Confidential

Global Challenge Exploration Award

Collaborating to focus STFC physics research in SUPA to address the Global Healthcare Challenges in Medical Imaging

Report on
interdisciplinary workshops
addressing medical imaging and
associated applications

March 2015, Scotland

Executive Summary

The Science and Technology Facilities Council (STFC) has stressed that its research must provide solutions to the challenges faced in healthcare; so research must be implementable and of value in the health system.

The Scottish Universities Physics Alliance (SUPA) and the Scottish Imaging Network A Platform for Scientific Excellence (SINAPSE) ran two STFC-funded workshops with researchers and medical and clinical physics experts to explore the potential of new research to improve medical imaging and impact patient care.

Five minute presentations outlined the scientific concept and potential medical application.

Technology	**Potential clinical applications**
Very high power short pulse lasers	• More focused radiotherapy • Proton beam therapy for neuroscience • Radioisotope production for imaging and therapy
Optic parametric oscillators to produce ultrafast lasers	• Cardiac and liver microscopy
Silicon detection platforms for Positron Emission Tomography (PET)	• Higher sensitivity imaging in whole body PET • Loco regional PET • Interoperative probes • Multimodal scanners
Silicon particle detector technology	• Full spectral CT images • Multi x-ray detection
Medipix silicon detector	• Improved processes for production of radiopharmaceuticals
Microultrasound probes and pill	• Improved resolution of ultrasound • New delivery mechanisms for ultrasound (such as pills and injections) that can reach the area of interest
High power broadband terahertz amplifiers for magnetic resonances	• Increase sensitivity of MRI • Identification of cancer biomarkers
Software to improve signal to noise ratio in PET	• Reduced imaging time, better resolution, lower dose of radioisotope

Small group and plenary discussions explored the potential of the research and proposed areas of focus that would be of most importance in clinical practice – improving image quality closer to the site of investigation and reducing radioisotope dose. Experiences were shared of technology development “from bench to bedside”, noting the challenges of commercialisation, regulatory requirements and the need to understand the value chain, including the clinical desire to improve lesion characterisation and the need to demonstrate value for money.

Discussions also established individual connections between researchers, clinical scientists and clinicians that will enable clinic visits and further cooperation. Networking among researchers was also important to share research findings and commercial experience.

These workshops were helpful in starting discussions that could inform research priorities but more sustained and organised opportunities for such interdisciplinary interaction are needed to foster discussion that will develop basic science into clinically important advances.

Contents

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1. Introduction

The Science and Technology Facilities Council (STFC) has established a Global Challenge Programme to ensure that the research, technology, applications and expertise that it funds in physics, astronomy and space science helps develop solutions to global challenges in energy, environment, security and healthcare. In light of this the Scottish Universities Physics Alliance (SUPA) commissioned a report from Optimat to identify STFC funded research in Scotland that aligns with these priority areas[1]. From 160 STFC funded grants to Scottish Universities, 30 were selected for more detailed review and showed outputs that are highly relevant to the global challenges.

Scotland has a track record of excellent interdisciplinary research to develop technologies that have had a real impact in healthcare. The foremost of these was the development from the 1950s of medical ultrasound by Professor Ian Donald and colleagues. This involved a collaboration including the University of Glasgow, the Health Board and Kelvin and Hughes, a scientific instrument company originally founded by Lord Kelvin. Current research in astrophysics, space science and advances in technology and engineering presents exciting possibilities to improve healthcare – from diagnosis to optimal treatment. The Optimat report identified 18 Scottish projects showing promise in healthcare, but to translate promise into a technology of value, research needs to be focussed on clinical implementation, understanding the clinical pathway, drivers, constraints and regulations that impact the health system.

The STFC Healthcare Global Challenge Programme was established to promote interdisciplinary collaboration to understand these issues and awarded SINAPSE (Scottish Imaging Network A Platform for Scientific Excellence) and SUPA a grant to run a series of stakeholder engagement workshops with physics researchers and leading medical experts and clinical physicists from across Scotland. The focus of the workshops was medical imaging and related techniques, including imaging technology, detectors, radioisotope production, radiotherapy and medical informatics. The priority areas outlined for the Challenge Led Applied Systems Programme (CLASP) call 2014 summarise the areas of interest (Box 1).

