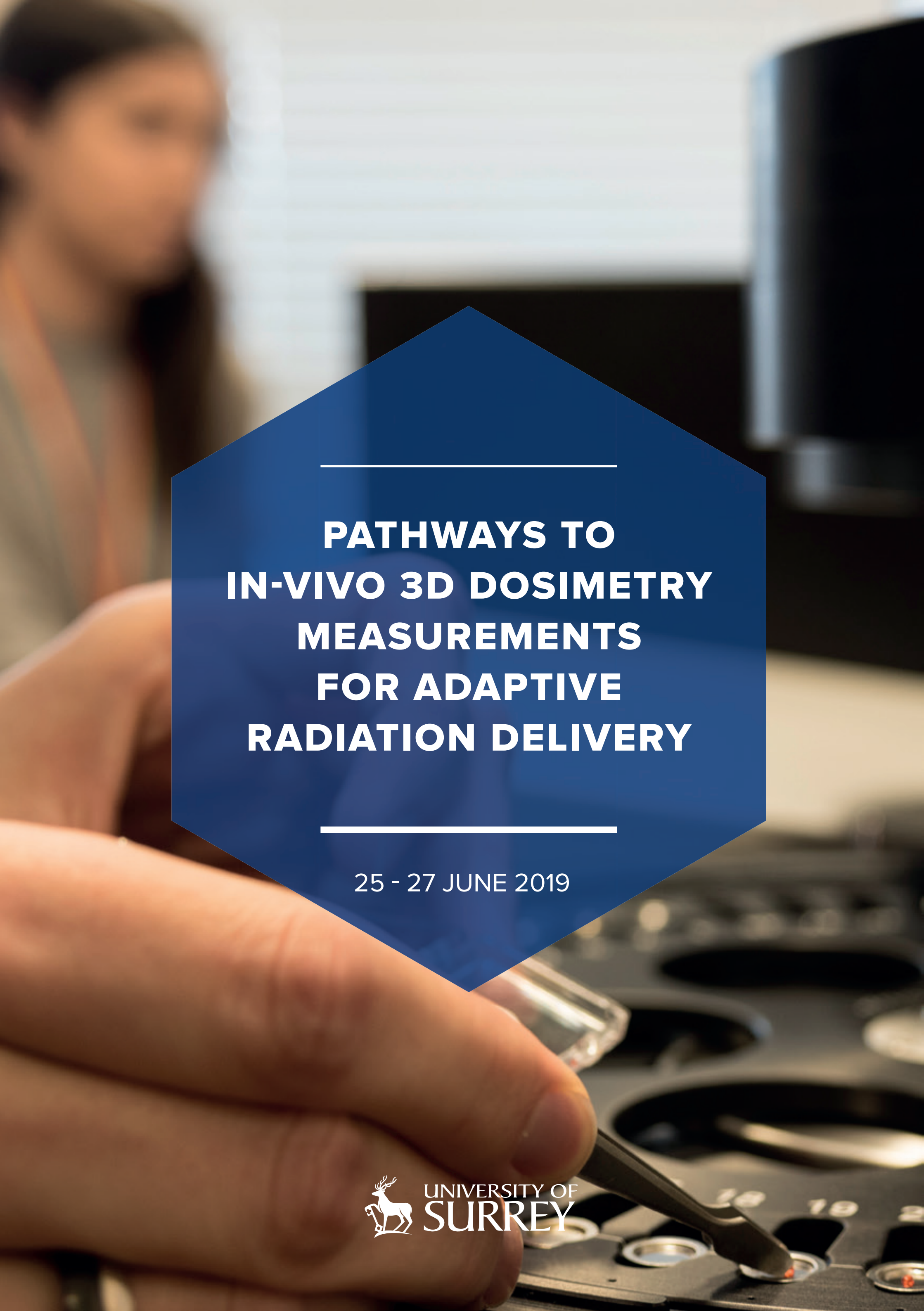

PATHWAYS TO IN-VIVO 3D DOSIMETRY MEASUREMENTS FOR ADAPTIVE RADIATION DELIVERY

25 - 27 JUNE 2019

UNIVERSITY OF SURREY

OUR SPONSORS

Trueinvivo

This workshop would not have been possible without the generous support and commitment from Trueinvivo, who have been supporting this event from its very beginning. Trueinvivo are dedicated to making a difference to radiotherapy patients as well as industrial applications worldwide through their innovative dose mapping silica bead array technology. The award winning company was set-up as a result of the innovative doctoral project of Dr Jafari, who Co-Chairs our workshop. Trueinvivo collaborates with a wide range of academic, industrial, government and hospital partners.

trueinvio.co.uk

The workshop has also gratefully received financial support from Elekta and Oncology Imaging Systems.

Elekta.com I Oncologyimaging.com

The Institute of Advanced Studies

This workshop is funded and supported by The Institute of Advanced Studies (IAS). The IAS was established in 2004, at the University of Surrey (IAS), and sponsors workshops on interdisciplinary topics suggested at the ëcutting edgeí of science, engineering, social science and the humanities. Through this scheme, the Institute fosters interdisciplinary collaborations and encourages a flow of international scholars to visit, enjoy their stay at Surrey and leave behind excellent ideas and innovations. Over the years IAS events have resulted in many research grants, new collaborations, journal articles and books. The Institute is principal objectives in supporting these workshops, are to attract international scholars to the University and to encourage new and productive research collaborations

ias.surrey.ac.uk

INTRODUCTION

One of the key challenges in radiotherapy is the accurate delivery of sufficiently high radiation doses to the tumour in order to control it, while sparing the surrounding tissues from radiation dose and associated damage. New technologies in treatment delivery developed in recent years enable steep dose gradients with high spatial resolution to be achieved, with the potential to treat tumours effectively close to organs at risks. This includes use of proton and hadron (in particular carbon) beams and strong magnetic fields in MR Linacs. These improvements and new treatment modalities in radiotherapy require dosimeters with enhanced spatial resolution and a wide dynamic range, which are not commonly available in clinical practice yet.

