ACCELERATOR TECHNOLOGY

Education Course

putting innovation to work

February 26 – March 1, 2018, Toronto, Canada

Radiation Oncology
UNIVERSITY OF TORONTO

accelerated education program
ATec
putting innovation to work

UHN Princess Margaret Cancer Centre

Welcome to ATec

Modern linear accelerators incorporate advanced beam delivery systems and imaging technologies to deliver radiation therapy treatments with accuracy and precision. Maintaining a linear accelerator to high performance standards requires knowledgeable staff with a thorough understanding of the various systems found in a linear accelerator, their servicing requirements, and how they interact to deliver patient treatments as intended.

Given the Radiation Medicine Program's experience in both maintaining and pushing the boundaries of the technology on which we rely to deliver high-quality care, we are collaborating with the University of Toronto to offer an educational program to provide the opportunity for physics staff to enhance their skills and knowledge in this area. This Accelerator Technology Education Course addresses the training needs of those responsible for ensuring the proper functioning of this equipment. The primary objectives are for participants to appreciate the theory of operation and servicing requirements of linear accelerators, multi-leaf collimators (MLCs) and accelerator-based imaging systems, to understand the safety issues related to accelerator servicing, to optimize dynamic beam delivery accuracy, and to be equipped to develop and participate in an effective service and quality control team.

"Nothing is particularly hard if you divide it into small jobs."
-Henry Ford

Bern Norrlinger
Co-Course Director

Nathan Becker PhD
Co-Course Directors

aep | ATec

Contributors

Planning Committee

Nathan Becker
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Andrea McNiven
Michael Milosevic
Doug Moseley
Dave Niven
Bern Norrlinger
Raina Park
George Parsons
Murray Rice
Frank Tourneur
Carlos Varon
Ivan Yeung

Guest Speaker

Malcolm McEwen is Discipline Leader of the Ionizing Radiation Standards Group at the National Research Council. His activities focus on research and dissemination of primary standards for megavoltage photon and electron beam dosimetry. He has developed water and graphite calorimetric absorbed-dose standards and carried out experimental and theoretical work on the performance and calibration of secondary dosimeters – ionization chambers, diodes, and chemical dosimeters such as the alanine and Fricke systems.
As part of this work he is involved in the maintenance and operation of the electron linear accelerators sited at the NRC. An Elekta Precise linac has been operated since 2002 but more interesting is the 3-40 MeV Vickers research linac installed in 1968 and capable of a wide range of operational modes, from single electron emission to intense industrial doserates.

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Accreditation

Commission on Accreditation of Medical Physics Education Programs: 25.21 Credit Hours (Pending)

Monday, February 26, 2018

11:30 – 12:00	***Registration & Lunch***	***PM 1B-615***
12:00 – 12:10	**Welcome** David Jaffray PhD	
12:10 –12:50	**Motivation for Advanced Imaging Systems on Linear Accelerators** Mike Milosevic MD	
12:50 – 1:00	Discussion	
1:00 – 1:45	**COMP Webinar: SIMAC** Marco Carlone PhD	
1:45 – 2:00	**Introduction to the Course** Bern Norrlinger & Nathan Becker PhD	
2:00 – 2:15	***Break***	

Session 1: Linear Accelerator Technology

2:15 – 3:00	**Introduction to ATec & Review of Background Material** Nathan Becker PhD	**PM *1B-615***
3:00 – 3:45	**Microwave Devices** Carlos Varon P.Eng	
3:45 – 4:15	**High Voltage Modulator** Bern Norrlinger	
4:15 – 4:20	**Discussion**	
4:20 - 4:35	***Break***	
4:35 – 6:05	**Lab #1: Beam Output** Bern Norrlinger, Nathan Becker PhD	**PM *2B Skills Lab***
6:05	**END OF DAY**	
6:30	***Social Event***	***Reds Midtown Tavern*** ***382 Yonge St***

