

COLLABORATIVE STRATEGIES FOR MEETING THE GLOBAL NEED FOR CANCER RADIATION THERAPY TREATMENT SYSTEMS

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Abstract

The idea of designing affordable equipment and developing sustainable infrastructures for delivering radiation treatment for patients with cancer in countries that lack resources and expertise stimulated a first International Cancer Expert Corps (ICEC) championed, CERN-hosted workshop in Geneva in November 2016. Which has since been followed by three additional workshops involving the sponsorship and support from UK Science and Technology Facilities Council (STFC). One of the major challenges in meeting this need to deliver radiotherapy in low- and middle-income countries (LMIC) is to design a linear accelerator and associated instrumentation system which can be operated in locations where general infrastructures and qualified human resources are poor or lacking, power outages and water supply fluctuations can occur frequently and where climatic conditions might be harsh and challenging. In parallel it is essential to address education, training and mentoring requirements for current, as well as future novel radiation therapy treatment (RTT) systems.

BACKGROUND AND CHALLENGE

The expected increase in annual global incidence of cancer from 15 million cases with 8.2 million deaths in 2015 to 25 million cases with 13 million deaths in 2035 is a critical global health and societal issue [1]. It is estimated that 65 - 70% of these cases will occur in LMICs where there is a severe shortfall in RTT capacity (Fig. 1).

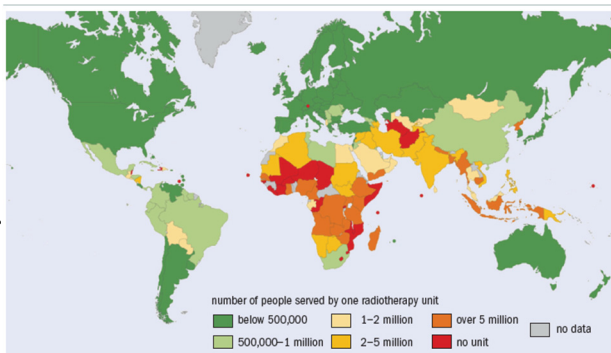


Figure 1: RTT shortfall in the African Continent (IAEA).

The provision of a fundamental cost-effective modality for the curative or palliative treatment for ~50% of new patients with cancer need RTT for cure, but 100% of patients with metastatic disease may require RTT at some stage. This growing burden of cancer, as well as other non-communicable diseases (NCDs) in these countries, was recognized by the UN General Assembly in 2011 [2] and is reflected in World Health Organisation data [3].

In Sept 2015, the Global Task Force on Radiotherapy for Cancer Control released a comprehensive study of the global demand for radiation therapy that highlighted the estimated need for as many as 12,600 megavolt-class treatment machines in LMICs by 2035 and, based on current staffing models, the need for an additional 30,000 radiation oncologists, over 22,000 medical physicists and almost 80,000 radiation technologists [4].

In summary, factors limiting the development and implementation of high quality radiotherapy in LMICs include the cost of equipment and infrastructure and the shortage of trained personnel in several disciplines (engineers, medical physicists, radiation oncologists and radiotherapy technicians) to install, run and maintain the equipment and to plan and deliver high quality treatment for patients.

TAKING ACTION

Motivated by these factors and the Sustainable Development Goals of the UN [5], four multi-disciplinary international workshops have been conducted;

- “Design Characteristics of a Novel Linear Accelerator for Challenging Environments”, November 2016 sponsored by ICEC [6] and hosted by CERN; <https://indico.cern.ch/event/560969/>
- “Innovative, Robust and Affordable Medical Linear Accelerators for Challenging Environments”, October 2017, co-sponsored by ICEC and STFC and hosted by CERN; <https://indico.cern.ch/event/661597/>
- “Burying the Complexity: Re-engineering for the Next Generation of Medical Linear Accelerators for Use in Challenging Environments”, March 2018, hosted by STFC in UK in collaboration with CERN and ICEC; <https://indico.cern.ch/event/698939/>

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- “Accelerating the Future: Designing a Robust and Affordable Radiation Therapy Treatment System for Challenging Environments”, March 2019, hosted by STFC in Gaborone, Botswana.
<https://indico.cern.ch/event/767986/>

The goals have been to brain-storm and initiate planning for a robust (environmentally-tolerant) and affordable low-cost linear accelerator (linac) with computer-based solutions for treatment planning and quality assurance for use primarily in resource-poor settings. The workshops included a multidisciplinary group of international experts in accelerator physics, medical physics, radiation and clinical oncology, epidemiology and global cancer policy including representatives from UK specific Overseas Development Agency (ODA) countries.

