Science & Technology Facilities Council

UK Research and Innovation

Previous Workshop Outputs
Challenges to Address

Peter McIntosh STFC Daresbury Laboratory

ICEC-CERN-STFC

Accelerating the Future

Designing a Robust and Affordable Radiation Therapy Treatment System for Challenging Environments

20th – 22nd March 2019, AVANI, Botswana

Focussing on RTT Technologies

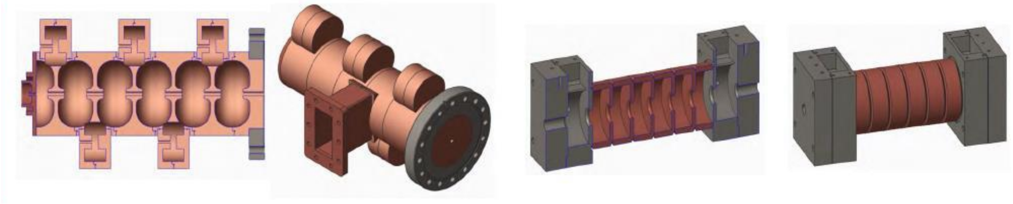
Workshop 1: 7 – 8 November 2016 at CERN

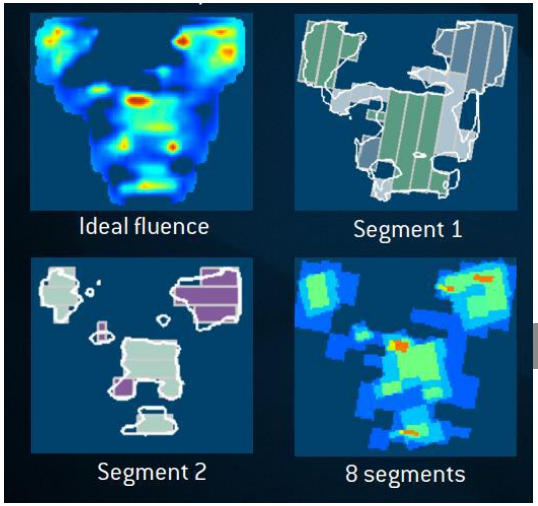
6 MeV Linacs:

- S-Band, TW, BTW and SW:
  - Pakistan, CERN, Elekta.
- C-Band, IORT, SW:
  - ENEA, ADAM.
- UHF-Band, TW:
  - CERN.

- RF Power Sources:
  - Magnetrons (<10 MeV).
  - Klystrons (>10 MeV).

- MLCs.
- Shielding.
- Modularisation.





Workshop 1 Summaries

Workshop 1: 7 – 8 November 2016 at CERN

General Guidelines

Ahmed Meghzifene IAEA

- Fulfil existing safety and performance standards.
- Be better protected against environmental variations; temperature and humidity.
- Interface for remote diagnostics and adjustments.

Industrialisation Benefits

John Allen Elekta

- High quality and low cost products are best produced by industry.
- Volume and standardisation are key drivers of lower cost.
- Producing a ‘linac for everybody’ will be more sustainable than any ‘special’ device.

Session Summary

David Jaffray

- Need to consider the treatment device in context of the system.
- The scale of the problem should push us to pursue highly innovative and disruptive solutions that cross boundaries.
- Focus on the problem: Radiotherapy for 12.5M people by 2035.
- Think beyond the scaling of current solutions.

Further RTT System Evaluation

Workshop 2: 25 – 27 October 2017 at CERN

Electron sources:
- STFC, BC CA:
    - ➢ Diode, triode, cold & photo cathodes

Simulations:
- BC CA, VCU:
    - ➢ SIMAC

Beam delivery:
- Oxford, VCU, BC CA:
    - ➢ Configurations
    - ➢ Magnet options – electro/permanent

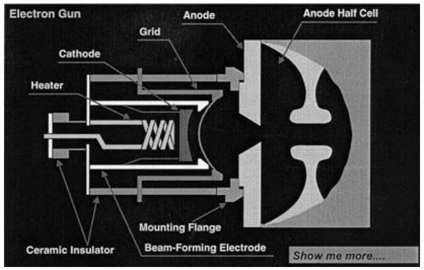
Linacs:
- STFC, Oxford:
    - ➢ TW & SW
    - ➢ S, C and X-Band

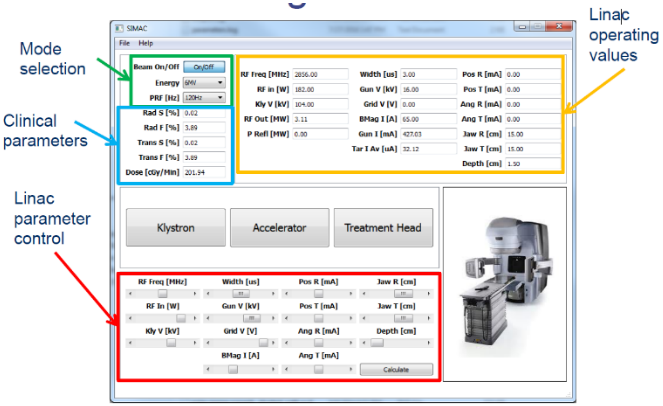
RF Sources:
- STFC, Oxford:
    - Magnetron, Klystron and SSA

Safety and Operability:
- RHUL:
    - ➢ QA/QC
    - ➢ Controls & Instrumentation
    - ➢ Shielding – Self & External

