

SIMAC: A Simulation Tool for Teaching Linear Accelerator Physics

M Carlone, N Harnett, W Harris, B Norrlinger, M MacPherson, M Lamey, R Anderson, M Oldham

Princess Margaret Cancer Centre, University of Toronto, Duke University Medical Centre, The Ottawa Hospital, Trillium Health Partners



Radiation Oncology
UNIVERSITY OF TORONTO



Linac Physics is Complicated

- Electron beam acceleration in waveguide is advanced physics.
- There is a convoluted relationship between the basic physics and clinical beam properties.

Teaching Linac Physics

- Should relate basic physical principles to clinical parameters.
- Needs a hands on component.
- Jargon issues between service engineers and physicists.
- Few teaching resources
 - Other than Karzmark text there is very little.

The Accelerated Education Program

Princess Margaret Cancer Centre



Upcoming Course

Accelerator Technology (ATec)

February 28 - March 3, 2017

Led By: Dr. Marco Carlone &
Mr. Bern Norrlinger

Connect with Us!



Web: www.aepeducation.ca



Email: aep@rmp.uhn.ca



Twitter: @AEPcme



YouTube: AEP Education



LinkedIn: Accelerated Education Program

Challenges with the ATec Course

- 4 day length is too short for any in depth teaching.
- Relating linac theory to linac service/QA problems is difficult.
- Clinical linacs at PMH were not available.

SIMAC

Simulate Linac

SIMAC

File Help

Beam On/Off

Energy

PRF [Hz]

Rad S [%]

Rad F [%]

Trans S [%]

Trans F [%]

Dose [cGy/Min]

RF Freq [MHz] Width [us] Pos R [mA]

RF in [W] Gun V [kV] Pos T [mA]

Kly V [kV] Grid V [V] Ang R [mA]

RF Out [MW] BMag I [A] Ang T [mA]

P Refl [MW] Gun I [mA] Jaw R [cm]

Tar I Av [uA] Jaw T [cm]

Depth [cm]

Klystron Accelerator Treatment Head


RF Freq [MHz] Width [us] Pos R [mA] Jaw R [cm]

RF In [W] Gun V [kV] Pos T [mA] Jaw T [cm]

Kly V [kV] Grid V [V] Ang R [mA] Depth [cm]

BMag I [A] Ang T [mA]

Calculate



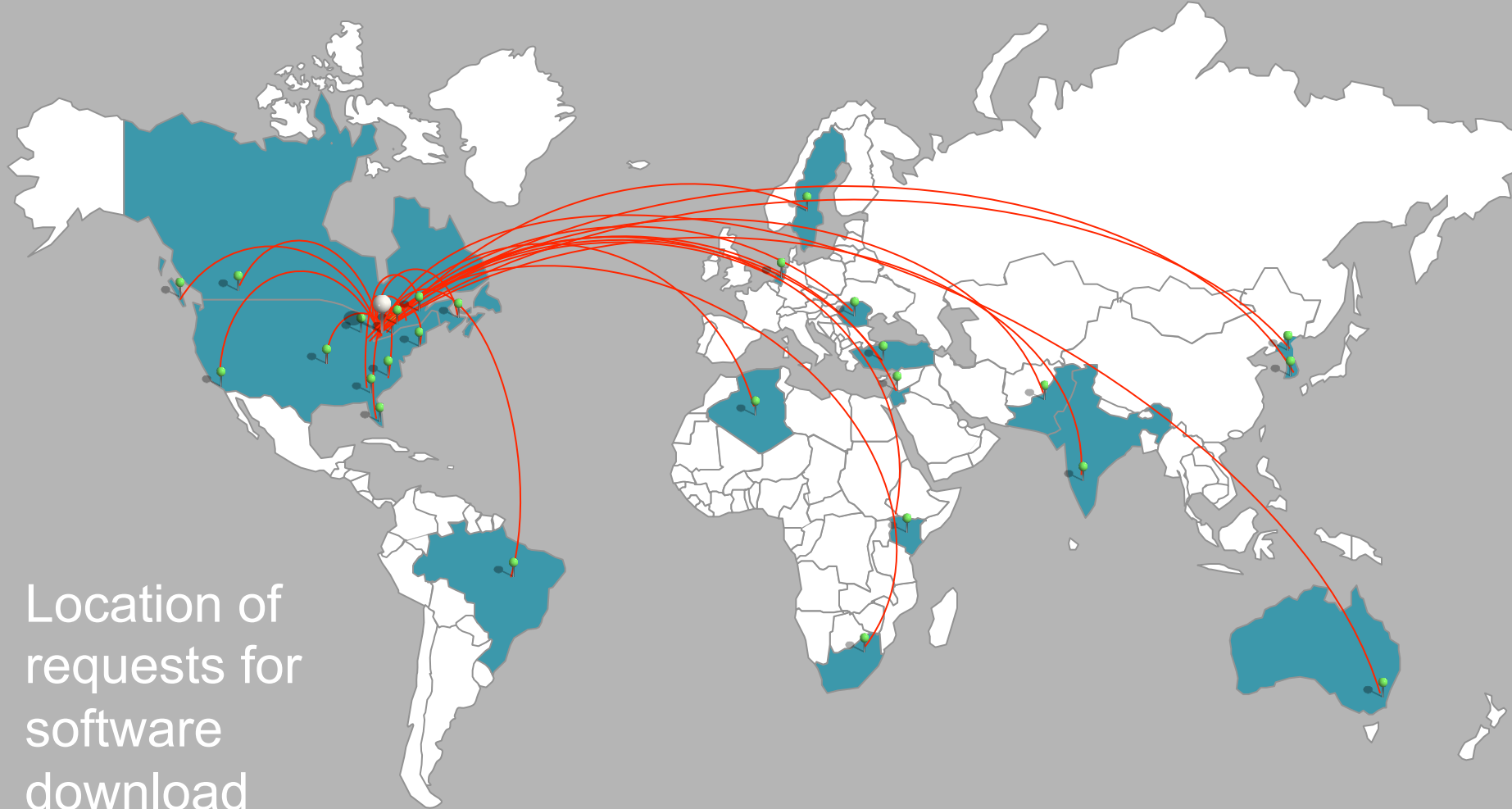
- Most linac physics can be modeled using simple analytical approximations
- Response is consistent with a real linac response.
- Meant to simulate the service mode of a clinical linac