ODA COUNTRY PERSPECTIVE

Workshop input from ODA country representatives emphasized the shortage of good radiotherapy equipment, the difficulty of keeping the machines running, the chronic shortage of adequately trained personnel (of all types), the need to retrain staff in order to maintain the quality of patient treatment as well as to retain staff. In LMICs, the costs of equipment, building infrastructure and salaries are 81%, 9% and 10% of the total cost of the facility respectively, compared to 30%, 6% and 64% in high-income countries (HICs). It was agreed that design considerations for a RTT system for ODA countries should include modularity for ease of repair and upgrading, ease of operation, reliability, self-diagnostics, insensitivity to power interruptions, low power requirements and reduced heat production.

Design Considerations from the Workshops

The ideal RTT system for LMICs is thought to be as modular as possible so that it can be easily shipped, assembled in-situ, repaired and upgraded as local expertise in patient treatment develops.

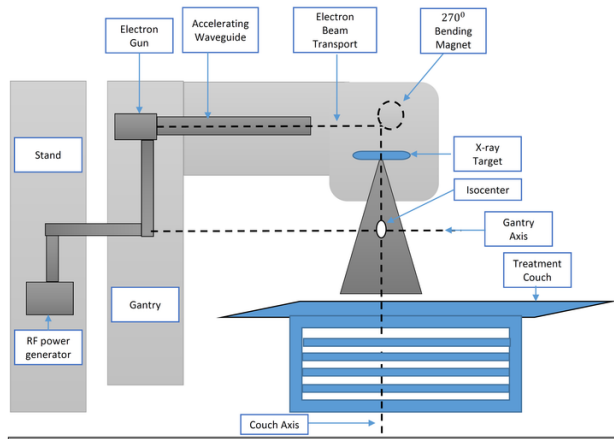


Figure 2: Schematic of a Conventional RTT System.

Systems that might be improved or redesigned include RF power systems, modulators, power supplies, beam production, control units, ion sources, waveguides, steer-

ing and bending magnets, as well as vacuum systems (Fig. 2).

In addition, software developments can improve imaging, provide integrated safety systems and automate many operational features and treatment planning (dosimetry) to improve efficiency and expertise of the staff. Software that exploits automation to the fullest extent could include auto-planning and operator monitoring and training, even to the point of having a treatment system that depends on limited on-site human involvement, to allow high quality treatment to be delivered by an on-site team with less technical expertise.

RTT TECHNOLOGY SOLUTIONS

To satisfy these requirements, a single energy system of < 10 MeV (to avoid material excitation) is being investigated, which includes utilising a variety of technology solutions from S, C or X-band accelerator technologies (linac and RF power sources), compact Klystron RF sources, integrated design of thermionic electron sources with the linac RF structure, with less beam loss for self-shielded linacs, removable cathodes for gun maintenance and permanent magnet guided electron beams.

Electron Beam Source

A key potential failure point in the RTT linac is the thermionic cathode of the electron gun, which is sensitive to vacuum at elevated temperature. The project has adopted an integrated approach to the electron beam source and the rest of the linac to minimise risk of failure. This includes consistent start to end simulations to optimise both the source and RF structure together, novel gridded thermionic gun concepts, as well as methods to reduce required maintenance or to make it simpler to operate. The project is currently considering making the cathode removable to aid repair or to have a fully brazed unit to reduce the possibility of vacuum leaks. The position and type of vacuum pump is also being considered.

Linac Accelerator

We have considered an X-band Travelling Wave (TW) linac, as well as S and C-band Standing Wave (SW) structures. These have been designed in an integrated way with the electron source, with new methods developed to increase the capture of electrons between the source and linac.

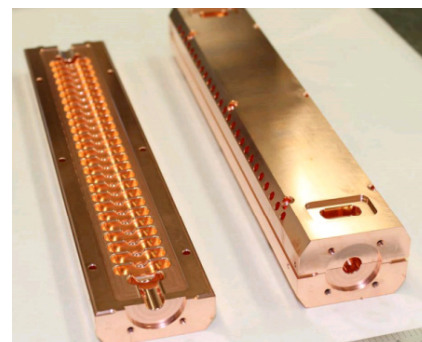


Figure 3: Linac manufacturing possibilities (CERN).

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RF structures are normally manufactured by brazing individual cells/cups together requiring multiple parts, with tight alignment tolerances. Recent work at CERN [7] has demonstrated a high gradient travelling wave structure by machining the entire structure in two halves (Fig. 3). Such an approach simplifies tuning and alignment and requires less parts.

