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Session Summary: RTT Technology Options Study

Peter McIntosh (STFC Daresbury Laboratory)

CERN-ICEC-STFC Burying the Complexity:

Re-Engineering for the Next Generation of Medical Linear Accelerators for Use in Challenging Environments

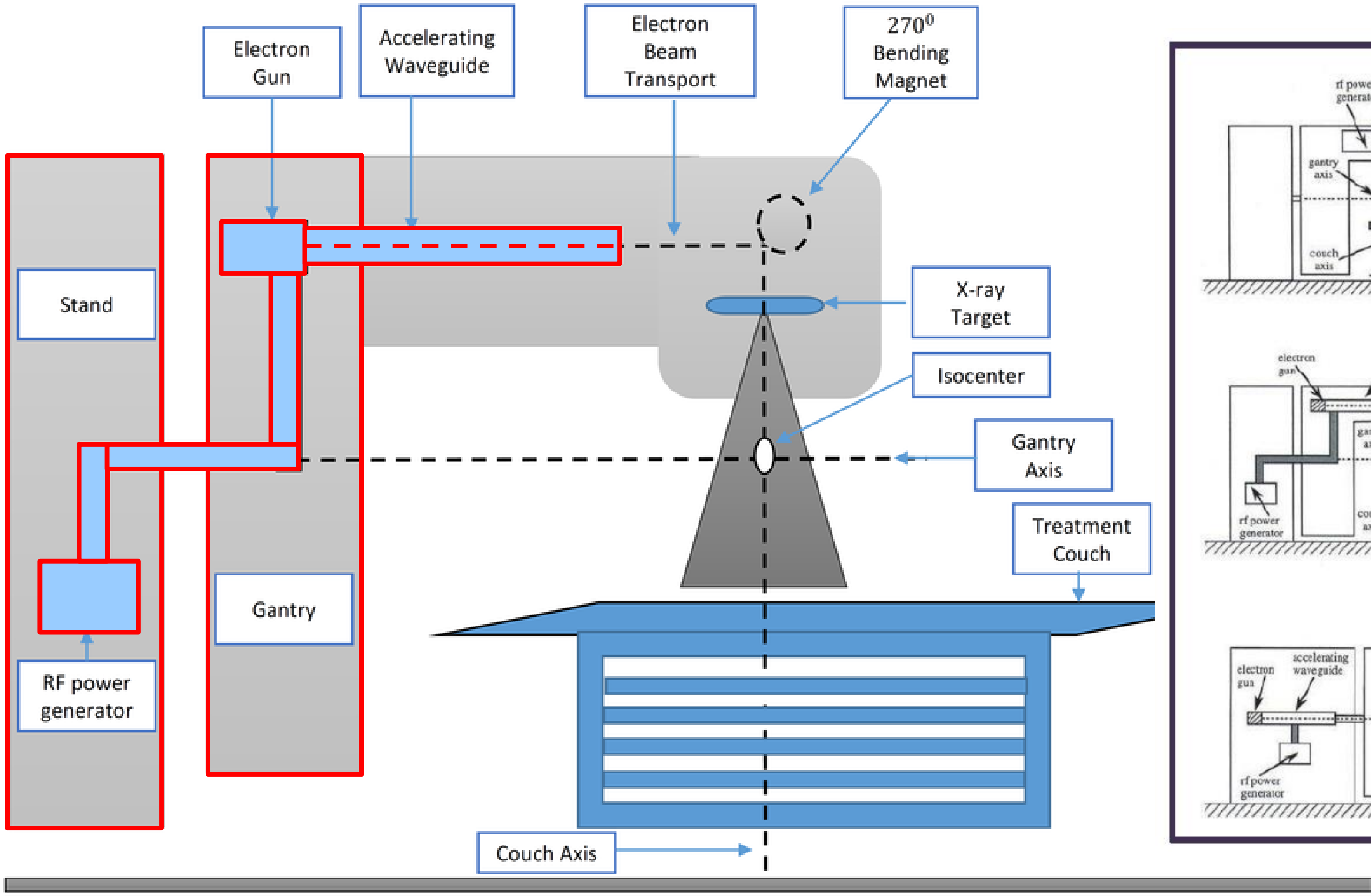
Park Royal Hotel, 22 – 23 March 2018

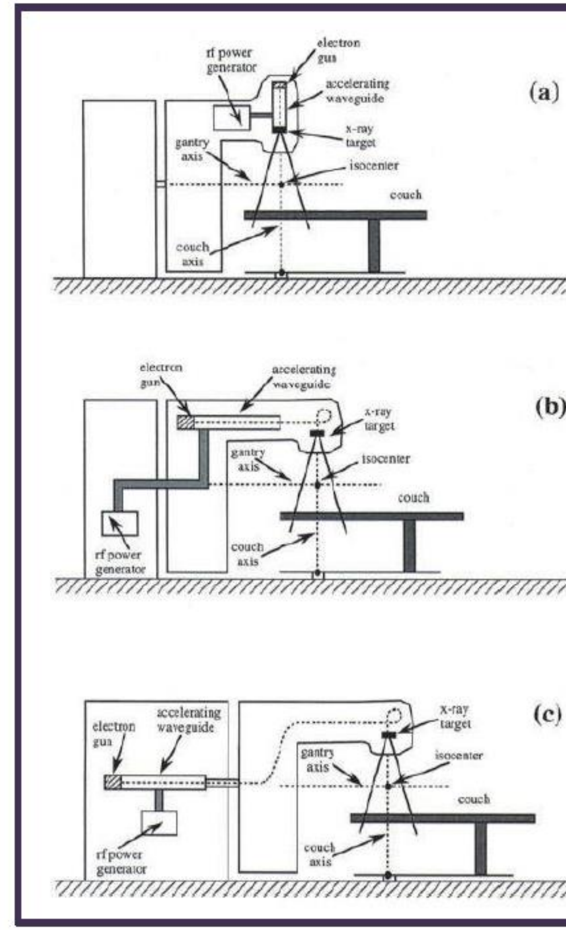
Accelerators in a new light

Session 2: Study of Accelerator Technology Options

Time	Title	Speaker
11:00	Overview of RTT Technology Options Study	Peter McIntosh (STFC)
11:15	RTT platform specification	Rob Apsimon (Lancaster)
11:35	ODA Country RTT Operation Perspectives	Hubert Foy (ACSIS, Ghana)
11:50	Preliminary RTT Technology Option Capture	Graeme Burt (Lancaster)
12:10	Discussion	
12:30	Session Close	

Conventional RTT Technology





Scope of RTT Options Study Programme

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 RTT system integration.

Low Frequency:

- Taking advantage of high power, solid-state amplifier solutions at frequencies below 1GHz are of particular interest, whereby such implementation can **significantly simplify the RTT system integration complexity** through **removal of all high-voltage power supply systems**.

High Frequency:

- 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**.

