- POFGaRD -
Plastic Optical Fibre Gamma Radiation Dosimeter
Final Summary Report

Abstract:

This project investigates the use of PMMA (polymethyl methacrylate) based Plastic Optical Fibre as ionising radiation sensors, suitable for use in small-field radiotherapy dosimetry. The optical fibre tip is coated with a scintillation material that fluoresces under ionising radiation, with the emitted signal penetrating the fibre and propagating along the fibre for remote monitoring using a spectrometer.

Motivation

Cancer is the second leading cause of death in the European Union, with more than 2.4 million new cases of cancer (excluding non-melanoma skin cancers) diagnosed within the EU in 2008 [1]. Radiation therapy is involved in the treatment of over 40% of cancer patients [2]. In addition to cancer treatment, radiotherapy also plays an important role in palliative care [3]. With the increasing use of radiation therapy, comes the need for improved radiation monitoring systems. Ensuring safe operating and working conditions for both recipients of ionising radiation in radiotherapy applications, and for those who work and operate in ionising radiation affected environments, is of extreme importance. Radiotherapy is delivered in the form of External Beam Radiotherapy, using linear accelerators, or Brachytherapy, which involves the delivery of miniature radio-active 'seeds'' that are delivered to the cancerous area directly using hypodermic needle-like applicators. Radiation therapy destroys cells in a precisely controlled manner in an area being treated, referred to as the "target tissue", by damaging the genetic material of the tumour, making it impossible for these cells to continue to grow and divide. In reality, some surrounding healthy cells also get damaged and so it is important that, during radiotherapy, damage to nearby healthy cells is minimised. Direct measurement of radiation dose to critical structures is vital to ensure intervention before an accident occurs.

Sensor Fabrication

The optical fibre sensor, described by figure 1, is constructed by coating the end of an exposed PMMA optical fibre, after the cladding was removed, with a specific radiation sensitive scintillating material. The scintillating phosphor material, an inorganic phosphor, terbium-doped gadolinium oxysulfide (Gd_2O_2S:Tb), supplied by Phosphor Technologies [6], is mixed with an epoxy mix and injected into a cylindrical mould containing the exposed PMMA fibre optic core and allowed to cure. The complete fabrication process is described in more detail by McCarthy *et al* [4]. The radiation sensitive scintillating material tip of the sensor fluoresces on exposure to ionising radiation. The resultant emitted fluorescent light penetrates the PMMA optical fibre and propagates along the fibre to a distal scientific-grade spectrometer from Ocean Optics, where the intensity of the peak wavelength of the fluorescent light is measured.

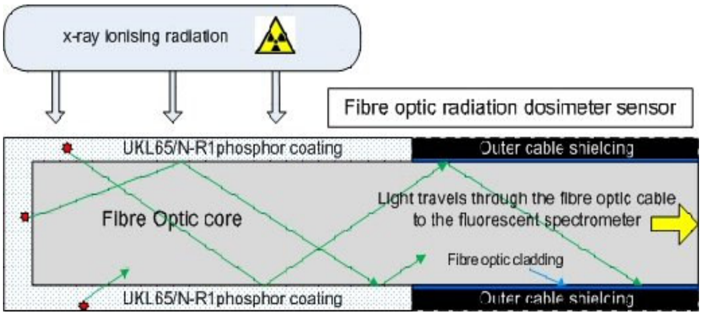

Fig. 1: X-ray fibre optic sensor

Fig.2: Fibre sensor, with cross section view (inset)

Results

Tests were carried out at the Galway Clinc, Ireland, and the University of California Los Angeles (UCLA). The Linear Accelerators (Linacs) used were a Siemens Artiste at the Galway Clinic and a Varian Truebeam at UCLA, with water equivalent phantom of varying depths used. The sensor was connected to a fluorescent spectrometer using a 19 meter long POF cable. The spectrometer and a computer for analysing the resultant optical signal were located at the control console, allowing for real-time remote monitoring of the radiation, while keeping all electronic components away from the radiation environment.

During radiation exposure there is a clear and discernable increase in optical intensity at the peak emission wavelength, 544nm. Investigations at the Galway Clinic examined the response to known incident radiation exposure patters from the linac, as well as the repeatability and stability of the measurement.

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The sensor demonstrated excellent response to a wide range of exposure conditions including different levels of ionising energy and exposure duration. Figure 3 shows the repeatability (a maximum of 2% variance) of measurement over the four iterations at 15MV for 100cGy dose [5]. The peak intensity monitored during each on phase remains consistent and stable, while during each off phase it returns to zero. Further testing at UCLA was used to determine the reproducibility of the results from different types of linacs and its response to varying dose rates. The results were consistent for the same test procedures and demonstrated good repeatability and reproducibility.

