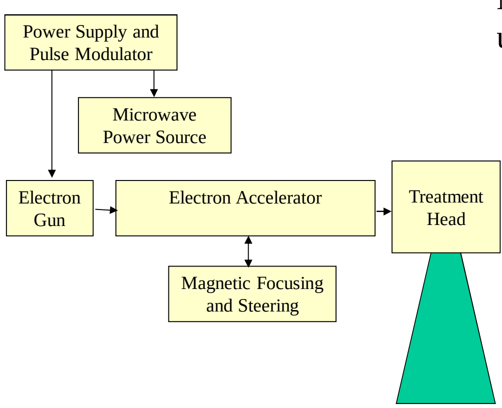
Clinical Radiation Generators

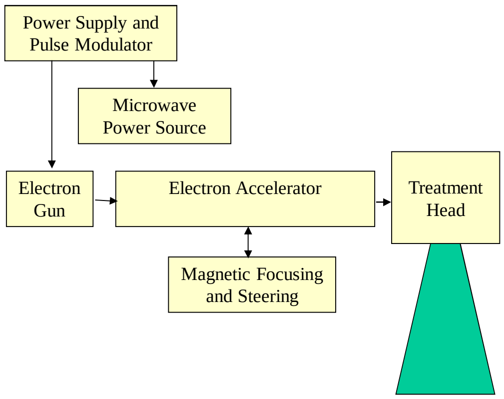
Introduction to the Linac



Medical Linear Accelerators are used in Radiation Oncology

- Electrons are produced by thermionic emission in the electron gun
- The accelerator transfers energy to the electrons from RF fields setup by microwaves
- The microwaves are supplied in short pulses by applying high voltage pulses to a microwave generator.

Introduction to the Linac



- The electron gun and the microwave source are pulsed so that the high-velocity electrons are injected into the accelerator at the same time
- The electron gun and accelerator must be evacuated to low pressure such that the mean free path of electrons between atomic collisions is long
- Magnetic focusing is used because the accelerating electrons tend to diverge due to mutual Coulomb repulsion and the electric fields in the waveguide

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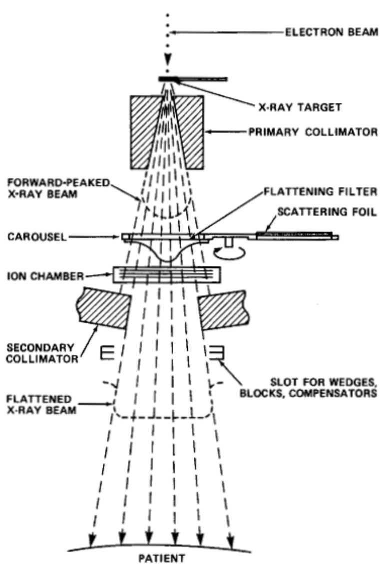
Introduction to the Linac



- The accelerator delivers pulses of high-energy electrons into the treatment head, where the useful radiation beam is produced
- X-rays are produced by directing the electrons onto an x-ray target
- The electrons are stopped with the emission of x-rays by bremstralung
- The treatment head also contains beam monitoring and shaping equipment

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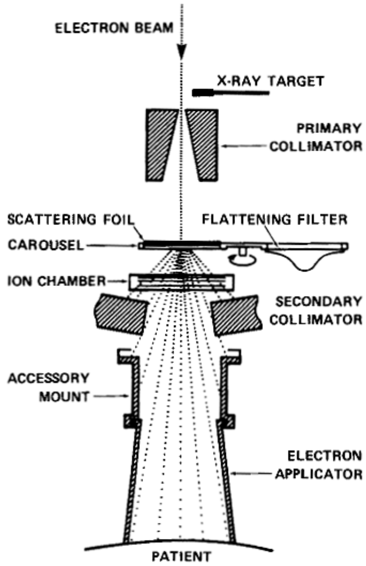
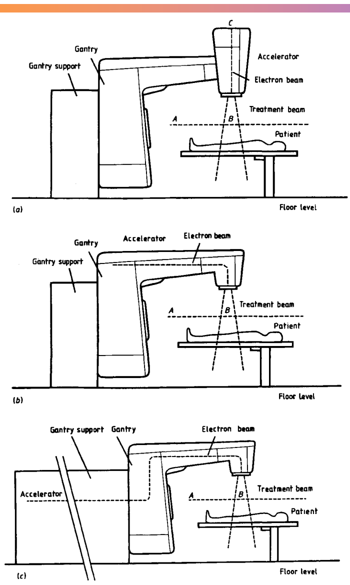