This report summarizes two stakeholder engagement workshops. Section two outlines the purpose and format of the workshops. Sections three and four summarize presentations, discussion and learnings from the workshops. The final section makes proposals to strengthen interdisciplinary collaborations to inform research priorities.

[1] Optimat. Global challenges opportunities from STFC funded research. April 2014.

Box 1. CLASP Priorities for healthcare

Radioisotopes
- New methods for the production of medical radioisotopes for 99Tc as well as other new radioisotopes for diagnosis and therapy.
- New detectors for novel radioisotopes.

Imaging Technology (ensuring high efficiency and high throughput)
- Software solutions and data processing methods for improved pattern recognition and more quantitative medical imaging.
- New software for digital imaging.
- New imaging technology e.g. allowing reduced doses, imaging though fat.
- New imaging technology and software for the management of organ movement.

Medical Informatics
- New software allowing integration of data from multiple sources e.g. combining imaging, biological and genetic data, to aid personalized medicine.

Early Diagnosis
- New technology developed for use in GP surgeries and hospitals as well as at home e.g. high and low tech imaging.
- Software tools for data collection and sharing for GPs, as well as combining data sets for personalized screening and stratified medicine.
- Software tools for risk analysis and predictive modelling to inform personalized screening.
- Remote sensing to measure multiple parameters e.g. breathing patterns.

2. Methods

Two interdisciplinary workshops were undertaken in March 2015. The objectives of each workshop were to:
- initiate dialogue between physicists and leading clinicians about the potential of new research in STFC global healthcare challenges areas
- consider future clinical/physics collaborations to ensure implementation issues are built into future research plans.

The workshops included medical and clinical physics experts, with an experienced facilitator to stimulate discussion. A third workshop is planned in May 2015 to discuss this report and develop ideas to strengthen an interdisciplinary network to support physics research that is focussed on medical needs and enhance networking in the physics community. It will focus on engagement with industry.

Approximately 20 people attended each workshop as outlined in Appendix 1. The meeting began with an introduction to the STFC Global Challenge initiative from Keith Dingwall STFC IPS Fellow at SUPA. This was followed by six short presentations from physicists. Clinical experts then asked questions in plenary. Discussion continued in small groups over dinner, encouraged by the organisers. The facilitator then asked for key points of feedback about the potential of the research, challenges in technology development and opportunities for collaboration. Professor David Wyper from SINAPSE closed with reflections and next steps.

3. Workshop presentations

Imaging developments

Medical applications of laser plasma accelerators - Jaroszynski, Wiggins (University of Strathclyde), Glasgow & Edinburgh workshops

Technology
The Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) is a flagship SUPA initiative based at the University of Strathclyde which uses very high power (multi-terawatt) short pulse lasers that can be used to generate high energy bunches of electrons, protons and light ions or to produce radioisotopes.

Clinical applications and discussion
High-energy electrons or ions could provide more focussed radiotherapy (tested in cancer cell lines), but there are engineering challenges associated with delivering this.
Proton beam therapy has limited clinical applications – only in paediatric neuroscience.
Alternatives to current methods for radioisotope production in nuclear reactors could be valuable, but regulatory requirements for quality control must be enacted. Proof of principle studies on production of the copper-62 radioisotope suggest that there is scalability, but application to other isotopes and consideration of half-life and distribution is needed. There is potential to produce actinium 225 for targeted alpha therapy. The importance of having a "pure" product (99.5%) for clinical use and the need to achieve scalability of processes was stressed.

Ultrafast laser technologies: telescopes to microscopes – Leburn (Heriot-Watt University), Edinburgh workshop

Technology
Optic parametric oscillators (OPOs) have been developed to create broad bandwidths that are necessary for precision calibration of longer wavelengths. Chromacity are a spin-out from Heriot-Watt University to commercialise this technology in life sciences microscopy which has emerged through research funded by STFC in collaboration with the UK ATC. Chromacity's laser architecture is air cooled (not water cooled), which has allowed development of a smaller unit that is stated to be less expensive than current competitors.

