Developing medical LINACs for challenging environments

Aim: Getting cancer care to the underserved world

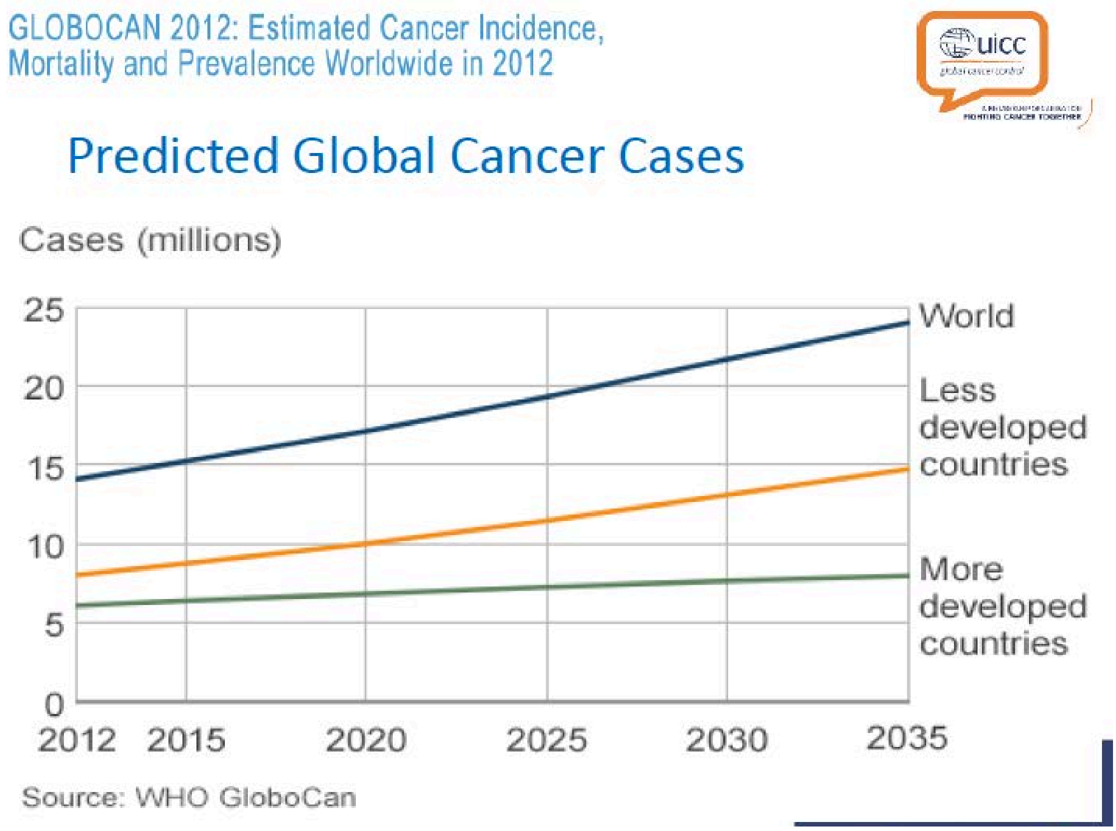
Executive Summary

Background

Cancer is a critical societal issue, the annual global incidence of cancer is expected to rise from 15 million cases in 2015 with 8.2 million deaths and this number will rise to as many as 25 million cases in 2035 and projects deaths to 13 millions.

Of these cases, it is estimated that 65-70% will occur in low-and middle-income countries (LMICs) where there is a severe shortfall in radiation treatment capacity. The growing burden of cancer and other non-communicable diseases (NCDs) in these countries has been recognized by the United Nations General Assembly in 2011[1] and the World Health Organization data.

[1] http://www.who.int/nmh/events/un_ncd_summit2011/political_declaration_en.pdf



Radiotherapy is a fundamental component of effective cancer treatment and control. It is estimated that about half of cancer patients would benefit from radiotherapy for treatment of localised disease, local control, and palliation. The growing burden of cancer will place increased demand on the already scarce radiotherapy services worldwide. RT also plays an important role in pain relief for incurable patients and is by far the most cost-effective modality for cancer treatment with the added advantage of conserving normal tissue function.