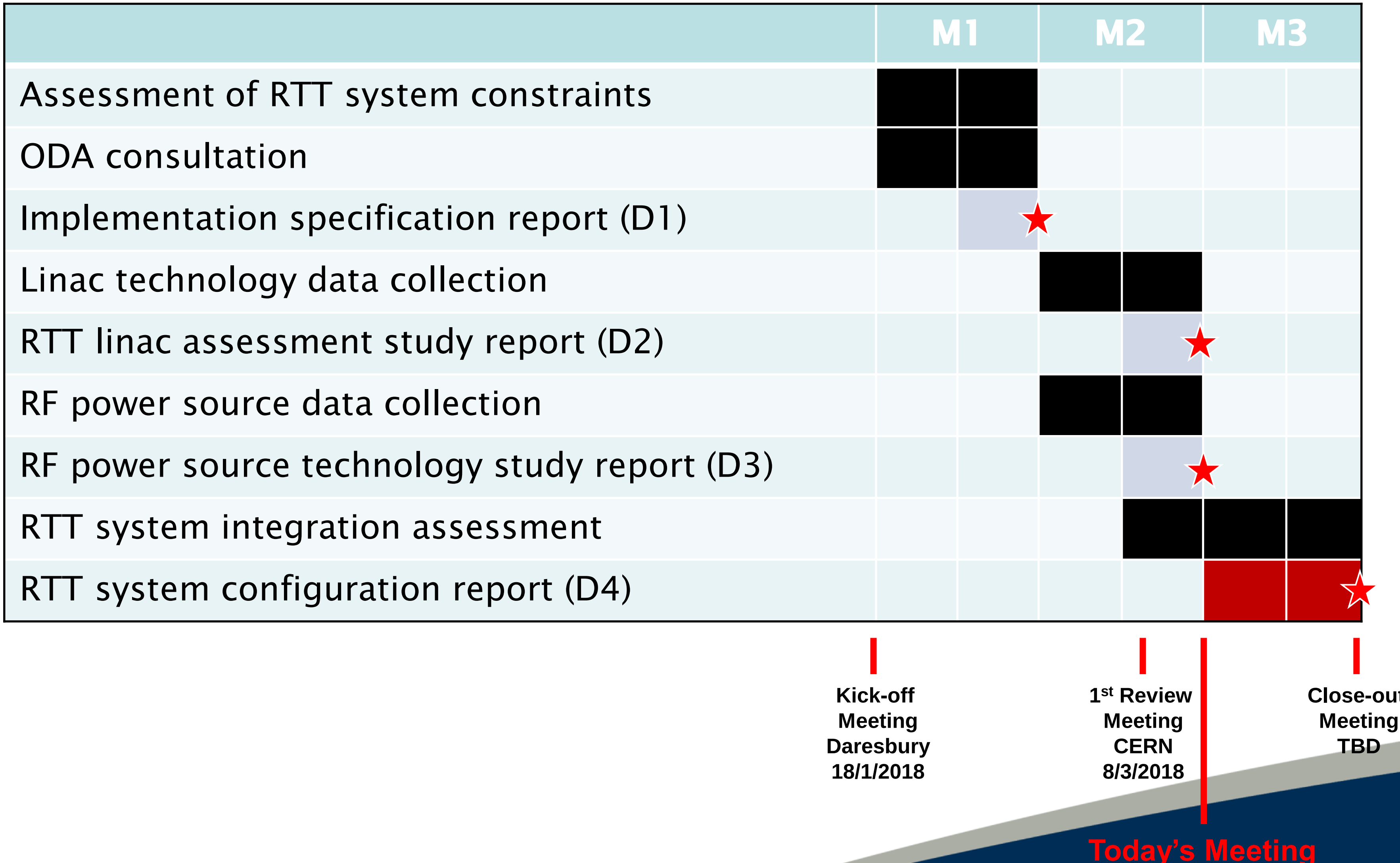
Configurations:

- 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**.

Technology Limitations:

- 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.