SIMAC Global Reach

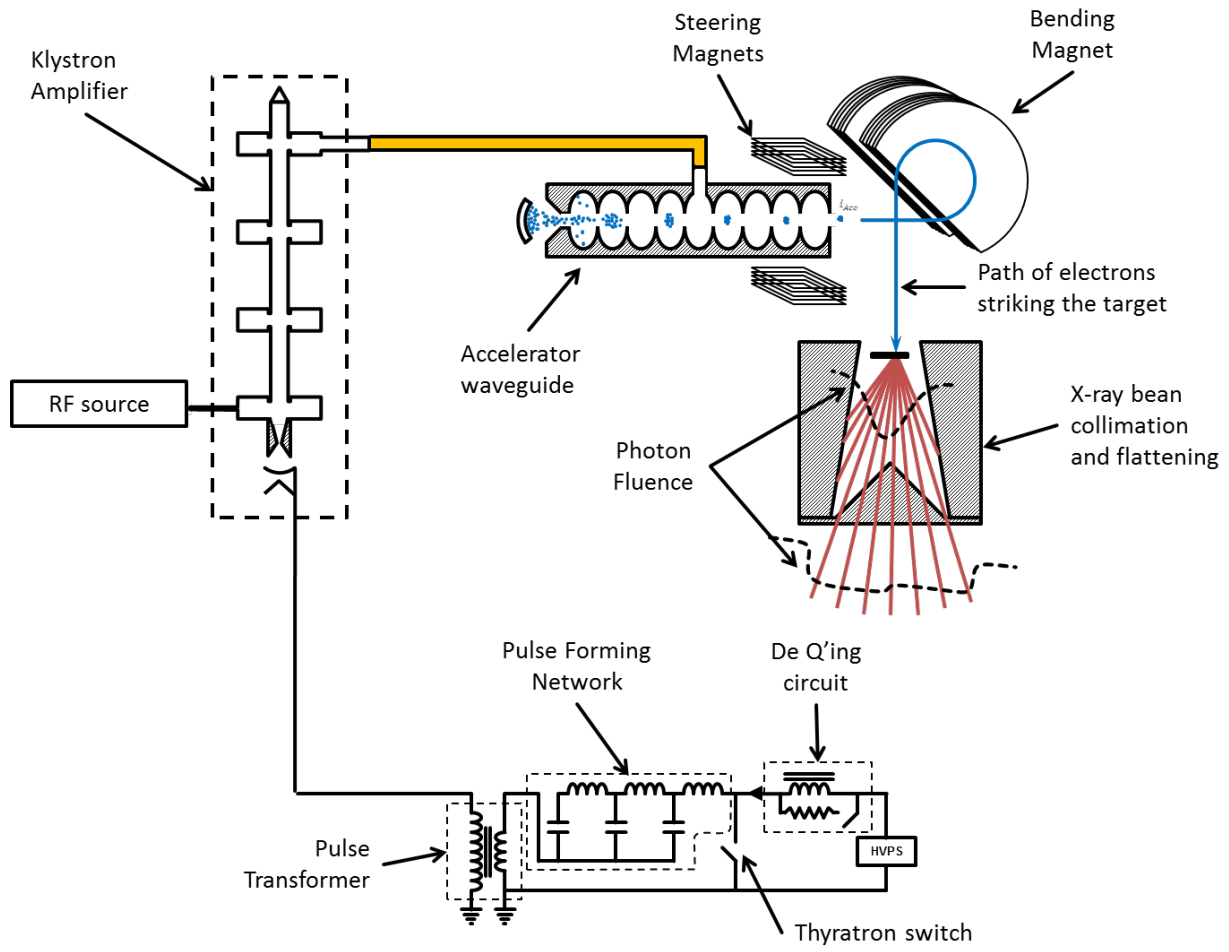
Simulation of a medical linear accelerator for teaching purposes