Clinical applications and discussion
OPOs could allow cardiac and liver microscopy down to 1.5 micron. This smaller, low maintenance technology could be valuable in clinical practice.

Silicon technology for positron emission tomography (PET) – Stewart, Seitz (University of Glasgow), Glasgow workshop

Technology
PET manufacturers are moving away from photomultiplier tube technology to much smaller silicon device based photomultiplier detection platforms. These are insensitive to magnetic fields, have improved resolution and are lower cost.

Clinical applications and discussion
Silicon detection platforms have the potential to create higher resolution images in whole body PET, loco regional PET imagers (e.g. for brain or breast), interoperative probes and multimodal scanners such as PET/MRI.
Interoperative probes were seen as important developments in the future.

There were different opinions about the value of neuro PET (without CT). Some thought that the high performance, lower cost (estimated 10% of current machines) and increased mobility possible meant that it was an exciting opportunity for development. Others felt that given the lack of treatments for dementia and the short half-life of the radioisotopes required in neuroimaging, its potential was limited. One person suggested that it could be used in stroke and given England's focus on whole body PET there was potential for Scotland to lead in this area. All agreed that there would be high need for neuro PET if an effective treatment for dementia became available.

Novel detection techniques using semiconductor sensors – O'Shea (University of Glasgow), Glasgow workshop

Technology
Dual-energy CT making use of silicon particle detector technology developed for particle physics research to produce full spectral CT images and multispectral x-ray detection.

Clinical application
Improved resolution, particularly to determine bone density.

Applications of the Medipix Detector - Maneuski (University of Glasgow), Glasgow workshop

Technology
Silicon detector developed for particle physics research (Medipix) is being applied in a range of medical imaging applications.

Clinical Applications
Several potential applications, with the current focus being improved production of radiopharmaceuticals. A prototype radioisotope generator has been successfully trialled at Gartnavel Hospital in Glasgow.

Microultrasound packaging for clinical imaging applications – Cochran (University of Dundee), Edinburgh workshop

Technology
Ultrasound provides a low-cost, non-ionizing radiation that can be used in real time at the point of care, but its resolution is poor. Very small probes would be required to produce the higher frequencies that could lead to increased resolution, but this would limit depth of penetration. New microultrasound probes are being developed by making use of advanced device fabrication techniques developed for particle and space physics to overcome these problems.

Clinical applications
Improved resolution of ultrasound and new delivery mechanisms for microultrasound to get the imaging technology closer to the area of interest, e.g. needles in neurosurgery, pill for ultrasound capsule endoscopy could be valuable. In addition to the physical challenges in producing the probes, there will be computational image analysis challenges.

High power broadband terahertz amplifiers for magnetic resonances – He (University of Strathclyde), Glasgow & Edinburgh workshops

Technology
High power broadband terahertz amplifiers for magnetic resonances. This technology allows amplification of terahertz radiation (between microwave and infrared) to high power over a wide frequency band.

Clinical applications
Terahertz radiation is harmless to tissue and DNA, and so is potentially safer than other imaging techniques. It can penetrate clothing and bandages but it is strongly absorbed by water so is only useful for shallow imaging of the skin. It is stated that there is potential to increase the sensitivity of MRI and identify cancer biomarkers through use of Electron Paramagnetic Resonance and Dynamic Nuclear Polarization.

Analytical developments

PET imaging with entangled photons – Watts (University of Edinburgh), Edinburgh workshop

Technology
PET imaging depends on the detection of true coincides. Random uncorrelated coincidences create noise in the image and can form up to 40% of the image; hence sophisticated analysis is needed to correct the image. New data capture and analytical correction methods have been developed to suppress false coincidences and improve the signal to noise ratio. In principle this could be done in real time.

Clinical applications and discussions
This could be used to reduce imaging time or provide better resolution with a lower dose of the radioisotope. The new concept was received favourably. The possibility to retrofit the method onto existing PET devices was discussed. Further contacts for industrial PET manufacturers were suggested as additional possibilities to the existing collaborators.