RTT Options Study Project Planning



Project Start: 18th January 2018
Project End: 18th April 2018

Table of Commercial RTT Data – R Apsimon

Device	Manufacture	manufacture dates	energy	RF source	RF power (MW)	Linac type	device size LxWxH (m)	min. room size needed LxWxH (m)	Linac length (m)	RF frequency (GHz)	Max. Dose rate (rad/min) (e): electron (x): X-ray
600C/D	Varian	1989 +	4/6 MeV	magnetron	2.5	SW	2.72 x 1.27 x 2.69	6.7 x 6.1 x 3.2	0.3	2.856	250-400 (x)
6EX	Varian	1999 +	4/6 MeV	magnetron	3	SW	2.72 x 1.27 x 2.69	6.7 x 6.1 x 3.2	0.3	2.856	400-600 (x)
Unique	Varian	2012 +	6 MeV	magnetron							100-600 (e)
2100/2300 C/CD	Varian	1988-2007	6-20 MeV	klystron	5.5	SW	2.59 x 1.24 x 3.71	6.1 x 7.1 x 3.1	1.3 - 1.45	2.856	400 (e) 250-600 (x)
21/23 series	Varian	1998-2006	6-20 MeV	klystron	5.5	SW	2.59 x 1.24 x 3.71	6.1 x 7.1 x 3.1	1.3	2.856	250-600 (x) 1000 (e)
Trilogy	Varian	2005 +	6-25 MeV	klystron	5.5	SW	3.71 x 1.24 x 2.64	7.8 x 6.1 x 3.1	1.3		600 (x) 1000 (e)
iX	Varian	2004 +	6-25 MeV	klystron	5.5	SW	3.71 x 1.24 x 2.64	7.8 x 6.1 x 3.1	1.3	2.856	300-600 (x) 1000 (e)
TrueBeam	Varian	2010 +	6-22 MeV	klystron							
Edge	Varian	2013 +		klystron							
Clinac 4	Varian		4 MeV	Magnetron	2	SW			0.3	2.856	
Clinac 6X	Varian		6 MeV	Magnetron	2	SW			0.3	2.856	
Clinac 12	Varian		6-12 MeV	Magnetron	2	SW			1.0	2.856	
Clinac 18	Varian		6-18 MeV	Klystron	5	SW			1.4	2.856	
Clinac 35	Varian		7-28 MeV	Klystron	20	TW			2.25	2.856	
Precise Systems	Elekta	1997-2005	4-22 MeV	magnetron	5	TW	3.51 x 3.90 x 2.48	6.5 x 6.0 x 3.2	2.5		400(e) 600(x)
Synergy Platforms	Elekta	2002 +	4-20 MeV	magnetron	5	TW	3.51 x 3.90 x 2.48	6.5 x 6.0 x 3.2	2.5		400(e) 600(x)
Axesse/Infinity	Elekta	2009 +	4-18 MeV	magnetron	5	TW	3.51 x 3.90 x 2.48	6.5 x 6.0 x 3.2	2.5		400(e) 600(x)
MRLinac/Unity	Elekta										
Versa HD	Elekta	2013 +		magnetron							
Primus	Siemens	1998-2005	6-21 MeV	klystron	7.5	SW	3.09 x 1.43 x 2.60	6.1 x 5.8 x 3.0			300/900 (e)
Oncor mid-energy	Siemens	2004-2011	5-14 MeV	magnetron	2.6	SW	2.83 x 1.31 x 2.64	6.1 x 5.8 x 3.0			300/900 (e) 200-300 (x)
Oncor high energy	Siemens	2004-2011	6-21 MeV	klystron	7.5	SW	3.09 x 1.43 x 2.60	6.1 x 5.8 x 3.0			300/900 (e)* 200-300 (x)*
Artiste	Siemens	2009-2011	6-23 MeV	klystron	7.5	SW	3.14 x 1.43 x 2.60	6.25 x 6.1 x 2.95	1.2		300/900 (e)* 300-500 (x)*
Mevatron 6	Siemens		6 MeV	Magnetron	2	SW			0.95	2.9985	
Mevatron 12	Siemens		3-11 MeV	Magnetron	2	SW			1.35	2.9985	
Mevatron 20	Siemens		3-18 MeV	Klystron	7	SW			1.38	2.9985	
TomoHD	Accuray	2012 +	6 MeV	magnetron	2.5	SW	4.63 x 2.81 x 2.52	6.0 x 4.6 x 2.7	0.3		850 (x)
Hi-Art II	Accuray	2004 +	6 MeV	magnetron	2.6	SW	0.62 x 1.07 x 0.97	6.7 x 5.2 x 2.7	0.3		850 (x)
Radixact	Accuray	2016 +	6 MeV	magnetron							
Cyberknife	Accuray	2003 + (6 generations)	6 MeV	magnetron							
Vero	Mitsubishi	2011									
Coline4	NCBJ		4 MeV	magnetron	2.6						
Coline6	NCBJ		6 MeV	magnetron	3.1						
Neptune10	NCBJ		≤26 MeV	magnetron							

Table 3: Summary of RTT design parameters [1, 19-46]. SW stands for standing wave and TW stands for traveling wave.

* Other dose rates possible with optional extras

All systems believed to operate at 3 GHz, but difficult to find information publicly available

Almost all systems are standing wave (except for Elekta), which is more efficient for shorter structures (< ~1.5 m)

Travelling wave structures more efficient in longer structures (>~2 m)

