existing Matlab analysis program. Using the Birmingham cyclotron, Radiochromic film was exposed to known dosages of protons to collect data to test the calibration creation program. Several stacks were exposed, including monoenergetic stacks and polyenergetic stacks created using a modulation wheel.

The calibration files were created using the GUI, and the files used in the Matlab analysis program to determine the energy deposited in each RCF active layer of the monoenergetic stacks as well as calculating the proton spectra for the polyenergetic stacks. The resulting figures were compared to theoretical data created using the Stopping Ranges of Ions in Matter (SRIM) software.

It was found that the energy deposited graphs for the monoenergetic stacks as output by the Matlab code overstated the energy by approximately a factor of two. Furthermore, it was found that the positions of the Bragg peaks only matched when the proton energy input in SRIM was outside of the error stated by the Birmingham cyclotron.

The modulation wheel did not provide a fair assessment of the codes ability to generate a proton spectra as the calibration tests did not fit the assumptions made by the code.

References

1. Wilks S C et al; Energetic proton generation in ultra-intense laser–solid interactions, *Phys. Plasmas* **8** 542 (2001)
2. Jerrold T et al; The essential physics of Medical Imaging. Chapter 3: Interaction of Radiation with Matter, Lippincott Williams and Wilkins; 2nd Revised edition (Nov. 2000)
3. Ezzawam W; Design of a Range Modulation System for Low Energy Proton and Ion Beams, University of Birmingham (Oct. 2010)