The most common radiotherapy approach is to target beams of high-energy photons at tumours while leaving surrounding tissue undamaged. The first Linac in the Western Hemisphere was built at Stanford in 1956 and used clinically until 1972. The vast majority of modern radiotherapy facilities use linear accelerators (linacs) to accelerate electrons and to both utilize the electrons directly for superficial tumours and also to hit targets (tungsten) to produce X-rays to treat deep-seated tumours. More than 10,000 linacs are currently used worldwide. Great advances in treatment with photons have been due to improved imaging, real-time beam shaping and intensity modulation of the beam with multi-leaf collimators (MLCs), increased knowledge of the radiation doses to kill tumours alone and in combination with "drugs" and also in understanding normal tissue toxicity.

In September 2015, the Global Task Force on Radiotherapy for Cancer Control (GTFRCC) released a comprehensive study of the global demand for radiation therapy[2]. It highlighted the inadequacy of current equipment coverage and the

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[2] http://www.thelancet.com/commissions/global-cancer-surgery

resources required, as well as the costs and economic and societal benefits of improving that coverage. Limiting factors to the development and implementation of radiotherapy in lower-resourced nations include the cost of equipment and infrastructure and the shortage of trained personnel to properly calibrate and maintain the equipment and to deliver high quality treatment. The GTFRCC report estimated that as many as 12,600 megavolt-class treatment machines will be needed to meet radiotherapy demands in LMICs by 2035. Based on current staffing models it was estimated that an additional 30,000 radiation oncologists, over 22,000 medical physicists and almost 80,000 radiation technologists would be required.

Motivated by the goal of reducing the global burden of cancer, A workshop was convened on November 7-8, 2016 by the International Cancer Expert Corps (ICEC) ICEC organized a brainstorming workshop which was hosted by CERN and attended by leading experts coming from key international bodies, research institutes, universities, hospitals, companies producing equipment for conventional x-ray to share their knowledge and expertise and to discuss needs, goals and possible solutions.

One of the major challenges is designing a linear accelerator and associated instrumentation needed to deliver radiotherapy that could be operated in places where general infrastructures are poor or lacking, power outages and water supply fluctuations can occur and whose climatic conditions might be harsh.

Following the workshop, an oversight committee and three task forces were established:

A technology task force will stimulate innovation in radiotherapy technologies and systems focusing in the near-term to develop optimal design requirements for novel, high quality, lower cost treatment solutions that incorporate intelligent software and are modular, rugged and easily operated yet sufficiently sophisticated to also benefit therapy in high-income countries. The long-term effort will be to identify shortfalls in existing critical subsystems and to stimulate development of next generation solutions to these important needs.

A second task force will identify education, training and mentoring requirements for current as well as future novel treatment systems in addition to evaluating the impact of evolving patterns of practice and treatment techniques, changes in cancer incidence and the population mix and shifts in core responsibilities on education and training needs.

A third task force will work on solutions to improve global connectivity of cancer control efforts and will develop strategies for securing financial support for the other task forces in client countries as well as from governmental, academic and philanthropic organizations in high resource countries.

Outlook

The overall aim is to make treatment available for increased numbers of cancer patients in LMICs and other geographically underserved regions in the next 5–10 years. This requires initiating the recommended actions by simultaneously providing systems at two levels of sophistication over two-time ranges (near- and long-term) in conjunction with the requisite education, training and mentoring associated with sustainable global connectivity and development to insure success of the program to improve access to radiotherapy worldwide.

October 2017 technology workshop

The purpose of this workshop was to bring a selection of invited experts from the accelerator and medical fields together with people from selected ODA countries[3] where this technology might be used in the future for a brainstorming session to understand the issues and challenges.