This interdisciplinary workshop will bring together the research community committed to addressing the challenges that must be overcome in order to make the vision of routine 3D and even 4D in-vivo dosimetry measurements a reality. The workshop will be an opportunity to share knowledge, experiences, best practice and ideas between established experts in dosimeter development and medical physics practitioners in the field as well as early career researchers or those who are joining this exciting and rapidly developing field. We expect that the workshop will lead to the development of collaborations between the participants, which will allow the scientific community to overcome the challenges leading to 3D in vivo dosimetry in an efficient, coordinated and fast manner, for the benefit of patients and the wider society.

Joint Workshop Co-Chairs:

Dr Annika Lohstroh, University of Surrey

Dr Shakardokht Jafari, Trueinvivo Ltd, QA Hospital Portsmouth, University of Surrey

Local Organising Committee:

Dr Silvia Pani, University of Surrey

Prof Giuseppe Schettino, University of Surrey, National Physical Laboratory

Prof Phil Evans, University of Surrey, National Physical Laboratory

Dr Lucia Florescu, University of Surrey

Administrative support:

Lisa Fletcher, Mirela Dumic,
University of Surrey

PROGRAMME

TUESDAY 25 JUNE 2019

7:30pm	Welcome dinner

WEDNESDAY 26 JUNE 2019
LECTURE THEATRE J

9:30am	Introduction and Welcome (**Annika Lohstroh/Shakardokht Jafari, Nigel Biggs**)
Session 1	(**Lucia Florescu** - Chair)
9:50am	**Ramin Jaberi,** Cancer Institute of Tehran, University of Medical Science (invited): *Challenges in using Micro Silica Beads TLDs as in-vivo dosimeter in Brachytherapy of Cervical Cancers*
10:20am	**Sarah Wilby**, Portsmouth Hospitals NHS Trust, University of Portsmouth: *Deformable Pelvic Phantom for 3D/4D Dosimetric Quality Assurance of a New Robotic LDR/HDR Brachytherapy Device*
10:40am	**Conor McGarry**, Radiotherapy Physics, Northern Ireland Cancer Centre, Belfast City Hospital, Centre for Cancer Research and Cell Biology, Queen's University: *A bespoke modular 3D printed pelvis phantom for validation of prostate SABR with dominant intra-prostatic lesion (DIL) boost regions*
11:00am	Coffee break
Session 2	(**Silvia Pani** – Chair)
11:30am	**David Bradley,** Sunway University (Malaysia) University of Surrey (invited): *Doped-silica real-time luminescence sensing of radiation*
12:00pm	**Hima Bindu**, Osmania University Hyderabad, University of Surrey: *Verification of consistency of micro-silica glass bead thermoluminescent detectors for neutron irradiation*
12:20pm	**Lorenzo Isolan**, Industrial Engineering Department, Alma Mater Studiorum, University of Bologna: *Micro-silica beads sensitivity analysis in phantoms via direct and adjoint Monte Carlo calculations*
12:40pm	**Chutima Termsuk**, University of Surrey: *Directionality studies of the light emission from optical fibre thermoluminescent dosimeters*
1:00pm	Lunch
2:00pm	Lab tours
3:00pm	(**Annika Lohstroh** - Chair) Dr **Jérôme Benoit**, Specialist in Veterinary Diagnostic Imaging and Radiation Oncology, Oncovet (invited): *State of the Art Radiotherapy and Dose QA in Veterinary Radio-Oncology / The role animal "patients" may be able to play in cancer research*
3:30pm	Coffee break
Session 3	(**Giuseppe Schettino** – Chair)
4:00pm	**Sonja Wegener,** University of Würzburg, Department of Radiation Oncology, Germany (invited): *In-vivo dosimetry for head and neck treatments*
4:30pm	**Richard Hugtenburg**, Swansea University Medical School, Department of Medical Physics and Clinical Engineering, HH Wills Physics Laboratory, School of Physics, University of Bristol (UK): *The use of diamond detectors for real-time, in-vivo dosimetry of intensity modulated radiotherapy*
4:50pm	**Giulio Villani**, STFC Rutherford Appleton Laboratory, Particle Physis Department: *A monolithic 180 nm CMOS dosimeter for wireless In Vivo Dosimetry*
5:10pm	**Lana Beck,** University of Bristol, Physics Department: *Novel approaches to contamination suppression in upstream detectors for radiotherapy*
5:30pm	Break
6:00pm	Dinner buffet (Upper concourse, Lecture Theatre Block)
7:30pm	Public Engagement event (**Ramin Raberi, Shakardoth Jafari, Heather Campbell**), Lecture Theatre Block

PROGRAMME

THURSDAY 27 JUNE
LECTURE THEATRE J

Session 4	(**Phil Evans** – Chair)
9:30am	**Ana Folgueras,** Elekta, UK (invited): *Approaches to dose monitoring for safer radiotherapy: a manufacturer's perspective*
10:00am	**Chiara De Sio**, University of Bristol, Physics Department: *Towards an AI-driven real time verification of Radiotherapy treatments*
10:20am	**Ian Hanson** The joint Department of Physic, The Royal Marsden NHS Foundation Trust and the Institute of Cancer Research: *3D & 4D dosimetry in practice*
10:40am	**Jaap Velthuis**, University of Bristol, Physics Department, Swansea University, Medical School (UK): *Using a TRAPS Upstream Transmission Detector to Verify Multileaf Collimator Positions during Dynamic Radiotherapy Delivery*
11:00am	Coffee break
Session 5	(**Annika Lohstroh**– Chair)
11:30am	**Aaron Axford,** University of Surrey: *Assessing the Accuracy of Adaptive Radiotherapy for Changes in Target Shape and Position in the Elekta MR-linac*
11:50am	Discussions & Conclusion (**Annika Lohstroh** – Chair)
12:30pm	Lunch & Departure

KEYNOTE SPEAKERS

Ramin Jaberi
Cancer Institute of Tehran, University of Medical Science

Dr Jaberi, a specialist in brachytherapy with extensive expertise to conduct pre-clinical trials on innovative new dosimeters. He works at Tehran University of Medical Sciences in the Department of Radiation Oncology.