Hello from the world of astro-physics – Messenger (University of Glasgow), Glasgow workshop

Technology
Traditional (Frequentist) statistical modelling is complex and can be limited by necessary distributional assumptions. Bayesian analysis uses a different theoretical construct that builds on prior information. Greater computing power has seen increased use of Bayesian analysis in all fields to analyse large, complicated datasets. In physics, this has proven valuable in finding very weak signals in gravitational wave astronomy.

Clinical applications
Bayesian analysis could be used to improve medical imaging software, particularly when dealing with large, complicated datasets or situations where data is poorly modelled.

Professor Sandy Cochran presents at the Royal Society of Edinburgh under the watchful eye of Lord Kelvin!

4. Workshop discussions and learnings

Discussions

Glasgow

General discussion about technologies

Improved resolution in medical imaging could lead to better characterisation of lesions, improved edge detection and reduced dosage of radioisotope. It was stressed by one of the reviewers that dose reduction is likely to be more important than improvement in image quality. Some technologies have potential for therapeutics as well as imaging, providing more targeted interventions.

Production of new isotopes is interesting, but given the short half-life of many isotopes there was concern about distribution to the cancer centres across Scotland. A single Centre of Excellence would be needed.

Commercialisation

At the outset of development, a business case is needed that focuses on how the technology will be used in clinical practice – a development plan that goes from bench to bedside.

The time taken to develop research into demonstrator prototypes, scale up and proceed to commercialisation was discussed. Researchers were keen to understand how other groups had commercialised their technologies and to share experiences of what had worked well and good potential collaborators in the UK and internationally.

The importance of understanding regulatory requirements early in the development (particularly in terms of radioisotope production and radiation restrictions) was stressed.

Interdisciplinary collaboration

There was concern that despite Scotland's small size, opportunities for collaboration are being missed and there is a need to think big. Could Scotland be the new Cambridge for medical imaging (i.e. an internationally recognised hub for medical innovation)?

Technologies need to be focussed not only on areas of clinical need, but need to show good value for money. It is essential to understand the value chain.

There was concern raised at the lack of drive from clinical staff to help define areas of highest need (e.g. in terms of isotope development). It was also recognised that new medical training processes and health system pressures (waiting times, 24/7 working etc) are not conducive to research. Specialist trainees are no longer encouraged to undertake research. Innovation should be part of the clinical mindset and clinical research should be encouraged in the health system. To do this there needs to be political buy-in and leadership. Perhaps the most realistic way forward will be for NHS employees to deliver healthcare, including clinical trials; for academics in partnership with industry to undertake research into improved technologies; and to foster strong collaborative networks to harmonise the developments. Such a collaborative network to discuss future research should include:

- academic researchers
- healthcare professionals
- regulators
- health economists
- R&D departments
- Government representatives
- Innovation Centres
- industry.

Edinburgh

<u>Commercialisation</u>

Regulatory requirements need to be understood and opportunities should be taken to meet with the Medicines and Healthcare products Regulatory Agency (MHRA). However, technology development should not be driven solely by regulatory issues; focus needs to be on the route to market. Issues such as place in clinical pathway and procurement methods (who will pay?) need to be addressed in the target product profile.

It is important to be aware of competitors, recognising that if there are competitors there is probably a market.

Some technologies could be developed in a range of directions and it will be important to identify which area will have most clinical impact and for which scalability is possible.

<u>Collaboration</u>

North America is an important region from which to gain opinions and insights.

The importance of early engagement with regulators and clinicians was stressed, recognising that it is important for a technology to be embedded in the clinical pathway and so clinical applications matter, not just the next grant. However, the challenges of getting medical input to research were discussed, given the lack of encouragement for medical staff (both training and consultant grades) to undertake research.

To overcome concerns about intellectual property, clear rules of interaction are required in any collaboration.

Some in Scotland have the experience of setting up small business spin-offs from university research settings. This experience could be shared across Scotland, to the benefit of those academic researchers who have entrepreneurial ambitions (one current and two past STFC/RSE Enterprise Fellows participated in our workshops).

Post-workshops
After the workshops the Global Challenge Exploration Awards template describing potential future research applications relating to healthcare was completed, with input from the presenters. This is presented in Appendix 2.