Prior to the event participants from ODA countries were sent a questionnaire (Appendix 1) regarding the facilities, the availability of support and training in their country. The information received in response was used to inform the development of each of the sessions, including that from some who were later unable to attend (Kenya). In addition a representative from each of the ODA countries was invited to give a short presentation in the opening session in which they were asked to address the 3 most important problems and challenges facing them and their colleagues in the coming years (Appendix 2)

The agenda was structured to allow flexibility to take account of the information and challenges facing those in the ODA countries and incorporated time for discussion in each area.

Building on the outcome[4] of the previous CERN ICEC meeting, the driving force of the discussion at this workshop was to consider radical re-designs rather than small engineering improvement, to take the system back to the physics in order to see what might be done differently. It was recognized that machines should be reliable, robust, cheap to operate and easy to use. The challenge is then to look at each sub-system and to optimise the whole to bury the complexity. The importance of being able to easily train those that maintain and operate the systems was also highlighted

[3] Botswana, Ghana, Jordan, Nigeria, Tanzania

[4] Developing medical linacs for challenging regions https://cds.cern.ch/record/2253385/files/vol57-issue2-p031-e.pdf

Appendix 1
Questions for ODA Representatives

In preparation for the workshop, "Innovative, robust and affordable medical linear accelerators for challenging environments", to be held at CERN on October 26 and 27, 2017, we are soliciting information from you to help develop design criteria for a radiation treatment system for challenging requirements. We would appreciate your providing brief answers to the questions below as soon as possible. We will arrange to have the responses from you and other participants summarized and presented by representatives of ODA countries at the CERN-hosted workshop in October.

1. From your current perspective, what are the three most important problems/challenges that you and others in radiation therapy in your country are facing?

2. Looking ahead:

   a. How do you see the physical infrastructure in your country changing over the next 5-10 years?

   b. Do you sense that there is increased interest among healthcare providers in the care of patients with cancer in your country?

3. What radiation therapy system(s) do you have at this time?

a. Linear accelerator(s): x-ray energies?, do you have electrons? electron energies?
b. Cobalt-60 units
c. Brachytherapy system(s)
d. Treatment planning system(s)
e . Simulation equipment: conventional simulator?, computed tomography (CT)-based simulator?, do you access to magnetic resonance imaging (MR)for simulation?, positron emission tomography (PET/CT) scanner?
f. Treatment capability. Do you have: 3DCRT, intensity modulated radiation therapy (IMRT), image-guided radiation therapy (IGRT), stereotactic body radiation therapy (SBRT)?

4. What additional radiation therapy technologies would you like to have at your facility?

   a. What linear accelerator capabilities would you like to have?

      1) x-ray beam energy: 6 MV, 8 MV, 10 MV, other?

      2) Electrons? Energies?

   b. Brachytherapy system?

   c. Simulation equipment: CT?, MR?, PET/CT scanner?

   d. Treatment planning system?

   e. What additional treatment capabilities would you like to have? 3DCRT, IMRT, IGRT, SBRT?

5. Infrastructure and environment

   a. Do you have a reliable power supply for the linear accelerator?

b. Do you have a reliable water supply for the linear accelerator?

c. Do you have an air-conditioned facility for the equipment?

d. Do you face harsh environmental conditions? If so what kind(s) and for what fraction of the year?

6. Adequacy of your workforce (staffing)

   a. Radiation oncologists

   b. Physicists

   c. Dosimetrists

   d. Oncology nurses

   e. Engineers

   f. Data manager(s)

7. Education and training

a. Do you have in-house education and training programs? If so, what kinds?

   b. How do you arrange for education and training of your staff elsewhere, if needed?

   c. Does your equipment supplier provide training? If so, how long?

   d. Do you have a degree-awarding program for physicists? Other staff?

8. Procurement
   a. Is procurement of radiation therapy equipment done locally? Regionally? Country level?

   b. Is procurement a simple process or complicated? "Red tape?"

   c. Does the Ministry of Health have a multi-year procurement plan?

9. Funding
   a. Is funding done yearly at a national level such as the Ministry of Health?

   b. Is all or some of your funding local?

   c. Do you compete with other departments for funds?

   d. Is funding adequate for your needs?

   e. Is your funding reliable year–on-year?

