



BC Cancer Agency

CARE + RESEARCH

An agency of the Provincial Health Services Authority

Teaching linear accelerator physics using simulation software

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About the presenter



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Marco Carlone, M.Sc., P.Eng.
Accelerator Systems Engineer

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

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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]

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]



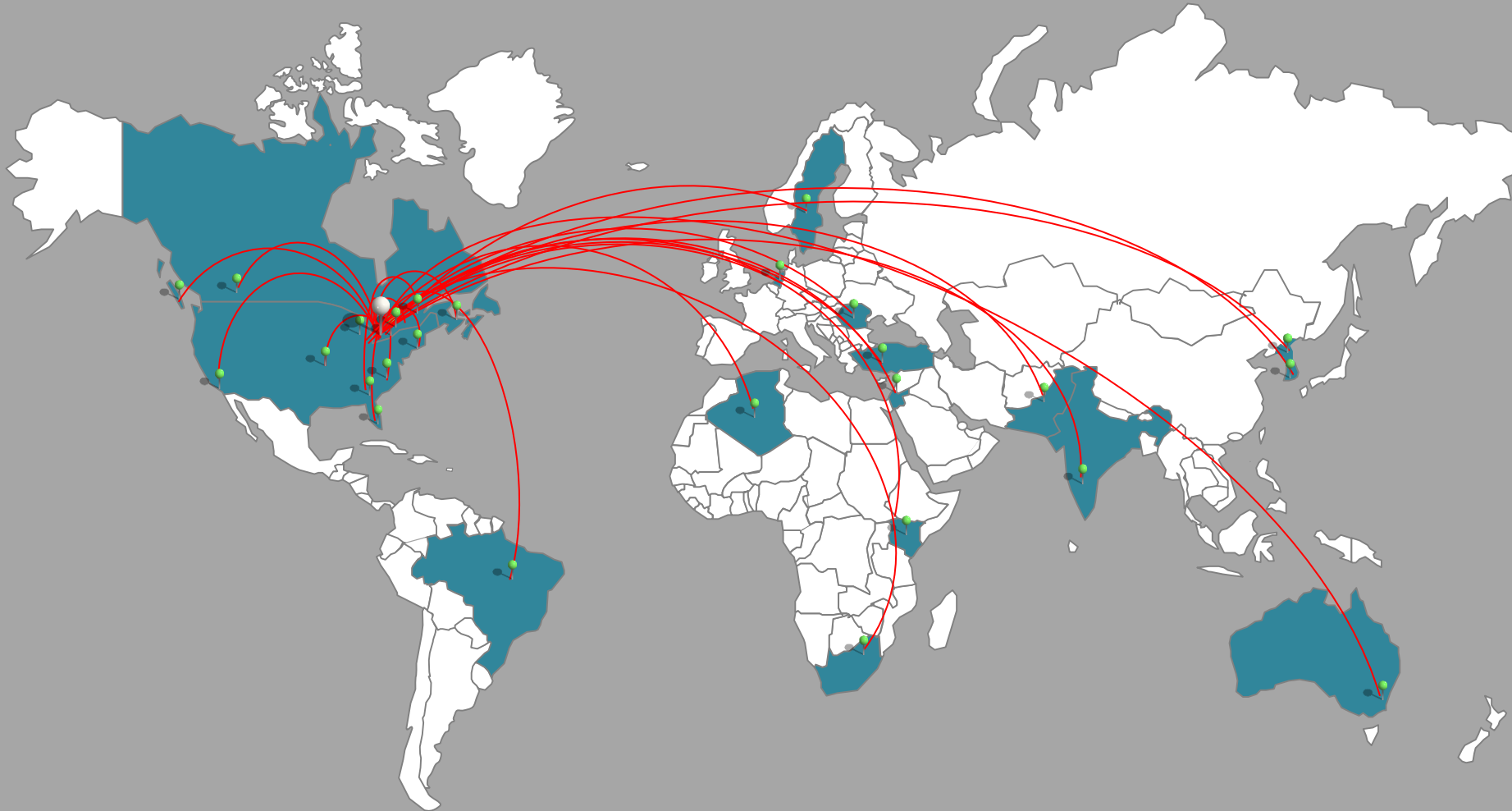
- Most linac physics can be modeled using simple analytical approximations
- Response is consistent with a real linac response.
- Meant to simulate the service mode of a clinical linac