RF Power Source

New compact, multi-beam klystrons (MBK) are becoming available that challenge the weight and costs of a magnetron, but at higher powers and lifetimes [8]. Such a device may be well suited to challenging environments where increased lifetime would mean less maintenance required. Due to the short structure lengths required, TW is only feasible with an appropriate RF power source at X-band frequencies. To drive this structure a 6 MW MBK is required, while a SW structure at S or C-band could be driven by a 3 MW magnetron or an MBK solution. In Fig. 4 the MBK is shown as a possible candidate to drive an S, C-or X-band accelerating structure.

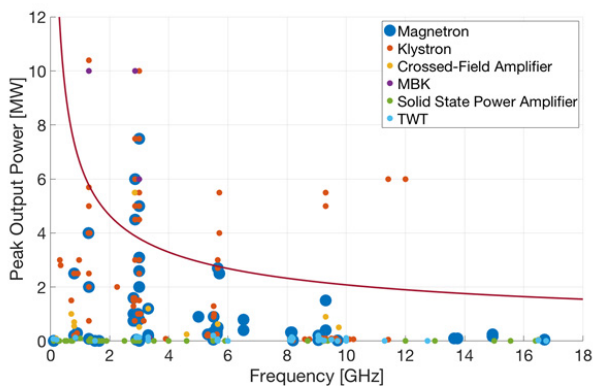


Figure 4: RTT RF power source options for a 6 MeV electron beam energy linac.

Beam Delivery and Magnets

Permanent magnet technology for accelerators has undergone rapid development in the last 10 - 15 years, resulting in high quality, low cost magnets that have been adopted in the high energy accelerator community. [9] Thus far, they have not been applied to medical LINACs. The collaboration have studied this option to provide focusing in a proposed modular linac, in order to reduce electrical and water cooling costs and complexity (Fig. 5).

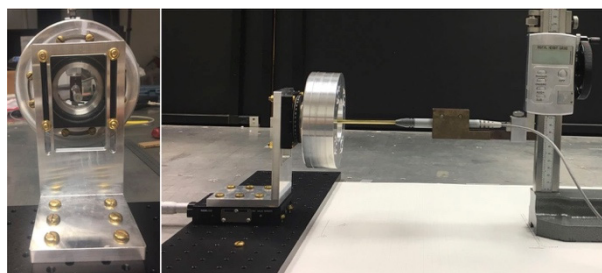


Figure 5: Low-cost permanent quadrupole magnet test apparatus (Oxford).

The studies undertaken to date assume a simplified LINAC design with no final bend magnet. In this case, only focusing is required and permanent magnets can be used to control the electron beam spot size at the X-ray target. Some small electromagnetic steerers are however likely to still be required.

Cloud Based Electronic Infrastructure

A cloud-based medical informatics infrastructure to support the delivery of high-quality radiotherapy based cancer treatment in developing countries by strengthening the training of a multidisciplinary healthcare work force is proposed (Fig. 6). This infrastructure which requires basic internet access, provides a knowledge sharing portal by enabling peer review of treatment plans, facilitates twinning partnerships within or between countries and enables remote radiation therapy quality assurance to facilitate international research trial participation.

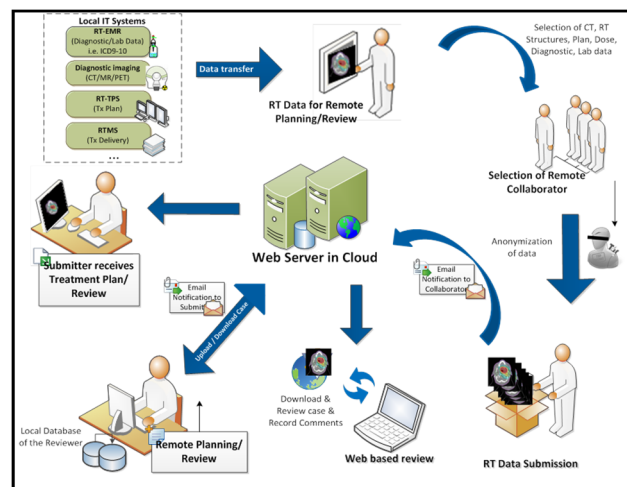


Figure 6: Cloud Based Electronic Infrastructure [10].

CONCLUSION

The aim of this project is to make treatment available for increased numbers of cancer patients in LMICs and other geographically underserved regions in the next 5 – 10 years. The primary goal is to develop design specifications for and to build the prototype of a modular, robust and affordable linear accelerator that, as part of an integrated RTT system with intelligent software, will be able to “bury the complexity of the treatment” of patients with cancer in the challenging environments for ODA countries. The RTT system needs to be capable of delivering state-of-the-art treatments that are equal in quality to those provided in major cancer centres in HICs.

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