Tuesday, February 27, 2018

8:30 – 9:00	***Sign In***	***PM 1B-610***

Session 1 (cont'd): Linear Accelerator Technology

9:00 – 9:10	**Overview for the Day** Bern Norrlinger, Nathan Becker PhD	
9:10 – 9:55	**Accelerator Beam Control** Bern Norrlinger	
9:55 – 10:15	**Synchronization Pulse** Bern Norrlinger	
10:15 – 10:25	**Discussion**	
10:25 – 10:40	***Break***	
10:40 – 11:25	**Multileaf Collimators & Dynamic Beam Delivery** Andrea McNiven PhD	
11:25 – 11:30	**Discussion**	
11:30 – 12:10	**Beam Steering** Andrea McNiven PhD	
12:10 – 12:15	**Discussion**	
12:15 – 1:00	***Lunch***	
1:00 – 3:00	**Lab #2: Finding Beam** Bern Norrlinger, Nathan Becker PhD	***PM 2B Skills Lab***
3:00 – 3:15	***Break***	***PM 1B-610***
3:15 – 3:45	**Standard Imaging Equipment as Accessories to Medical Linacs** Jean-Pierre Bissonnette PhD	
3:45 – 4:35	**2D Imaging Principles** Jean-Pierre Bissonnette PhD	
4:35 – 4:40	**Discussion**	
4:40 – 5:30	**Good Practices for Service Groups** Bern Norrlinger	
5:30 – 5:35	**Discussion**	
5:35	**END OF DAY**	

Wednesday, February 28, 2018

8:30 – 9:00	***Sign In***	***PM 1B-615***

Session 1 (cont'd): Linear Accelerator Technology

9:00 – 9:10	**Recap** Bern Norrlinger, Nathan Becker PhD
9:10 – 9:30	**Advanced Topic: Vacuum Systems** George Parsons
9:30 – 10:30	**Demonstration: Basic Vacuum Practice, Roughing Pumps, Leak Detection** George Parsons
10:30 – 10:45	***Break***

Session 2: Linac-Based Imaging (IGRT)

10:45 – 12:25	**Lab #3: Beam Steering** Bern Norrlinger, Nathan Becker PhD	***PM 2B Skills Lab***
12:25 – 1:25	***Lunch***	***PM 1B-615***

1:25 – 2:15	**Safety with Medical Devices in Canada** Ivan Yeung PhD, Bern Norrlinger

Session 3: Quality & Safety

2:15 – 3:00	**Accelerator Safety** Carlos Varon P.Eng
3:00 – 4:00	**Radiation Safety** Raina Park, Dave Niven
4:00 – 4:05	**Discussion**
4:05 – 4:35	**Patient Safety** Murray Rice P. Eng, Bern Norrlinger
4:35 – 5:20	**Quality Management: Responsibility for Holders of a Service License** Frank Tourneur
5:20 – 5:25	**Discussion**
5:25	**END OF DAY**
5:30 – 6:00	***MRgRT Tour – Teo Stanescu PhD***

Thursday, March 1, 2018

8:30 – 9:00	***Sign In***	***PM 1B-610***

Session 2 (cont'd) Linac-Based Imaging (IGRT)

9:00 – 9:40	**3D Imaging Principles** Doug Moseley PhD	
9:40 – 9:45	**Discussion**	
9:45 – 10:30	**Image Troubleshooting** Doug Moseley PhD	
10:30 – 10:35	**Discussion**	
10:35 – 10:50	***Break***	
10:50 – 11:25	**kV Beam Generation** Carlos Varon P. Eng	
11: 25 – 11:30	**Discussion**	
11:30 – 12:35	**Image Viewing & Evaluation Lab** Doug Moseley PhD	***PM 2B Skills Lab***
12:35 – 1:20	**Lunch**	***PM 1B-610***
1:20 – 1:55	**Water Systems** George Parsons	
1:55 – 2:00	**Discussion**	

Session 4: Panel Discussion

2:00 – 2:45	**Linac Archaeology: Using the past to explain the present and foretell the future (maybe)** Malcolm McEwen PhD	
2:45 – 2:55	**Discussion**	
2:55 – 3:10	***Break***	
3:10 – 4:40	**Panel Discussion – Moderator: Andrea McNiven PhD** Discussants: Bern Norrlinger, Nathan Becker PhD, Malcolm McEwen PhD	
4:40 – 4:50	**Course Wrap Up & Evaluation** **END OF COURSE**	

SESSION DESCRIPTIONS

MONDAY, FEBRUARY 26, 2018

Motivation for Advanced Systems on Linear Accelerators

Michael Milosevic MD

The success of radiation therapy depends on the correct dose being delivered to the tumour as well as the correct placement of the dose distribution over the tumour. To achieve the required positional accuracy for modern radiotherapy, modern linear accelerators are equipped with advanced imaging equipment enabling imaging of patients at the time of treatment. Three dimensional cone beam CT (CBCT) imaging systems are now standard with almost all new linacs, and other modalities, such as MRI, are also being explored. This session will outline, from a medical needs perspective, the motivation for including advanced imaging systems on radiotherapy linear accelerators.