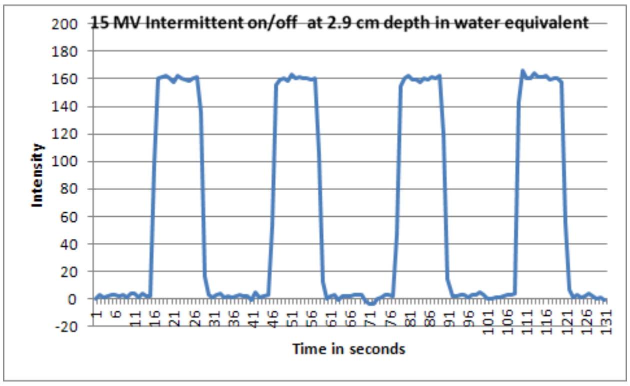

Fig. 3. Repeatability of sensor

Social and Economic Impact

Cancer represents a major cause of death in the world with 7.6 million people dying worldwide in 2008 alone. The World Health Organisation (WHO) estimates that this figure will rise to 12 million by 2030. Within Western Europe, the annual number of deaths is expected to reach 630,000 in the same period with an expected five year survival rate of between 50% and 60%. Clearly this represents a major health issue within the EU. Significantly improving the treatment procedure promotes the possibility to save many thousands of lives. Development of accurate treatment instrumentation has the potential for world wide application. The impact of the availability of such instrumentation is multidimensional e.g. A) social impact of saved lives; B) economic impact of a reduction in the years of lost productivity for a national workforce; C) commercial implications for the technology leaders in this application space and D) reduction in patient treatment efficacy and cost burden to the public health system.

Training and Professional Development of Researcher

The project also focussed on the reintegration and career development of the lead researcher, Dr Sinéad O'Keeffe. During the project duration, she attended training courses on Project Management and on writing successful project proposals. She is co-supervisor for 5 PhD students in optical fibre sensing and sensor networks, including two PhD candidates in the area of radiation monitoring. She has graduated one PhD candidate. She was also involved in the development of the Environment Graduate Programme for Ireland and was the local organiser for its first Summer School.

In 2009 Dr. O'Keeffe prepared and led a successful COST Action proposal (COST Action TD1001 "Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications" (OFSeSa)), which was the highest ranked proposal in its category (Trans-Domain) of all proposal submitted from Europe in that call. In November 2010, she was elected Chair and Grant Holder of the Action, involving over 100 participants from 26 countries worldwide. Dr. O'Keeffe was recently awarded the IEEE Sensors Council Early Career GOLD Award 2012 for her "*contributions to optical fiber sensors for radiation monitoring, particularly in patient monitoring during radiotherapy, and leadership in European efforts to develop reliable and standardized optical fiber sensors for safety and security applications.*"

Fig. 4. Prof Elfed Lewis, Scientist-in-Charge and Dr Sinead O'Keeffe, lead researcher, during the trials at UCLA.

Conclusions

Results from trials undertaken at the Galway Clinic and UCLA demonstrate the suitability of the optical fibre based system to monitoring radiation during radiotherapy dosimetry. There is a distinct, measurable signal emitted at 544nm on exposure to ionising radation that can be used to monitor the amount of radiation a patient in receiving. The optical fibre set-up allows for real-time monitoring of the radiation, for improved patient safety. The current set-up could be used to monitor radiation externally on the patient, with its small size making it particularly suitable for monitoring critical areas, such as around the eyes.

Recent advances in the state of the art have resulted in the emergence of radiotherapy beam delivery systems (Linear Accelerators or LinAcs) combined with MRI in a single system. In this way world leading oncology centres (e.g. UCLA) can deliver radiotherapy treatment and scan the tissue in a single treatment session. Optical fibres generally comprise only silica (glass) or plastic as their constituent material and therefore optical fibre sensors are uniquely and ideally suited for use in the MRI environment as they are non magnetic and do not cause interference on the image and are themselves immune to the intense Magnetic Field and Radio Frequency pulses present in the MRI environment. The collaboration with UCLA and the Galway Clinic has been consolidated and strengthened during this project and project proposals have been submitted for continuing the research in developing optical fibre based radiotherapy dosimeters, particularly for MRI-guided linac, such as that at UCLA. Further work is also ongoing to investigate the use of the probe in brachytherapy and cathetar based applications. New collaboration has also been established with Oakridge Lab, USA and Queens University Belfast, UK, developing optical fibre radiation sensors for soil monitoring near nuclear facilities.

References

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