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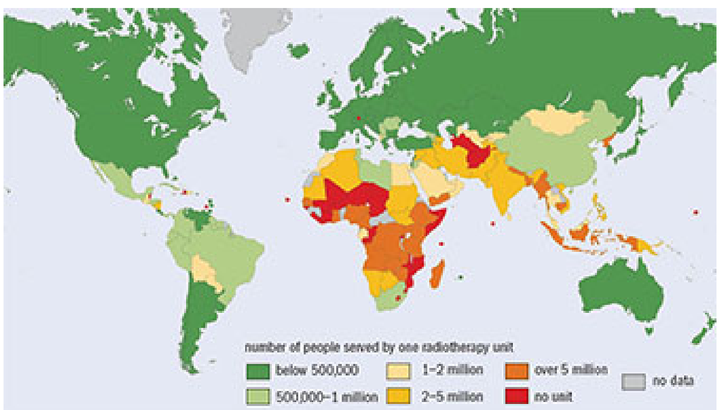
Developing medical linacs for challenging regions

A workshop held at CERN late last year saw physicists, oncologists and industry experts define the design characteristics of a novel linear accelerator that will make radiotherapy more readily available in lower-resourced countries.



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Access to radiotherapy treatment centres (http://images.iop.org/objects/ccr/cern/57/2/22/CClin1_02_17.jpg)

Résumé

Des linacs médicaux pour des régions défavorisées

Il manque actuellement plus de 5 000 machines de radiothérapie dans les pays en développement, et certains pays d'Afrique et d'Asie n'ont pratiquement aucun accès à cette thérapie. Un atelier réunissant des physiciens, des oncologues et des experts de l'industrie a été organisé au CERN fin 2016, dans le but d'imaginer les caractéristiques d'un accélérateur linéaire novateur capable de faciliter l'accès à ce traitement crucial contre le cancer dans les pays les plus défavorisés. Les compétences étendues du CERN et de la communauté des physiciens dans les domaines de la physique des hautes énergies, du réseautage au niveau mondial et de l'innovation sont essentielles pour faire avancer cet ambitieux projet.

The annual global incidence of cancer is expected to rise from 15 million cases in 2015 to as many as 25 million cases in 2035. Of these, 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 in these countries has been recognised by the United Nations General Assembly and the World Health Organization.

Radiation therapy is an essential component of effective cancer control, and approximately half of all cancer patients – regardless of geographic location – would benefit from such treatment. The vast majority of modern radiotherapy facilities rely on linear accelerators (linacs) to accelerate electrons, which are either used directly to treat superficial tumours or are directed at targets such as tungsten to produce X-rays for treating deep-seated tumours.

Electron linacs were first used clinically in the 1950s, in the UK and the US. Since then, great advances in photon treatment have been made. These are due to improved imaging, real-time beam shaping and intensity modulation of the beam with multileaf collimators, and knowledge of the radiation doses to kill tumours alone and in combination with drugs. In addition, the use of particle beams means that radiotherapy directly benefits from knowledge and technology gained in high-energy-physics research.

Meeting global demand

In September 2015, the Global Task Force on Radiotherapy for Cancer Control (GTFRCC) released a comprehensive study of the global demand for radiation therapy. It highlighted the inadequacy of current equipment coverage (image at top) and the resources required, as well as the costs and economic and societal benefits of improving 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, more than 22,000 medical physicists and almost 80,000 radiation technologists will be required.

Approximately three years ago, with the aim of making cancer treatments accessible to underserved populations, initial discussions took place between CERN and representatives of the US National Cancer Institute and an emerging non-government organisation, the International Cancer Expert Corps (ICEC), whose aim is to help LMICs establish in-country cancer-care expertise. The focus of discussions was on an "out-of-the-box" concept for global health, specifically the design of a novel, possibly modular, linear accelerator for use in challenging environments (defined as those in which the general infrastructure is poor or lacking, where power outages and water-supply fluctuations can occur, and where climatic conditions might be harsh). Following further activities, CERN hosted a workshop in November 2016 convened by the ICEC, which brought together invited experts from many disciplines including industry (see panel below).

In addition to improving the quality of care for cancer patients globally, linac-based radiotherapy systems also reduce the reliance on less expensive and simpler systems that provide treatment with photons from radionuclide sources such as ^{60}Co and ^{137}Cs. While some of the ^{60}Co units have multileaf collimators for improved beam delivery, they do not have the advanced features of modern linacs. Eliminating radionuclides also reduces the risk of malicious use of medical radioactive materials (see panel below).

Design characteristics

It is important that the newly designed linac retains the advanced capability of the machines now in use, and that through software advances, resource sharing and sustainable partnerships, the treatments in

LMICs are of comparable quality to those in upper-income countries. This not only avoids substandard care but is also an incentive for experts to go to and remain in LMICs.

The ideal radiation-therapy treatment 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. Another critical issue concerns the sustainability of treatment systems after installation. To minimise the need for local specialised technical staff to maintain and promptly repair facilities, procedures and economic models need to be developed to ensure regional technical expertise and also a regional supply of standard spare parts and simpler (modular) replacement procedures. Difficulties due to remoteness and poor communication also need to be considered.

There are several design considerations when developing a linear accelerator for operation in challenging environments. In addition to ease of operation, repair and upgradability, key factors include reliability, self-diagnostics, insensitivity to power interruptions, low power requirements and reduced heat production. To achieve most of these design considerations relatively quickly requires a system based on current hardware technology and software that fully exploits automation. The latter should 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.