COMP Webinar: SIMAC

Marco Carlone PhD

This webinar will introduce a linear accelerator simulation program, SIMAC, and the environment created at simaclinac.com. We will discuss the special needs for teaching linear accelerator physics, and the challenges that make these devices difficult to learn about. Finally, we will introduce a study we are conducting where we hope to show that the SIMAC simulation program can improve the way we teach linear accelerator physics.

Introduction to the Course

Bern Norrlinger, Nathan Becker PhD

The purpose of this session is to introduce the basic components and modes of operation of a medical linear accelerator. The session will serve as a starting point for other lectures in the course and give delegates an overview of what they should expect to learn in each lecture of the course, in subsequent days of the course.

Session 1: Linear Accelerator Technology

Group Discussion: Review of Background Material

Nathan Becker PhD

The purpose of this session is to review the course pre-reading material and to explain the basic operating mode of medical linear accelerators. The lecture will be interactive in nature. The concept of the linear accelerator shunt impedance will be discussed, and how this affects the electron beam's energy, given the RF power and beam current that are input. As well the concept of matching the accelerator output to the pass through energy of the bending magnet will be introduced and discussed.

This concept will be used in discussing the principles of linac beam tuning, where the output of the linear accelerator is maximised by ensuring an energy match of the linac and bending magnet. The lecture will also give an overview of the linac simulation software SIMAC, which will be used in three labs of the ATec course. The purpose of the session is to prepare course delegated for the first lab session.

Microwave Devices
Carlos Varon P.Eng
Linear accelerators use high power microwaves to achieve electron acceleration. Devices such as klystrons and magnetrons produce the levels of microwave power required for linac operation. This session discusses the basic principles of microwave technology, transmission line theory and wave propagation in waveguides. An overview of various types of microwave devices employed in linear accelerators is presented, highlighting their function and method for controlling microwave power and frequency.

High Voltage Modulator
Bern Norrlinger
The high voltage modulator produces the high power pulses required by the microwave tubes used in a linear accelerator. The amplitude, duration and shape of the pulse generated by the modulator are all critical to the performance of the linac. In this session the basic concepts of modulator theory and how they pertain to the operation of a linac will be presented. The major components of the high voltage modulator and the theory of their operation will be introduced, including the pulse forming network and its charging and discharging circuits, thyratrons and the pulse transformer.

Lab #1: Beam Output
Bern Norrlinger, Nathan Becker PhD
The purpose of this lab is to understand the impact of basic linear accelerator adjustments on the clinical performance of the linac. The lab uses simulated software, SIMAC, to simulate the effect of linac setup parameter adjustments.

PART 1: Explores the effect of klystron power adjustments on beam energy and dose rate.

TUESDAY, FEBRUARY 27, 2018

Session 1 (cont'd): Linear Accelerator Technology

Accelerator Beam Control
Bern Norrlinger
Beam energy and beam current are the fundamental parameters that define the linac's mode of operation. This presentation describes various methods for controlling these parameters, including use of feedback servos to maintain constant dose rate and energy. The relationship between microwave

power, electron beam current and the electrical properties of the accelerator waveguide will be discussed. The session concludes with a discussion of the effects of beam loading on machine output.

Synchronization Pulse
Bern Norrlinger
After this presentation the student will be able to:
- Differentiate between Gun, RF, X-ray and Computer timing pulses.
- Set the sample and hold timing pulse for best stability.

Linear accelerators produce radiation beams in very short, rapid pulses. This presentation highlights the importance of proper timing relationships between the pulsed systems activating the klystron and electron gun. Factors contributing to instability of the accelerator beam, such as improper synchronization, improper sampling, timing jitter and excessive RF noise will be discussed.

Multileaf Collimators & Dynamic Beam Delivery
Andrea McNiven PhD
The Multi-Leaf Collimator (MLC) has become an integral part of modern linear accelerators. Originally developed as a shielding block replacement, the use of MLCs has evolved to allow complex leaf motion during irradiation to dynamically shape the beam intensity. For this reason, the efficiency and accuracy of treatment delivery is highly dependent on the performance of the MLC. In this session, the fundamental characteristics of MLCs will be discussed, with an emphasis on those parameters that can affect the accuracy of treatment delivery. We will also review the various methods of dynamic beam delivery and the quality control details that are specifically relevant for dynamic delivery, with a particular focus on intensity-modulated radiotherapy (IMRT) and VMAT.