Keynote address: *Challenges in using Micro Silica Beads TLDs as in-vivo dosimeter in Brachytherapy of Cervical Cancers*

Brachytherapy as one of the most conformal dose delivery technique is used for treating many cancers in all around the world.

In High Dose Rate (HDR) brachytherapy one active source carried out and placed near the tumors by some kind of applicators. The purpose of this kind of dose delivery is treating the tumors with very high dose and sparing Organ At Risk (OAR) which are near the lesion with very rapid dose fall-off of source.

Accordingly to these restrictions if we could find a device to measure the dose of OARs so we will be in good situation for patient specific quality assurance (PSQA).

Micro silica bead TLDs were introduced as a novel dosimeter by our colleagues from Surrey University in 2014(Jafari et al.). These beads have suite size, linearity in large dose range, having non-toxic chemical components and easy using.

So there was a suggestion for collaboration in using micro silica beads as an in-vivo dosimeter in brachytherapy. We started from cervical cancers which in the most using BT disease.

1. As first step on anthropomorphic female pelvic phantom designed and constructed to allow assembly of the cervical ring applicator (Eckert & Ziegler GmbH) and beads placing on the surface of relevant organs. In this part the ability of the beads in measuring of delivered dose in cervical HDR BT treatments was proved.
2. Right now we are involved in preparing some devices which we can insert the beads in to the patientís body without changing the anatomy and geometry of OAR. This purpose is solved for rectum and bladder till now.
3. Finding a suite protocol of CT scan from our patient is the next step, so we can use portable sonography, at the time of CT scan and treatment for being sure about the position of beads during patient movement from Operation Theater to the BT department.

Also at the last step reading the beads and comparing with the reported dose by the treatment planning software will done.

David Bradley
Sunway University (Malaysia) University of Surrey

David Bradley (PhD (USM), MSc (London), BSc (Essex)) is Emeritus Professor of Radiation and Medical Physics at the University of Surrey. He has taught and researched in Universities for some 35 years. For some 14 years he directed MSc programmes in Medical Physics. He was for six years the Secretary of the International Radiation Physics Society (IRPS), currently is its President and is a past Editor-in-Chief of the British Journal of Radiology. He is Consulting Editor to the Elsevier journals 'Applied Radiation and Isotopes' and 'Radiation Physics and Chemistry', previously being Editor in Chief of both. Dr Bradley is the author of over 400 publications and has made more than 150 presentations at Conferences. His research interests are in the interactions of radiation in matter as well as their applications in biomedical areas and in industry.He spends a large proportion of his time at the Centre for Biomedical Physics, Sunway University in Malaysia.

Keynote address: *Doped-silica real-time luminescence sensing of radiation*

We discuss development of Ge- and P-doped silica fibres for luminescence dosimetry with the focus on real-time radioluminescence (RL). Particular points of interest are magnitude of signal (namely exposure sensitivity) and rates of change. Comparative rates of defect filling are discussed for a given dose-rate, from initiation of exposure through to stable response, as are de-trapping rates on exposure termination through to return to baseline and range of sensitivity, from detection threshold to saturation. These have importance in regard to the ultimate utility of such fibres, not least for high duty cycle pulsed beams or short duration (sub-millisecond) exposures. From a non-dosimetry perspective, the RL assembly based on these fibres provides for what could be referred to as defectoscopy, response being dependent on defect density, distribution and mobility. In prior TL studies, various manipulations of the media were carried out in efforts to improve the radiation sensitivity, also providing a measure of defect density and depth, from superficial to deep. What is clear is that the extent to which radiation response can be regarded useful will depend on the particular application. Examples include a need to provide high sensitivity at low dose but more limited sensitivity for higher dose regimes, in the latter case seeking to avoid saturation. The RL system herein makes use of just two of a range of fibres evaluated in such studies, all MCVD-produced, with subsequent pulling of preforms to obtain fibres of the desired cross-sectional dimensions, also creating strain-related defects.

In regard to use of RL in diagnostic x-ray regimes, we have compared the signal originating from Ge- and P-doped silica optical fibres and commercial nanoDot Al2O3:C dosimeters, the RL signal being guided through PMMA optical fibre cables to obtain real-time measurements. For the doped fibres the manifest absence of an appreciable memory effect or afterglow favours their use in real-time evaluations. For well calibrated systems, an additional opportunity would be for rapid termination of exposure in the event of for instance erroneous operator settings, in effect providing a safety circuit/switch.

Jérôme Benoit
Specialist in Veterinary Diagnostic Imaging and Radiation Oncology, Oncovet
American and EBVS recognised Specialist in Radiation Oncology
2005 Graduated from Veterinary School of Lyon, France
2009 Completed a Radiation Oncology Residency in North Carolina, USA
2010 Diplomate of the American College of Veterinary Radiology ñ Radiation Oncology
2015 Diplomate of the European College of Veterinary Diagnostic Imaging ñ add. rad. Oncol.