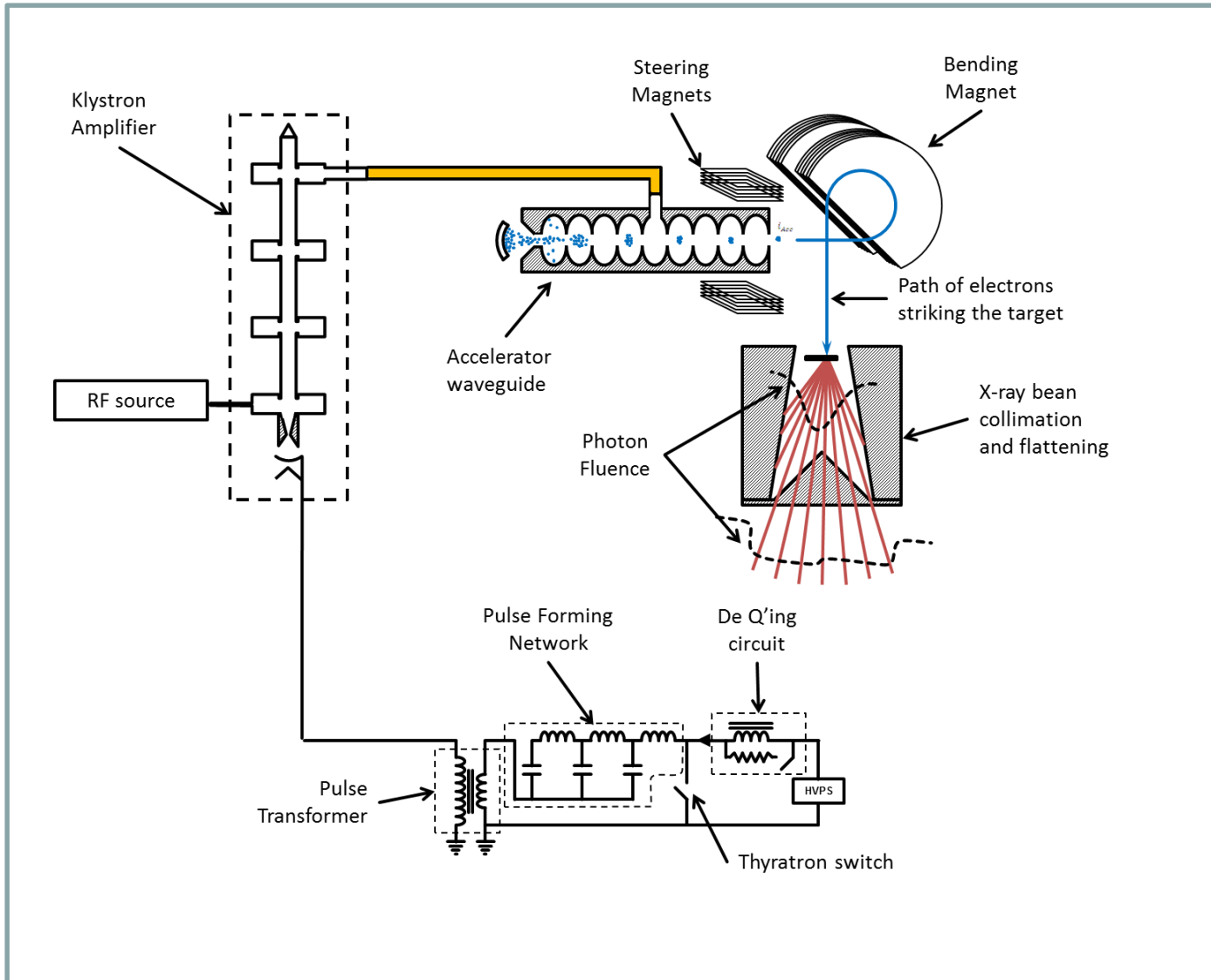
Simulation of a medical linear accelerator for teaching purposes