MLCs:
- VCU:
    - ➢ Single & Double focus

Constraints:
- Size, beam quality, stability, reliability and maintenance





Mode selection

Clinical parameters

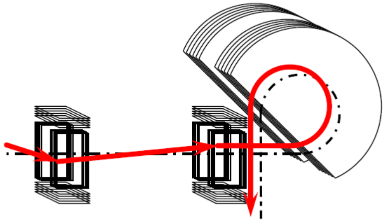
Linac parameter control

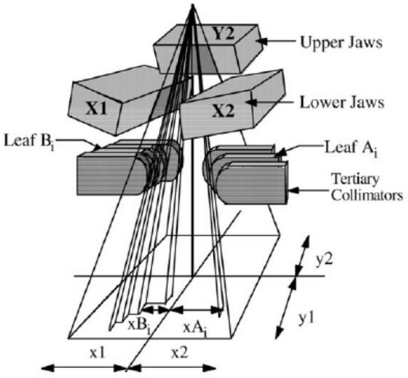
Linac operating values

Beam On/Off: On/Off
Energy: 6MV
PRF [Hz]: 120Hz

Rad S [%]: 0.02
Rad F [%]: 3.89
Trans S [%]: 0.02
Trans F [%]: 3.89
Dose [cGy/Min]: 201.94

RF Freq [MHz]: 2856.00
RF in [W]: 182.00
Kly V [kV]: 104.00
RF Out [MW]: 3.11
P Refl [MW]: 0.00
Width [us]: 3.00
Gun V [kV]: 16.00
Grid V [V]: 0.00
BMag I [A]: 65.00
Gun I [mA]: 427.03
Tar I Av [uA]: 32.12
Pos R [mA]: 0.00
Pos T [mA]: 0.00
Ang R [mA]: 0.00
Ang T [mA]: 0.00
Jaw R [cm]: 15.00
Jaw T [cm]: 15.00
Depth [cm]: 1.50





General Workshop Conclusions

Accelerator Technologies

- Electron beam source:
  - Eliminate HV stage.
  - Eliminate filament heating.
  - Automatic phase synchronization with RF.
- Linac that does not need a focus magnet, and are stable with orientation in earth's B field.
- Magnet systems:
  - Simplified energy stability (re-think the 270 degree bend magnet).
- Can we use a linac simulation model to improve linac repair?
  - Predictive maintenance and support staff training.

Diagnostics

- Ideally passive, self correcting systems for beam instrumentation - alternative is cost reduction and replication.

Costs

- RTT system costs overwhelmed by indirect factors:
  - Marketing, servicing, treatment planning, informatics and support.
- Operational costs are very important:
  - System reduction, simplification, improved efficiency, standardised components.

Operations

- Priority to have easy maintenance, rapid recovery times, better upgradability and functionality.
- Open access software would be preferred - allowing cooperative development and better standardisation:
  - Simple to use and intuitive interfacing.

General

- Reduce number of high technology, difficult to replace components with more generic components.
- Modularity and redundancy critically important..

