Shortfalls of current RT technology in developing countries

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- Jake van Dyk – London, Ontario
- Yakov Pipman
Cost and ROI in a Global Deployment of RT

Atun et al., Lancet Oncology 2015
RT: Global Demand and Benefit

2012

7 million indications
119 million fractions
1.5 million local controls
580 000 lives

2035

12 million indications
204 million fractions
2.5 million local controls
950 000 lives

Atun et al., Lancet Oncology 2015
Linear increase in RT Capacity in LMICs: Cost of 100% Coverage by 2035

<table>
<thead>
<tr>
<th></th>
<th>Nominal Model</th>
<th>Efficiency model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low income</td>
<td>$26.6 Bn</td>
<td>$14.1 Bn</td>
</tr>
<tr>
<td>Lower-middle income</td>
<td>$62.6 Bn</td>
<td>$33.3 Bn</td>
</tr>
<tr>
<td>Upper-middle income</td>
<td>$94.8 Bn</td>
<td>$49.4 Bn</td>
</tr>
<tr>
<td>Total</td>
<td>$184.0 Bn</td>
<td>$96.8 Bn</td>
</tr>
</tbody>
</table>

Global GDP: $80,000 Bn/Yr X 20 Yrs = $1,600,000 Bn

Atun et al., Lancet Oncology 2015
CERN-hosted Workshop on Design Characteristics of a Novel Linear Accelerator for Challenging Environments - Improving global access to radiation therapy

7-8 November 2016

Ugo’s ‘Branching Point’

- Branch Type 1: Define specifications for novel, ‘Starter Machine’ and engage industry.

- Branch Type 2: Identify ‘Program Team’ to ‘bury the complexity’ of radiotherapy.

Or a hybrid approach for LICs.
Task Force 1: Technical Task Force

From a technical and systems perspective stimulate innovation in radiotherapy technologies and processes.

**Near-term:** Develop optimal design requirements for a novel high quality lower-cost treatment solution that leverages existing linac technologies and incorporates intelligent software designed for robust operation in a range of challenging environments. Such a system would be modular, rugged, easily operated, less reliant on personnel, and easily repaired but sufficiently sophisticated to also bring benefits to radiotherapy in high-income countries.

**Long-term:** Clearly identify shortfalls in existing critical subsystems (radiation production, power consumption, heat dissipation, automated maintenance, electromechanical collimation, imaging, safety, and training) and, through engagement of international technical centers of excellence, stimulate the development of next generation technologies to address these important needs.
Bigger Picture: ‘BOXCare’

- Factory Manufactured Complete Solutions
  - Imaging, Treatment, Shielding, Compute, Power Supply and Management
- Cloud-based Support; Automated TPS; Educating;
- Embedded Financing; Ruggedized;

Engineered to Ship and Operate  Cancer Care Solutions at Scale
ISO CONTAINER TYPES

Photos of 50 types of specialty ISO Shipping Containers used globally.
BOXCare: Shielding Feasibility

Linear Accelerators:

Summary: Shielding mass fits within 30t constraint; Current systems “fit”.

Brachytherapy:

Support Space

Summary: Dedicated HDR suite fits within 20’ and 4.1t shielding.
Robust Essential Components of Effective Cancer Control
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~$50,000

>$20,000

>$100/motor
Overview

Is Africa a ‘Graveyard’ for Linear Accelerators?

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Table 1
Contrast of typical personnel who may execute maintenance and repair of linear accelerators in high income countries and Africa

<table>
<thead>
<tr>
<th>High income countries</th>
<th>Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance work carried out by an engineer</td>
<td>Maintenance work carried out by a physicist</td>
</tr>
<tr>
<td>First level repairs carried out by a hospital engineer</td>
<td>First level repairs carried out by a physicist</td>
</tr>
<tr>
<td>Higher level repairs carried out by the manufacturer</td>
<td>Exceptionally, higher level repairs may be assisted by the International Atomic Energy Agency</td>
</tr>
</tbody>
</table>

Table 2
Comparison of typical linear accelerator repair situations between high income countries and African countries