SIMAC Downloads

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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 '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.
- Control Buttons:** Three large buttons labeled 'Klystron', 'Accelerator', and 'Treatment Head' are located below the parameter boxes.
- Linac Image:** A photograph of a medical linear accelerator machine is shown on the right side of the interface.

Using SIMAC

Mode selection

Clinical parameters

Linac parameter control

Linac operating values

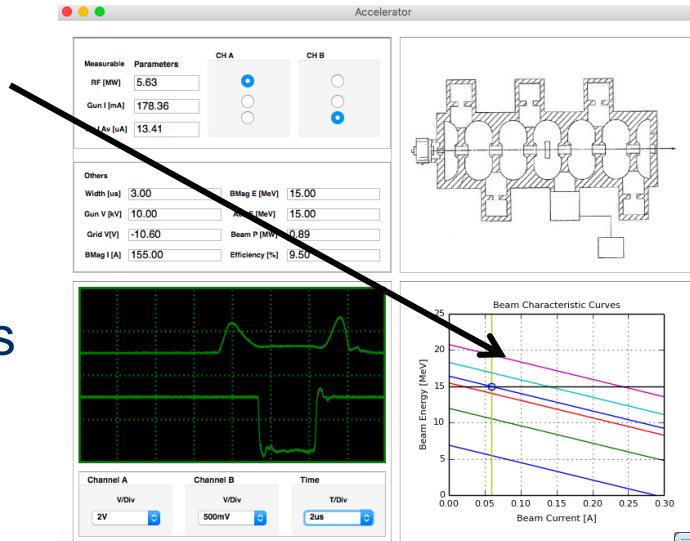
The SIMAC software interface is divided into several functional areas:

- Mode selection:** A green-bordered box containing 'Beam On/Off' (On/Off), 'Energy' (6MV), and 'PRF [Hz]' (120Hz).
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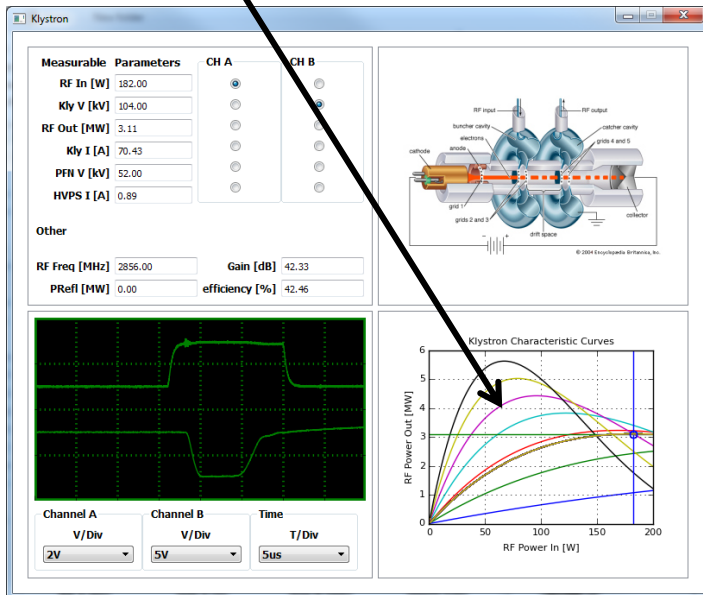
Linac Physics modules in SIMAC

