Investigating the Response of Gafchromic EBT-3 Film to High LET Radiation

K. Polin[1], D. Doria[1], C. Scullion[1], G. Candiano[2], G.A.P Cirrone[2], R. Manna[2], G. Milluzzo[2], G. Petringa[2], F. Romano[2], V. Scuderi[2], M.Borghesi[1]

[1] *Centre for Plasma Physics, Queen's University Belfast, Belfast, United Kingdom*

[2] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud, Catania, Italy*

Effective radiotherapy for cancer treatment is based on the ability to accurately bombard tumours with ionizing radiation without damaging the surrounding healthy tissue. To achieve the overall goal of cancer treatment using laser-accelerated ionising particles rather than traditional X-ray radiotherapy, it is crucially important that the spread of this radiation is to be carefully monitored. In this sense, accurate dosimetry is key in achieving a full understanding of the ionising beams in use, the effect that ionisations cause on their intended target, and indeed the effect caused on the surrounding area. As such, this report documents an experiment carried out in the LNS-INFN facility in Catania, using particle beams accelerated by a superconducting cyclotron, to aid the understanding of dosimetry method which has not been fully explored in terms of use with particle beams; Gafchromic EBT3 films.

Gafchromic EBT films are a self-developing radiochromic film (RCF) which offer sensitivity in the 0.1 Gy - 12 Gy dose range, and a sub-mm spatial resolution. The active layer within the film causes a visible darkening in response to incoming ionising radiation, where a greater darkening response corresponds to a larger energy deposited within the film. A customised version of EBT-3 was used within this experiment whereby the conventional protective layer was removed from the top surface of the film so as to ensure that any energy deposition by the particle beam upon the air-film barrier was accurately recorded.

The response of Gafchromic EBT is well understood for photon experiments, and as such, EBT films are commonly used in X-ray dosimetry experiments. However, an under-response in the films' optical density arises when RCF is used for beams of ionising particles in comparison with that of photons.[1] [2] This was investigated by *Reinhardt et al, 2012* in the case of low energy proton and carbon ion beams, as seen in Fig. 4. In this case, there is an underestimation of dose in the region of the Bragg Peak. As this under-response does not occur for high energy protons (of >10 MeV), and therefore the response of the film to both protons or high energy protons are indistinguishable, it can be hypothesised that this difference is due to the different Linear Energy Transfer (LET) values of the incoming particles.

LET is a measurement of a particle's energy deposition per unit length as it traverses through a medium; the higher the value of LET, the more energy is attenuated into the surrounding material.

$$LET = (dE_\Delta/dl) \qquad (1)$$

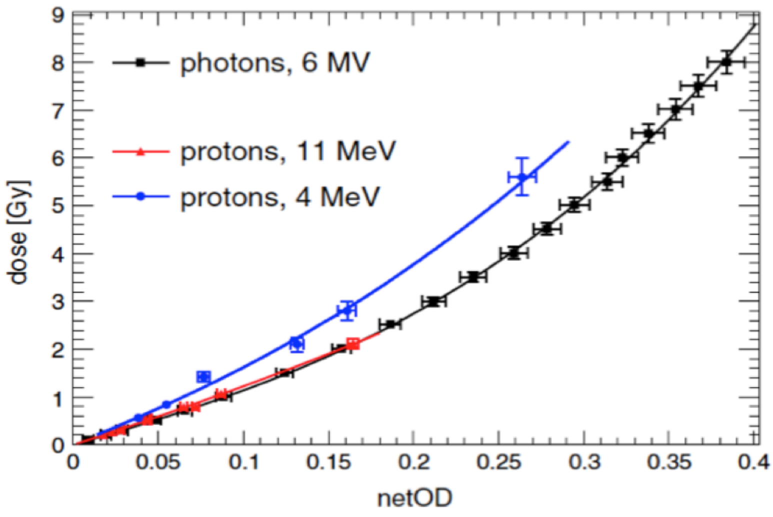

Figure 1: *Calibration of EBT2 Gafchromic films in response to protons and photons.[1]*

Equation 1 displays the relationship of Restricted Linear Energy Transfer, where dE_Δ is the energy loss of the charged particle due to electronic collisions whilst travelling though a distance dx. Restricted LET relates to the omission of secondary electrons with energy travelling far from the primary particle track, but if the Δ tends towards infinity, the LET is considered Unrestricted LET. In this case, all energy transfers are included in the calculations, and the particle's LET is equal to the value of the linear electronic stopping power. It is Unrestricted LET that was investigated within this experiment. Therefore, the primary aim of this experiment was to assess the dosimetric effect of an incoming ionising particle's LET upon Gafchromic EBT3 films, and to determine if the LET parameter had a primary influence in effecting the films' response to dose.