Workshop learnings

There were some challenges in the first workshop with complex presentations that did not clearly explain potential clinical applications or raise questions for clinicians. The format of the second workshop was altered to reduce the time of presentations from 10 to 5 minutes and allow questions after each presentation. As clinical experts had been chosen so there was at least one expert whose specialism was in the area of research, that expert was able to ask questions about clinical application and the response provided clarification to all attendees.

These workshops focussed on bringing clinical experts together with researchers. It was clear that future workshops should include other disciplines to discuss all aspects of value and promotion of research and innovation in Scotland.

The workshops were led by available physics research. Future workshops could focus on clinical challenges and needs for medical imaging.

5. Conclusions

These two three-hour workshops brought together leading physicists in Scotland with front-line clinical experts – scientists and doctors. A range of exciting developments in physics were presented, which could be developed in different directions.

Discussions with clinical practitioners and applied scientists helped identify areas in which research could be focused and some individual connections were established that will allow researchers to visit clinics and understand clinical use of technology. The opportunity for researchers to network was also important, to understand implications of others' research and share experiences about technology development and commercialisation. The feedback given at the meeting will start to inform research and development priorities, but more opportunities for such interdisciplinary interaction are needed.

There is an opportunity for Scotland to take a lead in interdisciplinary collaborative research to develop innovative medical imaging technology that can meet global healthcare needs. However, it will be important to establish and maintain strong links with centres throughout the UK where there are several academic groups working on technologies for application in medical imaging and also several companies with established market credentials.

It was agreed that broader discussions including other disciplines would be helpful, because as one participant said "we need meetings like this to shape our stunning science".

Appendix 1. Workshop participants

Glasgow workshop – 5 March 2015

Physicists			
Dr	Dima	Maneuski	University of Glasgow
Dr	Christopher	Messenger	University of Glasgow
Prof	Val	O'Shea	University of Glasgow
Dr	Bjoern	Seitz	University of Glasgow
Dr	Andrew	Stewart	University of Glasgow
Dr	Wenlong	He	University of Strathclyde
Prof	Dino	Jaroszynski	University of Strathclyde
Dr	Mark	Wiggins	University of Strathclyde
Dr	Rui	Prazeres	Université Paris Sud
Clinical experts			
Dr	Iain	Robertson	NHS Greater Glasgow and Clyde Health Board
Prof	Donald	Hadley	NHS Greater Glasgow and Clyde Health Board
Dr	Jonathan	Owens	NHS Greater Glasgow and Clyde Health Board
Dr	Gerry	Gillan	NHS Greater Glasgow and Clyde Health Board
Dr	Brian	Neilly	NHS Greater Glasgow and Clyde Health Board
Dr	Jozien	Goense	University of Glasgow
Dr	David	Dickie	University of Edinburgh
Organisers			
Mr	Keith	Dingwall	SUPA
Prof	David	Wyper	SINAPSE
Dr	Karen	Facey	Evidence Based Health Policy Consultant (Facilitator)

Edinburgh workshop – 9 March 2015

Physicists			
Prof	Sandy	Cochran	University of Dundee
Prof	Dan	Watts	University of Edinburgh
Dr	Gary	Smith	University of Edinburgh
Dr	Christopher	Mountford	University of Edinburgh
Dr	Rob	Mairs	University of Glasgow
Mr	Joel	Fearnley	Chromacity Lasers, Heriot-Watt University
Dr	Christopher	Leburn	Heriot-Watt University
Dr	Wenlong	He	University of Strathclyde
Dr	Mark	Wiggins	University of Strathclyde
Clinical experts			
Prof	Kurt	Anderson	Beatson Cancer Institute, Glasgow
Prof	George	Corner	University of Dundee
Dr	Bill	Nailon	University of Edinburgh
Prof	Ian	Marshall	University of Edinburgh
Dr	Adriana	Tavares	University of Edinburgh
Prof	Alex	Elliott	University of Glasgow
Prof	Rory	Duncan	Heriot Watt University
Industry expert			
Mr	Bill	Blair	Edinburgh Bioquarter
Organisers			
Mr	Keith	Dingwall	SUPA
Prof	David	Wyper	SINAPSE
Dr	Karen	Facey	Evidence Based Health Policy Consultant (Facilitator)