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

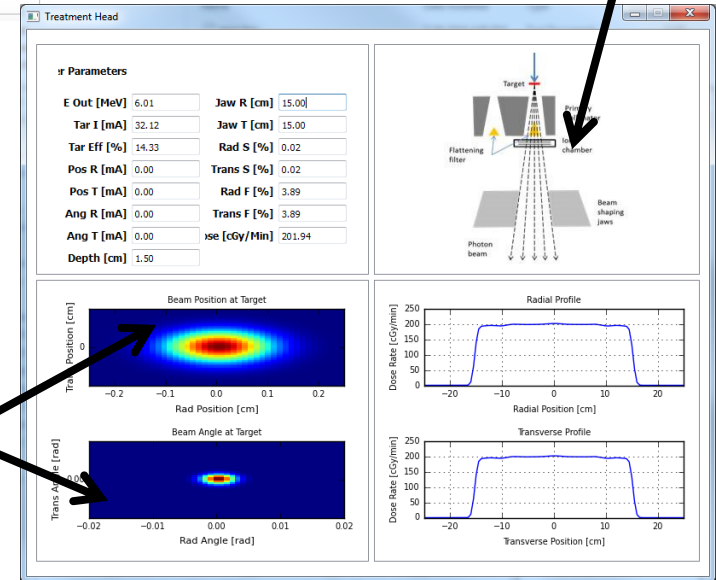
Klystron saturation is modelled using an analytical (Bessel) function



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

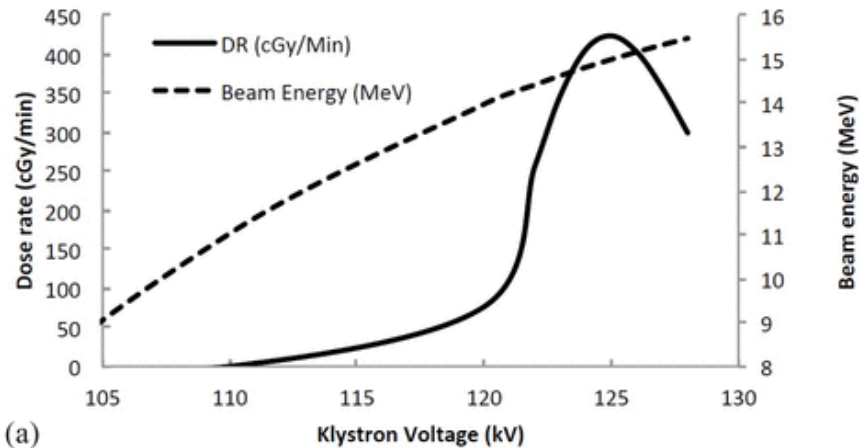


Electron beam position and angle on the target

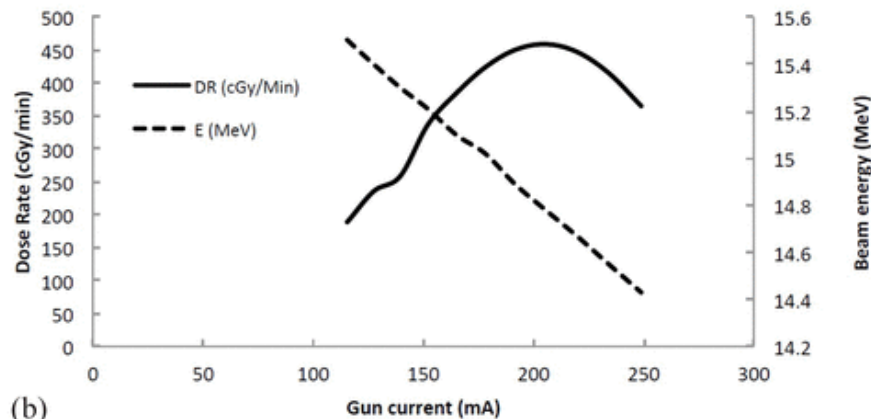


Atec Lab Exercise 1:

Teaching of beam “tuning” with SIMAC



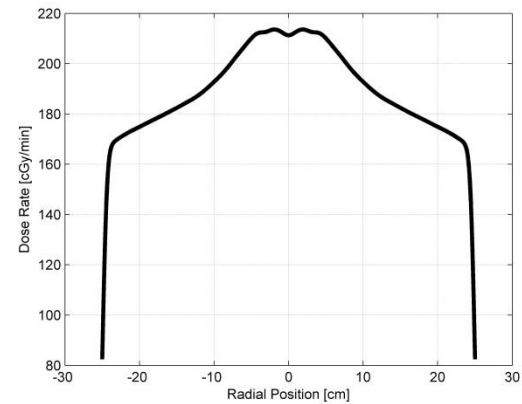
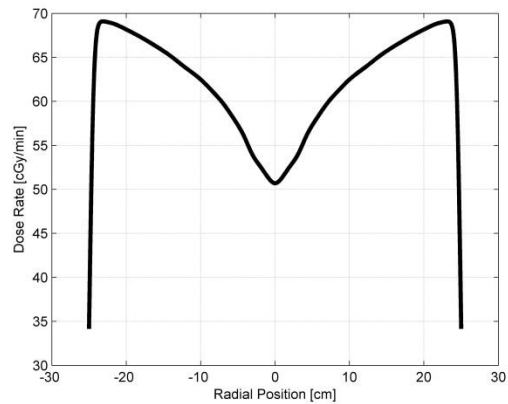
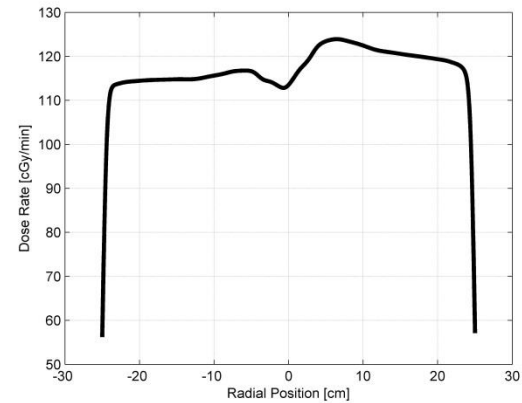
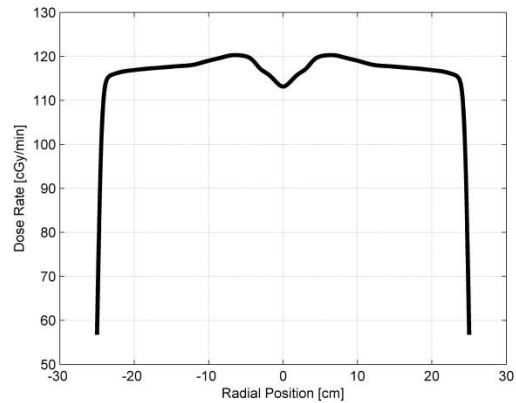
(a)



(b)

ATec Lab Exercise 2:

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



www.simaclinac.com

The screenshot shows a web browser window displaying the SIMAC website. The browser's address bar shows the URL <http://simac.technainstitute.com/>. The website's header features the SIMAC logo on the left and a navigation menu with links for HOME, BACKSTORY, LEARNING RESOURCES, COMMUNITY, CONTACT, and LOGIN. Below the header is a large hero image of a medical linear accelerator component with the following text overlaid: **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**. The main content area is divided into three columns, each with an icon, a title, a paragraph of text, and a button. The first column is titled 'BACKSTORY' and features a book icon. The second is 'LEARNING' with a person icon. The third is 'HELP OUT' with a group of people icon. At the bottom left of the browser window, the URL <http://simac.technainstitute.com/learning-resources/> is visible in the address bar.

