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PROGRESS REPORT FOR AINGRA08039

PROJECT TITLE	**IBIC studies of detectors for synchrotron X-ray dosimetry:** Silicon strip detectors for on-line X-ray microbeam characterisation and dosimetry	
INVESTIGATOR(S)		**Institution and Department**
Chief Investigator	**Dr Michael Lerch**	Physics, University of Wollongong
Other Investigators	Prof. Anatoly Rozenfeld	
Students	Andrew Baloglow	
ANSTO Investigators	Rainer Siegele	

SCIENTIFIC OBJECTIVES

Initial Objectives

The objectives of this project relate to dosimetry studies of synchrotron X-ray microbeams currently being researched as a treatment for children with inoperable and otherwise untreatable brain tumours. Such studies are very challenging due to the small dimensions (beam widths of 25 micrometers) of the X-ray microbeams involved that rule out traditional dosimetry methods. The project objectives are to monitor the radiation damage of new SOI microbeam dosimeters by studying the mechanism of charge collection using the ion beam induced charge collection method both prior and post irradiation at the medical beamline of the European Synchrotron Radiation Facility, France. We also plan to irradiate these detectors at the Australian Synchrotron.

Final Objectives

The project objectives are to monitor the radiation damage of new SOI microbeam dosimeters by studying the mechanism of charge collection using the ion beam induced charge collection method both prior and post irradiation at the medical beamline of the European Synchrotron Radiation Facility, France. These detectors will form the first stage of a quality assurance system for use with this new form of radiotherapy treatment for brain tumours in small children, who are otherwise untreatable.

The project is significant in that it provided the CMRP team with access to technology and international facilities for this leading radiation oncology modality for children undergoing brain cancer treatment. The Project results have led to an increased strategic alliance between Australia and France in the field of synchrotron medical radiation and instrumentation. The results of the project facilitated further collaboration between the two groups and brought new strategic alliances to Australia with European (Paul Sherer Institute (PSI), Institute of Pathology, Switzerland; Institute of Mathematic and Physics, Spain, National Metrology Institute (PTB), Germany; USA (BNL); and Canadian (Synchrotron Facility) groups involved in the MRT project. These strategic research links are paramount for the development of other cancer treatment radiation modalities and the improvement of treatment outcomes. Also, an MRT beamline will be included in the suite of beamlines at the Australian Synchrotron Facility and we plan to transfer the methodology and experience gained at the European Synchrotron Radiation Facility (ESRF), France, to Australia.

In 2007 two new silicon strip detectors were designed at the Centre for Medical Radiation Physics and manufactured at SPA-BIT Detector, Ukraine. These detectors were designed in a more radiation hard technology than the previous version. The new detectors were also mounted such that they could be incorporated into the quality assurance beam abort system for MRT.

DATA, PROGRESS REPORT and RESEARCH OUTCOMES

Microbeam radiation therapy is a new form of radiation treatment being developed for children with inoperable and otherwise untreatable brain tumours. A new on-line dosimetry system is currently under development at the Centre for Medical Radiation Physics, University of Wollongong, Australia, which will be used to measure peak dose for each microbeam and the instantaneous MRT peak-to-valley dose ratio (PVDR). The peak dose and PVDR is an important physical parameter in MRT that indicates the quality of the MRT beam and must be measured with an accuracy of better than 5%. The detector will also be used to act as a fast beam-stop trigger to avoid an Undesirable dose being delivered to the patient undergoing MRT treatment that has several tens of milliseconds treatment time delivery. The project also researched the radiation damage induced in the silicon strip detectors. Such radiation damage studies have not been widely studied under the very intense pulsed, low energy (average energy 100 keV) synchrotron X-ray photons.

The detector is made up of 128 p+ p-n junction strips each with a width of 20 microns, length of 500 microns and with a strip-pitch of 200 microns. The detectors were produced on a 375 micron, n-silicon substrate, one batch with resistivity of 5000 Ωcm and the other with resistivity of 10 Ωcm. Figure 1 shows a schematic cross sectional view of the detector design.