Currently Head of Radiation Oncology, Oncovet, Villeneuve díAscq,France. Consultancy work for other European institutions

Voluntary Work:
ESVONC EC - Member-at-Large (2015 to present)
ESVONC - Head of Scientific Committee (2016 to present)
ECVDI - Member of the Scientific Committee (2017 to present)

ECVDI - Member of the ROECC (2018 to present)
IAEA - Member of the Veterinary Radioprotection Task Group (2015-2018)

Keynote address: *State of the Art Radiotherapy and Dose QA in Veterinary Radio-Oncology / The role animal "patients" may be able to play in cancer research*

From the very early days of (RO) times, radiotherapy has been used on animals in clinical veterinary and research settings. Yet, Veterinary Radio-Oncology (RO) has really emerged as a discipline in the 80's and the first College of specialists was established in the USA in 1992. Today, veterinary oncology knows an exponential rise globally and radiotherapy is becoming more available in academic as well as private institutions with the use of State of the Art equipment and techniques (3D-CRT, IMRT, VMAT, SRS; HDR brachytherapy).

The large majority of our animal "patients" are pets, suffering from spontaneous malignancies and being treated with a multimodal approach (surgery, RT, chemotherapy, and immunotherapy). The RO principles are comparable in all aspects to human medicine (dosimetry, planning, patient positioning, QA). Only RT protocols tend to be slightly less fractionated (RT under anaesthesia, no risk of very delayed toxicity).

Large animal models (canine) are perfectly suited for RO-based research because their size allows better comparison with humans. Healthy laboratory dogs were used in the past to evaluate normal tissue tolerances to various irradiation regimens. The first patients to undergo whole body RT were canine patients with lymphoma in the late 70's. Nowadays, client-owned dogs with cancers are taking part of numerous clinical trials for human and veterinary research.

Beyond our motivation to provide the best possible care for our patients, the more demanding technology involved (e.g. SRS), and the use of dogs, as models in research are reasons to further develop accurate dose QA methods and dose monitoring. Animals undergoing RT are not considered as patients by the Authorities yet there is a growing interest in the protection of animals being exposed to medical radiations (ICRP Task Group 110).

Sonja Wegener
University of Würzburg, Department of Radiation Oncology, Germany
Sonja Wegener has been working as a medical physicist at the University of Würzburg since 2013. She aims to obtain her PhD this year for her work on dosimetry in non-equilibrium situations, such as in small fields, at the field edge, out of field, near the surface and in magnetic fields. For her master thesis she evaluated a transmission detector for patient-specific plan QA. In a current project in collaboration with our radiation oncologists, her group performs in-vivo measurements around patient-individual bolus devices.

Keynote address: *In-vivo dosimetry for head and neck treatments*

Head and neck plans typically include dose application in inhomogeneous regions where dose computation is potentially less accurate than deeper in homogeneous media. For example, the desired high dose region often extends to the patient surface. There, the reduced dose in the build-up region of MV photon beams can be compensated by adding bolus material onto the skin. Although normally used for this purpose, standard bolus sheets often leave air gaps between the bolus and the patient surface, which may alter the dose distribution. Further, dose to structures around nasal or oral cavities or near added materials needs to be verified. For all these reasons, it is desirable to perform in-vivo measurements on individual patients to verify planned dose distributions.

The applicability of different in-vivo surface dose measurements (MOSFET, radiochromic film) was analyzed on a simple slab phantom and for treatments of the head and neck region of an anthropomorphic phantom. Additionally, patient surface doses were measured using Gafchromic film for irradiations with bolus. Differences between planned and applied doses were studied for both, fields from conventional beams as well as volumetric modulated arc therapy (VMAT) treatments. Air gaps between the patient surface and the bolus were quantified from cone beam CT images. Surface dose as a function of gap diameter was measured and compared to the TPS calculations.

While usable on the surface, both MOSFET and radiochromic film are impractical for intracavitary measurements. Alternative dosimetry approaches need to be tested for these applications.

Ana Folgueras,
Elekta, UK

Ana Folgueras is Team Leader of Radiation Physics within the Physics and Research group of Elekta. In her current role, Ana combines developing her team with contributing to a variety of research and development activities. Since joining Elekta in 2013 as an R&D physicist, she has been involved in bringing several innovative products into clinical use, such as Unity, iViewDose (Elekta Portal Dosimetry solution) or AQUA (Elekta QA management solution). Before joining Elekta, Ana previously worked in a radiotherapy department in Germany after getting her Medical Physics Expert degree in Spain. Ana has an MSc in Physics with post-graduate studies in Theoretical Solid State Physics.

Keynote address: *Approaches to dose monitoring for safer radiotherapy: a manufacturer's perspective*

With the increasing demand on modern radiotherapy to perform the most advanced treatment techniques whilst sustaining a very high patient throughput, large and small clinical centres all around the world face the everyday challenge of delivering safe, efficient and high-quality treatments. As a manufacturer, how can we ensure the safety of our treatment solutions and help our customers to deliver the highest possible quality in their treatments?

This presentation will discuss the potential hazards that may occur as part of the radiotherapy workflow, with a focus on those that could take place during the treatment delivery and how they could be detected with on-line dose monitoring and patient-specific Quality Assurance solutions. An overview will be given of different methods that are available for use with Elekta systems, including in-vivo dosimetry, and how they provide risk control measures towards safer radiotherapy.

