EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

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http://193.49.43.2:8080/smis/servlet/UserUtils?start

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- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** **3-D DOSIMETRY OF SCANNED SYNCHROTRON RADIATION THERAPY MICROBEAMS**	**Experiment number**: MI-949
Beamline: ID-17	**Date of experiment**: from: 30 January 2009 to: 1 February 2009	**Date of report**: 17 July 2009
Shifts: 6	**Local contact(s)**: T. Brochard, E. Bräuer-Krisch	*Received at ESRF:*

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Report:

1. INTRODUCTION

The use of synchrotron radiation in X-ray microbeam therapy has previously been studied extensively at ESRF e.g., [1]. However, although point detectors, such as MOSFETs [2], and 2-D radiochromic film [3] have been investigated there is as yet no established physical dosimetric system for simultaneously providing accurate measurement of the dose in the microbeam peaks and valleys. Monte Carlo simulations have been obtained [4] but these have yet to be validated by measurements. This experiment investigates two new candidate systems for dosimetry of the microbeams: 3-D optical computed tomography [5], using the PRESAGE^{TM} solid polyurethane dosimeter, and thermoluminescence dosimetry with optical fibres.

In standard clinical radiotherapy, recent years have seen a rapid introduction of the technology for delivering a number of new and complex radiotherapy methods, for which it is extremely difficult to provide quality assurance measurements using traditional dosimetric methods. A lack of confidence in the ability to commission these techniques has led to a reluctance to implement them in practice. The field of 3-D radiation dosimetry (sometimes called "gel dosimetry") has the potential to provide the required information for techniques such as intensity-modulated radiotherapy (IMRT), tomotherapy, arc therapy and brachytherapy. PRESAGE^{TM} is one of a number of 3-D dosimeters that measure absorbed radiation dose by quantitative determination of a chemical change. In the case of PRESAGE^{TM}, the plastic changes from light to dark green upon absorption of radiation and this change can be detected and mapped in 3-D using the technique of optical computed tomography (CT). This experiment represents the first attempt to apply this technique to synchrotron microbeam therapy and the twin aims were (a) to obtain the dose-response characteristic of PRESAGE^{TM} to the synchrotron radiation, and (b) to investigate the facilities available at the synchrotron for depositing microscopic dose patterns and the abilities of the optical CT scanner for reading these out.

A further means of obtaining micro dosimetry is by use of the thermoluminescence (TL) produced by optical fibres. Previous studies at conventional electron linac radiotherapy facilities have shown germanium doped silica fibres to offer useful sensitivity to radiotherapy doses [6], and it has also been established that the fibres can provide a TL-yield reproducibility of better than 4% (1 SD). The objective of the present experiment was to investigate the sensitivity of thermoluminescence response of such fibres at incident energies of several tens of keV, for a wide range of doses, from 1 Gy to 10 kGy.

2. METHODS

Four different sizes of PRESAGE™ sample were evaluated. Six cylinders of diameter 60 mm and height 60 mm were irradiated. These are our standard samples and were imaged with a well characterised parallel-beam optical CT scanner [7,8] . Cylinders of diameters 25, 22 and 16 mm were also tested and were the first samples to be used in a novel 3-D microscopy optical CT scanner, which has recently been developed at the University of Surrey. The samples were irradiated with a variety of test patterns designed (a) to obtain the dose-response of the PRESAGE™; (b) to test the facilities available on ID-17 for microbeam "writing" and the ability of the optical CT scanning system to reproduce the microbeam pattern; and (c) to provide a set of high-quality test samples for benchmarking the optical CT scanner. Radiochromic film (EBT) was attached to the front face of each dosimeter at the time of irradiation in order to obtain an independent measurement of the dose deposited. Films were read out on both a commercial film scanner and the microscopy optical CT scanner (acting in projection mode). Finally 15 cuvettes, each containing approximately 5 ml of the same PRESAGE™ formulation, were irradiated to a set of doses in the range 1 – 5000 Gy, and subsequently scanned in a spectrophotometer to provide an independent measurement of the dose-response curve.

Ge-doped silica fibres of 5.0 ± 0.1 mm length and 125.0 ± 0.1 µm cladding diameter were placed in gelatine capsules (40 fibres in each capsule, to allow dose reproducibility to be investigated at each delivered dose). Each capsule was then exposed to the beam, providing investigation of dose response for on-sample doses of between 1 Gy and 10 kGy. The irradiations were performed by moving the samples through the beam to provide a treatment field of 18mm width x 12 mm high, at a distance of approximately 1m from collimator.