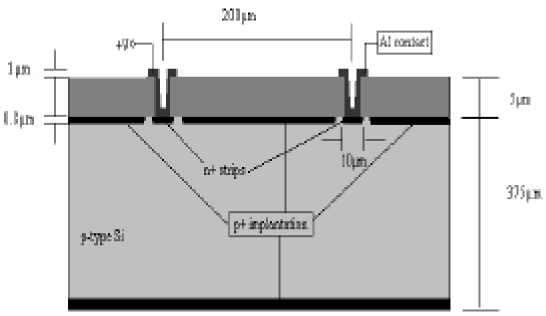


Fig. 1

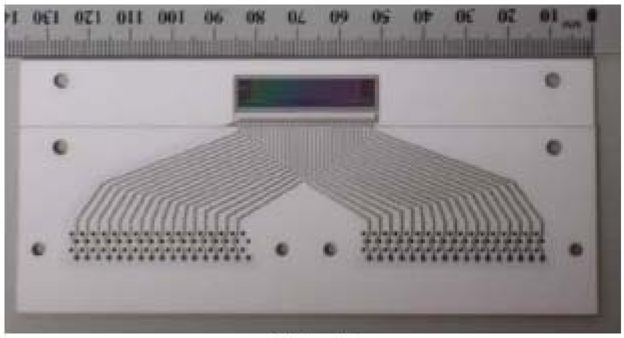


Fig. 2

Figure 2 show a photograph of the new silicon strip detector mounted on our custom designed fan-out printed circuit board (PCB). The PCB is designed such that there is minimal interaction between the detector and the radiation beam. It has a window behind the detector (cannot seen) and each strip connection is made via a wire bond to the fanout tracks that connect to the readout system. The readout system is made up of 128 parallel channels that samples and measures the instantaneous current induced in the detector.

Figure 3 shows a photograph of the detector system as mounted in the MRT beam at the biomedical beamline (ID17) at ESRF, France. The red arrow indicates the direction of the beam that passes through the detector, which is just upstream of the patient. The detector continuously monitors the radiation dose in all 64 microbeam peaks and all 64 microbeam valleys between each peak. The dose delivered in a single fraction to the patient is typically 625 Gy (compared to 3 Gy, which is typical for a standard radiation therapy from a linear accelerator in a hospital) and this dose is delivered in a fraction of a second.

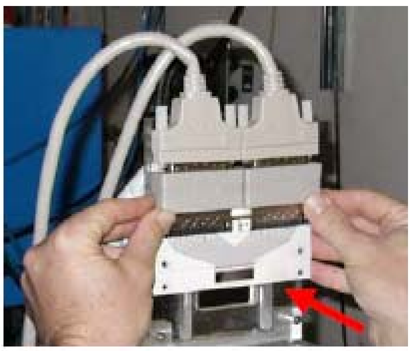


Fig. 3

Two modes of operation were tested. First the beamdump trigger system. If the radiation dose rate reaches an undesirable level at any stage during the treatment fraction the system will sense, measure and send out a fast trigger that can be used to terminate the radiation beam.

Figure 4 shows a screen shot from the fast oscilloscope. It shows a typical response curve (upper trace) and corresponding trigger pulse (lower trace) from the strip detector readout system. The time of interest is the delay time between the start of the upper trace (that represents when the radiation beam is first turned on) and the start of the lower trace (logic trigger pulse for synchrotron beam dump). The delay is 3.6 ms which is an excellent result since all 128 channels are simultaneously measured independently. ***Any*** channel that exceeds a software-set level, (each channel level can be individually set for each channel if necessary as set by the user in the CMRP readout software), will activate the fast trigger pulse.