Sarah Wilby,
Portsmouth Hospitals NHS Trust, University of Portsmouth
Antony L. Palmer, Portsmouth Hospitals NHS Trust, University of Portsmouth, University of Surrey
Wojciech Polak, Portsmouth Hospitals NHS Trust
Rochdi Merzouki, University of Lille

Deformable Pelvic Phantom for 3D/4D Dosimetric Quality Assurance of a New Robotic LDR/HDR Brachytherapy Device

We describe the development of a novel deformable phantom for the dosimetric verification of a new robotic brachytherapy device.

Prior to clinical acceptance of any new technique, thorough validation is required; firstly for patient safety but also for justification of investment. To achieve this for the new robotic brachytherapy device, a deformable, anthropomorphic pelvic phantom is being designed, with tissue mimicking properties and radiation measurement functionality.

The authors will firstly present an evaluation of potential 3D dosimeters for the phantom. This includes work underway on the use of silica beads as an array of measuring points within a deformable matrix, focussing on their suitability for brachytherapy sources, Co-60, Ir-192, and I-125 seeds. The possibility of using deformable 3D dosimeters for the phantom, including polymer gel and radio-chromic materials will also be covered.

Secondly we will present details of deformable materials with appropriate tissue mimicking properties of prostate and perineal skin based on the literature and early experimental work. 3D printing has been used in the phantom development project to obtain realistic prostate moulds from clinical MR datasets and for manufacturing the pelvis. The benefits and pitfalls of 3D printing determined to date will be discussed.

This work is part of the CoBra (Cooperative Brachytherapy) project, funded by EU Interreg 2 Seas body and many institutions across northern Europe, led by the University of Lille. The primary aim is to develop innovative technology for robotic biopsy and brachytherapy under MRI guidance. The main deliverable will be a robotic arm for both biopsy and brachytherapy treatment (LDR and HDR), utilising a small number of perineal puncture needles, with high precision and accuracy.

Conor K McGarry, Northern Ireland Cancer Centre, Belfast City Hospital and Queen's University Belfast

Craig McCreery, School of Mechanical and Aerospace Engineering, Queen's University Belfast,

Prakash Jeevanandam, Northern Ireland Cancer Centre, Belfast City Hospital

Sarah O Osman, Queen's University Belfast

Raymond B King, Northern Ireland Cancer Centre, Belfast City Hospital

Alan R Hounsell, Northern Ireland Cancer Centre, Belfast City Hospital, and Queen's University Belfast

Suneil Jain, Queen's University Belfast

Fraser Buchanan, Queen's University Belfast

A bespoke modular 3D printed pelvis phantom for validation of prostate SABR with dominant intra-prostatic lesion (DIL) boost regions.

Introduction
Patients with prostate cancer are increasingly receiving a boost dose to dominant intra-prostatic lesions (DILs) as part of their radiotherapy treatment. Validation of the dose to the boost region is challenging due to the small volume. The aim of this investigation was to 3D print a patient-specific phantom to validate prostate SABR boost plan.

Method
The patient outline and bone structure were segmented on their CT scan using the treatment planning system. A cylindrical module positioned at the location of the prostate was added and used to encapsulate dosimeters (film and pinpoint ionization chamber (PP)). Each element was printed using a RepRap X400 3D printer. The bone was printed using Stonefil filament with variable infill. The pelvis and dosimetry inserts were printed using PETG as shells and filled with water.

A SABR plan was delivered to the phantom with film placed through the boost region and a PP placed at positions within the prostate and boost regions. The films were compared to the dose calculation using the FilmProQA with global gamma analysis performed using a 2%/2mm criteria and 10% threshold. The plans were recalculated on the phantom and directly compared with the original patient plan using the Verisoft software (global gamma analysis at 1%/1mm and 10% threshold).

Results
Outlines of the external contour and the bones were consistent between the phantom and patient CT scans. Dose comparisons between the phantom and patient plan calculation revealed 99.0±0.3% of pixels were within 1%/1mm. Prostate and boost point doses were within ±1.5% of expected. Pass rates for film were > 91% at 2%/2mm and > 98.5% at 3%/3mm. Areas of failure coincided with air gaps between the slices of the phantom.

Conclusions
A bespoke pelvic phantom was designed, constructed and validated to ensure the safe delivery of SABR prostate boost plans.

Hima Bindu Pitta, Department of Physics, University of Surrey, United Kingdom, Department of Physics, Osmania University, Hyderabad, India

Chutima Termsuk, Department of Physics, University of Surrey, United Kingdom

Matthew Taggart, Department of Physics, University of Surrey, United Kingdom

Annika Lohstroh, Department of Physics, University of Surrey, United Kingdom

Experimental verification of consistency of micro-silica glass bead thermoluminescent detectors for neutron irradiation and variable parameters

A series of experiments have been performed to investigate the thermoluminescent (TL) yields from micro-silica beads irradiated in mixed neutron gamma fields produced by an AmBe neutron source immersed in a water tank. The beads were purchased from M/S Toho, Czech Republic and read-out using a Risø reader. The study considered experimental variations like ambient light effects, the neutron source bead distance, and changing the delay between irradiation and readout. Previous work had identified TL yield spikes, when similar beads had been irradiated at a range of distances from the neutron source in a similar geometry, but different read-out system. However the origin of the spikes could not be confirmed.

In this work, sets of beads were initially irradiated at a constant distance from the neutron source in order to establish their baseline response to the mixed radiation field. The same sets of beads were also exposed to the neutron gamma field arranged on a string with distances from the source ranging between 2 cm and 45 cm.

Here, we will present the TL yield of the micro silica beads as a function of distance which shows the combined effect of the geometry effects and the reduction in neutron moderation, resulting in the expected substantial fall-off in signal within a few cm from the AmBe source. The quasi-regular spikes in the thermoluminescence intensity observed in earlier studies can also be seen in this work which confirms that they are not specific to one glass bead make or dimension. There is some sub-structure that can be observed for the fixed distance measurements, which will be discussed.