- In electron mode, the beam is extracted from the vacuum system through a thin window
- The electron beam diameter is only a few millimeters as it emerges from the accelerator
- A scatter foil is used to broaden the beam to a clinically useful size
- An electron applicator placed close to the patient is used to to collimate scatter electrons

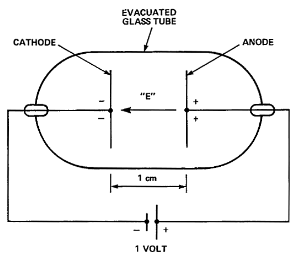
Introduction to the Linac

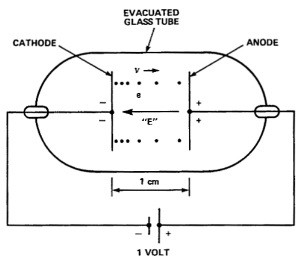


Three alternative arrangements have been used for moving the gantry with respect to the patient

- The accelerating waveguide is mounted so that the central axis of the accelerator is in-line with the treatment beam
- The accelerating waveguide is mounted perpendicular to the treatment beam in the rotating gantry
- The accelerating waveguide is mounted in the gantry stand

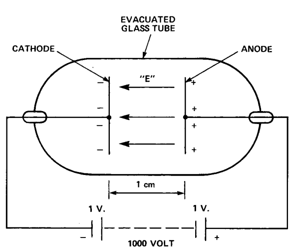
Basic Accelerator

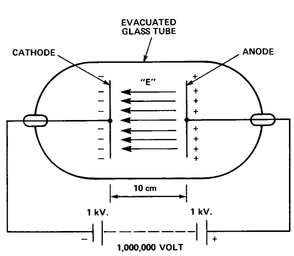




- An electric "E" Field is used to accelerate electrons
- The "E" Field is directed to the left from the positive anode to the negative cathode
- The size of the "E" Field is the force that a unit positive charge would feel if placed between the two plates
- Electrons released from the negative cathode plate will be accelerated to the positive plate

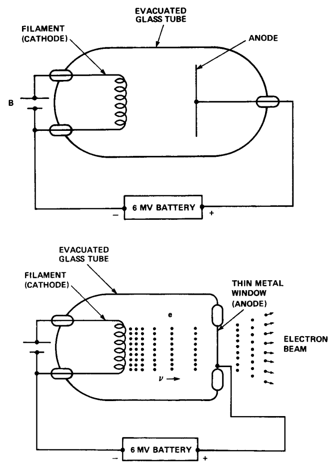
Basic Accelerator





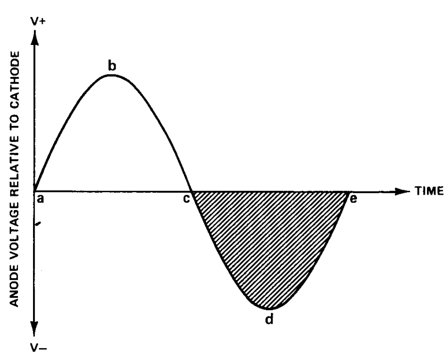
- Exerting a force through a distance is a basic measure of work and energy
- On the atomic scale, the electron volt is the adopted unit of energy
- With a 1,000 Volt potential between two plates separated by 1-cm, the electron would arrive at the anode with an energy of 1,000 eV
- A 1,000,000 Volt potential between two plates separated by 10-cm would yield 1 MeV electrons
- In this case, the "E" field would be 100,000V/cm