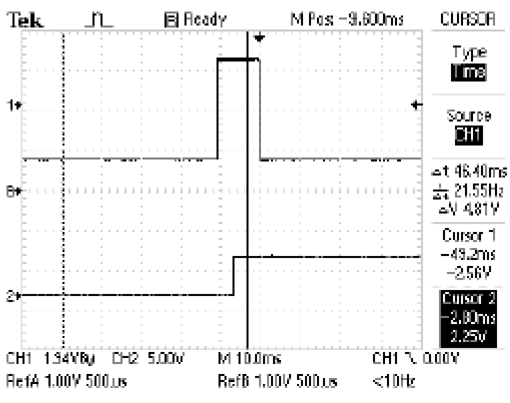


Fig. 4

Other research carried out included examining how well the response of the detector system matched the X-ray flux from the synchrotron beam. Figure 5 shows a typical example plot of the response (the detector current) of the detector system as a function of measurement number (which is proportional to time). One can clearly see when the beam if off (blue dots) and on. More interesting is the plot of the red dots which is a measure of the change in the X-ray flux from the synchrotron with time. The decrease in flux is due to the finite lifetime of the electron current in the synchrotron storage ring, which is well known. We have shown that we can monitor this decrease in flux to within one part in ten thousand. Such accurate direct measurements will allow very precise post irradiation dosimetry analysis, which has important clinical implications for MRT.

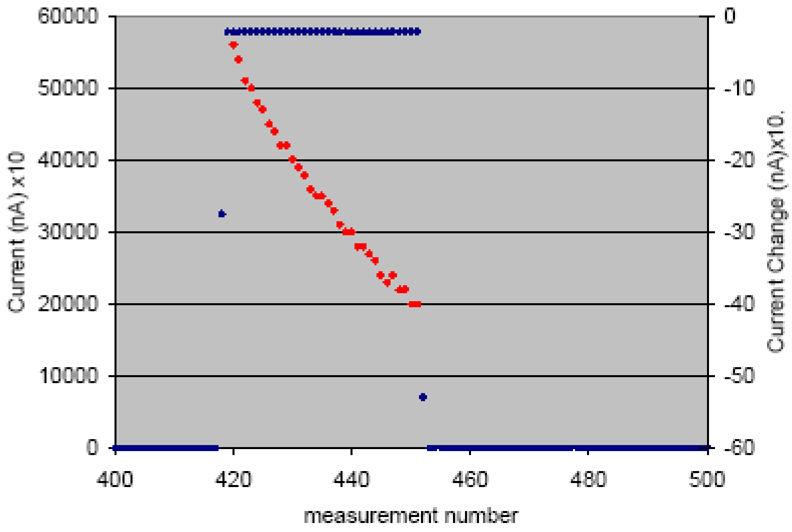


Fig. 5

Ultimately we wish to perform realtime *absolute* dosimetry with this detector system. Figure 6 shows the response of the detector system as a single microbeam (width 75 μm) is scanned across the high resistivity silicon strip detector. The detector was encased within a Perspex phantom at a depth of 10 mm. Each curve indicates the instantaneous readout current from a particular strip, where each strip is physically separated by 200 micrometres.

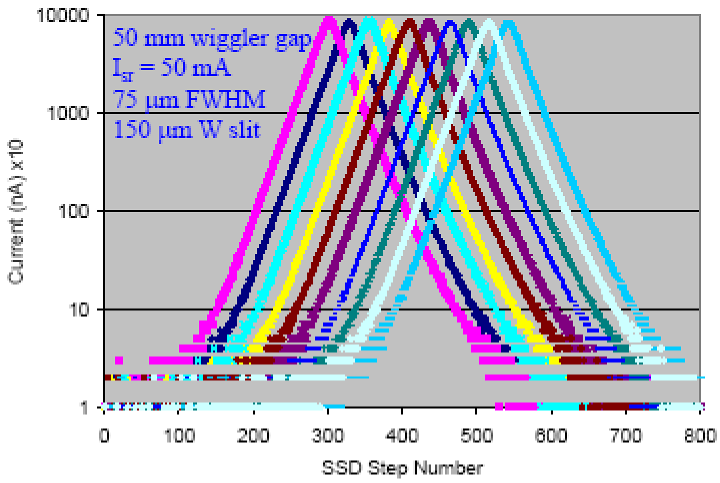


Fig. 6

The data indicates that we need to reduce the charge diffusion length by a factor of 1000 before any absolute dosimetry measurements can be attempted. To facilitate this we are planning to expose the detectors to high energy protons at the radiation facility in CERN, Geneva. Such exposure will reduce the diffusion length through the creation of point defects within the silicon. It is planned to do these irradiations in August 2008 before the next allocated MRT beam time at the synchrotron in Grenoble in September.