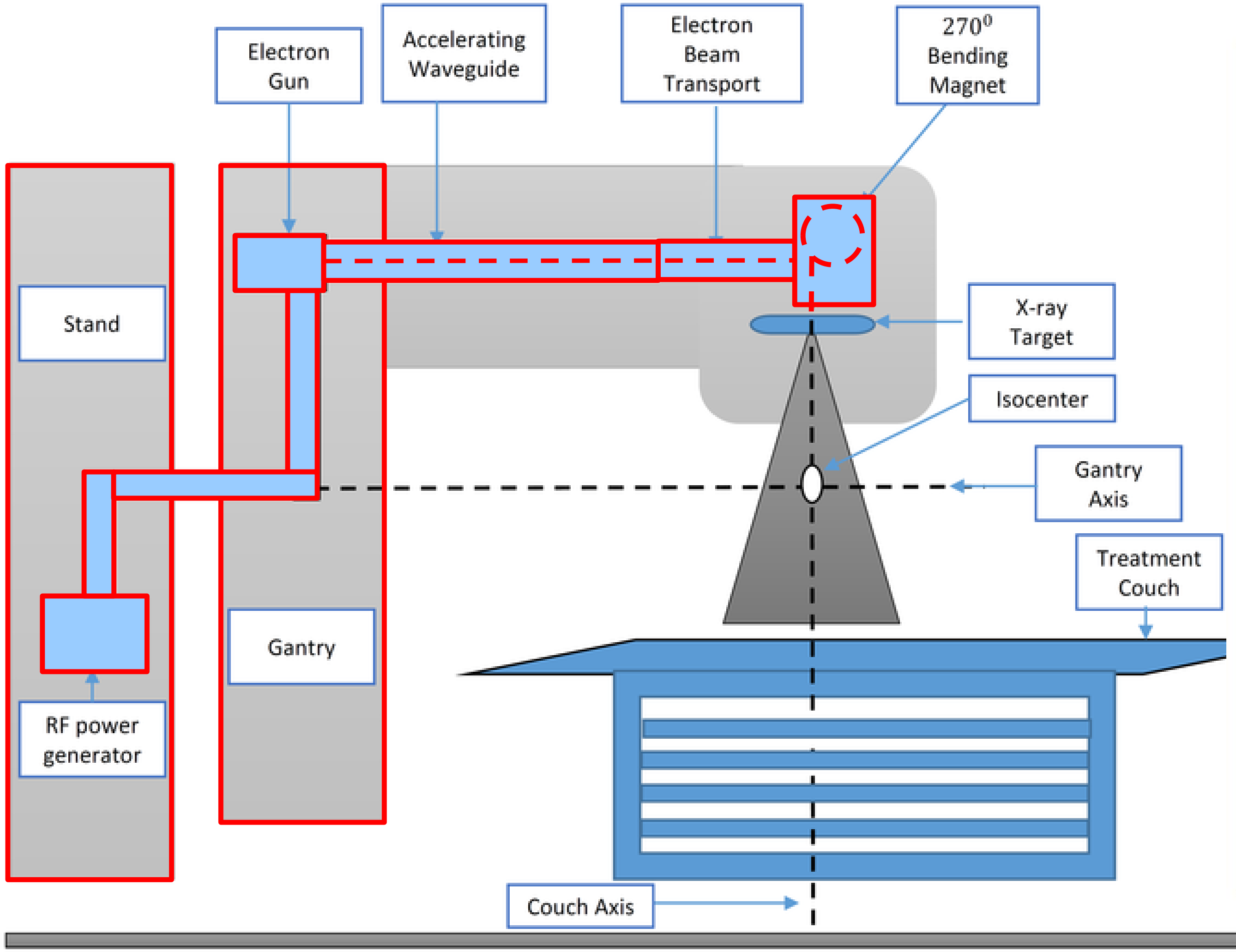
Funded RTT Developments

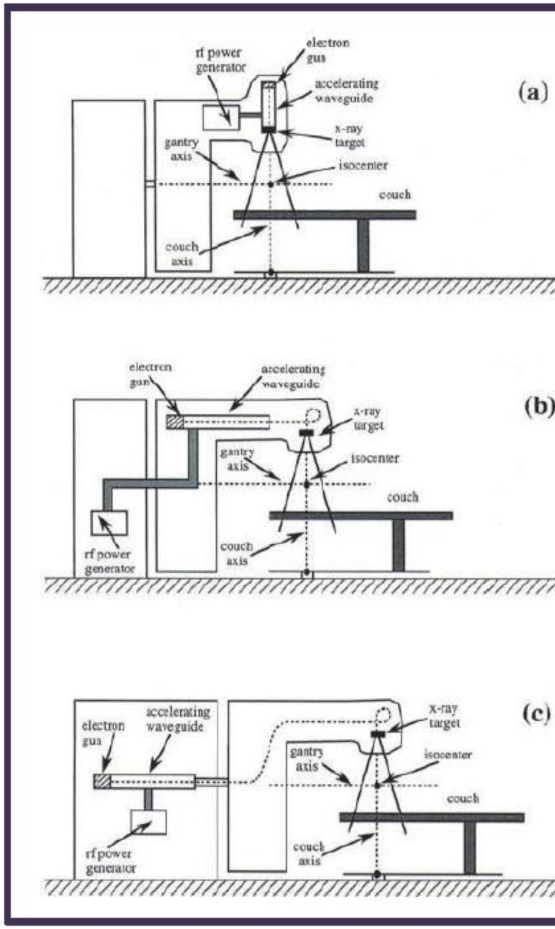
Workshop 3: 21 – 23 March 2018 at Stretton

STFC Funded Activities:

- Study of accelerator Technology Options
  Peter McIntosh (STFC)
- Study of robust beam delivery systems
  Suzie Sheehy (Oxford)
- Power systems and optimised RF structures for electron beam acceleration
  Ivan Konoplev (Oxford)
- Linac simulations for stable and sustainable operation of developing country RTT linacs
  Stewart Boogert (Royal Holloway)
- Cloud-based electronic infrastructure in support of linac-based Radiotherapy in challenging environments
  Ajay Aggarwal (Kings College London)