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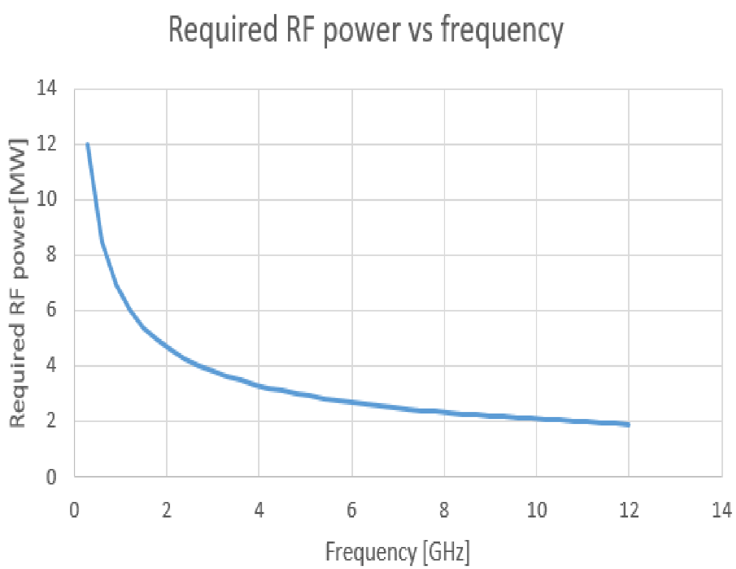
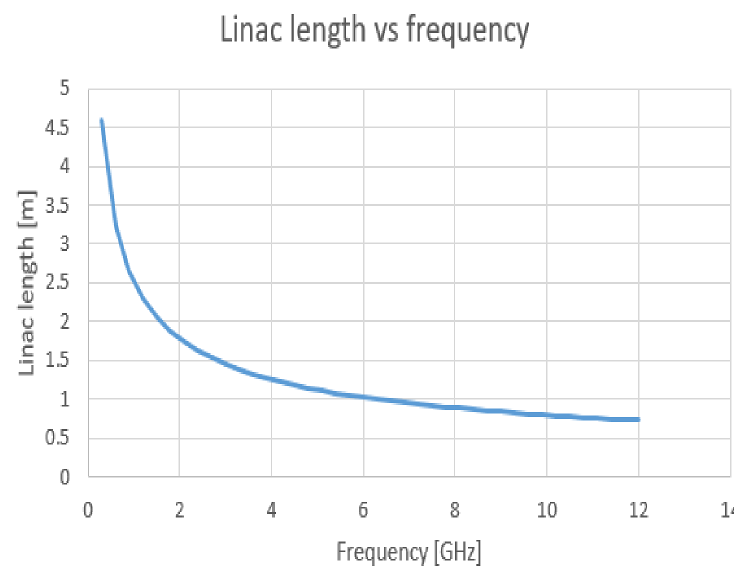
Design Considerations: Frequency

- RF power: $P_{RF} \propto \dfrac{V_{linac}^2}{\cos^2(\phi_s)\sqrt{\omega_{RF}}L_{linac}}$
- Effective shunt impedance: $R/L_{linac} \propto \sqrt{\omega_{RF}}$





* Based on Varian Clinac 2300 C/D specifications

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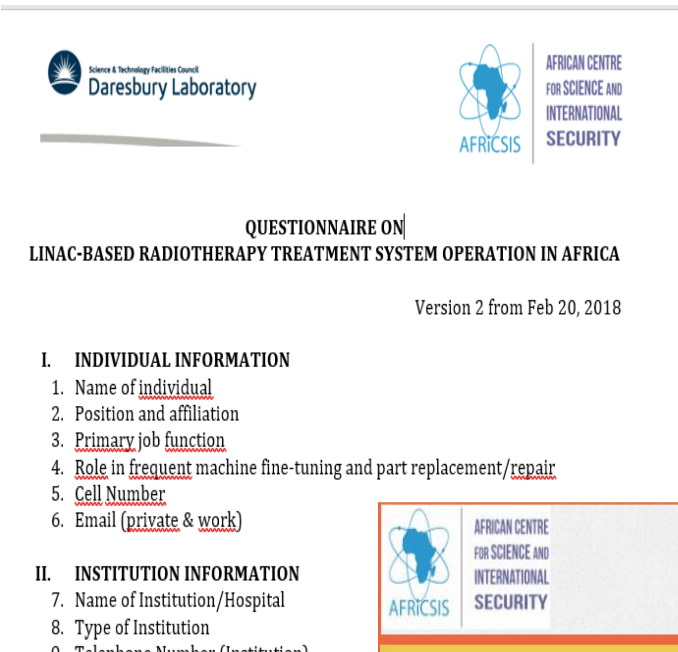
ODA Country RTT Operator Survey – H Foy

- ❑ Questionnaire
  - ❑ Topics development
  - ❑ Questions alignment
  - ❑ Online form (https://goo.gl/cssDRv)
- ❑ Audience
  - ❑ Professional societies
  - ❑ Geographic spread
  - ❑ 30 professionals via Emailing
- ❑ Feedback
  - ❑ 8 submissions, 5 countries, 5 subregions
  - ❑ Engineer, physicist, consultant, prof
- ❑ Institutions
  - ❑ University affiliated, public, private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QUESTIONNAIRE ON
LINAC-BASED RADIOTHERAPY TREATMENT SYSTEM OPERATION IN AFRICA