Rhys Anderson,¹ Mike Lamey,¹ Miller MacPherson,^{2,3} Marco Carlone^{2,3a}
*Department of Medical Physics,¹ Trillium Health Partners, Mississauga, ON, Canada;
Radiation Medicine Program,² Princess Margaret Cancer Centre, Toronto, ON, Canada;
Department of Radiation Oncology,³ University of Toronto, Toronto, ON, Canada
marco.carlone@rmp.uhn.on.ca*

Received 12 June, 2014; accepted 26 January, 2015



Location of requests for software download



Using SIMAC

SIMAC File Help

Beam 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


Klystron **Accelerator** **Treatment Head**

RF Freq [MHz] **Width [us]** **Pos R [mA]** **Jaw R [cm]**

RF In [W] **Gun V [kV]** **Pos T [mA]** **Jaw T [cm]**

Kly V [kV] **Grid V [V]** **Ang R [mA]** **Depth [cm]**

BMag I [A] **Ang T [mA]**



Using SIMAC

Mode selection

Clinical parameters

Linac parameter control

Linac operating values

The SIMAC software interface is divided into several functional areas:

- Mode selection:** A green-bordered box containing 'Beam On/Off' (On/Off button), 'Energy' (6MV dropdown), and 'PRF [Hz]' (120Hz dropdown).
- Clinical parameters:** A blue-bordered box containing percentage-based parameters: Rad S [%] (0.02), Rad F [%] (3.89), Trans S [%] (0.02), Trans F [%] (3.89), and Dose [cGy/Min] (201.94).
- Linac operating values:** A yellow-bordered box containing numerical parameters: 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), and Depth [cm] (1.50).
- Linac parameter control:** A red-bordered box containing sliders for: RF Freq [MHz], Width [us], Pos R [mA], Jaw R [cm], RF In [W], Gun V [kV], Pos T [mA], Jaw T [cm], Kly V [kV], Grid V [V], Ang R [mA], Depth [cm], BMag I [A], and Ang T [mA]. A 'Calculate' button is located at the bottom right of this section.
- Component Selection:** Three buttons labeled 'Klystron', 'Accelerator', and 'Treatment Head' are positioned above the parameter control sliders.
- Linac Image:** A photograph of a linear accelerator machine is shown on the right side of the interface.

Using SIMAC

Mode selection

Clinical parameters

Linac parameter control

Linac operating values

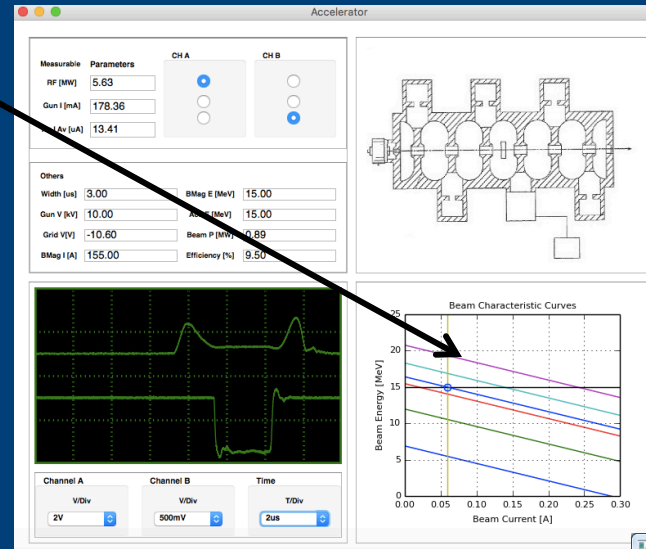
The SIMAC software interface is divided into several functional areas:

- Mode selection:** A green-bordered box containing 'Beam On/Off' (On/Off), 'Energy' (6MV), and 'PRF [Hz]' (120Hz).
- Clinical parameters:** A blue-bordered box containing 'Rad S [%]' (0.02), 'Rad F [%]' (3.89), 'Trans S [%]' (0.02), 'Trans F [%]' (3.89), and 'Dose [cGy/Min]' (201.94).
- Linac operating values:** A yellow-bordered box containing a grid of numerical input fields for parameters such as RF Freq [MHz], Width [us], Pos R [mA], RF in [W], Gun V [kV], Pos T [mA], Kly V [kV], Grid V [V], Ang R [mA], RF Out [MW], BMag I [A], Ang T [mA], P Refl [MW], Gun I [mA], Jaw R [cm], Tar I Av [uA], Jaw T [cm], and Depth [cm].
- Linac parameter control:** A red-bordered box containing a grid of slider controls for the same parameters as the Linac operating values, plus a 'Calculate' button.
- Component Selection:** Three blue-bordered buttons labeled 'Klystron', 'Accelerator', and 'Treatment Head'.
- Linac Image:** A photograph of a medical linear accelerator machine on the right side of the interface.