Conventional RTT Technology



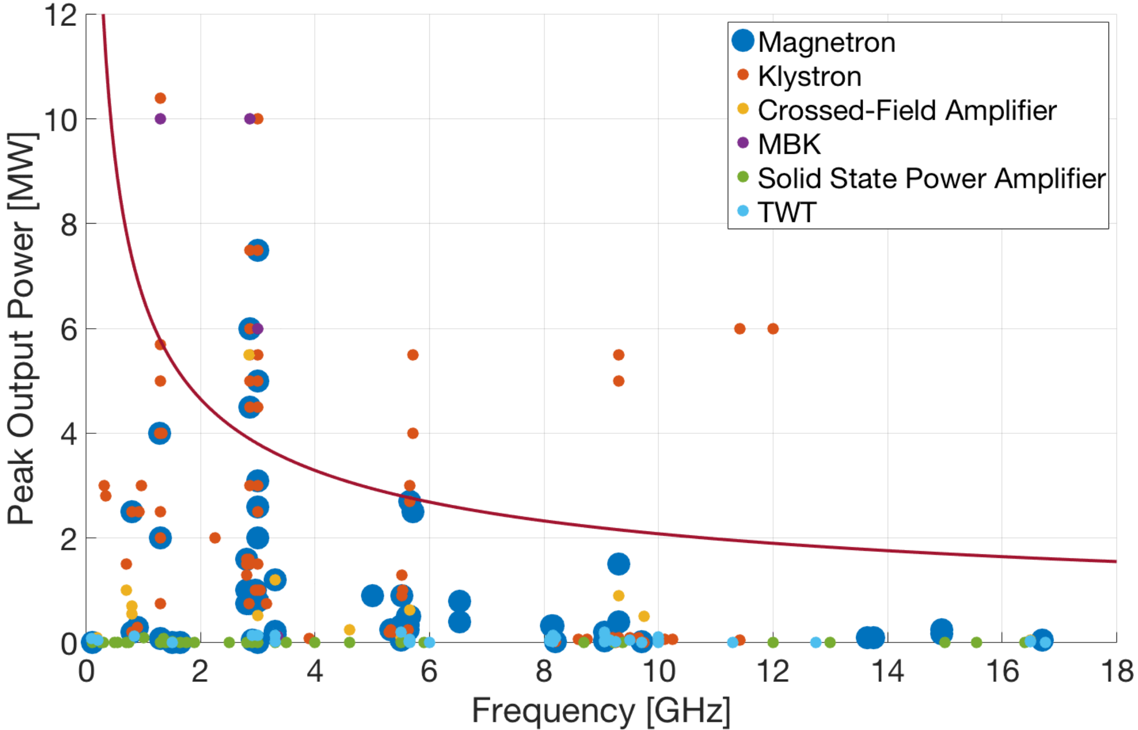


RTT Peak Output Power Comparison

David Constable Lancaster

$$P_{RF}^{linac} \propto \frac{1}{\sqrt{\omega} L_{linac}}$$

- Comparison of single devices:
  - Larger RF power required for lower frequency.
  - Magnetrons & klystrons offer largest peak power across all frequencies.
  - TWTs and SSPAs would require multiple devices to meet example specification.
  - Few single devices meet required specification.



RTT RF Source Summary

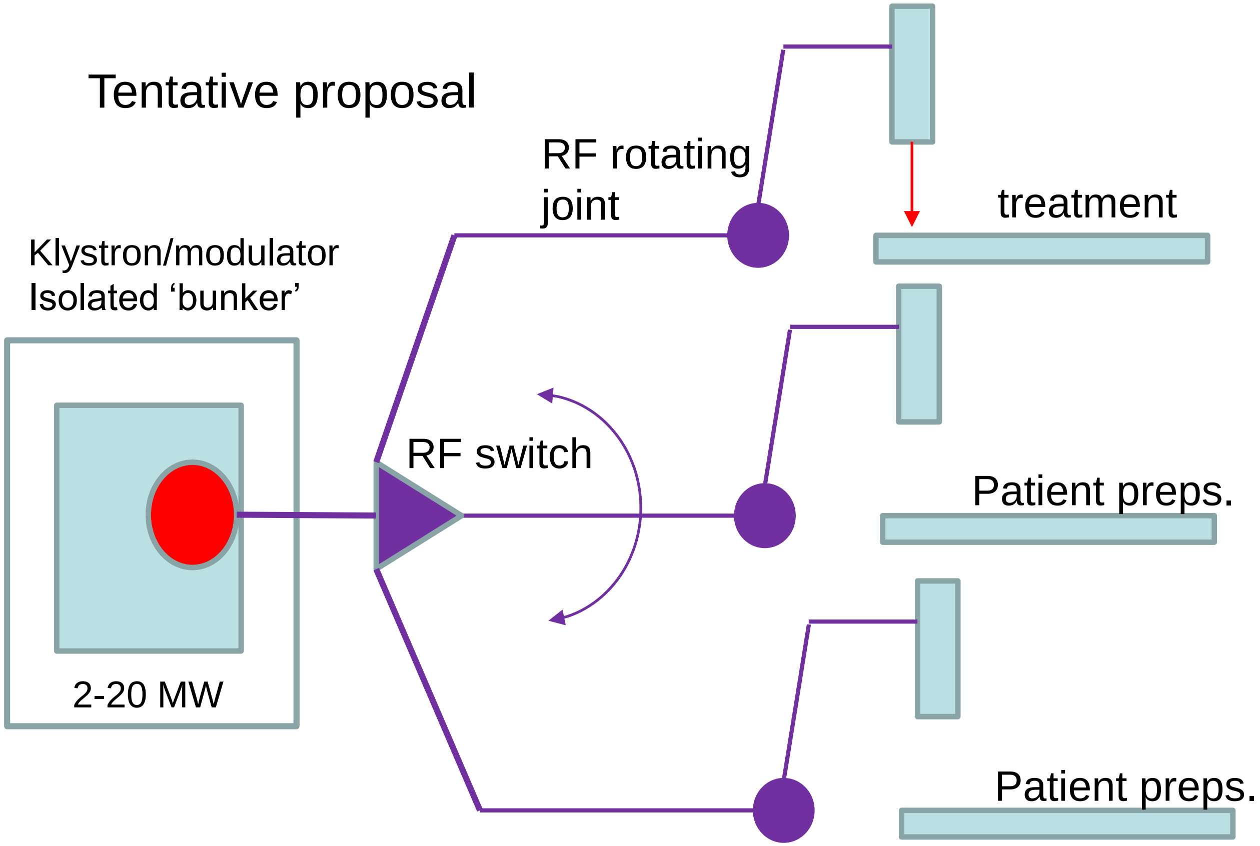
Device Type	Magnetron	Klystron	Crossed-Field Amplifier	Solid State Power Amplifier	Travelling Wave Tube	Multiple-Beam Klystron
Individual Unit Peak Output Power (MW)	5	5	0.5	0.1	0.2	6
Frequency (GHz)	2.86	2.86	9.75	0.4	5.5	2.998
Efficiency (%)	60	50	~50	No data	~25	60
Required RF power (MW)	3.9	3.9	2.68	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 – Igor Syratchev CERN

“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 throughput in the most economic way.