Finally, we investigated the radiation hardness of the new p-type silicon strip detectors (high resistivity and low resistivity) using ion beam induced charge collection (IBIC) studies, after exposure in a synchrotron X-ray microbeam radiation field to an equivalent tissue dose of almost 1 MGy. Such a total absorbed dose is equivalent to over 1000 patient treatments. The radiation damage induced in these detectors is important for understanding the reliability of the deduced dose using these detectors and will determine their useable lifetime. Such radiation damage studies have not been widely studied under the very intense pulsed, low energy (average energy 100 keV) synchrotron X-ray photons. Figure 7 is an ion beam induced charge (IBIC) collection image of the two detector types, high resistivity (left) and low resistivity (right) prior to irradiation as measured in 2007. As expected, the high resistivity device shows slightly better charge collection than the low resistivity device. After irradiation at ESRF some damage was measured in the high resistivity device, which was the subject of further IBIC investigation. No effect of any radiation damage was measured in the low resistivity device.

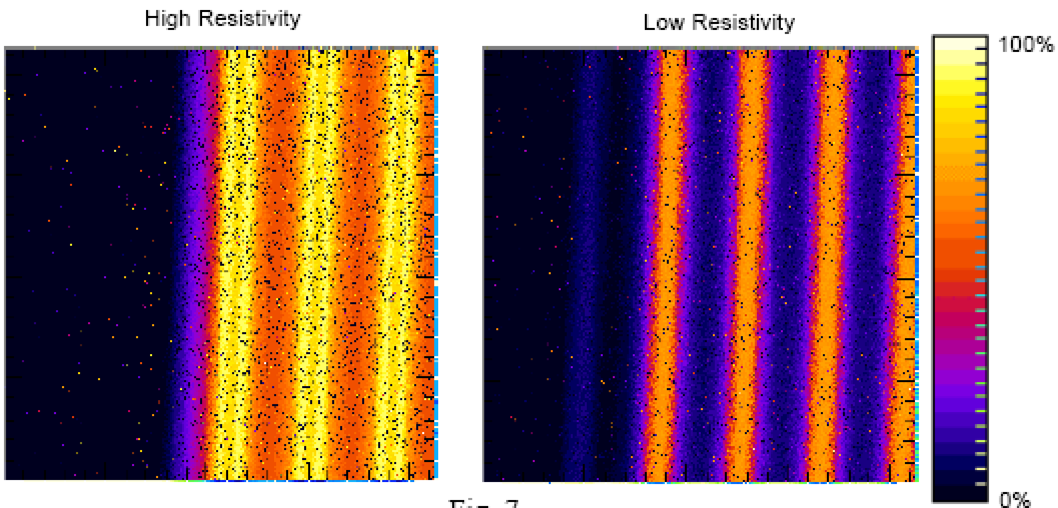


Fig. 7

For verification of the nature of the radiation damage in the strip detector under the synchrotron radiation we have carried out the Ion Beam Charge Collection (IBIC) study. Fig. 8 and 9 shows a colour coded images of the collected charge on 4 consecutive n+ strips of the unirradiated high resistivity p-type device, under two different bias voltages, 30 and 90 V respectively. The corresponding energy spectrum is also shown.