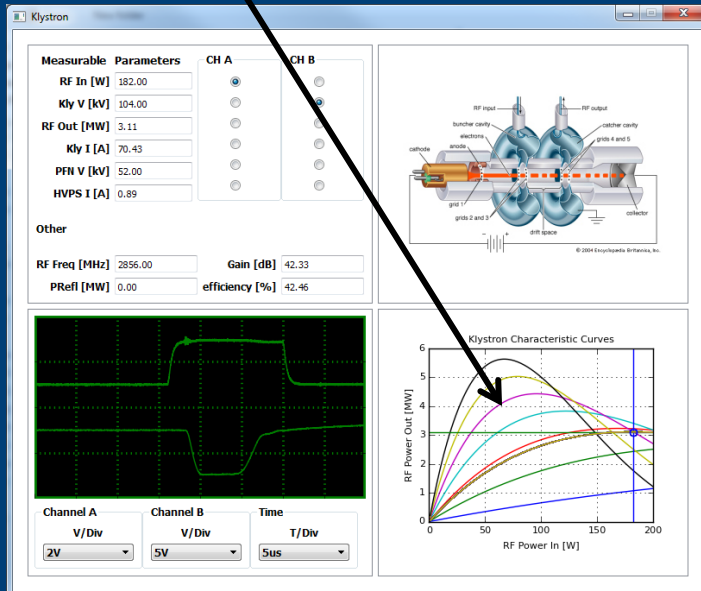
Linac Physics modules in SIMAC

The linac Load line is modelled using the concept of "Shunt Impedance"

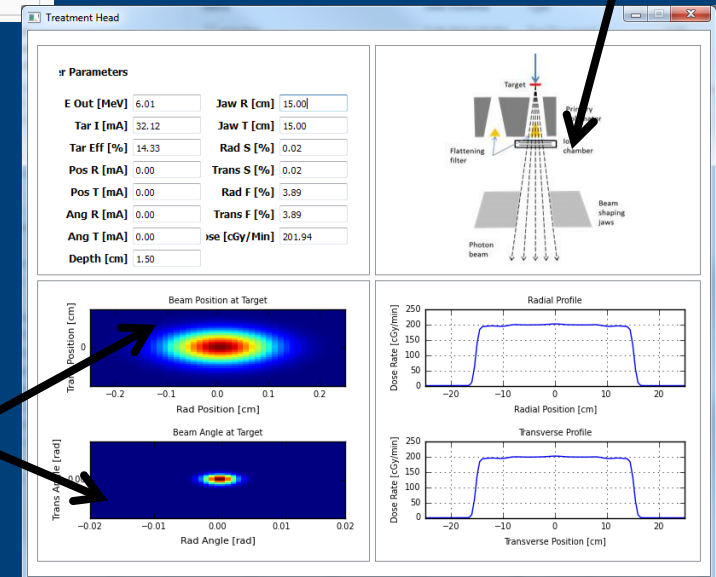
Klystron saturation is modelled using an analytical (Bessel) function



Photon transport is modelled using bremsstrahlung yield tables (NIST) and linear attenuation in the FF and water phantom