Linac Manufacturing Techniques

Ivan Konoplev Oxford

1/

Oxford, UH-FLUX project

3a/

Oxford, UH-FLUX project

2/

A 3D Printed Superconducting Aluminium Microwave Cavity

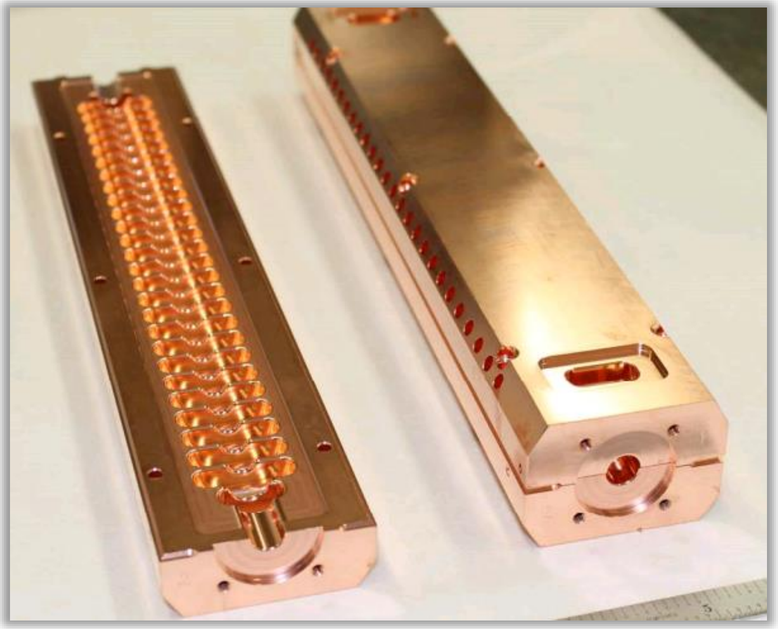
arXiv:1604.04301v2 [physics.ins-det] 1 Jun 2016

[1] *School of Physics, University of Melbourne, Parkville, Victoria 3010, Australia*

3b/

CERN, CLIC

Manufacturing Using CNC Lathe Machining



Benefits:
- Surface preparation and conditioning
- EM properties
- Cost effective
- Easy aligning and quality control

Challenges:
- Vacuum sealing
- Design of asymmetric geometries

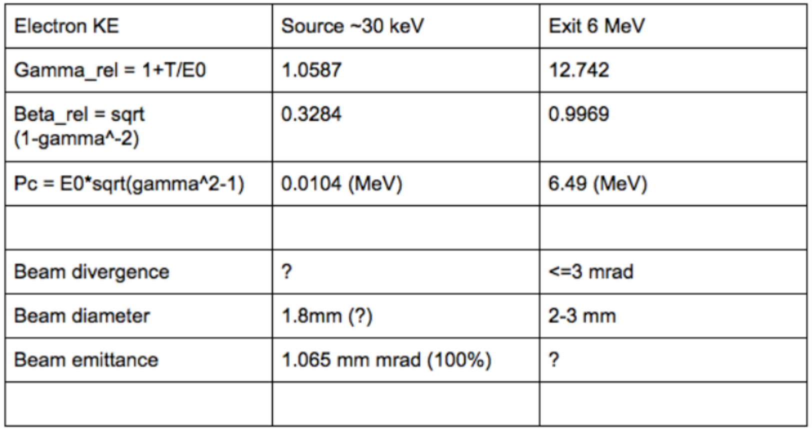
RTT Linac and RF Specifications

- Frequency:
  - > 1 GHz seems to be only solution
    - 3 GHz seems to be the preferred value for Western RTT (W-RTT)
    - What about for ODA recipient countries? Is this still the best option?
- Linac:
  - Standing wave:
    - Better choice for linac lengths < ~1.5 m
    - Preferred choice for W-RTT
  - Travelling wave:
    - Better choice for longer structures
  - Most RTT devices are a standard size:
    - Reducing linac length (higher shunt impedance) does not reduce device size
    - Increasing linac length will increase device size
- RF power source:
  - Depends on choice of RT energy range:
    - Low-energy (4-6 MeV): Magnetron c. 2 MW
    - High-energy (6-25+ MeV): Klystron c. 5-7.5 MW