Current technology can be upgraded with software upgrades, but generally it requires the purchase of an entire new unit to substantially improve technology – often costing many millions of dollars. A modular design that allows major upgrades of components on the same base unit could be much less expensive. Major savings would also result from developing new advanced software to expand the capability of the hardware.

Participants in the CERN workshop agreed that we need to develop a treatment machine that delivers state-of-the-art radiation therapy, rather than to develop a sub-standard linac in terms of the quality of the treatment it could deliver. The latter approach would not only provide lower-quality treatment but would be a disincentive for recruitment and retention of high-quality staff. As used in virtually all industries, the user interface should be developed through interaction with the users. Improved hardware such as a power generator in conjunction with energy management should also be provided to control electrical network fluctuations.

The task ahead

Experience from past and current radiation-therapy initiatives suggests that successful radiotherapy programmes require secure local resources, adequate planning, local commitment and political stability. To make a highly functional radiotherapy treatment system available in the near-term, one could upgrade one or more existing linear accelerators with software optimisations. The design and development of a truly novel radiation treatment system, on the other hand, will require a task force to refine the design criteria and then begin development and production.

Following the November workshop, an oversight committee and three task forces have been established. A technology task force will focus on systems solutions and novel technology for a series of radiation-treatment systems that incorporate intelligent software and are modular, rugged and easily operated yet sufficiently sophisticated to also benefit therapy in high-income countries. A second task force will identify education and training requirements for the novel treatment systems, in addition to evaluating the impact of evolving treatment techniques, changes in cancer incidence and the population mix. Finally, a global connectivity and fundraising task force will develop strategies for securing financial support in client countries as well as from governmental, academic and philanthropic organisations and individuals.

The overall aim of this ambitious project is to make excellent near-term and long-term radiation treatment systems, including staffing and physical infrastructure, available for the treatment of cancer patients in LMICs and other geographically underserved regions in the next 5–10 years. The high-energy physics community's broad expertise in global networking, technology innovation and open-source knowledge for the benefits of health are essential to the progress of this ambitious effort. It is anticipated that an update meeting will take place at the International Conference on Advances in Radiation Oncology (ICARO2) to be held in Vienna in June 2017.

CERN workshop initiates discussions for novel medical linacs


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CERN workshop (http://images.iop.org/objects/ccr/cern/57/2/22/CClin2_02_17.jpg)

On 7–8 November 2016, CERN hosted a first-of-its-kind workshop to discuss the design characteristics of radiotherapy linacs for low- and middle-income countries (LMICs). Around 75 participants from 15 countries addressed: the role of radiotherapy in treating cancer in challenging environments and the related security of medical radiological materials, especially ^{60}Co and ^{137}Cs; the design requirements of linear accelerators and related technologies for use in challenging environments; the education and training of a sustainable workforce needed to utilise novel radiation treatment systems; and the cost and financing of the project. Leading experts were invited from international organisations, government agencies, research institutes, universities and hospitals, and companies that produce equipment for conventional X-ray and particle therapy.

Treatment, not terror

(http://images.iop.org/objects/ccr/cern/57/2/22/CClin3_02_17.jpg)

^{60}Co (http://images.iop.org/objects/ccr/cern/57/2/22/CClin3_02_17.jpg)

With the rise in global terrorism comes the threat of the use of un- or poorly secured radioactive sources that would have enormous health, economic and political consequences. This includes medical sources such as ^{60}Co that are generally not highly protected, many of which are located in relatively under-resourced regions. Interest in developing alternative technologies has brought together medical practitioners who currently use these sources, governmental and global agencies whose mission includes the security of radiological and nuclear material, and organisations dedicated to the non-proliferation of nuclear weapons.

This confluence of expertise resulted in meetings in Brazil and South Africa in 2016, with the realisation that simply removing ^{60}Co would leave people in many regions without cancer care. Removing dangerous sources while establishing a better cancer-care environment would require education, training, mentorship and partnerships to use more complex linear-accelerator-based radiotherapy systems. The austerity of the environment is a challenge that requires new thinking, however.

The ability to offer a state-of-the-art non-isotopic radiation treatment system for challenging environments was emphasised by the Office of Radiological Security of the US National Nuclear Security Administration, which is responsible for reducing the global reliance on radioactive sources as well as protecting those sources from unauthorised access. The benefit of replacing ^{60}Co radiation treatment units with linear accelerators from the point of view of decreasing the risk of malicious use of ^{60}Co by non-state (terrorist) actors was also emphasised in a report from the Center for Nonproliferation Studies that offered the new paradigm “treatment, not terror”.

About the author

David Pistenmaa and Norman Coleman, International Cancer Expert Corps, Inc., and Manjit Dosanjh, CERN.

Further reading

M Pomper *et al.* 2016 *Treatment, Not Terror: Strategies to Enhance External Beam Cancer Therapy in Developing Countries While Permanently Reducing the Risk of Radiological Terrorism* (report) www.stanleyfoundation.org/publications/report/ TreatmentNotTerror212.pdf (http://www.stanleyfoundation.org/publications/report/TreatmentNotTerror212.pdf).
International Cancer Expert Corps www.iceccancer.org (http://www.iceccancer.org/)
R Atun *et al.* 2015 *Lancet Oncol.* **16** 1153.