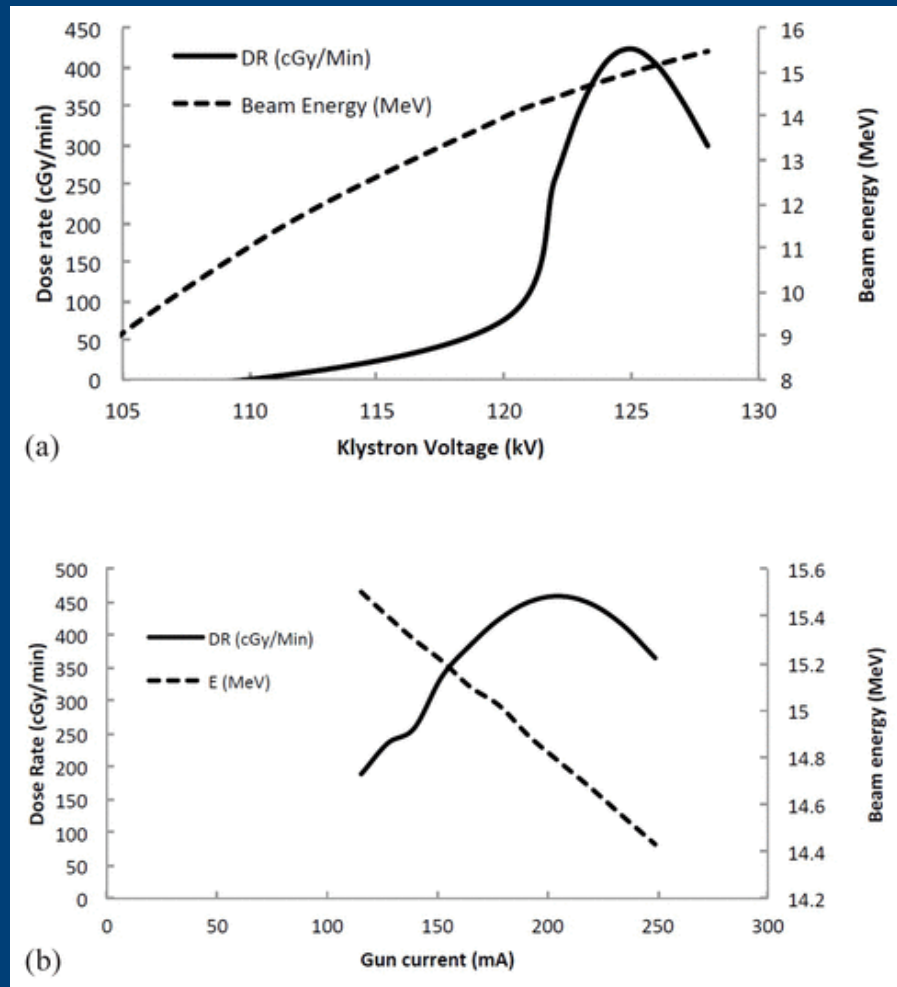


Electron beam position and angle on the target



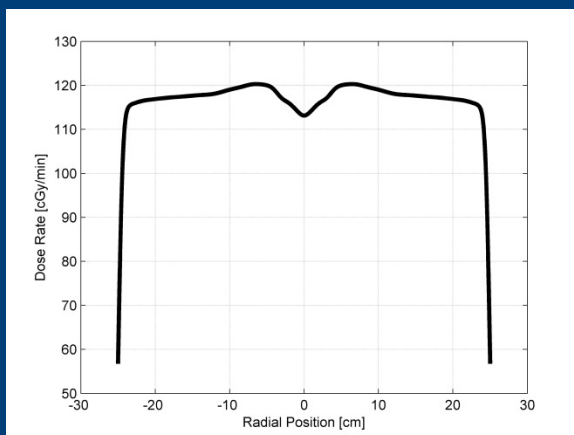
Atec Lab Exercise 1:

Teaching of beam “tuning” with SIMAC

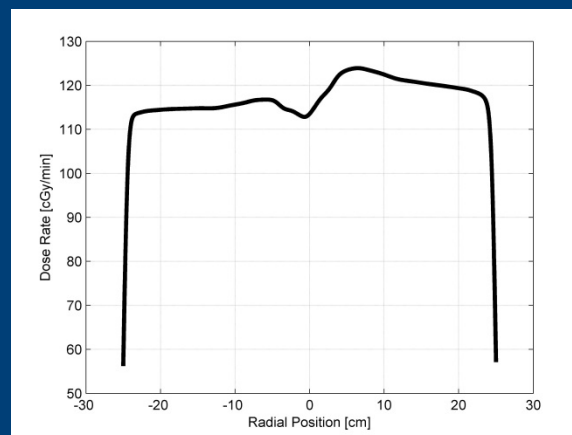


ATec Lab Exercise 2:

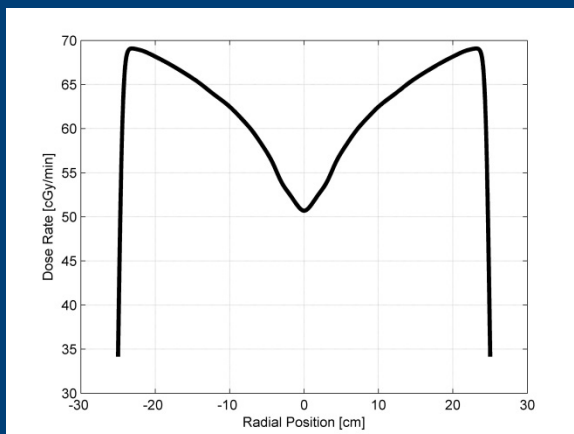
Using SIMAC to teach Flatness & Symmetry as a response to beam steering and energy