SIMAC HOME BACKSTORY LEARNING RESOURCES COMMUNITY CONTACT LOGIN

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

BACKSTORY

We have developed an open-source medical linac simulation product called SIMAC, which allows users to simulate the physics of beam formation in a medical linac in real time. It replicates the relationship between the various beam production components and provides a platform to manipulate the components and observe the implications of those changes.

LEARNING

We propose to develop and implement an evaluation methodology that will demonstrate the impact of SIMAC on knowledge acquisition of MPs and trainees (level 2 learning outcome) as it relates the basic functionality of a linac and the production of high quality radiation beam. There will be three key activities associated with this phase of the overall project.

HELP OUT

SIMAC is freely available to anyone who wants to learn or teach about linac physics. If you have an interest in teaching linac physics, we would like to hear from you. If you want to make the physics within SIMAC better, we could use your help. If you want to teach and use SIMAC as an aid, we want to know how you do it so others can also use SIMAC in the same way.

READ FURTHER **GET INVOLVED** **OPPORTUNITIES**

<http://simac.technainstitute.com/learning-resources/>

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?

The future

- Expand the physics within SIMAC:
 - Model temperature, ion chambers, magnetron linacs, frequency control, dose rate servo, etc.
- Find a permanent home for the project through an educational institution.
 - Has mandate for educating in the medical devices domain.

Table 1. New Linac component models to be applied.

Type of model	Brief description	Source material
Accurate modulator model	Component level model of Pulse Forming Network, Charging and discharging circuits	Lamey and colleagues[1]. Glasoe[2].
Magnetron model	Employ a modeled or digitized magnetron performance chart.	Manufacturer specifications, Collins[3].
Microwave frequency control	Linac resonant frequency depends on temperature (50kHz per degree Celsius). Linac reflected power can be modeled with impedance change as a function of frequency.	Description of Stanford Linear Accelerator[4]. Automatic Frequency Control circuits from schematics.
Linac ion chamber	Convert exposure to dose assuming ion chamber size and use for dose rate servoing.	AAPM TG21 dosimetry protocol[5].
Steering servo	Model beam steering servo circuits.	Standard beam steering circuits from linac schematics

Table 2. Virtual laboratories to be developed.

Laboratory topic	Brief description	Source material
Microwave circuits	Waveguide measurements, wave reflection, impedance matching, and other concepts.	Ginzton[6], Slater[7], Marcuvitz[8]. Moreno[9].
RF generation	Virtual RF generation from a Klystron and magnetron	Collins[3], Hamilton[10]
Electron optics	Space charge and temperature limited effects. Charged particle focusing.	EGUN[11]
Beam steering	Dipole magnets. Effect of beam energy on particle trajectory. Energy measurement using a bending magnet.	Anderson and colleagues[12]
Modulator	Explore charging and discharging of a pulse-forming network. Effects of clamping diodes, pulse shaping with a PFN load line.	Lamey and colleagues[1]. Glasoe[2].
Heat dissipation	Relationship between water flow, heat transfer, and the microwave properties of device: frequency changes, impedance change, power transfer change.	Stanford accelerator design[4]
Photon transport	Alignment of beam and flattening filter. Filters shape. Target thickness.	Anderson and colleagues[12].



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Full-time Diploma

Overview

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Biomedical engineering applies science and engineering to healthcare and medical device industries. Our grads help develop new medical devices and products or maintain specialized medical equipment that is used to support patient care.

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- Lectures, labs, **research, and design projects** deliver a strong foundation of knowledge

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Can we use a linac model to
improve linac repair?



If we can have a self driving car, why not a linac that can fix itself?

An idea

- Apply basic linac physics model (like in SIMAC) to a baysean based linac fault model.
- Use the model to predict the nature of the linac failure after it is detected.
- The machine can then suggest a repair procedure that can be executed by a service technician with less training
 - Reduce the skill level required for the service technician.

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