Basic Accelerator



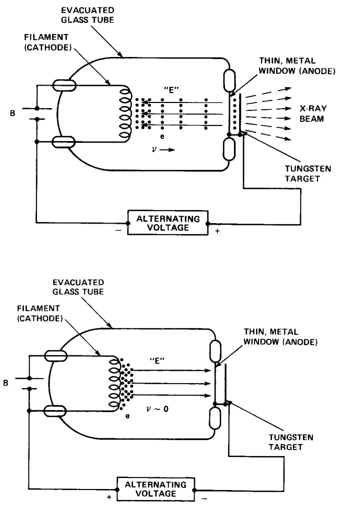
- A simple linear accelerator can be built by using a heated cathode for the negative plate
- A small battery heats the filament causing it to “boil off” electrons
- A theoretical 6MV battery is connected between the cathode and anode
- The electrons are accelerated to 6 MeV and strike the anode, or pass through a thin metal window

Basic Accelerator



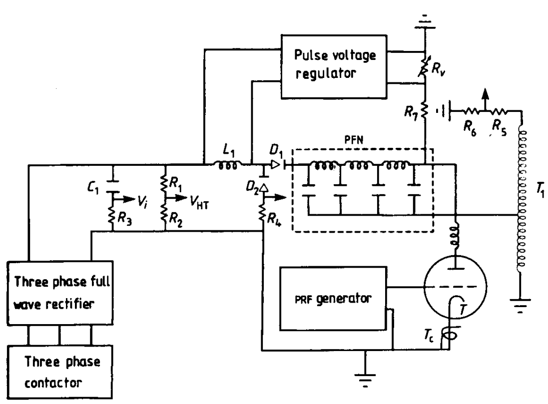
- Instead of using a battery to create the potential, use an alternating voltage
- The magnitude and polarity of such a voltage changes regularly and repeats itself periodically with time
- The frequency is the number of complete cycles per second (1 hertz = 1 cycle/second)
- The frequency of home electric power is 60Hz, FM radio is 100MHz, and a medical linac is 3,000 MHz (microwave)

Basic Accelerator



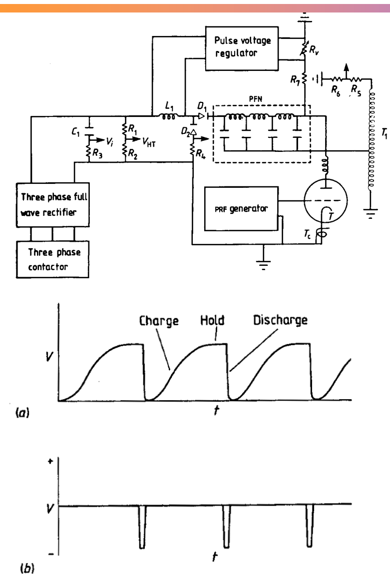
- With the target positive and the filament negative, electrons are accelerated by the 3,000 MHz voltage
- With the target negative and the filament positive, electrons are emitted and form a "cloud" around the filament (but are not accelerated)
- This elementary linac accelerates electrons and emits radiation in pulses

The Modulator



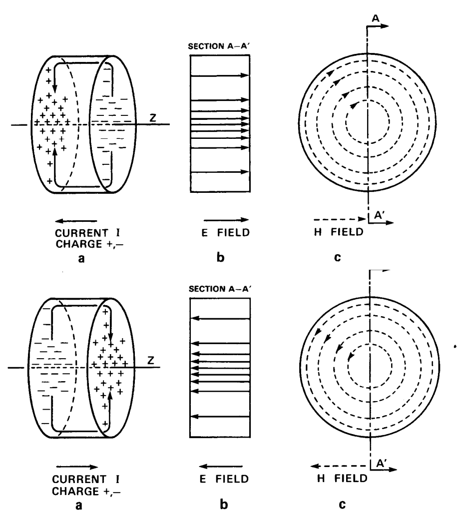
- The modulator supplies negative high voltage pulses to the cathode of the microwave generator and the electron gun
- The three-phase full-wave rectifier uses solid state diodes and delivers about 10kV to the smoothing capacitor C1
- This voltage is monitored using the high-value resistance chain R1, R2 as VHT