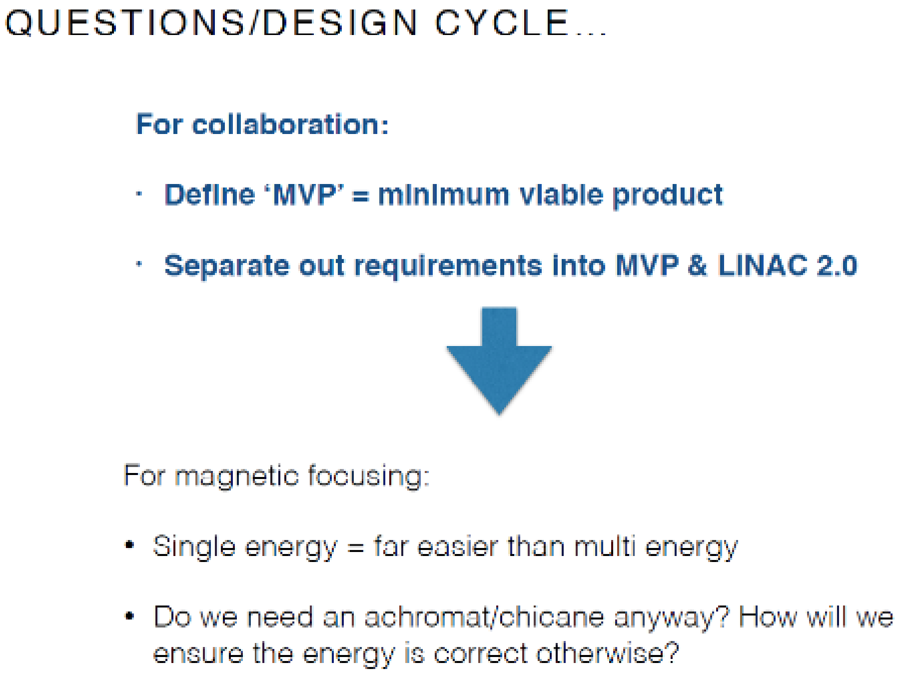
Robust Permanent Beam Delivery

Suzie Sheehy Oxford

- What focussing does the robust medical linac need?
  - What is the emittance at the source?
  - Set up method of simulation to determine required focusing and beam quality.
- Are permanent magnets suitable for this application?
  - The electromagnets used are often *water cooled* - should aim to remove this complexity.
  - PMs may offer another option (cheap, easy to maintain, no power required), but fields are *temperature dependent* and have *less flexibility* compared to electromagnets.
- Bring this together with beam dynamics model & study beam quality.



Electron KE	Source ~30 keV	Exit 6 MeV
Gamma_rel = 1+T/E0	1.0587	12.742
Beta_rel = sqrt (1-gamma^-2)	0.3284	0.9969
Pc = E0*sqrt(gamma^2-1)	0.0104 (MeV)	6.49 (MeV)
Beam divergence	?	<=3 mrad
Beam diameter	1.8mm (?)	2-3 mm
Beam emittance	1.065 mm mrad (100%)	?



QUESTIONS/DESIGN CYCLE…

For collaboration:

- **Define 'MVP' = minimum viable product**
- **Separate out requirements into MVP & LINAC 2.0**

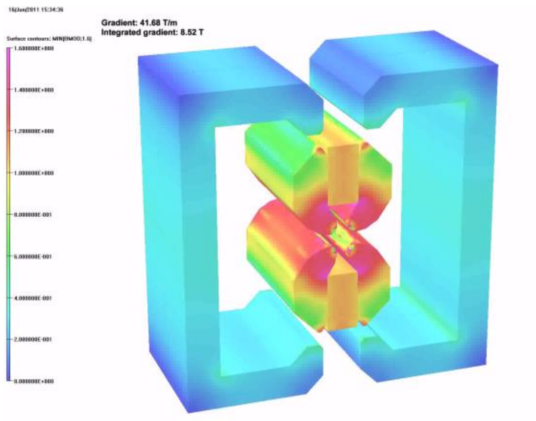
For magnetic focusing:

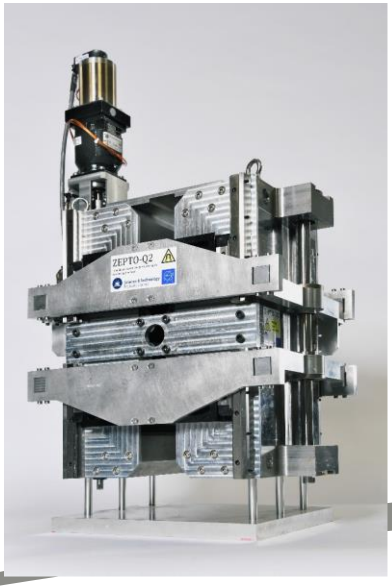
- Single energy = far easier than multi energy
- Do we need an achromat/chicane anyway? How will we ensure the energy is correct otherwise?

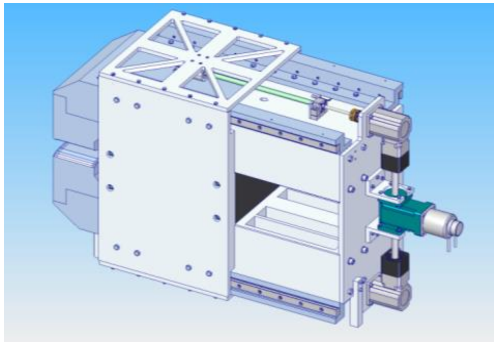
Permanent Magnets in Accelerators

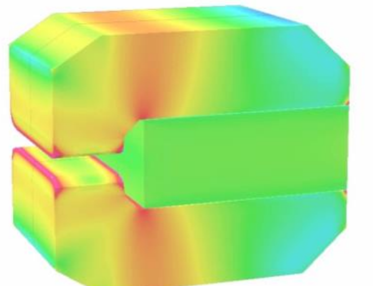
Ben Shepherd STFC

Advantages	Disadvantages
No AC power required	Temperature dependent
Low operating costs	Radiation damage
No heat generated	Tuning difficult – and slow
No cooling water, no vibration	PMs variable
Compact	