Beam Steering
Andrea McNiven PhD
In radiation therapy, a treatment plan is generated using data that has been carefully measured during linac commissioning. The success of the patient's treatment is highly dependent on the precise alignment and calibration of the accelerator beam. Variations in beam steering and drifts in calibration translate directly into potential errors in treatment delivery. Therefore it is essential that linac beams be maintained to a "gold standard". In this session, the learner will be exposed to apparatus commonly used to measure the beam symmetry and flatness, as well as the final calibration of radiation monitor units. Beam steering by magnetic deflection and beam extraction through the bending magnet will be discussed. Methods of calibrating the dosimetry circuits used to count monitor units from the linac ionization chamber will be described.

Lab #2: Finding Beam
Bern Norrlinger, Nathan Becker PhD
The purpose of this lab is to understand the impact of basic linear accelerator adjustments on the clinical performance of the linac. The lab uses simulated software, SIMAC, to simulate the effect of linac setup parameter adjustments.

PART 2: Explores the effect of beam current on beam energy and dose rate. The third part of the lab addresses large scale beam adjustments. In this part, the energy of a "tuned" beam is changed significantly, and the accelerator beam properties must be adjusted to match the energy selection of the bending magnet. This is performed recursively until a beam energy is changed from low (6 MV) to high energy (10 MV).

Standard Imaging Equipment as Accessories to Medical Linacs
Jean-Pierre Bissonnette PhD
Modern linear accelerators are equipped with standard on-board imaging systems. This session provides a brief overview of the most commonly used systems, including electronic portal imaging detectors and kV imagers. We will conclude by discussing novel imaging systems, including the MRI-linac.

2D Imaging Principles
Jean-Pierre Bissonnette PhD
A review of projection radiography physics is presented, including contrast, noise, spatial resolution and x-ray scatter. Both indirect and direct detectors will be introduced, finishing with a description of the state of the art in amorphous silicon detectors. Performance and quality control of these detectors will be discussed.

Good Practices for Service Groups
Bern Norrlinger
The important role of accelerator service staff in the maintenance and performance of the linac has been explored throughout the course. Although service staff typically have a background in electronics or mechanical technology, they must also possess knowledge of a number of unique systems. They must be able to assess and address malfunctions in the clinical environment, and, after repairs, make an initial determination of proper equipment operation and safety. Equipment reliability, uptime, safety and operating costs can all be affected by the activities performed by the accelerator service group. In this session, we will discuss the best practices to ensure effective and safe maintenance of equipment in a radiation therapy department. Topics discussed include training, continuous education, record keeping, preventative maintenance, inventory control and alert and recall management.

WEDNESDAY, FEBRUARY 28, 2018

Session 1 (cont'd): Linear Accelerator Technology

Advanced Topic: Vacuum Systems
George Parsons
Without a vacuum, the production and travel of electrons in a linear accelerator would not be possible. This session will introduce the various pump systems and components that create the necessary vacuum levels and the requirements for operation, including how contamination will affect the outcome of achieving a desired pressure. The hardware and instrumentation in a typical vacuum system will be

discussed, highlighting the advantages and disadvantages of these systems. The basics of troubleshooting vacuum systems will be covered, and participants will engage in a demonstration of leak detection.

Demonstration: Basic Vacuum Practice, Roughing Pumps, & Leak Detection
George Parsons
No description provided.

Session 2: Linac-Based Imaging (IGRT)

Lab #3: Beam Steering
Bern Norrlinger, Nathan Becker PhD.
The purpose of this lab is to understand the impact of basic linear accelerator adjustments on the clinical performance of the linac. The lab uses simulated software, SIMAC, to simulate the effect of linac setup parameter adjustments.

PART 3: Explores the effect of steering coil adjustments on the beam's flatness and symmetry.

Safety with Medical Devices in Canada
Ivan Yeung PhD, Bern Norrlinger
Medical devices are health or medical instruments used in the treatment, mitigation, diagnosis or prevention of a disease or abnormal physical condition. Medical devices in Canada are regulated by Health Canada, through the Medical Devices Bureau of the Therapeutic Products Directorate. Certain devices must have a Medical Device Licence before they can be sold. All medical devices have been categorized based on the risk associated with their use. In this session, we will review the classes of medical devices, discuss types of licenses and permits, and consider how Health Canada regulations affect hospital policies and maintenance activities for medical devices.