The LNS Superconducting Cyclotron was used to accelerate two different ion species for this experiment; a ^{12}Carbon beam and a ^{16}Oxygen beam at two different energies (45 MeV/nucleon and 75 MeV/nucleon, respectively). These two energies correspond to a common LET value of 70 keV/μm. Therefore, if the RCF darkening response was the same for both ion species across a range of doses, this would indicate a confirmation of the hypothesis that LET is the main parameter in causing a change in RCF response, as it would dismiss the

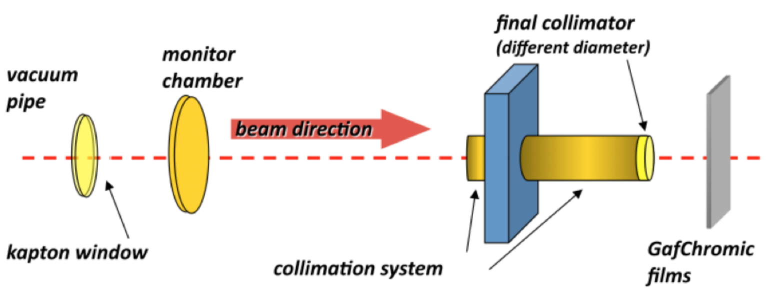

Figure 2: *Schematic of experimental setup to use high energy oxygen and carbon ion beams to irradiate RCF, accelerated by the LNS Cyclotron.*

possibility that ion species would also have a prominent effect.

This experiment was performed in the 0° experiment hall using ^{12}Carbon and ^{16}Oxygen ions accelerated by the LNS Cyclotron. The exposure of the RCF occured in air; the high energies of the ion beams mean that any scattering of ions with particles in the air was negligable. The beam first encounters a monitor ionisation chamber, which was cross-calibrated with a reference ionisation chamber (an Advanced Markus plate parallel chamber) at the end of the beamline, where the RCF was to be placed after calibration. (See Figure 2.) These cross-calibrations allowed an online estimation of the delivered dose at the RCF point of irradiation. To ensure beam homogeneity, a collimation system was used to select only the central part of the Gaussian beam spread. A scintillator coupled to a CCD camera was then also used to monitor the beam stability.

The RCF were irradiated at the end of the beamline. Films of the customised EBT3 were irradiated between 0.25 Gy - 12 Gy for both ^{12}Carbon ion and ^{16}Oxygen ion beams, and then films of HD-V2, used due to their lower sensitivity than EBT3 films, were irradiated with doses ranging between 10 Gy-1000 Gy. The comparison of the **Mean Optical Density** against **Dose [Gy]** for both low and high doses can be seen in Fig. 3. The optical density response of the Gafchromic films to both ^{12}Carbon ion and ^{16}Oxygen at the same LET were found to be the same, lying within the 4% uncertainties of the experiment. Therefore, this provides a plausible indication that the RCF