The Modulator



- The pulse forming network is charged through inductance L1 and diode D1 when the hydrogen thyratron T is in its non-conducting state
- The inductance L1 and the PFN act as a series resonant circuit and the voltage across the PFN will swing up to twice that from the power supply
- When the hydrogen thyratron is fired, it will discharge the PFN and the current pulse will pass through the pulse transformer T1
- The pulse length is 3-6 ms and current through the hydrogen thyratron is 500A

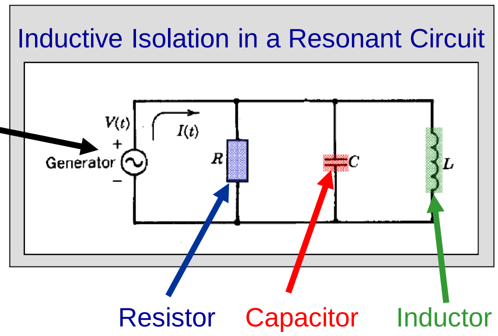
Microwave Devices



- Microwave devices, including klystrons, magnetrons, waveguides and accelerating structures make use of resonant microwave cavities
- A resonant cavity is a volume enclosed by metal walls that supports an electromagnetic oscillation
- The oscillating electric fields accelerate charged particles while the oscillating magnetic fields provide inductive isolation

Microwave Devices

Harmonic Voltage Generator
$V(t) = V_0 \exp(j\omega t)$

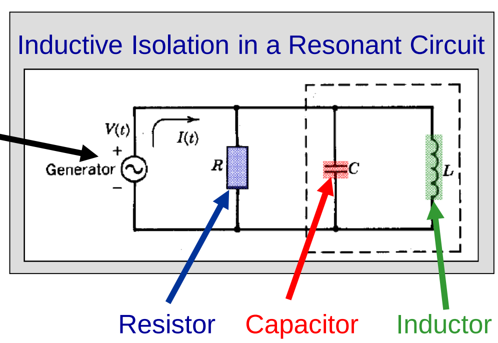


The total circuit impedance (Z) at the voltage generator is

$$Z(\omega) = V_0 \exp(j\omega t) \,/\, I_0 \exp(j\omega t) = (1/Z_r + 1/Z_C + 1/Z_L)^{-1}$$

Microwave Devices

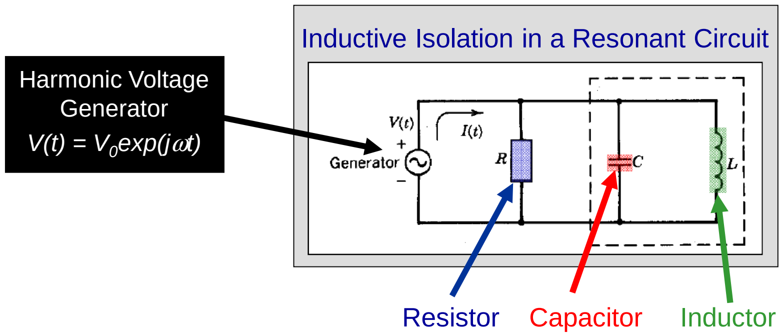
Harmonic Voltage Generator
$V(t) = V_0 \exp(j\omega t)$