M. Sumini, Industrial Engineering Department, Alma Mater Studiorum University of Bologna

L. Isolan, Industrial Engineering Department, Alma Mater Studiorum University of Bologna

S. Jafari, Trueinvivo Ltd, QA Hospital Portsmouth, University of Surrey

D. Bradley, Sunway University (Malaysia) & University of Surrey

Micro-silica beads sensitivity analysis in phantoms via direct and adjoint Monte Carlo Calculations

Considering previous experimental results, obtained in [1] using micro-silica beads TL dosimeters [2], the beads sensitivity has been tested through direct and adjoint calculations in Monte Carlo MCNP models [3]. We used a computational PMMA phantom for the calibration of the X-rays irradiation emitted by a Plasma Focus device for medical applications. The multigroup/adjoint capabilities of MCNP have been used for this problem where the detector region is relatively small with respect to the source. The generation of adjoint importance function to enhance the efficiency in the continuous energy or forward multigroup estimations has been exploited. This allowed the evaluation of the representativeness of our experimental results with respect to the effective source.

[1] Marco Sumini, Lorenzo Isolan, Francesco Teodori, David Bradley, S. Jafari, Francesca Mariotti, Francesca Buontempo. Dosimetric Analysis and Experimental Setup Design for In Vivo Irradiation with a Plasma Focus Device. Radiation Physics and Chemistry - Volume 155, February 2019, Pages 17-21. https://doi.org/10.1016/j.radphyschem.2018.06.025.

[2] Jafari, S.M., et al., 2014. Glass beads and Ge-doped optical fibres as thermoluminescence dosimeters for small field photon dosimetry. Phys. Med. Biol. 59, 6875ñ6889.

[3] John C. Wagner, Everett L. Redmond II, Scott P. Palmtag, John S. Hendricks. MCNP: Multigroup/Adjoint Capabilities. LA-12704, Los Alamos National Laboratory.

Chutima Termsuk, Department of Physics, University of Surrey, Guildford UK

Annika Lohstroh, Department of Physics, University of Surrey, Guildford UK

Caroline Shenton-Taylor, Department of Physics, University of Surrey, Guildford UK

Directionality studies of the light emission from optical fibre thermoluminescent dosimeters

Previous work has shown the suitability of commercial optical fibres subjected to a variety of radiation beams for use as thermoluminescent (TL) dosimeter. Most of the previous experiments use TL dosimeter readers to acquire TL yields. The fibre dosimeters are a tiny cylindrical shape on the microscale with slight difference of refractive index (n) between the core and cladding, which normally ensure transmission of light signal along the core for light entering the fibre within the acceptance angle. For the luminescence light generated within the fibre The preferential TL emission direction out of the sample has been unclear. The optical fibres purchased from CorActive (Canada) were used in this work. Approximately 5 mm long undoped fibres were investigated for the comparison of light emission from the outer cylindrical surface of the fibre and the cross sections of both ends. Approximately7 mm long fibres were used to study the light distribution along the length 1 to 5 mm of surface fibre. All samples were irradiated at 10 Gy using a Riso TLD/OSL system which contains a Sr-90 radioisotope source. Fibres were subsequently readout in the same machine one-day post-irradiation. . The majority of the TL yield for the 5 mm long fibres at 77.79±0.04% originates from the fibre surface and 18.15±0.01% from the cross section at both ends. The light emission detected from the cylindrical surface of fibre increases linearly as the length of fibres was extended, which shows that the TL yield of the surface contribution fibre has a uniform contribution with R^2 value of 0.977. An average TL signal from the undoped cylindrical fibre surface is 9814±6 counts per Gy per mm.

Richard P. Hugtenburg, Swansea University Medical School, Singleton Park, Swansea SA2 8PP, U.K.,Department of Medical Physics and Clinical Engineering, Swansea Bay University Health Board, Swansea SA2 8QA, U.K., HH Wills Physics Laboratory, School of Physics, University of Bristol, Bristol, BS8 1TL

M. Arif M. Hanifa, Swansea University Medical School, Singleton Park, Swansea SA2 8PP, U.K.

Jaap J. Velthuis, Swansea University Medical School, Singleton Park, Swansea SA2 8PP, U.K., HH Wills Physics Laboratory, School of Physics, University of Bristol, Bristol, BS8 1TL

The use of diamond detectors for real-time, in-vivo dosimetry of intensity modulated radiotherapy

Intensity modulated radiotherapy (IMRT) is characterised by large variations in the radiation intensity traversing the patient. It is typically assumed that point detectors placed on the patient are not effective for in-vivo dosimetry due to enhanced uncertainties. Chemical vapour deposition (CVD) electrical conductivity diamond detectors offer high sensitivity at high spatial-resolution, and excellent tissue-equivalence. Diamond detectors therefore have the potential to achieve high-orders of dosimetric precision motivating an examination of their use in real-time dosimetry, including pre-treatment verification and in vivo dosimetry. Measurements of open and intensity modulated radiation fields delivered by a medical linear accelerator (LINAC) have been performed and sufficient temporal resolution was achieved to quantify the dose in individual LINAC pulses as small as 5 µGy, when the beam is strongly attenuated by the multileaf collimator (MLC) system. Analysis of the pulse structure enables accurate assessment of variations in the leakage current and the instantaneous dose-rate for which small corrections are then able to applied. Pulse counting enables the measured dose to be compared to planned dose at defined control-points, because the pulse count is closely associated with the LINAC monitor unit (MU) output. New methods for quantifying agreement of the measured cumulative dose against the expected dose as defined in the treatment plan are demonstrated and heuristics for determining the failure of treatment at doses less than the prescribed dose, but that could lead to a dangerous or reportable errors, are examined. Diamond detectors are shown to offer advantages over other forms of point detection that support further consideration of their use as an in vivo dosimeter suited to modern intensity modulated techniques.