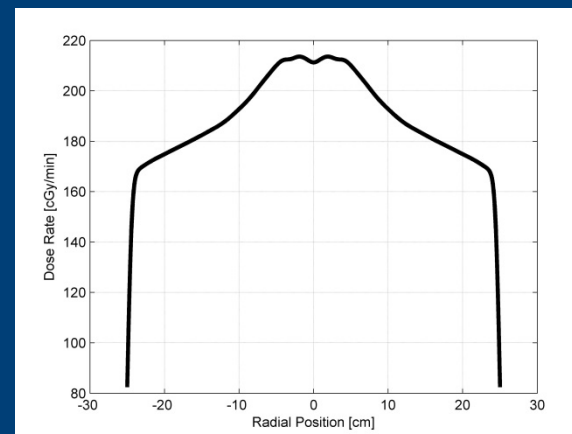
6 MeV beam on 6MV flattening filter



Pos_R = 100 mA, Ang_R = 0



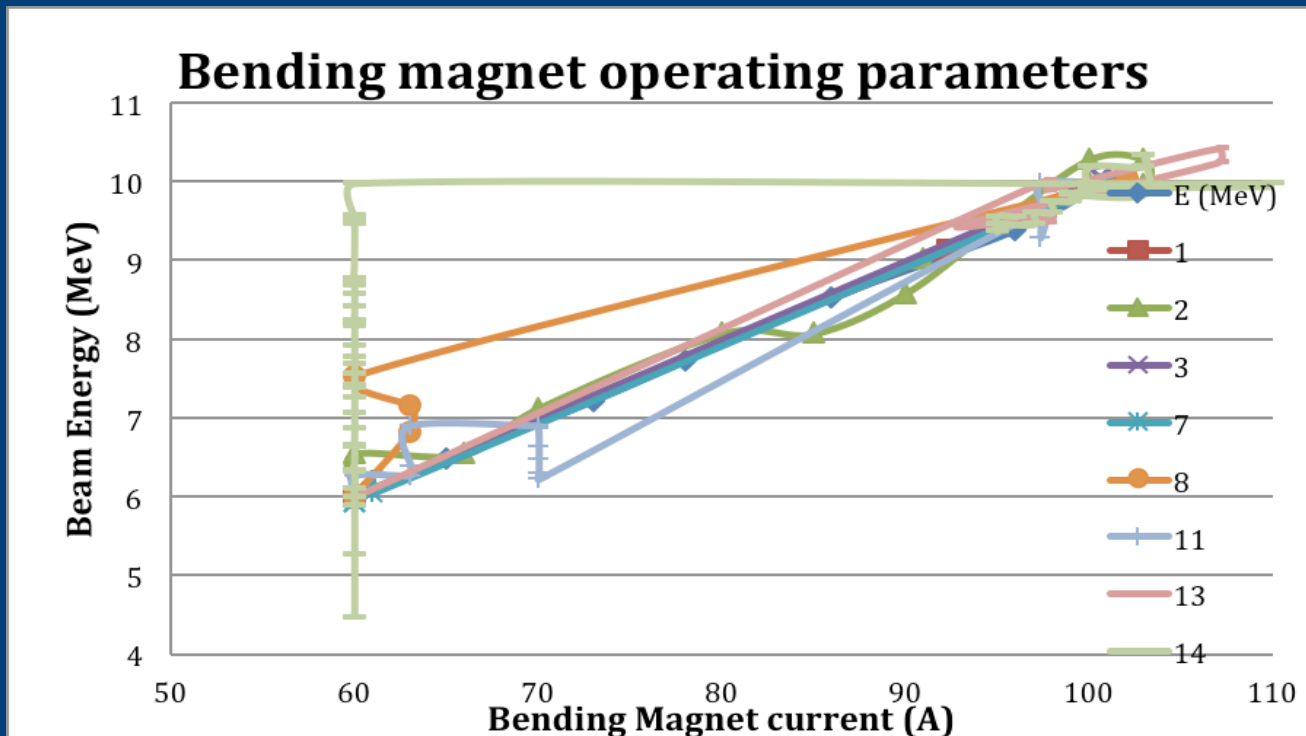
4.5 MeV beam on 6MV flattening filter



7.5 MeV beam on 6MV flattening filter

Laboratory teaching with SIMAC

Setting up a new energy



User feedback and Testimonials

- Found this lab extremely useful. Really helped me understand all topics discussed so far.
- The SIMAC software is great to work with. Whom ever worked on creating it did an amazing job.
- The lab was very helpful in bringing all the concepts together.
- Excellent! Found both really helped my understanding of topics in course.
- Very informative and interesting. More scenarios/ exercises would be fun.
- The simulation program is extremely useful and a great learning tool. It helped me to understand and connect many of the concepts.
- The lab was excellent; learning the various traits to work a linac.

www.simaclinac.com

The screenshot shows a web browser window with the URL <http://simac.technainstitute.com/>. The page features a navigation bar with the SIMAC logo and links for HOME, BACKSTORY, LEARNING RESOURCES, COMMUNITY, CONTACT, and LOGIN. The main content area has a large image of medical linac components with the text: "USING SIMPLIFIED LINAC PHYSICS AND FUNCTIONING IN REAL TIME" and "A MEDICAL LINEAR ACCELERATOR SIMULATION SOFTWARE THAT ALLOWS USERS TO SIMULATE THE PHYSICS OF MEDICAL LINEAR ACCELERATORS". Below this are three columns: "BACKSTORY" (with a book icon), "LEARNING" (with a person icon), and "HELP OUT" (with a group icon). Each column contains descriptive text and a button: "READ FURTHER", "GET INVOLVED", and "OPPORTUNITIES". A footer at the bottom left shows the URL <http://simac.technainstitute.com/learning-resources/>.

Four levels of learning effectiveness

1. Reaction

Were the users satisfied?

2. Learning

Was knowledge gained?

3. Behaviour

How knowledge gain applies to work.

4. Results

Work habits changed.

Four levels of learning effectiveness

1. Reaction

Were the users satisfied?



2. Learning

Was knowledge gained?

3. Behaviour

How knowledge gain applies to work.