The impedance for the part of the circuit of enclosed in dashed lines (*capacitor in parallel with an inductor*) is:

$$Z(\omega) = (j\omega C + 1/j\omega L)^{-1} = j\omega L/(1-\omega^2 LC)$$

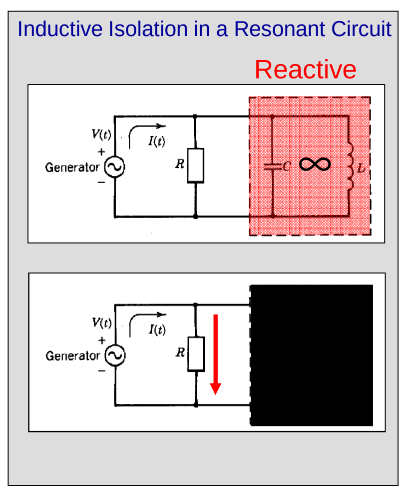
Microwave Devices



- At low frequency $(\omega < 1/\sqrt{LC})$, the impedance is positive, implying that the circuit is inductive and current flow through the inductor dominates the behavior of the circuit
- At high frequency, the impedance is negative and the circuit acts as a capacitive load

Microwave Devices

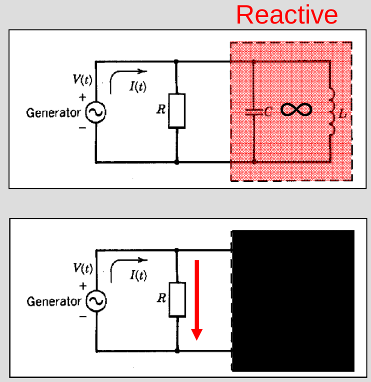
- When the frequency $\omega = \omega_0 = 1/\sqrt{LC}$, the impedance of the combined capacitor and inductor becomes infinite
- This condition is called resonance and the quantity ω_0 is the resonant frequency
- At resonance, the reactive part of the total circuit draws no current when a voltage is applied across the resistor and all current from the generator flows into the resistive load



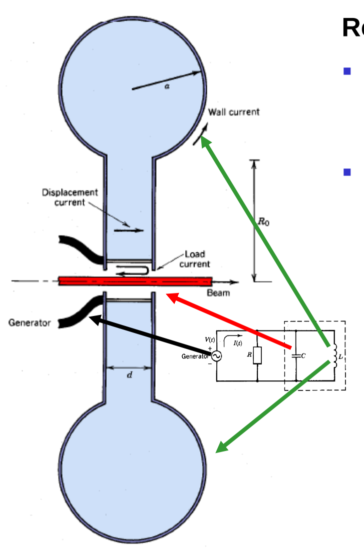
Microwave Devices

- The reactive part of the circuit draws no current because current through the inductor and is supplied completely by displacement current through the capacitor
- At resonance, the net current from the generator is minimized for a given voltage, which is the optimum condition for energy transfer if the generator has nonzero output impedance

Inductive Isolation in a Resonant Circuit



Microwave Devices



Reentrant Cavity

- This cavity is used in systems with space constraints, such as klystrons, because it oscillates at relatively low frequency for its size
- The reentrant cavity can be divided into predominantly capacitive and predominantly inductive regions
  - *In the central region, there is a narrow gap, the capacitance is large, and the inductance is small*
  - *A harmonic voltage generator connected at the center of the cavity induces displacement current*
  - *The enlarged outer region acts as a single-turn inductor, and real current flows around the wall to complete the circuit*
  - *If the walls are not superconducting, the inductor has a series resistance*

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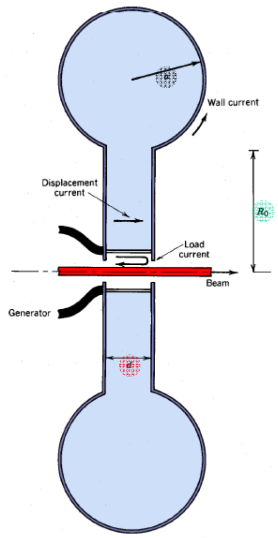
Microwave Devices