Version 2 from Feb 20, 2018

I. INDIVIDUAL INFORMATION
1. Name of individual
2. Position and affiliation
3. Primary job function
4. Role in frequent machine fine-tuning and part replacement/repair
5. Cell Number
6. Email (private & work)

II. INSTITUTION INFORMATION
7. Name of Institution/Hospital
8. Type of Institution
9. Telephone Number (Institution)


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Burying the Complexity:

Re-engineering for the Next Generation of Medical Linear Accelerators for Use in Challenging Environments

SURVEY OF

LINAC-BASED RADIOTHERAPY TREATMENT SYSTEM OPERATION IN AFRICA

Guidelines: This survey form has six sections: I, II, III, IV, V, VI and VII. Please complete all sections and questions as much as possible. Compulsory fields are marked with asterik (*). Leave blank the fields that do not apply to you. Your information will be kept strictly confidential. If you have questions or need assistance, please email admin@africsis.org

Results – Equipment Service

Service Consideration	Input
Linac per institution	1-2
Fine tuning frequency	Private (4-6), Public (1-2)
Part replacement/equip repair frequency	2
Fine tuning/repair entity	In-house, manufacturer, 3rd party
Major challenges	Spare parts, power, tax, personnel, culture
Cost be linac (land, construction, equipment)	$4-5M
Frequently replaced parts	Field light, motion control knob system on treatment couch, hand control, Electronic Card Motors of MLC
Failure by irradiation disabled per year	2-7

Results – Operational Experience

Uptime clause
- 98%

Failure period, rad dos syst
- 1-2 years

Avge downtime per year
- 3-4 days, service work

- ❑ Expensive service contract
- ❑ Lack of trained local engineers
- ❑ Medical insurance system
- ❑ Low single energy linacs + features

Results – Expected Needs

How to improve machine stability:

- Preventing maintenance/service
- Cooling system
- Less digitization
- Dedicated stepdown transformer
- Back up generator
- Change over switch
- Reliable and stable power supply
- Training of locals

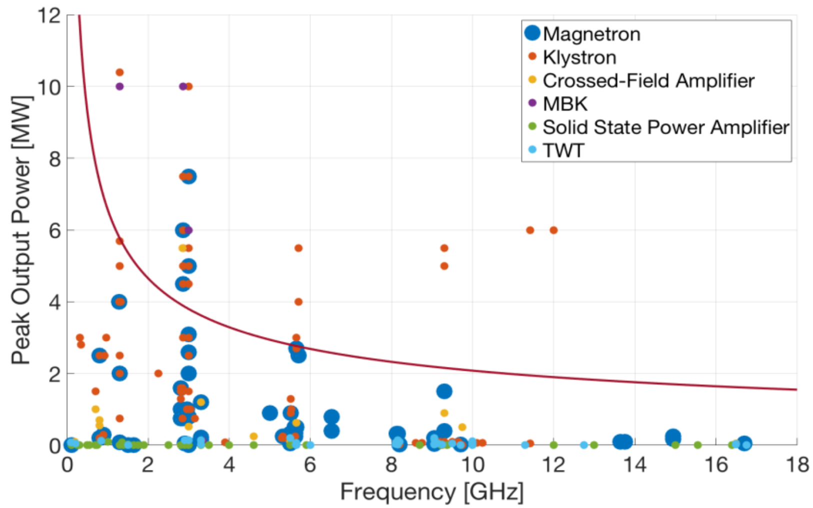
Need	Importance
Machine stability	**Most/More**
System operation	**Most**
Operational cost	**Most**
System efficiency	**Most**
Multi-leaf collimators system ability to run with fluctuating power supply	More
System robustness	More
System modularity	More
Maximum Photon Energy	More
Capital cost	**Most**
System performance	More
Max electron energy	Not/Important
Rotating gantry as opposed to fixed target or rotating patient	Important/more