E.G.Villani, STFC Rutherford Appleton Laboratory, Particle Physics Dept., UK

M.Crepaldi, IIT, Istituto Italiano di Tecnologia, Politecnico di Torino, Italy

D.DeMarchi, IIT, Istituto Italiano di Tecnologia, Politecnico di Torino,Italy

A.Gabrielli, Physics Dept., University of Bologna and INFN, Italy

A.Khan, Dept. of Electronic and Computer Engineering, Brunel University, UK

E.Pikhay, TowerJazz Semiconductor Ltd., Migdal Haemek, Israel and Technion, Haifa, Israel

Y.Roizin, TowerJazz Semiconductor Ltd., Migdal Haemek, Israel and Technion, Haifa, Israel

A.Rosenfeld ,CMRP, University of Wollongong, Australia

Z.Zhang, STFC Rutherford Appleton Laboratory, Particle Physics Dept., UK

A monolithic 180 nm CMOS dosimeter for wireless In Vivo Dosimetry

The design and development of a monolithic system-on-chip dosimeter fabricated in a standard 180 nm CMOS technology is described. The device is intended for real time In Vivo measurement of dose of radiation during radiotherapy sessions. Owing to its proposed small size, of approximately 1 mm3, such solution could be made in-body implantable and, as such, provide a much-enhanced high-resolution, real-time dose measurement for quality assurance in radiation therapy. The device transmits the related information on dose of radiation wirelessly to an external receiver operating in the MICS band. The various phases of this two years project, including the design and development of radiation sensors and integrated RF to perform the readout, will be described.

Lana Beck, University of Bristol, Physics Department

Novel approaches to contamination suppression in upstream detectors for radiotherapy

IMRT treatments are becoming increasingly complex with higher dose rates and higher energy beams. Therefore, methods to verify the accuracy and precision of the treatment delivery in real time are becoming increasingly necessary. Measuring beam intensity fluctuations downstream is difficult as the beam is heavily distorted after leaving the patient and upstream detectors will attenuate the beam. Monolithic Active Pixel Sensors (MAPS) are ideal detectors to measure the 2D beam profile of a radiotherapy beam upstream. MAPS sensors can be made O(~20µm) while maintaining very good signal-to-noise performance. This means that the beam would pass through the sensor virtually undisturbed (<0.1% attenuation). Large area devices (~15x15cm^2) have been produced and can be tiled 2x2 to cover the full beam area. MAPS can be made radiation hard enough to be fully functional after a large number of fractions. All this makes MAPS a very realistic sensor candidate for upstream monitoring. A remaining challenge for thin, upstream sensors is that the detectors are sensitive to the signal of both therapeutic photons and electron contamination. In current dosimetry devices, the photons are converted in a layer of PMMA into signal generating electrons to be detected, making the electron contamination negligible in comparison. However, this extra material can lead to devices with absorptions of up to 10% of the beam that change the beams energy spectrum.

We have demonstrated a method to distinguish between the signal due to electrons and photons and thus real dosimetry information, in very thin sensors. This is in addition to high resolution MLC position monitoring in real-time, which would allow the treatment to be halted if deviations from the plan occur. Our method involves patterning the sensor so the beam passes through different material thicknesses allowing the two signals to be disentangled and does not require Monte Carlo simulation.

C. De Sio, University of Bristol,

J. J. Velthuis, University of Bristol, Swansea University, University of South China

L. Beck, University of Bristol

R. P. Hugtenburg, Swansea University

J. Pritchard, University of Bristol

Towards an AI-driven real time verification of Radiotherapy treatments

Monolithic Active Pixel Sensor (MAPS) devices are an effective tool for upstream verification of Intensity Modulated Radio Therapy treatments. It is crucial to measure with high precision the positions of the Multi Leaf Collimators (MLC) used to shape the beam, in order to enhance the quality and safety of treatments.

This work describes a two-step procedure applied to the problems of leaf detection and position reconstruction. This procedure represents the building block towards the definition of a real-time capable of detecting and reconstructing the position of the MLC used in the everyday radiotherapy treatments. A Fully Convolutional Neural Network model is used to analyse the high-resolution images produced by Lassena MAPS devices in order to automatically detect the multiple leaves. A Random Forest regression model is then applied to estimate the positions of the detected leaves.

The dataset used in the experiments contains 1200 images, referring to 4 leaf positions in the range 1-25 mm, split in training and test sets with the 80% and 20% of the total samples, respectively. Performance has been evaluated using the Dice loss coefficient for leaf detection, and mean squared error (MSE) as for leaf position estimation. The proposed approach obtained an average Dice loss coefficient of 0.85 ±0.03 on the images in the test set; the MLC positions are estimated with a MSE of 0.04, and a resolution of 68± µm on the same images.

Ian Hanson, The joint Department of Physic, The Royal Marsden NHS Foundation Trust and the Institute of Cancer Research

James Bedford, The joint Department of Physic, The Royal Marsden NHS Foundation Trust and the Institute of Cancer Research

Nia JOnes, The joint Department of Physic, The Royal Marsden NHS Foundation Trust and the Institute of Cancer Research

Patrick Downes, The joint Department of Physic, The Royal Marsden NHS Foundation Trust and the Institute of Cancer Research

D & 4D dosimetry in practice

In-vivo dosimetry can be an important tool in ensuring the safe delivery of radiotherapy, especially when considering the trend towards daily adaptive and hypo-fractionated treatments. Since 2008 the Royal Marsden Hospital has been using an in-vivo dosimetry system based on the electronic portal imaging device (EPID) [1]. Initially 2D analysis [2], this has been expanded to a full 3D analysis [3] where the EPID measured dose is reconstructed on the patients CT scan and compared to the expected planned dose using a 3D gamma-analysis (criteria 3%, 3mm). In-vivo measurements are now routinely performed for the majority of our radical and palliative patients, with over 12,500 patients (with greater the 14,800 treatment plans) having undergone this measurement. We will show the % agreement between a reference point in the EPID reconstructed dose and the expected dose for these plans, illustrating the good agreement that is seen.