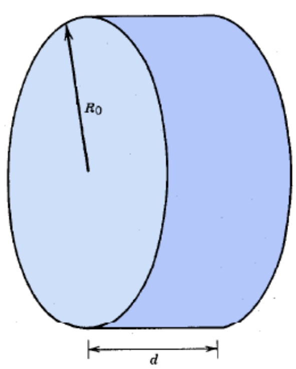


Reentrant Cavity

- If the generator frequency is low, most of the input current flows around the metal wall (*leakage current*) and the cavity is almost a short circuit
- If the generator frequency is high, most of the current flows across the capacitor as displacement current
- At the resonance frequency of the cavity, the cavity impedance is infinite and all the generator energy is directed into the load and the cavity can be useful for particle acceleration
- The resonant frequency of the reentrant cavity can be estimated by

$$\omega_0 = 1/\sqrt{LC} \cong \sqrt{2\pi(R_0+a)d/\varepsilon_o\mu_o R_0^2 a^2\pi^2} = c\sqrt{2(R_0+a)d/R_0^2 a^2\pi}.$$

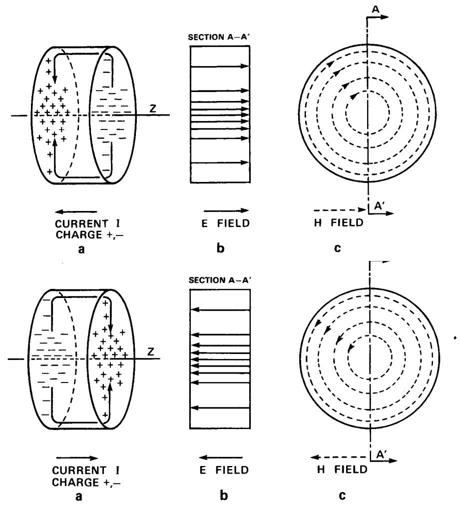
Microwave Devices



Cylindrical Cavity

- The cylindrical cavity has some features in common with the reentrant cavity
- A capacitance between the upstream and downstream walls carries displacement current.
- The circuit is completed by return current along the walls and inductance is associated with the flow of current
- The main difference from the reentrant cavity is that regions of electric field and magnetic field are intermixed
- In this case, a direct solution of the Maxwell equations is more effective than an extension of the lumped element analogy

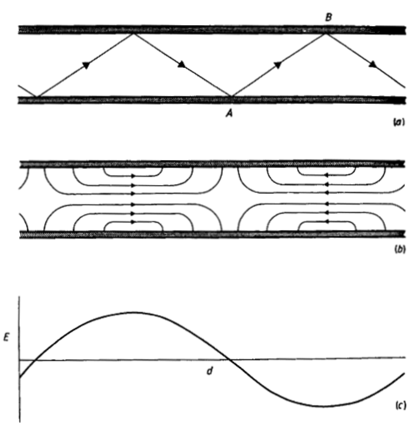
Microwave Devices



Cylindrical Cavity

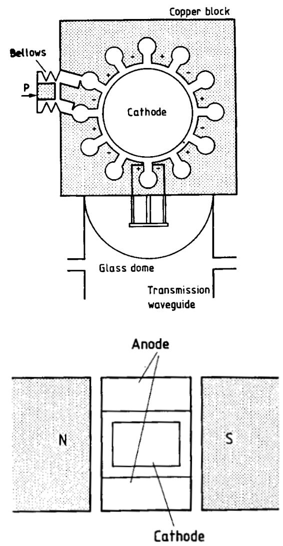
- Microwave devices, including klystrons, magnetrons, waveguides and accelerating structures make use of resonant microwave cavities
- A Microwave cavity is an accurately machined cylinder 10-cm in diameter and several cm in length
- Intense "E" Fields are established by small amounts of electrical power at a resonant frequency of 3000 MHz