<table>
<thead>
<tr>
<th>High income countries</th>
<th>Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance contracts with suppliers</td>
<td>In-house maintenance</td>
</tr>
<tr>
<td>Repair contracts with suppliers</td>
<td>In-house repairs</td>
</tr>
<tr>
<td>High labour costs</td>
<td>Low labour costs</td>
</tr>
<tr>
<td>Low material costs</td>
<td>Exorbitant material costs</td>
</tr>
<tr>
<td>Availability of hard currency</td>
<td>Hard currency restrictions</td>
</tr>
<tr>
<td>Replacement of defective parts</td>
<td>Repair of defective parts</td>
</tr>
<tr>
<td>Repair work by manufacturers</td>
<td>No financial resources for external support</td>
</tr>
<tr>
<td>Preventive maintenance</td>
<td>Crisis management</td>
</tr>
</tbody>
</table>
Uganda's radiotherapy machine for cancer treatment breaks

8 April 2016

The radiotherapy machine, which is now broken beyond repair, was donated in 1995

Uganda's only radiotherapy machine used for treating cancer is broken beyond repair, the country's main cancer unit says.

This leaves thousands unable to get potentially life-saving treatment.

Basic Elements of a Medical Linear Accelerator

- Cathode
- Acceleration
- Control
- Bremsstrahlung
- Targets
“The Devil is in the details, but so is salvation.”

— Admiral H.G. Rickover, USN
Can we make these subsystems robust, tolerant, self-healing?

- RF Power Systems
- Modulators and Power Supplies
- Beam Production and Control
- Safety Systems
- Imaging
- Computerization
RF Power Systems

Magnetron – UK - 1940

Klystron – Varian Brothers - 1937
Durable and Sustainable Power Supplies

Multiple power supplies; Numerous suppliers;
Beam Production

Ion Source

Accelerating Waveguide

Carbon-nanotube Technology – Cold Cathodes

Electron gun replacement cycle
~ 2-3 years.
$20-40k.$
Beam Control (location; profile; energy)

Beam Steering/
Energy Control
Bending Magnets
Dosimetry Subsystem

Ion chamber lifetime: ~2-3 years; cost $20,000
Universal adoption of multi-leaf collimation systems – significant capital and maintenance cost.
>100 leaves, motors, controllers
On-board Imaging

Traditional 600 kHU x-ray tube technology – 2-3 year life at $20k

Flat-panel Detectors

Traditional 600 kHU x-ray tube technology – 2-3 year life at $100k
Computerization

• Significant complexity in computerization of RT systems
• Numerous points of failure
• Even modern systems have complex networking architectures with cybersecurity/multiple point of failure vulnerabilities.
Innovation: Compute and Power

Software systems that automate the treatment planning process AND improve plan quality.

>Automated planning from 4 hours to 4 min.

Purdie et al. - Int J Radiat Oncol Biol Phys. 2011

Leverage rapid advances in renewable, sustainable power sources and management technologies.

Lake Constance Radiation Oncology Centre (Germany)  
Tesla – GigaFactory and PowerWall Technology
Safety and Operability/Support

• Optimize the systems for minimum human intervention
  – Integrated safety systems and open control system architectures

• IoT Approaches for extension/sub-systems.

• High speed real-time, distributed network architecture.
Innovation: Safety and Simplification

Integrated energy fluence field monitoring system.

> *Dosimetric checksum of dose and field shaping systems.*


NanoX radiotherapy system design including fixed linac and patient rotation system.

> *Significant construction cost savings.*

Keall et al. http://dx.doi.org/10.1594/ranzcr2014/R-0142
Environmental Factors

• Significant infrastructure needs
  – HVAC, air exchange rates, shielding, network

• Need for Clean, Reliable Power
  – Damage to systems; Reliable performance

• Assumption of ‘developed nation’ power
  – Significant peak and steady state power demands (magnetron 1000:1 duty cycle vs steady state water pumps and bending magnet currents).

Re-examine the power consumption of the components and overall system in the context of ‘unstable power’ or solar.
Is it possible to make core subsystems that never fail?

- Solid state/low maintenance.
- High efficiency/minimal cooling?
  - Power control system for metered energy use
- Self-annealing components?
  - Ion sources; targets;
- Pre-fail - self/remote diagnostics.
- Engineered for stability; Minimal human interaction.
- Redundancy.