4. Results

Work habits changed.

Four levels of learning effectiveness

1. Reaction

Were the users satisfied?

2. Learning

Was knowledge gained?

3. Behaviour

How knowledge gain applies to work.

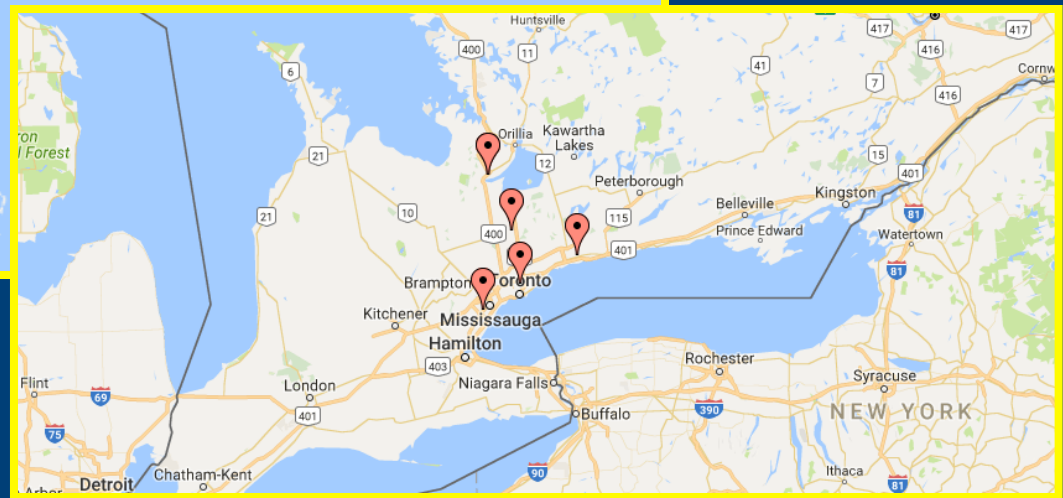
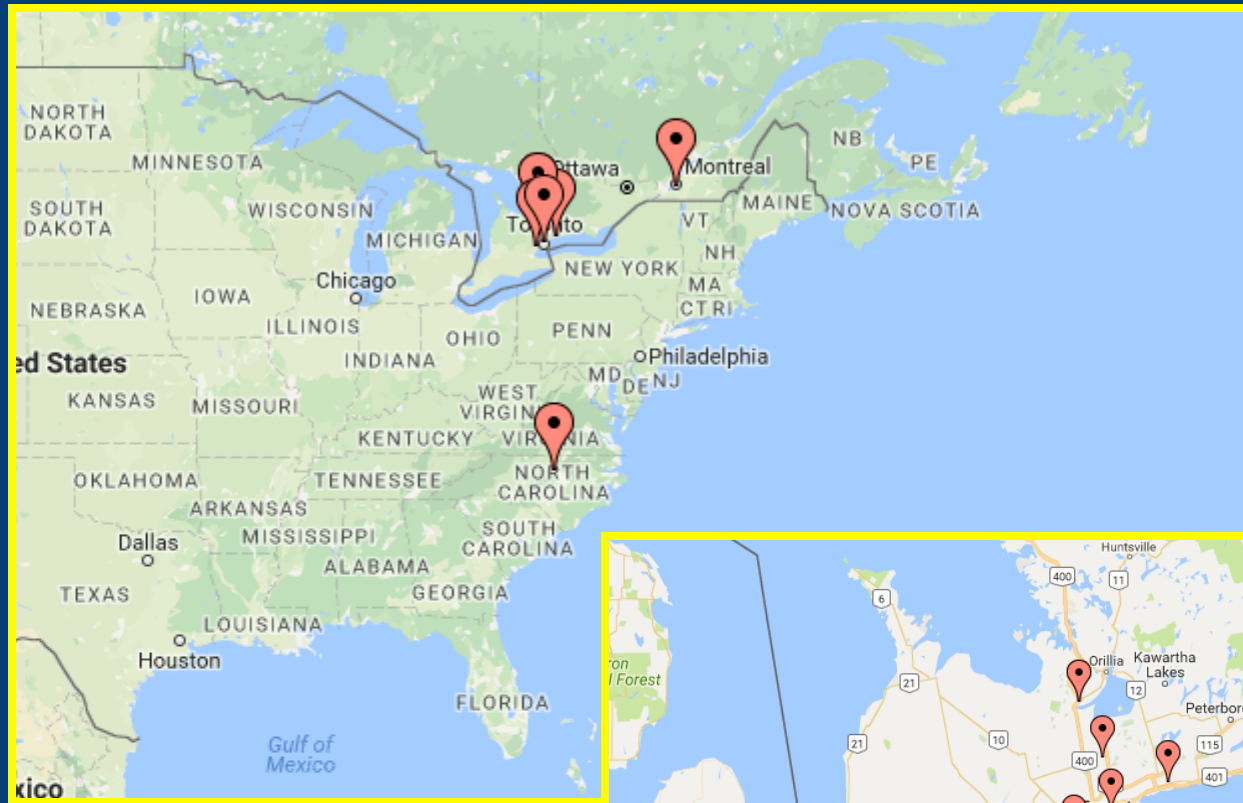
4. Results

Work habits changed.