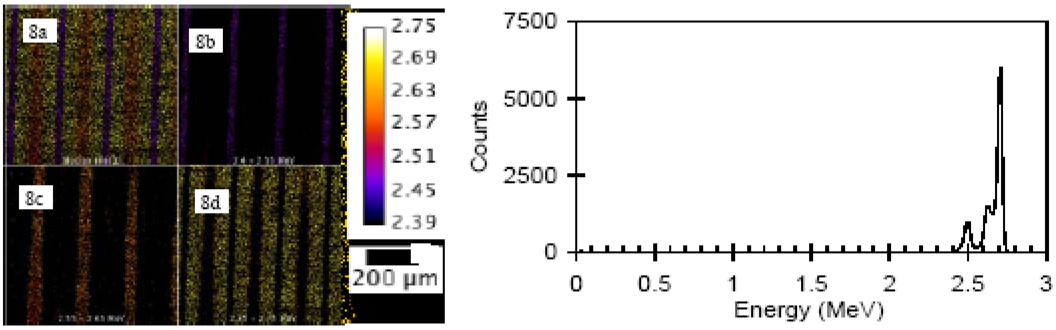


Fig.8. Image of the collected charge using IBIC technique on the SSD bias at 30 V, showing (a) the median energy map, (b) the 2.4-2.55 MeV energy window map, (c) the 2.55-2.65 MeV energy window map and (d) the 2.65-2.75 MeV energy window map. The corresponding IBIC energy spectrum that gives rise to the colour maps is shown in Fig 8e.

Fig. 8a shows the median energy map of all events from the energy spectrum and Fig 8b, 8c and 8d show windowed energy maps for the energy windows labelled that relate to the three features observed in the energy spectrum. The lowest energy window map (Fig. 8b) is made up of the energy events centred on the 2.5 MeV peak in the energy spectrum. These events are associated with ions traversing through the aluminium contact and n+-layer of each strip, and in doing so, (assuming the incident energy of the ions is 3 MeV) these ions have lost approximately 500 keV. Such an energy loss corresponds to approximately 2 microns of aluminium (assuming 100% charge collection in the SSD), which is consistent with the SSD design. The second energy map (Fig. 8c), centred on the peak at 2.65 MeV correlates with ions traversing through the undepleted portion of the SSD between two adjacent strips, which is as expected at 30 V for the given resistivity of the device. The final energy map (Fig. 8d) correlates with ions traversing through the depleted portion of the SSD between two adjacent strips. In figures 8c and 8d more charge is collected than figure 8a as the ions only lose energy as they traverse through the silicon oxide and p-spray layer.

In figure 9 the charge collection is obviously improved and effect of further depletion is clearly evident in both the median energy map (Fig. 9a) and both energy window maps (Fig. 9b and 9c). In the corresponding energy spectrum (fig. 9d) the small, lower energy satellite peak centred at 2.65 MeV observed in fig. 8d is no longer resolved from the high energy peak.

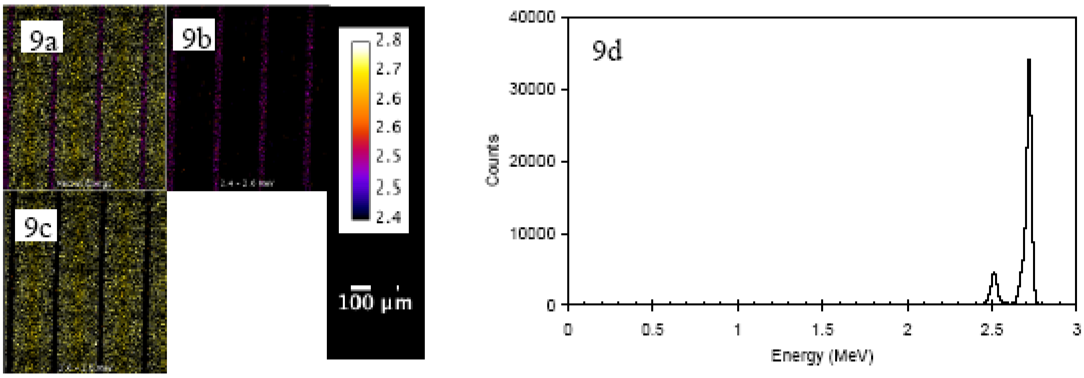


Fig.9. Image of the collected charge using IBIC technique on the SSD biased at 90 V, showing (a) the median energy map, (b) the 2.4-2.6 MeV energy window map, and (c) the 2.6-2.8 MeV energy window map. The corresponding IBIC energy spectrum that gives rise to the colour maps is shown in Fig 9d.