3. RESULTS

Figure 1 shows photographs of one of the 6 cm PRESAGE™ dosimeters. This was irradiated with a variety of rectangular patterns each with height 1 cm and consisting of sets of bars of varying widths between 3 mm and 50 μm.

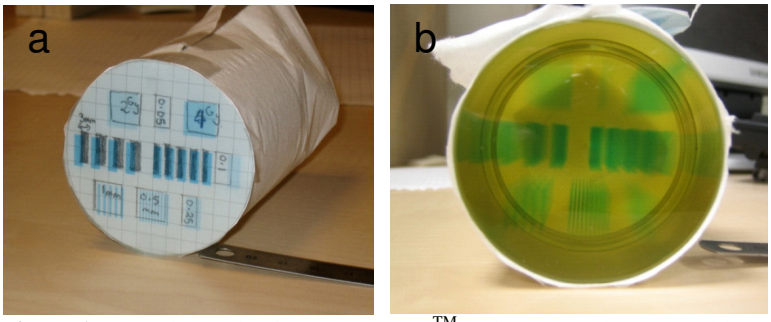

Figure 1: Two views of a 6 cm PRESAGE™ cylinder showing (a) position of film; (b) corresponding irradiated regions in polymer (dark green)

Figure 2 illustrates the results for a second sample designed to measure both the dose-response of the PRESAGE™ and the modulation transfer function (MTF) of the imaging system. There is a linear variation in optical CT image intensity with dose, from approximately 3 Gy upwards and the signal-to-noise ratio of the images is excellent, suggesting the possibility of relative dosimetry within 5%. The 8 Gy square was repeated three times in different parts of the sample. The reproducibility is somewhat poorer than expected, but this may be the result of two of the 8 Gy squares being positioned close to the wall of the cylinder, a region well known to be prone to refractive index mismatch artefacts during the optical CT readout. The image demonstrates the flexibility of "dose-painting" using the synchrotron, with the MTF test pattern created from a sinusoidally modulated set of vertical bars, with maximum dose 6 Gy.

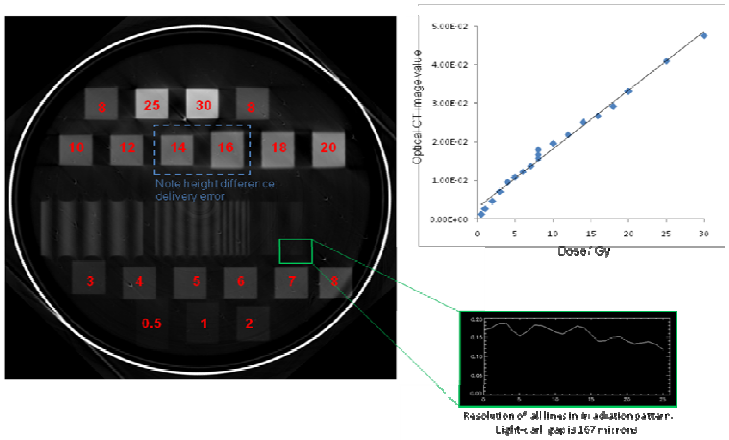

Figure 2: Single slice (thickness ~120 μm) from the 3-D optical CT scan of one of the 6 cm-diameter samples. The green box shows a profile across one of the sets of lines, showing that with this scanner, we are able to resolve features of order 150 microns. The dose-response plot is obtained by taking a mean intensity of the pixels in of each of the large (5 × 5 mm^2) squares.

However, this test also highlighted a previously undiagnosed problem with the dose delivery. Note the difference in height between the 14 and 16 Gy "squares" and the "cupping" at the top of the wide bars on the third row, which point to an error in shutter timing.

Figure 3 shows the first ever micro-optical CT image of a PRESAGE™ dosimeter. Excellent spatial resolution of bars down to a width of 83 μm is demonstrated. However, the sample was also irradiated with bars of width 33 and 16.7 μm and it is unclear why the former were not resolved better. The corresponding EBT film was also imaged at two different resolutions and we note that in Figure 3(d), the 33 μm bars appear much fainter and thinner than they should, given that the nominal dye molecule is of the order of nm not microns. It is thus possible that the sample irradiation did not occur correctly for these extremely narrow microbeams. A number of other sample irradiations were also performed, but limited space precludes their reporting here.