Appendix 2
Email sent by CERN to ODA participants
Please find attached the latest "draft" agenda for the workshop at CERN showing your presentation in Session 1, which is "setting the scene". As you can see, we have asked one person from each of the ODA countries to make a brief presentation on the **status of radiation therapy** in their country.
Each speaker is allowed 10 minutes, approximately 7-minutes for the presentation followed by 3 minutes for questions. We recommend no more than 7-8 slides. The presentation

should cover the information in the questionnaire sent to you, where you were asked to comment on the three most important problems/challenges you and your colleagues in radiation therapy faced in your country. Please comment on those problems and how you expect them to get better in the next several years.
Please can you also try to address the following?

1. Is your ability to treat patients with cancer limited by the types of equipment you have? Or by the number of treatment units you have?

2. What kind(s) of equipment do you now have? What equipment would you like to have?

3. Is your ability to treat patients limited by a lack of adequately trained personnel? What kind of training do you have for your staff? What kind of training do you need and for whom?

Your presentations are important and key for the participants to understand what is the current status and where you see are challenges and how one might try to address them both in the near-term and in the future.
Please note that these presentations are just for setting the scene however there will be ample discussion time over the two days for you to provide input and comments, to engage with other participants and to contribute to other sessions.

Session 2: Study of Accelerator Technology Options (Peter McIntosh, et al.)

Work Package Theme
Conventional and commercially available Radiation Therapy (RT) treatment systems utilise S-band linac technologies coupled to magnetron or klystron RF power sources, which invariably entails incorporation of the linac structure inside the rotating gantry for circumferential patient treatment. The theme of this activity is to assess a variety of different linac and RF source configuration options, taking advantage of recent technology developments in frequency ranges outside of the conventional provision. Advances in both Standing Wave and Travelling Wave linac operational performance and solid state, magnetron and klystron RF power delivery capabilities, have the potential to be able to define a new RT system configuration which can not only outperform, but also may offer a simpler, more efficient and robust system integration platform which can be more appropriately applied for ODA country exploitation. Such RT treatment systems must be able to operate in less stable power delivery environments, with challenging temperature and humidity conditions, thereby requiring an operational capability which is able to cope with such demanding specifications. The deliverables for this activity is broken down into the following work packages:

- WP1: Determination of RT system implementation constraints (M1)
  Deliverable: Implementation specification report.

- WP2: Assessment of SW/TW linac performance capabilities appropriate for RT treatment application (M2)
  Deliverable: RT linac assessment study report (M2)

- WP3: Assessment of RF amplifier technologies appropriate for RT treatment application (M2)
  Deliverable: RF amplifier technology study report (M2)

- WP4: RT system integration assessment
  Deliverable: Linac system configuration report which can define a more effective RT treatment platform, utilising more efficient, cost effective and robust linac and RF technologies (M3)

Description of Proposed Work
Assessment of suitable linac and RF amplifier configurations will enable exploration of both low and high frequency technologies which offer the ability to exploit modern, high operational performance devices which can provide a more modular approach for RT system integration. Taking advantage of high power, solid-state amplifier solutions at frequencies below 1GHz are of particular interest, whereby such implementation can significantly simplify the RT system integration complexity through removal of all high voltage power supply systems. At higher frequencies above S-band, advanced linac technologies also offer the advantage of very high accelerating gradients (approaching 50MV/m) which can significantly reduce the physical footprint of the linac structure within the RT treatment platform. In addition at such high frequencies, the development of multi-beam klystron technologies has advanced considerably, offering high efficiencies and reduced HVPS complexity and associated costs. In terms of the modularity which can then be employed, an assessment of configuration options will fundamentally explore the necessity for having the linac embedded within the rotating gantry and whether there are more effective approaches in detaching not only the RF amplifier system, but also the linac structure itself. The intricacies of then providing robust RF and/or electron beam delivery through rotating RF and beam delivery interfaces has been a fundamental inhibitor for limited commercial system solutions which

have adopted this approach in the past and so reassessing current technology viability will be of particular significance.