Appendix 2. Global Challenge Exploration Awards 2014 template

Application to STFC research				**Application to Global Challenges**								
Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future develop ment in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[2]	Contact	Dept	Partners/ collaborators
Medical Imaging with silicon detectors	Silicon detector technology for PET	Particle detection	Novel detection systems for fast and low yield photon counting	Outside	Whole body PET	Brain PET for the diagnosis of dementia; Full-body multimodal systems; Inter-operative probes.	Small & Compact; Insensitive to magnetic fields; Improved Spatial Resolution; Lower Cost Systems.	Nuclear Physics, Particle physics	Health-care	Dr Andrew Stewart, Dr Bjoern Seitz	School of Physics & Astronomy, University of Glasgow	SensL Ltd.; Toshiba Medical Systems Corp. ; Gartnavel General Hospital, Glasgow; Institute of Cancer Sciences, Glasgow; John Mallard PET Centre, Aberdeen;
Application to STFC research				**Application to Global Challenges**								

[2] For the purposes of this activity our focus on medical imaging means that the Application and global challenge area considered for each technology is in healthcare. However, the majority of the technologies listed have current of potential applications within other global challenge areas and within academic research.

Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future develop ment in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[3]	Contact	Dept	Partners/ collaborators
Data processing	Bayesian statistical Analysis	Gravit-ational wave detection	Gravit-ational wave data analysis and Bayesian methods	Outside	automated image artefact identificatio n in retina scanning	Parameter estimation; Model selection; Gaussian processes; Machine learning; Hierarchical modelling; Reduced order modelling; Approximate Bayesian computing.	Useful in large, complicate d datasets. Also in situations where data is poorly modelled.	Particle Astrophy sics	Health-care	Dr Chris-topher Mess-enger	School of Physics and Astronomy, University of Glasgow	

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Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future develop ment in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[4]	Contact	Dept	Partners/ collaborators
Medical imaging with Silicon detectors	Semi-conductor sensors and detectors	Experi-mental particle physics	Develop ment of semi-cond-uctor detector tech-nology for Particle Physics research	Outside	Radio-pharma-ceutical production and in security in radiation portal monitors.	X-rays Dual Energy CT Multispectral x-ray detection	The technology to take 'colour' x-ray images being developed. Offers an improve-ment on currently available dual energy CT techniques.	Experi-mental Particle Physics	Health-care	Prof Val O'Shea	School of Physics and Astronomy, University of Glasgow	

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Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future develop ment in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[5]	Contact	Dept	Partners/ collaborators
Terahertz imaging	High power broadband terahertz amplifiers for magnetic resonances	High current relativistic electron beams and their interaction with electro-magnetic fields and plasmas		Outside	Appli-cations in security and environ-mental monitoring	Electron para-magnetic resonance (EPR) & Dynamic Nuclear Polarization in MRI	Non-Ionizing: Harmless to tissues & DNA Pene-trating: Clothing, bandages, packaging materials. Resonating: with molecule oscillations & Electron spin in B field	Lasers & Plasma Physics	Health-care	Dr Wenlong He	Dept of Physics, University of Strathclyde	

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Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future develop ment in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[6]	Contact	Dept	Partners/ collaborators
laser- and plasma-accelerator technology	Radiotherapy	Laser-plasma particle accelerators	Will be further developed at SCAPA – new £5m Scottish Centre for the Application of Plasma-based Accelerators which will include 7 beam lines at up to 300 TW. Involved in research collaboration such as AWAKE at Cern.	Outside	R&D using existing 40 TW laser accelerator	Laser-based particle beams show potential for radiotherapy. Experimental studies to date have investigated the efficacy of very high energy electrons generated by the 40 TW laser as a radiotherapy source. Scalabiity needs to be explored.	Accurate dosimetry has been conducted on the source and measurements compare very well with simulations. Irradiation of selected cancer cell lines has been undertaken with promising results and the understanding of the underlying physical and biological processes is in progress.	Lasers & Plasma Physics	Health-care	Prof. Dino Jaroszinski, Dr Mark Wiggins	Dept of Physics, University of Strathclyde	SCAPA is a SUPA collaboration involving Universities of Strathclyde, Edinburgh, Glasgow and West of Scotland.