Session 3: Quality & Safety

Accelerator Safety
Carlos Varon P.Eng
As well as the concerns for patient's safety, there are hazards inherent to the complexity and power of linear accelerators that are unique to the service personnel. Radiation exposure, electrocution and chemical exposure are but a few of the potential hazards, all necessitating proper safety awareness and training for all accelerator service personnel. This session highlights the potential hazards that might be encountered when dismantling and repairing parts of a linac. Case histories and unusual failure

scenarios are presented to illustrate the risk and complexity of servicing accelerators. Methods of protection using specialized safety equipment and procedures will be discussed.

Radiation Safety
Raina Park, Dave Niven
Radiation fundamentals are integral to provide accelerator workers with a knowledge base which allows them to perform their tasks safely. Components of the fundamentals include (1) dosimetric quantities and units used in radiation safety, (2) international framework of radiation safety, (3) risks, hazards and biological effects of ionization radiation, and finally (4) radiation safety regulations and regulatory dose limits, all of which will be addressed in this session. The nature of exposures, such as where, when and how much they can occur, how to avoid them, and the tools that can facilitate this, will also be covered.

Patient Safety
Murray Rice P. Eng, Bern Norrlinger
Patient safety is one of the prime concerns of healthcare workers. While linear accelerator service personnel do not typically interact directly with patients, they are responsible for technology that is capable of inflicting considerable harm to patients if it is not functioning as expected in the clinical context. In this session, the safety principles of complex systems will be illustrated, as well as documentation methods for accelerator safety. The learner will be presented with tools to identify potentially unsafe situations and to understand the "fail safe" state.

Quality Management: Responsibility for Holders of a Service License
Frank Tourneur
Previous sessions have demonstrated that linacs are complicated devices, as are the image guidance systems now routinely used in clinical operations. Both require the same level of service management and quality control (QC). Defined as Class II devices by the CNSC, servicing of these devices is regulated federally. The primary purpose of this session is to describe a management structure necessary to ensure local oversight of linear accelerator servicing, which is a requirement of all CNSC service licenses. The systems and decision-making processes required to ensure uniform linac servicing and appropriate physics QC after linear accelerator servicing will also be highlighted.

THURSDAY, MARCH 1, 2018

Session 2 (cont'd) Linac-Based Imaging (IGRT)

3D Imaging Principles
Doug Moseley PhD
The principles behind acquisition and reconstruction of 3D volumetric images will be introduced. These images are the basis for image-guided radiation therapy. Hence, the geometric integrity of the images

(scale, orientation, location) is as important as the image quality. Both calibration and quality control of 3D imaging systems will be discussed.

Image Troubleshooting
Doug Moseley PhD
At the Princess Margaret, there is hardly an imaging failure that has not been observed in practice. This highly interactive case-based session will present a series of common image-based artifacts based on clinical operation as well as calibration and quality control failures. The problems in both 2D and 3D images will be shown. Participants will engage in active problem-solving to establish the source of the problem. For each case, the root cause will be presented and the resolution discussed.

kV Beam Generation
Carlos Varon P.Eng
X-ray imaging is becoming a fundamental tool in Radiation Oncology practice for patient positioning and procedure guidance. Many elements are part of an imaging systems, including X-ray tubes, imaging panels, and kV generators. This session will include the basic concepts and design considerations for development of a High Voltage generator, the physics involved in the x-ray generation, and the relationship between the generator output ripple and image quality.

Image Viewing & Evaluation Lab
Doug Moseley PhD
This session will present a number of calibration images from Quality Control phantoms. This will include the 2D MV Las Vegas contrast detail phantom, the 2D kV Leeds phantom, the CatPhan CT image quality phantom and the PentaGuide daily QA phantom. The attendees will have their own workstation with a database of these calibration images. Measurements on each of these phantoms will be collected and combined to examine the inter-observer variability.

Water Systems
George Parsons
Linear accelerators are highly inefficient in their use of power. The variability in the heat load and high operating temperature of the RF system complicate cooling efforts. In this session, the learner will be introduced to the basic performance requirements of linac cooling systems so that issues relating to facility cooling requirements can be more easily understood. Heat generation in different components of the linear accelerators will be discussed, highlighting the water flow requirements in these components.

Linac Archaeology - Using the past to explain the present and foretell the future (maybe)
Malcolm McEwen PhD
Clad in shiny paneling and equipped with the latest multi-leaf collimators and on-board imagers, today's

clinical linear accelerators appear to be everything one would expect of 21st century technology. This presentation will trace the history of linac development since the 1950s to the present day and show that the modern machines of 2015 have more in common with those early accelerators than one might think. Understanding some of the history to essential to understanding some key aspects of how and why today's clinical linear accelerators work as they do.