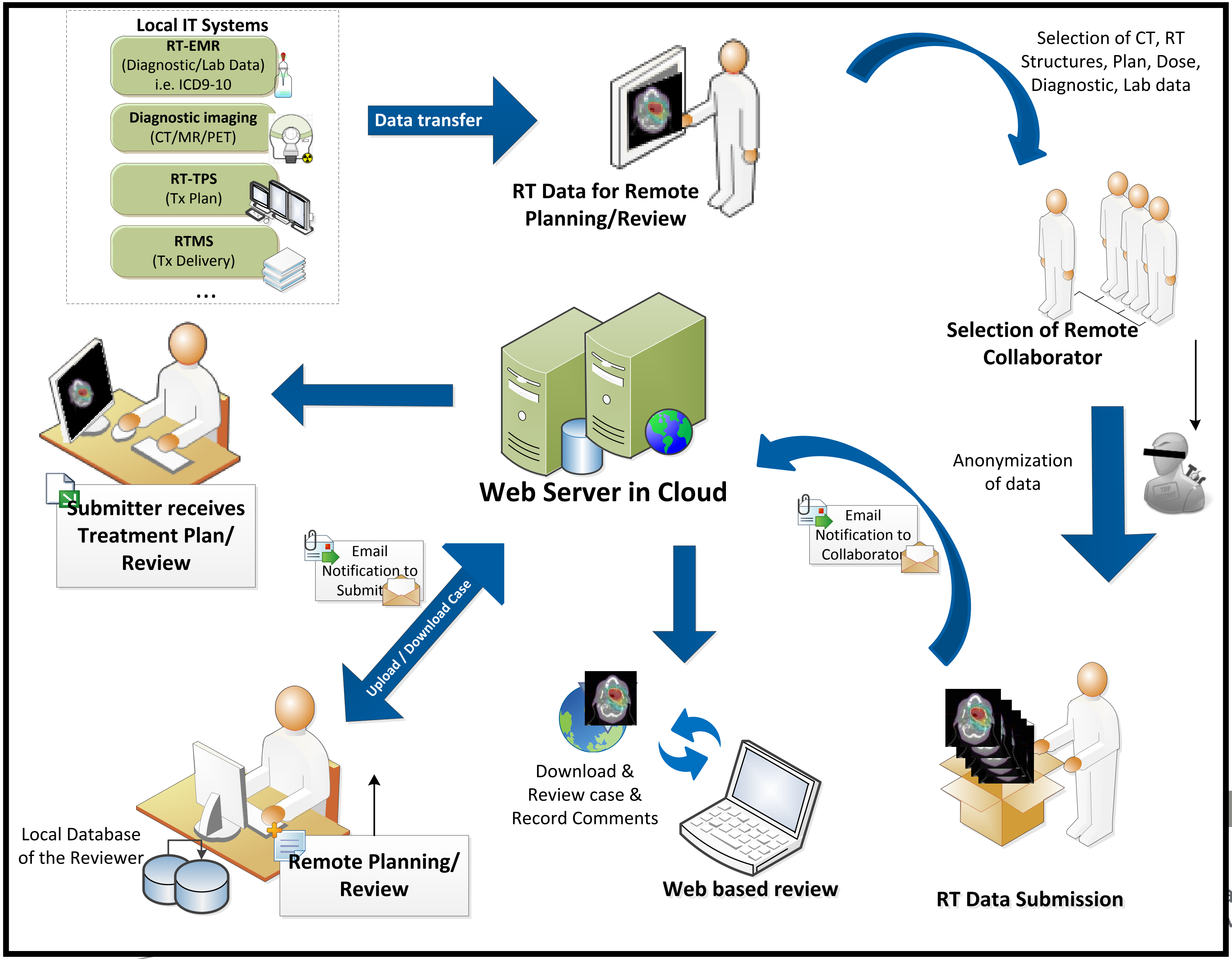
Cloud-based Electronic Infrastructure

Ajay Aggarwal Kings College

- Perform feasibility study for using the “Cloud”.
- Visits in June 2018 – Kumasi and Dar es Salaam.
- Preceded by detailed questionnaire regarding informatics capability.
- Initial development of Cloud-based Electronic Platforms in light of responses.

- Goal: To provide a cloud based software infrastructure to facilitate global collaboration in radiotherapy;
  - Electronic data sharing
  - Remote treatment planning
  - Remote peer review
  - Remote equipment troubleshooting

Process oriented view of the cloud-based electronic platform: Gen X



Local IT Systems

RT-EMR
(Diagnostic/Lab Data)
i.e. ICD9-10

Diagnostic imaging
(CT/MR/PET)

RT-TPS
(Tx Plan)

RTMS
(Tx Delivery)

…

Data transfer

RT Data for Remote Planning/Review

Selection of CT, RT Structures, Plan, Dose, Diagnostic, Lab data

Selection of Remote Collaborator

Anonymization of data

Web Server in Cloud

Email Notification to Collaborator

RT Data Submission

Download & Review case & Record Comments

Web based review

Upload / Download Case

Email Notification to Submit

Remote Planning/ Review

Local Database of the Reviewer

Submitter receives Treatment Plan/ Review

arch
vation

Electronic Infrastructure Benefits

Challenges

Staff shortages:

- Radiation oncologists.
- Physicists.
- Dosimetrists.
- Data managers.

Education and training:

- Need for technical expertise - especially for equipment use.
- Reliant on foreign sponsorship/fellowship.
- No standard training for some specialities within country.

EI Benefits

Specialist manpower:

- Cloud based peer review.
- On-demand treatment planning.
- Hub and spoke solutions.