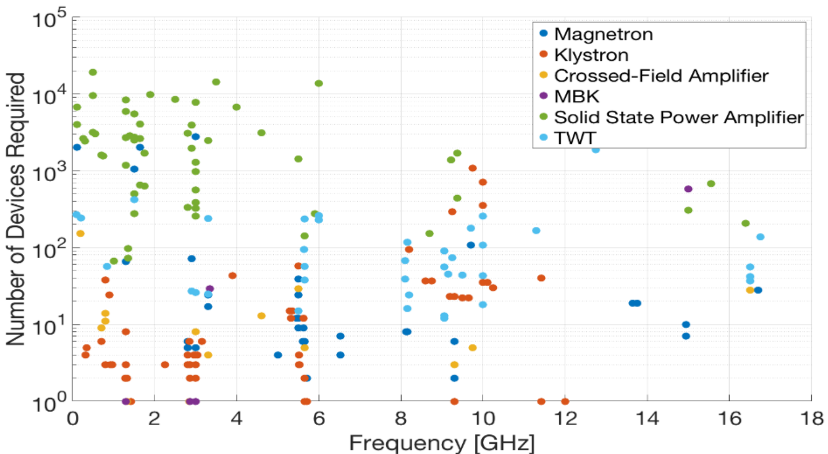
Design considerations for future linac

- Incorporate voltage stabilizers and UPS as integral parts of linac machine.
- Design TPS that can be powered with solar energy
- Add change over switch for generators as an integral part of the linac
- Add phase angle detector as an integral part of the linac
- Minimize digitization of machine to improve tolerance to external shocks
- Add step down transformer to align with machine input as an integral part of the linac
- Lower procurement cost, machine stability, and system operation most important design considerations for future linac technology

RTT Technology: Initial Conclusions from Data – G Burt

- Across entire frequency range, klystrons deliver desired output power in single device:
  - Other devices can be put into specific frequency categories.
  - Based on number of devices required.
- Low frequency (< 1.3 GHz):
  - SSPAs.
  - Crossed Field Amplifiers.
- Between 2-4 GHz:
  - Magnetrons.
  - Klystrons.
- Above 4 GHz:
  - Klystrons.
  - Magnetrons
  - TWTs.
  - Crossed Field Amplifiers.