Panel Discussion
Moderator: Andrea McNiven PhD
Panelists: *Bern Norrlinger, Nathan Becker PhD, Malcolm McEwen PhD*
This session will present 3 case studies of linear accelerator affecting patient treatments that resulted from linac failures or incorrect repairs of linear accelerators. Each case study will be presented sequentially with commentary from the panelists. Issues surrounding proper identification of a hazardous situation, assessment of the hazard and appropriate response will be discussed in a group format.

ACCELERATED EDUCATION PROGRAM FOUNDING COMMITTEE

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Radiation Oncologist

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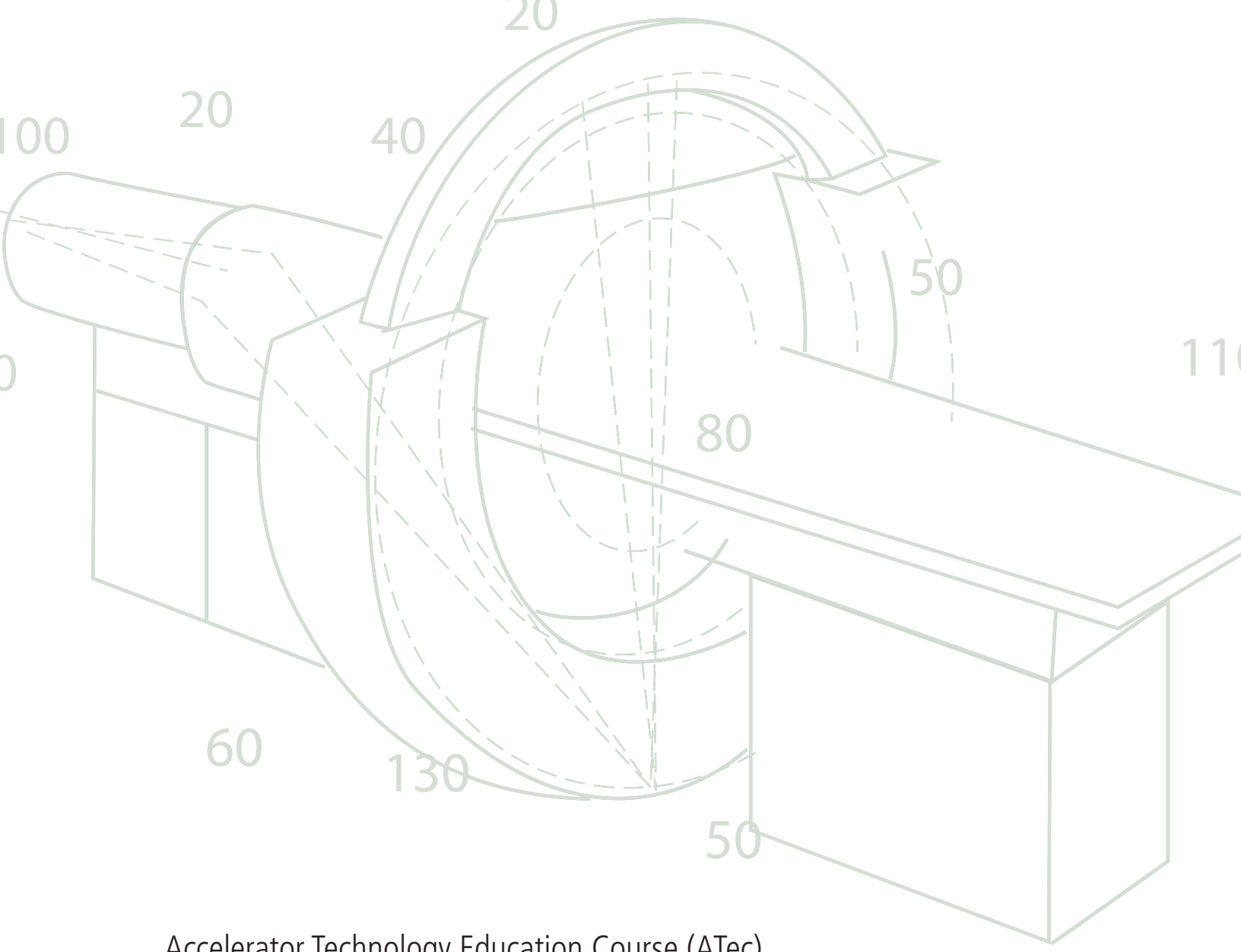
NOTES:



Accelerator Technology Education Course (ATec)

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VARIAN
medical systems

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