Fig. 10 and 11 shows a colour coded images of the collected charge on seven consecutive n+ strips of the high resistivity p-type device under two different bias voltages, 30 and 90 V respectively. Two, however, of the intended seven strips were not connected to the IBIC imaging data collection system and were floating. This device was irradiated with the 1.2 mm synchrotron beam to a dose of 500 kGy. The IBIC energy spectrum taken at 30 V reverse bias shows several features between the energy range of 2.1-2.7 MeV which are associated with the induced radiation damage (see figs 10c – 10f) leading to a reduction in the median charge collection efficiency of ~14%. The low energy features between the energy range of 0.3 – 2.1 MeV are clearly associated with the unbiased strips (see Fig 10b) and were therefore ignored in the analysis. At 90 V applied reverse bias, the median charge collection is improved compared to 30 V, however is still lower (approximately 7.5% reduction), on average, compared to when the SSD was unirradiated. The low energy features observed at 30 V in the IBIC energy spectrum, are still present at 90V (fig. 10b) as expected.

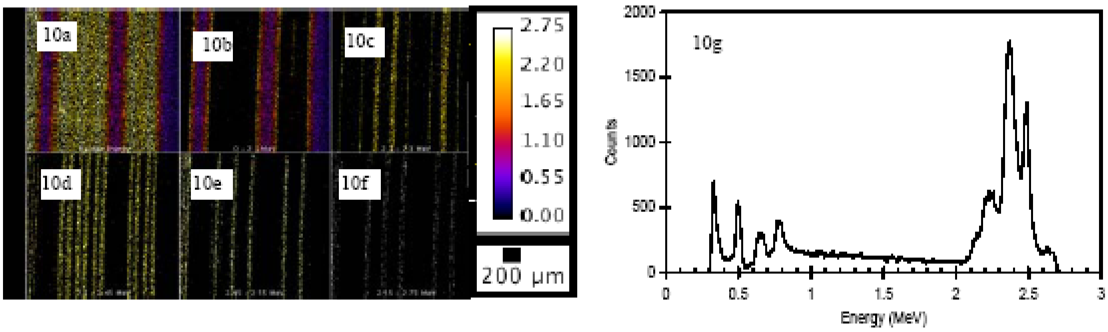
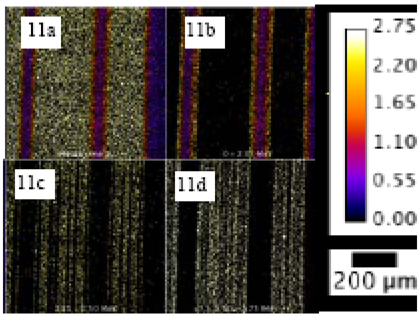


Fig.10. Image of the collected charge using IBIC technique on the SSD bias at 30 V, showing (a) the median energy map, (b), (c), (d), (e), and (f) the 0.3-2.1 MeV, 2.1-2.3 MeV, 2.3-2.45 MeV, 2.45-2.55 MeV, 2.55-2.75 MeV energy window maps respectively. The corresponding IBIC energy spectrum that gives rise to the colour maps is shown in Fig 10g.

The total accumulated dose to the SSD was 500 kGy, which equates to 800 MRT fractions (assuming a dose of 600 Gy per fraction) or 400 patients and hence the reduction in sensitivity of the SSD would be 0.02% per fraction at 30 V and 0.01% per fraction at 90 V shows that the radiation damage is not significant on a per patient basis, however it needs to be taken into consideration in the long term operation of these devices. One should also investigate possible annealing under 150o of these devices between exposures.