RF Source Examples Summary

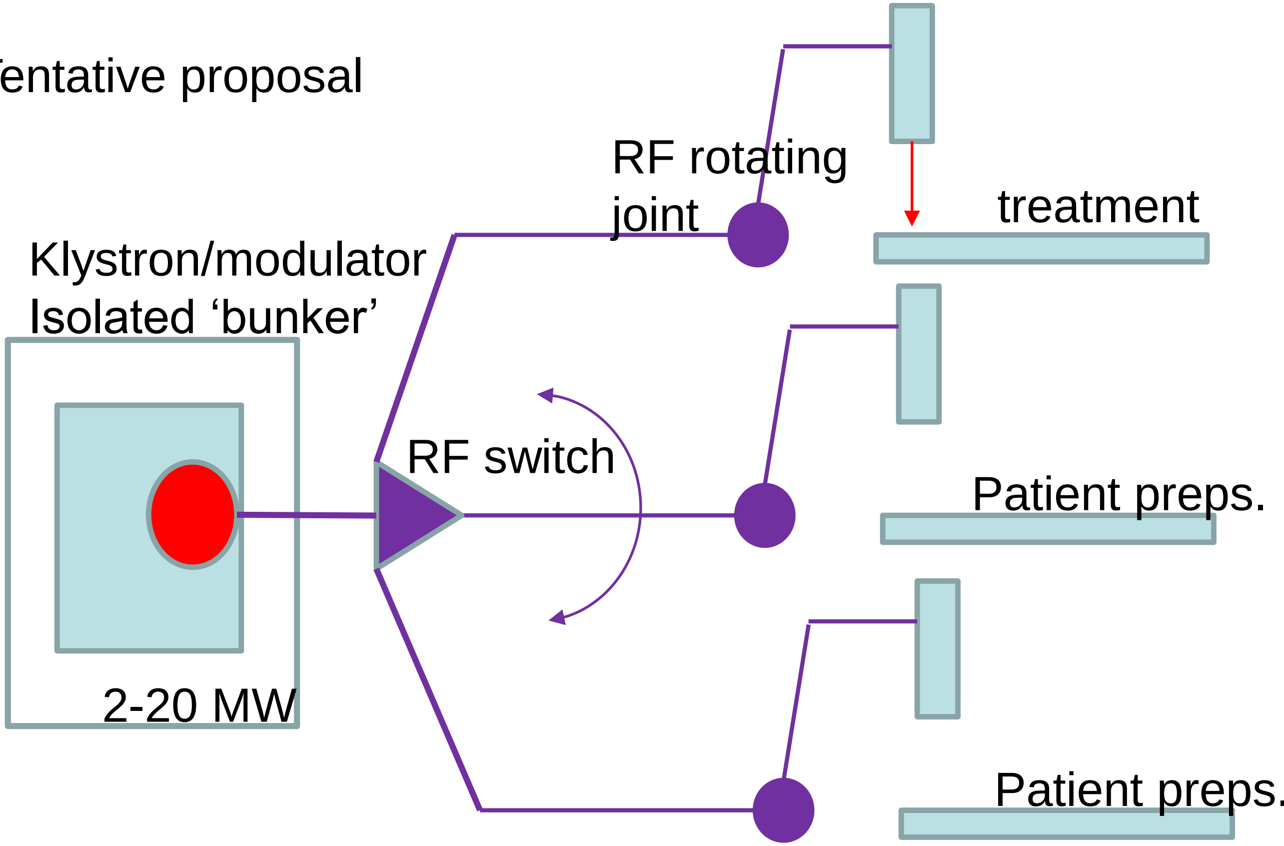
Device Type	Magnetron	Klystron	Crossed-Field Amplifier	Solid State Power Amplifier	Travelling Wave Tube	Multiple-Beam Klystron
Individual Unit Peak Output Power (MW)	5	5	0.5	0.1	0.2	6
Frequency (GHz)	2.86	2.86	9.75	0.4	5.5	2.998
Efficiency (%)	60	50	~50	No data	~25	60
Required RF power (MW)	3.9	3.9	2.68	10.4	2. 8	3.88
Units Required for ~5 MW at 3 GHz	1	1	6	140	14	1
Total Volume (m^3)	0.0103	0.2847	0.3	**739**	0.65	~0.2
Cooling	Forced air or water	Water	Forced air	Forced air	Water	Water
Magnet Required	Yes, electromagnet	Yes, PPM	Yes, electromagnet	No	Yes, PPM	Yes, PPM
Total Weight (kg) (incl. magnets)	58	150	150 (estimate)	**21,000**	1,850	95
Modulator Required	Yes	Yes	Yes	No	Yes	Yes

Example Implementation

I. Syratchev, "Personal overview of special issues of the robust/reliable medical accelerator," CERN-ICEC-STFC Workshop on Innovative, Robust and Affordable Medical Linear Accelerators for Challenging Environments, 2017.

- Multiple MBKs driving multiple linacs:
  - Over-pressurised bunker to isolate RF sources.
- Control over RF sources:
  - Single klystron feeds single linac.
  - Single klystron feeds multiple linacs.
  - Achieved with mechanical switches.
- Extension in lifetime of RF source:
  - Not all devices active at all times.
  - Should minimize downtime if one source fails.

Tentative proposal



Maximize facility put through in the most economic way.

RTT Technology Options Study

Objective:

The theme of this activity is to:

- Assess a variety of different linac and RF source configuration options:
  - Technology developments in frequency ranges outside of the conventional 2.856 GHz provision.
  - Solid state, magnetron and klystron RF power delivery capabilities.
  - Advances in both Standing Wave and Travelling Wave linac performance.
- To define a new RTT system configuration which can not only outperform, but also offer a simpler, more efficient and robust system integration platform which can be more appropriately applied for ODA country exploitation.

Such an RT treatment systems must be able to operate:

- in less stable power delivery environments, with challenging temperature and humidity conditions,
- requiring an operational capability which is able to cope with such demanding specifications.

Discussion

RTT specification critical – single/multi energy, upgradability, size, stability, training ???

RTT Technology options study analysis process:

- RF Power Source
- RF Frequency
- Beam Energy
- Linac Solution
- Cost
- Accelerator Configuration:
  - Simplification
  - Ease of maintenance
  - Modularity
  - Robust operation in challenging environments

Need to ensure:

- ODA country implementation compatibility
- Consistency with other R&D activities
- ICEC validation is fundamental
- Have a clear understanding for next steps:
  - Funding, industrialisation, implementation, ongoing development and support?