It is hoped that through such an assessment, a more optimum linac and RF source technology can be defined, which can be configured to provide a simpler, more efficient, operationally robust and cost effective RT technology solution which can be appropriately developed and value engineered to explicitly match ODA country implementation requirements.

Session 3: Robust Permanent Magnet Beam Delivery Systems for Medical Radiotherapy Linacs (Suzie Sheehy, et al.)

Work Package Theme

This work package aims to study and design a beam delivery system for a ~6MeV medical radiotherapy LINAC to reduce the number of required electromagnets and water cooling while providing a high quality beam to the target.

This is a 3 month project with the following deliverables (as a report):

1. Charged particle optics design (using open-source software such as MAD-X and BDSIM) of electron beam delivery system, including detailed studies of likely magnet errors arising from temperature and radiation environment.

2. Conceptual design of Halbach-type solenoid and/or quadrupole magnets with suitable magnetic field for this application.

3. Report on how this beam delivery system would be integrated into a robust medical LINAC for challenging environments.

Further aims (outside of scope of 3 months):

4. Start-to-end simulation of LINAC bringing together this and I. Konoplev's work package in optimised RF structure design. Note that 3 months is not sufficient for full start-to-end simulation and this is likely to be a 'next step'.

Description of Proposed Work

This proposal forms part of an initiative to design a linear electron accelerator for radiotherapy where all subsystems will be optimised to ensure it is robust, reliable, cost effective and appropriate for use in challenging environments including developing countries. This project aims to design a beam delivery system (magnetic focusing and steering) which uses modern capabilities in permanent magnets to ensure that a high quality electron beam can be taken from the source to the x-ray generating target with minimal losses. Replacing some or all of the existing electromagnets with permanent magnets should enable a maintenance-free focusing system which requires very little electricity, which has been highlighted as a barrier to providing this technology in ODA countries. (A few smaller, cheaper and replaceable adjustable electromagnets will be included for fine tuning, which would have minimal power requirements.)

A few key questions need to be addressed in this project for the proposed operating environment, including a review of magnet performance in the radiation environment induced by beam losses in the LINAC, and the stability of the magnetic field quality in temperature fluctuations (permanent magnets fluctuate with temperature, and we may expect larger fluctuations than normal in ODA operating environments). The result of these errors on the output beam will be studied, aiming to optimise beam quality and make it impervious to the challenging environment. This part of the project will use open source software wherever possible for the design work. Project members Collier (CERN) and Clarke (DL) bring expertise in permanent magnets to the team and will act as advisors.

Once the required magnetic field configurations are established, a conceptual mechanical design will be undertaken. Halbach magnet supports can be 3D printed, and some prototype designs will be produced, in consultation with collaborators (Oxford, CERN, KCL, MD Anderson) who will advise on the best way to achieve modularity together with the proposed RF structure of the LINAC. For example, a hinged Halbach magnet which can be opened up easily and removed to access the rest of the LINAC may be possible, depending on the mechanical forces at play.

Finally, the foundations will be laid for a start-to-end simulation of the LINAC, building on expertise at DL (Co-I Angal-Kalinin, Collaborators Jones, Militsyn), bringing together work packages on RF structure (Konoplev) and expertise in electron sources and simulation codes. This is likely to lead to a follow-on proposal for a full start-to-end simulation in the future.

Session 4: RF Power Systems and Optimized RF Structures for Electron Beam Acceleration (Ivan Konoplev, et al.)

Work Package Theme

The theme of the Work Package is a feasibility study and test of new manufacturing technologies to build a reliable and robust, cost effective and efficient, modular, vacuum sealed RF accelerating structure for a medical (cancer treatment) LINAC capable of operating in a challenging environment with additional constraints (funds, expertise, quality of energy) linked to ODA countries.