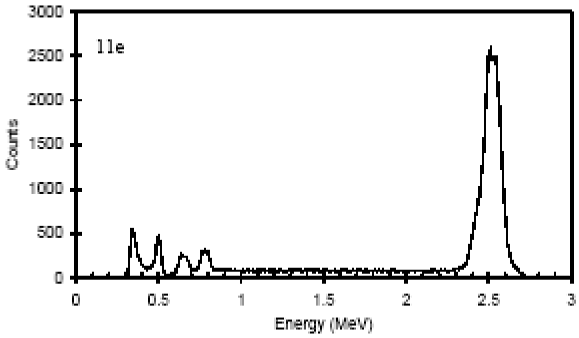


Fig.11. Image of the collected charge using IBIC technique on the SSD biased at 90 V, showing (a) the median energy map, (b), (c) and (d) the 0.3-2.35 MeV, 2.35-2.5 MeV, 2.5-2.75 MeV, energy window maps respectively. The corresponding IBIC energy spectrum that gives rise to the colour maps is shown in Fig 11e.

Conclusion.

As part of a larger research project related to the dosimetry of intensive synchrotron X-ray microbeams used in microbeam radiation therapy we have, in this project, investigated the resulting radiation damage induced in the p-type dosimeters from the pulsed, low energy X-ray field. The proposed SSD dosimetry system has shown to perform adequately in making a fast assessment of the PVDR of all microbeams and initiate a beam dump trigger if necessary. The high resistivity ptype SSD showed some minor signs of radiation induced bulk degradation of their response, which could also be annealed through raised temperature. The IBIC study of the low resistivity p-type SSD showed no sign of radiation induced bulk degradation of their response

Signature of Investigator preparing the report for **After signing this report please fax this page with your signature for our files**	**Proj: AINGRA08039** **Date:**

PUBLICATIONS / REPORTS arising as a result of your work.

H. Nettelbeck, G. Takas, M. Lerch, A. Rosenfeld “Influence of source and collimator geometry on MRT microbeam profiles”, Med. Phys. 36, 447-456, 2009

J.H.D. Wong, M. Carolan, M.L.F. Lerch, M. Petasecca, S. Khanna, V.L. Peterevertaylo, P. Metcalfe, & A.B. Rosenfeld, “Dose Magnifying Glass” Med. Phys. (accepted June 2009)

M.L.F. Lerch, A. Cullen, A.M. Baloglow, M. Reinhard, M. Petasecca, R. Siegele, D. Prokopovich, E. Brauer-Krisch, H. Requardt, V. Perevertaylo, A. Bravin, A.B. Rosenfeld “Dosimetry of intensive, pulsed synchrotron X-ray microbeams”, NSREC, July 2009, Canada

M.L.F. Lerch, H. Nettelbeck, H. Requardt, A. Cullen, S. Khana, A. Baloglow, E. Brauer-Krisch, A. Bravin, M. Reinhard, R. Siegele, V. Perevertaylo, A.B. Rosenfeld, “Multichannel silicon detectors for on-line synchrotron X-ray microbeam radiation dosimetry”, 10^{th} International Conference on Synchrotron Radiation Instrumentation, September, Melb. 2009

A.J. Cullen, M.L.F. Lerch, A.B. Rosenfeld, “Modelling the dosimetric effects of an in-line multichannel quality assurance silicon detector in Synchrotron X-ray Microbeam Radiation Therapy” 10th International Conference on Synchrotron Radiation Instrumentation, Sept., Melb. 2009

A.J. Cullen, M.L.F. Lerch, A.B. Rosenfeld, “IBIC studies of an in-line multichannel quality assurance silicon detector for Synchrotron X-ray Microbeam Radiation Therapy”, International Symposium on Radiation Physics, Sept., Melb. 2009

PhD STUDENTS

The students involved with the project in 2008 were:

Ashley Cullen (MSc(Research)) “Strip detector for high spatial resolution dosimetry in radiation therapy”

Andrew Baloglow (PhD) “Silicon strip detectors for on-line X-ray microbeam characterisation and dosimetry”

Sam Khana (Masters of Medical Radiation Physics) “Readout System for a Synchrotron Xray microbeam QA system”

Heidi Nettelbeck (PhD) “Magneto Microbeam Radiation Therapy”, Monte Carlo simulations.