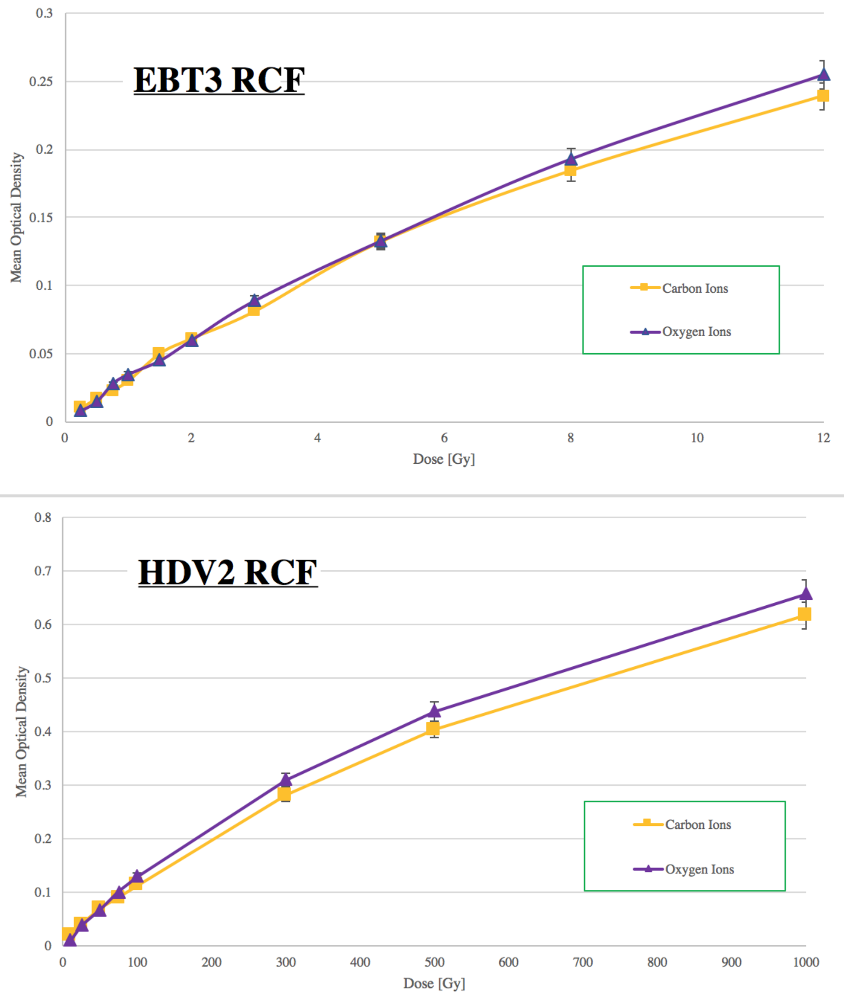

Figure 3: *The plot of optical density measurements against dose deposited by ^{12}Carbon and ^{16}Oxygen ion beams to show RCF response.*

optical density response difference found in [1] and [2] is dependent primarily on the particle LET, and not on the difference in ion species.

To give further credence as to the emerging pattern that these results provide, this data was plotted upon the same graph plotted by *S. Reinhardt et al., 2012*[2] to show the differences in optical density response of the different LET particle beams investigated within this experiment in comparison with the initial 6 MeV photon beam and 11 MeV proton beam used in [2]. (See Fig. 4.) The data used is the optical density from the EBT3 films under irradiation from 3 MeV/n Carbon, 6 MeV/n Carbon, 45 MeV/n Carbon and 75 MeV/n Oxygen (listed in order of decreasing LET, where 45 MeV/n Carbon and 75 MeV/n Oxygen have the same LET value).

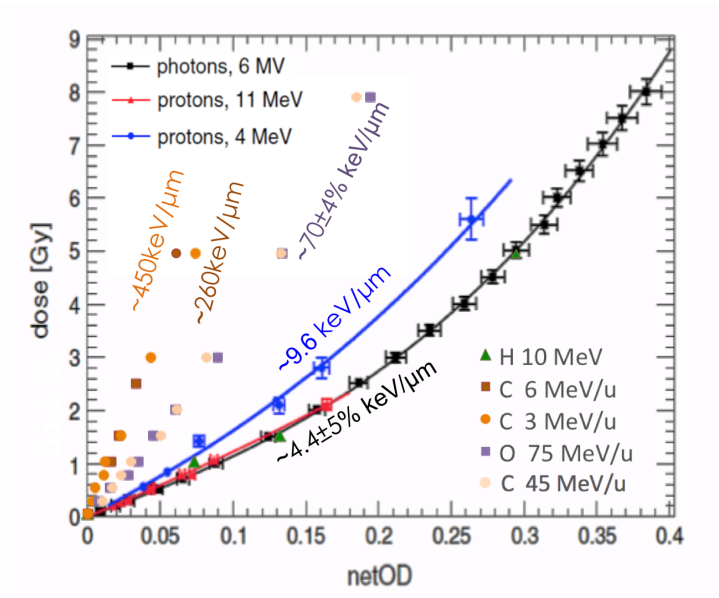

Figure 4: *The graph from [2] superposed with data from this experiment to show the further explored relationship between particle LET and RCF response.*

What is particularly notable is that with all data plotted onto this graph, a clear relationship of a decreasing response of Optical Density with irradiation of higher LET particles can be gathered. Therefore, based on the data acquired through investigating both high and low dose deliveries of two different ion species, there is a strong indication that LET is indeed the key parameter in effecting a RCF's darkening response to incoming ionising radiation. The further acceleration of at least one other ion species would be valuable in confirming the hypothesis that ion species is indeed not a prevalent factor in EBT3 optical density response. Another area of future work in this area is to investigate the effect that dose rate has on RCF response, particularly relevant for laser-driven ion acceleration which can provide dose rates of $> 10^9$ Gy/s as opposed to ~ 30 Gy/s for conventional particle accelerators.

References

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