The structures will be based on the design of the accelerating cavity developed for the CLIC project (CERN) and scaled to 1.3GHz to be driven by either a solid state RF power supply or other power supplies available to the ODA countries. This is a 3 month project which has the following work packages and deliverables:

WP 1. Design of 1.3 GHz RF cavity using CST Microwave studio. (1 month)
Deliverables: Technical drawings of the cavity.

WP 2. Machining of the RF cavity using novel materials (aluminium) and its assembly. Preliminary vacuum test and RF bead pull test in Oxford. (1 month)
Deliverables: Assembled and tested RF cavity ready for vacuum tests.

WP 3. Vacuum test of the cavity to reach requirements needed for high-power RF studies. If vacuum tests are successful a high power RF studies of the RF cavity at CERN facilities. (1 month)
Deliverables: New technology and materials for manufacturing the vacuum sealed accelerating structures. New approach to the construction of the RF accelerating structure as a fully sealed unit for application in challenging environments will be developed.

Description of Proposed Work

The proposed work is driven by the ultimate goal to design a modular linear accelerator for cancer treatment with minimum subsystems making it robust, reliable, cost effective and accessible to communities with lower incomes. The road map to achieve this goal was identified during the recent workshop hosted by STFC, CERN and ICEC in partnership with representatives from ODA countries. It is based on the idea to use the best available in accelerator science solutions and adapt them to specific problems linked to the challenging environments, financial situations and knowledge availability in the ODA countries. This project aims to design accelerating structures which can be affordable, robust, efficient and easy to look after, while keeping the design at the cutting edge of the technological solutions available. To achieve the goals the design of the RF accelerating structure will be based on the CLIC system and adapted to the 1.3GHz frequency enabling the use of either a low voltage solid state RF power supply or alternative sources like klystron or magnetron. To make it modular with minimum subsystems required the structure will be vacuum sealed i.e.no vacuum pumps will be needed to maintain the vacuum and LINAC operation. This will reduce the overall capital and maintenance cost. To reduce the manufacturing cost of the cavity a new technology of cavity manufacturing will be tested. The cavity will be machined from two aluminium blocks using CNC lathe. This will also reduce the weight of the beam energy of 6MeV - 8MeV in the distance around 30cm. The Department of Physics workshop has experience of building a 1.3GHz RF cavity using CNC lathe and will be able to manufacture the cavity in the time scale of the project. It also has experience with vacuum testing of the structures and has the equipment required.

The RF bead pull test facilities (JAI Oxford and Daresbury Laboratory) will be used to measure operating and high order modes. The cavity will be sealed and vacuum tested in JAI Oxford and transported to CERN for high power RF tests. The sealed cavity will be kept sealed to observe whether any vacuum degradation will take place with time. To ensure that the system is suitable for ODA countries the partners from Nigeria and Tanzania will be invited to the workshop in Oxford to test the system and advise on ergonomics of the design. We plan to communicate regularly (every two weeks) with all partners via web-meetings during the project to ensure stable and continuous progress as well as securing the impact of the deliverables to the overall aim of the project.

Session 5: Linear Accelerator Simulations for Stable and Sustainable Operation of Developing Country Radiotherapy Linear Accelerators (Stewart Boogert, et al.)

Work Package Theme

The driving vision of this work-package is to leverage current trends in accelerator science (AS), electrical engineering (EE) and computer science (CS) to support the development of robust and affordable medical linear accelerators. The key trends in these areas are advanced simulations, internet of things and machine learning. The proposed work potentially critically improves access to complex radiotherapy equipment in ODA countries by enabling automation technologies to assist in the operation and maintenance of this equipment.

The deliverables include a feasibility assessment for developing three sets of linear accelerator models to form the basis of a machine learning model used to support linear accelerator operations:

1. Simulation of electron and photon beam physics that can serve as a high-level LINAC operation model (based on SIMAC: https://simaclinac.com).
    - i. Simulation stored in online repository
    - ii. Simplistic background and shielding simulation in Geant4 (http://geant4.cern.ch)
    - iii. Web-page interface to simulation and outputs to facilitate usage and access from ODA countries.
    - iv. Develop a community of users in ODA countries

2. The development of electron and photon beam diagnostic data collection systems for fault detection and mitigation.
    - i. Protocols for collecting instrumentation data and preliminary data samples
    - ii. Report on potential designs of simplified transducer and computing elements
    - iii. Propose means of collecting operational data in ODA countries and transmitting to a cloud based digital storage system.