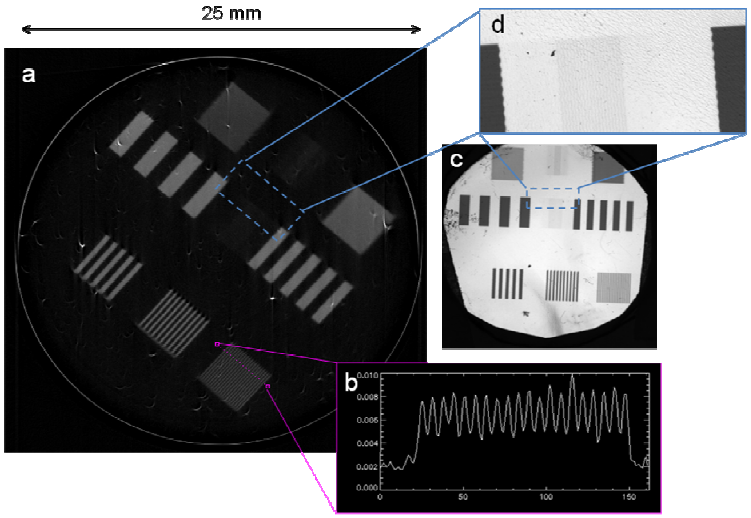

Figure 3: (a) Microscopic optical CT imaging of a 25 mm-diameter PRESAGE™ cylinder. The smallest bars visible have width 83 μm, whil the nominal pixel size in this image is 25 × 25 μm^2 and the slice thickness is ~50 μm. (b) profile through the 83 μm bars, showing extremely clear resolution of the structures. (c) Microscopy image of the corresponding EBT film. (d) High (2 μm) resolution image of small section of EBT film, showing poor definition of 33 μm bars.

Figure 4 shows the results for TL yield, normalised to the mass of each fibre. It is evident that the fibres are capable of sensitive dosimetry throughout the entire range of doses delivered but with non-linear response due to saturation for doses above 2 kGy. Uncertainties associated with each measured point are 4 %, being due for the most part to inherent non homogeneity in dopant concentrations along the length of manufactured optical fibres.

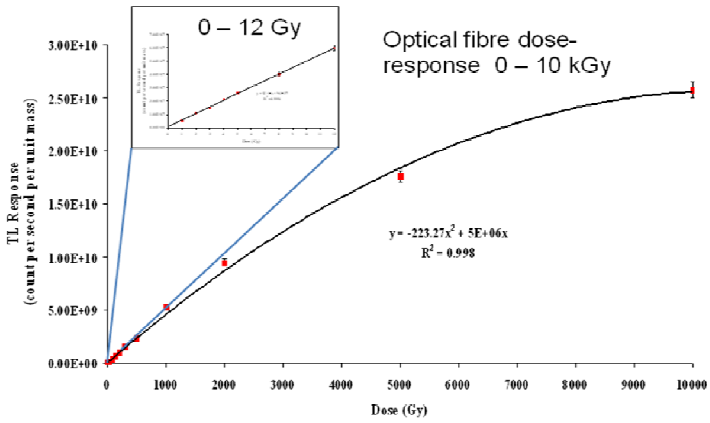

Figure 4: Dose-response for optical fibres from 0 – 10 kGy, with the 0 – 12 Gy response inset

4. CONCLUSIONS

Experiment MI-949 has succeeded in its aims. The combination of PRESAGE™ and optical CT has been shown to provide high quality imaging of synchrotron microbeams down to better than 80 microns. The nominal pixel resolution of 25 microns could not be fully tested because of uncertainties in the dose delivery of smaller beams. The experiment also identified a previously undiagnosed error in the software controlling the beam, resulting in incorrect field sizes. Excellent dosimetric performance has been demonstrated for regions of size 5 × 5 mm^2. Further development work and more synchrotron irradiations are necessary to investigate the potential for accurate dosimetry at these extremely high spatial resolutions. A linear response over the dose range 1 – 2 kGy has been demonstrated for Ge-doped optical fibres.

5. REFERENCES

[1] Regnard *et al.* 2008 *Phys.Med. Biol.* **53** 861-878; [2] Bräuer-Krisch *et al.* 2003 *Med. Phys.* **34** 583-589; [3] Bräuer-Krisch *et al.* 2005 *Phys. Med. Biol.* **50** 3103-3111; [4] Siegebahn *et al.* 2008 *Med. Phys.***33** 3248-3259; [5] Doran 2009 *J. Phys. Conf. Ser.* 012020; [6] Hashim *et al.* 2009 *App. Rad. Isotopes* **67** 423-7; [7] Krstajić *et al* 2006 *Phys. Med. Biol.* **51** 2055-2075; [8] Krstajić *et al* 2007 *Phys. Med. Biol.* **52** 3693-3713