Current work is looking at making this in-vivo analysis more streamlined by reducing the number of patient-specific measurements required [4]. It is expected that this work will also lead to a fully automated solution, where only those measurements outside of tolerance are brought to the attention of a duty physicist [5].

Additional work has looked at modifying a complementary EPID dosimetry system [6] to allow 4D in-vivo measurements of volumetric modulated arc therapy (VMAT) treatments. Phantom studies will be shown that demonstrate that this system is capable of detection gross errors in delivery in real-time.

[1] Hanson IM, Hansen VN, Olaciregui-Riuz I, van Herk M, Clinical implementation and rapid commissioning of an EPID based in-vivo dosimetry system. Phys Med Biol. 2014;59:N171-N179

[2] Wendling M, Lowe RJW, McDermott LN, Sonke J-J, Van Herk M, Mijnheer BJ. Accurate two-dimensional IMRT verification using a back-projection EPID dosimetry method. Med Phys. 2006;33(2):259-273.

[3] Mans A, Remeijer P, Olaciregui-Ruiz I, Wendling M, Sonke J-J, Mijnheer BJ, et al. 3D Dosimetric verification of volumetric-modulated arc therapy by portal dosimetry. Radiother Oncol. 2010;94(2):181-187

[4] Pecharroman-Gallego R, Mans A, Sonke J-J, Stroom J, Olaciregui-Ruiz I,van Herk M, Mijnheer B. Simplifying EPID dosimetry for IMRT treatment verification. Med Phys. 2011;38:983-992. 10.1118/1.3547714

[5] Olaciregui-Ruiz I, Rozendaal R, Mijnheer B, van Herk M, Mans A,. Automatic in vivo dosimetry of all treatments. Phys. Med Biol. 2013;58:8253-8264. 10.1088/0031-9155/58/22/8253.

[6] Bedford JL, Hanson IM, Nordmark Hansen V. Portal dosimetry for VMAT using integrated images obtained during treatment. Med Phys. 2014;41:021725.

Jaap Velthuis, University of Bristol,

Using a TRAPS Upstream Transmission Detector to Verify Multileaf Collimator Positions during Dynamic Radiotherapy Delivery

The advancement of radiotherapy treatments towards higher precision, higher dose rates and higher energies necessitates new means of monitoring treatments to detect errors. Here we propose using Monolithic Active Pixel Sensors (MAPS) to monitor dynamic treatments in which the multileaf collimators, which shape the beam, are continuously moving. This is a 2D+1 measurement in real-time. We use the TRAPS system consisting of the Achilles sensor, DAQ and custom firmware. A number of image processing techniques were applied in order to perform field-edge extraction.

Leaf errors as small as 0.5 mm, which is well within the MLC positioning accuracy of 1 mm, can be detected with high precision in static fields and IMRT step and shoot, and accurate leaf tracking is possible in Volumetric Modulated Arc Therapy. With the Achilles reading out at 41 frames per second, we show that it is possible to track leaves with speeds up to 3.5 cm/s. Comparison of the measurements from the TRAPS to the treatment planning system could result in automatic halting of the treatment if a deviation from the plan were to occur.

The Achilles has been shown to have an attenuation of 1.04 ± 0.03%, where a 1% attenuation is the benchmark for clinical use. As a significant proportion of the silicon in the sensor is there for support, it can be thinned significantly, reducing the attenuation. Hence it is possible to have the TRAPS system present for all treatment fractions. Future work will focus on a bigger detector capable of measuring a broader range of field sizes and higher beam energies.

A.Axford, CVSSP, University of Surrey

N.Dikaios, CVSSP, University of Surrey

D.Roberts, Elekta

C.H.Clark, National Physical Laboratory

P.Evans, CVSSP University of Surrey

Assessing the Accuracy of Adaptive Radiotherapy for Changes in Target Shape and Position in the Elekta MR-linac

Systems combining magnetic resonance imaging with external beam radiotherapy have the potential to significantly improve image guided radiotherapy capabilities. The Elekta Unity (Elekta AB, Stockholm, Sweden) is an MR-guided system composed of a 1.5T Phillips magnet, and a 7 MV Linac, allowing for simultaneous treatment and imaging with high soft tissue contrast. This enables online treatment plan adaptations to be made based on the patient anatomy while on the treatment couch, with the potential for real time adaptation.

This project aims to assess the accuracy of the Elekta Unit is ability to adapt the treatment plan to changes in the shape and position of a target volume. With some considerations required regarding phantom design and detectors used due to the strong magnetic field, additive manufacturing methods have been used to enable rapid prototyping of a phantom. A prototype test object has been developed which contains a deformable target volume that aims to replicate a 2D representation of a prostate, with realistic shape and position changes that occur to the prostate through the course of radiotherapy. This phantom has been designed to work with the Octavius II phantom and produce both 2D dose distributions, and absolute dose measurements for the target region before and after target changes have been made.

NOTES

8521-0618

FACULTY OF ENGINEERING
AND PHYSICAL SCIENCES

University of Surrey
Guildford, GU2 7XH, UK

surrey.ac.uk