3. Development of machine learning for combining functional and data based linear accelerator models into artificial intelligence models capable of assisting in the maintenance of linear accelerators in areas where technological expertise is limited.
    - i. Report on potential algorithms and trial implementation using simulation.

Description of Proposed Work

Operation of medical LINACs require a combination of high reliability hardware and trained personnel. Simplified physics based models, which include potential failure modes, of LINAC operation provide a key tool for optimising designs for reliability and cost. The added benefit of such a simulation is a training tool for experts within ODA countries and a flight simulator framework in which to test advanced machine learning (ML) techniques. ML facilitates the transfer of knowledge required to operate and maintain the complex technology used in radiotherapy linear accelerators.

It is proposed to create a feasibility assessment for automation of linear acceleration operation and repair. This will be accomplished by developing the necessary elements ML models of linear accelerator operations. In conjunction with this, the minimum knowledge of a linear accelerator operator will be assessed, and companion-training materials will be developed to accompany the machine learning algorithms. To have the largest impact the work will be focused on commercially available X-ray machines, as new designs become available the simulation can be appropriately adapted.

The ML models, combined with the training tools will form a suite of computer applications that can assist in teaching linear accelerator functionality, automate the diagnosis of linear accelerator faults, and suggest repairs/beam adjustments with the purpose of supporting the operation of linear accelerators where technological expertise is not available.

Work Package 1: Assembling a complete set of linear accelerator physics modules with the aim of building a comprehensive "flight simulator" for LINACS, expanding on the existing work in SIMAC.

- Maintain the above models in the public domain using code repositories such as GitHub.
- Build a database of linear accelerator faults with associated data descriptors. Use a web based method for the worldwide radiotherapy community to add real faults. Like radiotherapy incident reporting tools, but for technological failures instead.
- Store simulation results in open cloud data storage

Work Package 2: Design a network of transducers and data collectors (using technology e.g. single board computer or Red-Pitaya) to facilitate a data model of LINAC functionality.

- Consultation with SA on possible IoT inspired technical solutions
- Test on existing commercially available linear accelerators.
- Extend simulations to include output and failures of diagnostic systems

Work Package 3: Assess the feasibility of a high-level machine learning models to combine WP1 & WP2 into a control system for linear accelerator maintenance.

- Collection of data from existing machines
- Consultation with SB on potential algorithms and implementations
- Demonstration of simple predictive model of known failures

Work Package 4:

- Community development. There are approximately 100 individuals who have expressed interest in SIMAC, with approximately 10 from ODA countries. Expanding this community via a suitable web-page and outreach, including understanding the deployed systems.
- Define the infrastructure required to package the LINAC modules defined in WP1 into a web-based training software for linear accelerator repair.

Session 7: Cloud-based Electronic Infrastructure in Support of Linac-based Radiotherapy in Challenging Environments (Ajay Aggarwal, et al.)

Work Package Theme

The work package aims to adapt an existing Cloud-based Electronic Platform (CEP) to facilitate remote treatment planning, research, education and multidisciplinary training partnerships between radiotherapy teams working in high-income countries and those in low and middle-income countries (LMICs) which operate in challenging environments. As part of the proposed 3-month work package, four radiotherapy centre visits will be planned in Nigeria and Ghana.

Deliverables include:

1. To undertake a needs assessment to understand better the specific requirements and uses for a CEP in the clinical setting in each country.
2. To assess the local informatics infrastructure that is currently available to support CEP platforms.
3. To develop the framework for adapting the CEP given local infrastructure and environmental conditions.
4. To develop the framework for using the CEP to build training and research capacity, facilitate peer review and quality assurance including remote planning depending on each centre's individual requirements.
5. To build new sustainable international partnerships between organisations to develop expertise and capacity for radiotherapy delivery in LMICs.