[6] For the purposes of this activity our focus on medical imaging means that the Application and global challenge area considered for each technology is in healthcare. However, the majority of the technologies listed have current of potential applications within other global challenge areas and within academic research.

laser- and plasma-accelerator technology	Radioisotopes	Laser-plasma particle accelerators	Will be further developed at SCAPA – new £5m Scottish Centre for the Application of Plasma-based Accelerators which will include 7 beam lines at up to 300 TW. Involved in research collaboration such as AWAKE at Cern.	Outside	R&D using existing 40 TW laser accelerator	Radioisotope Alpha production	Offer promising methods for alleviating the demand on facilities. studies carried out using 40 TW laser to generate copper-62 radioisotope via photo-nuclear reactions in a zinc target. Experimental results compare well with simulations and parameter scaling demonstrate practical levels of production. This technique could be broadly applied to many other isotopes.	Lasers & Plasma Physics	Health-care	Prof. Dino Jaroszinski, Dr Mark Wiggins	Dept of Physics, University of Strathclyde	SCAPA is a SUPA collaboration involving Universities of Strathclyde, Edinburgh, Glasgow and West of Scotland.

Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future development in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[7]	Contact	Dept	Partners/ collaborators
Medical Imaging	PET Imaging	Use of high energy photons to obtain a deeper understand-ing of the nature of matter.	Develop ment of equip-ment for high energy physics research.	Outside		Entangled photons to improve PET images	The extra information available provides a means to improve signal to noise ratio; produce fast scatter-corrected images; and allow stronger sources to be used.	Nuclear Physics	Health-care	Prof Dan Watts, Dr Gary Smith	Sch of Physics and Astronomy, University of Edinburgh	

[7] For the purposes of this activity our focus on medical imaging means that the Application and global challenge area considered for each technology is in healthcare. However, the majority of the technologies listed have current of potential applications within other global challenge areas and within academic research.

Microscopy	Cellular imaging	Ultra-broadband OPO frequency combs for precision spectro-graph calibration	Astron-omy and astro-physics discovery of extra-solar Earth-like planets, and the measure ment of funda-mental constants.	Outside		High resolution confocal microscopy for cellular / sub-cellular imaging & multi-photon microscopy for deep-tissue imaging. Will enable (i) one-photon fluorescence imaging in confocal microscopy using tunable visible light; (ii) two-photon fluorescence imaging using near-IR femtosecond excitation; (iii) SPIM / light-sheet microscopy using two-photon excitation for 3-D volumetric imaging of tissue/whole organisms.	Combines the spatial coherence of a laser source with the flexible tunability normally only available by using a number of discrete lasers. The spectral brightness substantially exceeds the performance of the super-continuum sources currently applied in some biological imaging, and the time resolution and peak power also makes these sources of interest for nonlinear microscopy such as deep-tissue / brain imaging and CARS imaging.	Lasers & Plasma Physics	Health-care	Dr Chris-topher Leburn, Prof Derryck Reid	Institute of Physics and Quantum Sciences, Herriot-Watt University	Chromacity Ltd

Technology Level 1	Technology Level 2	Current application /use in STFC research	Potential future development in STFC research	Is the application outside of academic research or to academic research?[1]	Current application /use in Global Challenge	Future application/ development in Global Challenge	Outcomes /benefits	Theme/ discipline	STFC area[8]	Contact	Dept	Partners/ collaborators
Medical Imaging	Ultrasound	n/a		Outside	Gastro-intestinal & Neuro-surgical imaging	High frequency devices required to achieve high resolution imaging in small form factors for Gastro-intestinal micro-ultrasound and Neuro-surgical micro-ultrasound	Application of STFC data processing expertise could enhance images produced by gastro-intestinal micro-ultrasound. Fabrication capabilities of STFC research can enable the further shrinking of electronics for gastro-intestinal micro-ultrasound pill	Experi-mental Particle Physics collabor-ation being explored.	Health-care	Prof Sandy Cochran	School of Medicine, University of Dundee	University of Glasgow, Physics and Astronomy Experimental Particle Physics Group and James Watt Nano-fabrication Centre

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