Evaluating the effectiveness of SIMAC

- Received Funding through University of Toronto.
- Develop an assessment tool and validate
 - using physicists and residents from the U of T affiliated cancer centre and two other centres.

Map of center participants



Study methodology

1. Establish Learning Outcomes

- a) Ability to understand linac physics in relation to linac QA after servicing.

2. Develop Evaluation Methods

- a) Pre/post knowledge test design using clinical based scenarios.

3. Conduct Scale Assessment

- a) Recruiting Residents & physicists from the participating centers
- b) Complete in the Fall, 2016.

Example Learning Scenario

- New Low energy Linac to replace ^{60}Co unit
- Desire to drop beam energy to match to Cobalt
- Student must:
 - Complete the exercise using SIMAC and retune the unit for a lower energy
 - Report on Clinical parameters (Beam flatness, 2 point PDD)
 - Describe the operating condition at the lower energy
 - Is it a realistic operating point, and why?

Scenario based evaluation

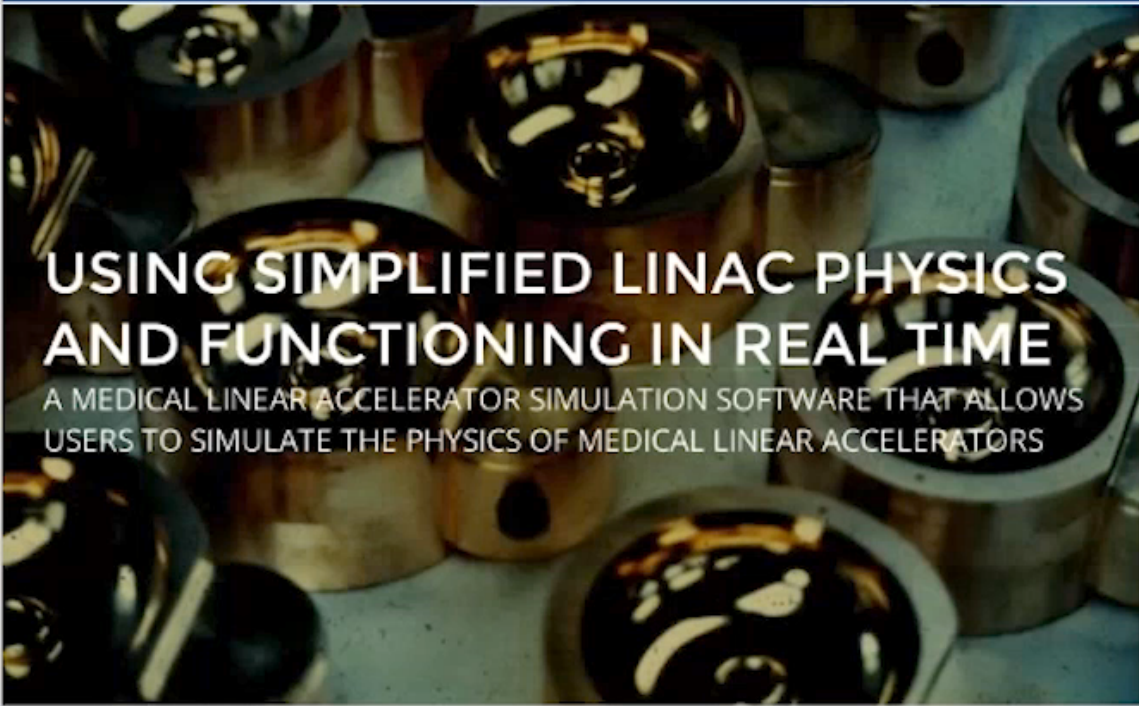
Menu

- Introduction
- SIMAC**
- Backstory
- LINAC Work
 - Scenario One
 - A Low Energy Linac
 - Commissioned Values
 - The Clinic
 - The Physicist
 - Values Q. 1
 - Values Q. 2
 - Values Q. 3
 - Continue
- Test
 - Test
 - Q 1.a)
 - Q 1.b)
 - Q 2.a)
 - Q 2.b)
 - Q 2.c)

SIMAC_Scenario1

Resources

SIMAC



**USING SIMPLIFIED LINAC PHYSICS
AND FUNCTIONING IN REAL TIME**

A MEDICAL LINEAR ACCELERATOR SIMULATION SOFTWARE THAT ALLOWS
USERS TO SIMULATE THE PHYSICS OF MEDICAL LINEAR ACCELERATORS

< PREV

NEXT >

The future

- Expand the physics within SIMAC:
 - Model temperature, ion chambers, magnetron linacs, frequency control, dose rate servo, etc.
- Distribute SIMAC package to Medical Physics community

Thank You!
www.simaclinac.com



Radiation Oncology
UNIVERSITY OF TORONTO