<u>Further aims</u>:

Going forward this feasibility project will enable us to design a CEP that meets the unique needs of LMICs, which will subsequently be piloted to demonstrate its potential to support high quality linac-based radiotherapy in challenging environments

Description of Proposed Work

This proposal forms part of an initiative to design a linear accelerator for radiotherapy (cancer treatment) that is reliable, cost effective and appropriate for use in developing countries. However, the planned integration of novel linac designs require concomitant investments in training, research, data collection and manpower capacity to ensure the delivery of high quality radiotherapy and up-scaling of existing resources. There is currently significant shortfall in these domains in low and middle income countries as highlighted by the recent Global Task Force on Radiotherapy for Cancer Control in 2015. Furthermore, the UN Sustainable Development Goals highlight the need to recruit, develop and train the multidisciplinary health work force in developing countries to strengthen the capacity to reduce premature mortality from non-communicable diseases such as cancer (Development Goal 3).

By evolving and adapting a cloud-based medical informatics infrastructure to support the delivery of radiotherapy based cancer treatment it is expected that the CEP will begin to address these needs. Currently, health records, diagnostic images, and radiotherapy data are located in disparate locations in a clinic and are not readily accessible. A CEP can facilitate the aggregation of these data and provide access to a wider range of services such as on-demand remote linac-based treatment planning, training and knowledge sharing in newer radiation modalities, and research trial participation. It will also facilitate the implementation of standard operating procedures for treatment planning, quality assurance and quality control (QA/QC). Cloud-based peer review allows radiation oncologists serving disparate populations in LMICs and in remote sites elsewhere to get expert advice from their clinical peers for linac-based treatments within each country (as part of a "hub and spoke system") or between international partners. A CEP can also obviate the need for local software modules such as treatment planning software and backup of data. The CEP infrastructure also links in with the linac service training and fault learning project.

WP1 - Perform a feasibility study for using the CEP in challenging environments and to undertake a needs assessment to understand better the specific requirements and uses for cloud based informatics technology in the clinical setting in developing countries.

A four-person research team comprised of medical physicists and radiation oncologists from the US and UK will visit four radiotherapy centres in Nigeria and Ghana over a period of one week to ten days. The purpose of the visits will be to assess the capability of each centre to support a cloud based informatics structure and to ascertain what core adaptations to the software are required. The team will also evaluate the workforce capacity that currently exists, the education and training needs of the multidisciplinary team (radiation oncologists, medical physicists, radiation technologists, junior faculty), and the potential for remote treatment planning. They will also evaluate local clinical processes to develop a workflow that would benefit patient populations in challenging environments and to jointly determine with the ODA representatives how the CEP could be utilized to collect data, develop rigorous processes of quality assurance and peer review, engage in clinical research, as well as how to implement standard operating procedures for remote collaboration in the future.

WP2 - Develop the framework for Cloud-based remote treatment planning, peer review, QA, and sharing of anonymized radiotherapy data

Following the feasibility study in the two ODA countries, the four investigators will take part in a virtual workshop with the named collaborators including a consultant from Botswana – Dr Surbhi Grover. She is a radiation oncologist who is a member of ICEC and has a detailed knowledge of the radiotherapy services infrastructure in Botswana through her clinical work.

The workshop will establish the main priorities areas for each ODA country following the visits e.g. need for remote planning, peer-review, training, provision of a secure patient database, upscale services or commissioning of new technologies. This will help us to develop a framework and set of procedures to enable us to adapt the CEP across three ODA countries given their differing resource constraints. Following this meeting, further work will be undertaken to make relevant adaptations to the software and identify additional resources and expertise that will be required to do so.

A follow up virtual workshop in the final month will be undertaken with the ODA representatives to discuss progress and plans for future work. Specifically, to work towards the piloting of an adapted CEP system in one or more of the ODA countries as part of a larger grant proposal and how future workflows can be established which involve real-time international collaboration.