Training of multidisciplinary teams:

- Training modules in newer RT modalities.
- Guidelines for all involved in treatment pathway.
- Training partnerships with international partners.

Quality control:

- Facilitates standard operating procedures for QA.
- Links with Linac service training and fault learning securely backs up data.

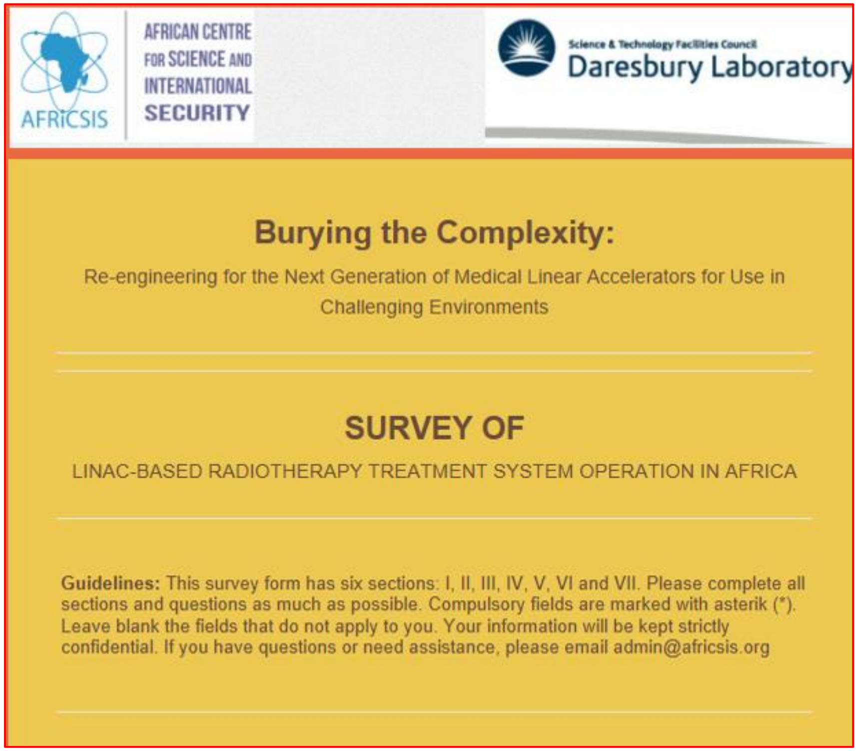
Data collection and research:

- Aggregates data from several locations.
- Audit of service and identify gaps.
- Enables involvement with international research initiatives.

RTT Operational Experience Survey

Hubert Foy AFRICSIS

- 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 sub-regions
  - Engineer, physicist, consultant, prof
- Institutions
  - University affiliated, public, private



AFRICSIS AFRICAN CENTRE FOR SCIENCE AND INTERNATIONAL SECURITY

Science & Technology Facilities Council Daresbury Laboratory

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 of 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/year	2 - 7

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

MVP Specification

Parameter	MVP	Upgrade	Comment
Fixed vs rotating gantry	gantry		type tbd
With or without rotating couch	without	without	
Beam energy or energies	single	single	4 to 10
Photon(s) only or also electrons	only	only	
With or without flattening filter			tbd, factor 10 current overhead needed
With or without MLC			tbd, design study needed
With or without bending magnet	straight ahead		may return
Combined gun-accelerator	no		
Vacuum sealed?	no		see above, modularity issue, may return
Travelling vs standing wave			tbd
Frequency			3, 6, 9 or 12 GHz (dimensions, pulse energy)
Klystron or magnetron or solid state	klystron or magnetron		
rf wave guide joints	not need with ring		avoid bending cables
Redundant RF source			later (depends on source type)
Expected dose rate	400	1500	cGy/min
Expected field size	35	40	cm
Minimum/maximum electron spot size	3 to 5	2 to 5	mm diameter FWHM, depends on MV imaging
Electro or permanent magnet			tbd, focusing and bending
All RF in gantry?	yes, objective		
RF cavity, Cu or Al?	tbd		
Beam stop	yes		
isocenter	125 cm	125 cm	
Other important issues/sub-systems to remember			
mains stabilization			
digital readout			
dose monitoring and control			
Air/water cooling			
Shielding			
Record and verify			

https://indico.cern.ch/event/698939/contributions/2942302/attachments/1622147/2584680/Parameter_Review_v2.xlsx

RTT Challenges to Solve

RTT Targetted Objectives

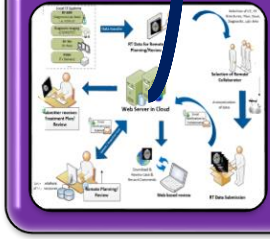
- Environmental compliant – electricity, temperature, humidity, dust ….
- High quality and low cost
- Innovative and disruptive
- Modular, low maintenance and robust

Accelerator Technologies

- For 6MeV linac:
  - Klystrons exist at 1.3 GHz, 3 GHz, 5.7 GHz, 9.3 GHz and 12 GHz.
  - Magnetrons only at 3 GHz

Recognise Challenges **Disruptive Thinking** **Design Work** **Technology Development** **Global Availability**

- Electrical/electronic components and cooling systems are key failu mechanisms.
- Capital and operation cost is significant constraint.
- Need easy maintenance, rapid recovery, better upgradability and functionality.



Cloud Infrastructure

- Significant benefits from cloud-based data management systems.
- Infrastructure, training, education and quality control are primary challenges.
- Optimised system can provide remote RTT equipment diagnosis.