Microwave Devices



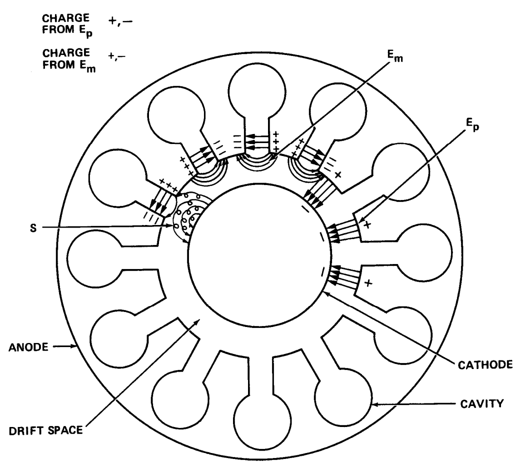
- An electromagnetic wave that is transmitted between conducting surfaces will be reflected
- These waves interfere and an electric field is created if the path length between reflections (AB) is an integral number of wavelengths
- The electric field has an axial component that can be used to accelerate electrons

The Magnetron



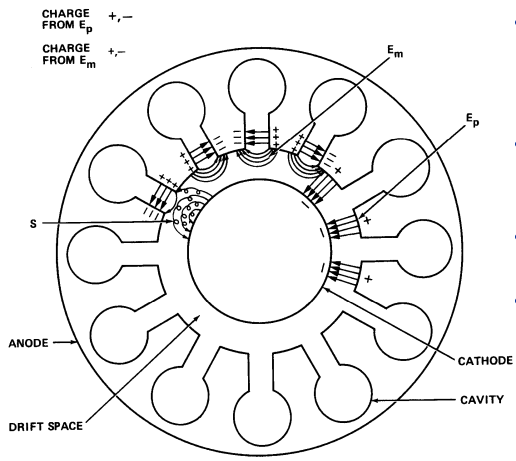
- The magnetron is a microwave source used to power lower energy linacs (*<12 MV)*
- It is a two-element tube with a cathode and anode with incorporated microwave cavities
- The central cylindrical cathode is oxide coated and heated by a tungsten spiral
- The outer anode has 12 cavities cylindrically arranged in a block of copper
- The whole structure is placed in a uniform magnetic field with its lines of force normal to the cavities

The Magnetron



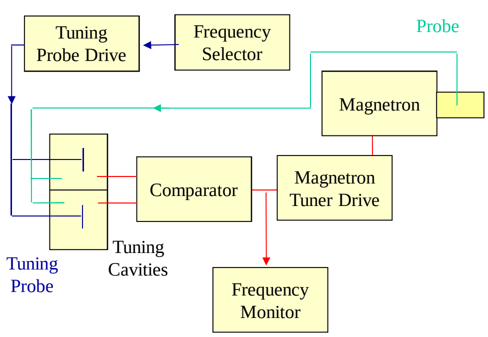
- The anode structure forms a set of tightly coupled resonant cavities
- These cavities will oscillate such that the potential differences will alternate with the opposite configuration of + and -
- An electron crossing the mouth of one of the cavities will start the system oscillating
- Electrons from cathode circulate concentrically round the drift space

The Magnetron



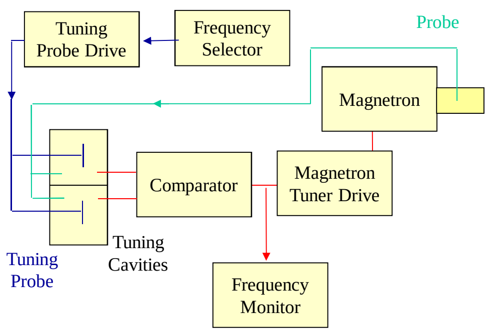
- The voltage pulses and the cavity oscillation causes electrons to either accelerate or decelerate as they pass the mouth of a cavity
- The circulating electrons form a spaced charge cloud like spokes on a rotating wheel
- The rotating electrons give energy to the oscillating cavities
- Wires from opposite sides of one of the oscillating cavities are brought through holes in the anode block to form a pair of symmetrical loops which couple directly into the magnetic mode of the transmission waveguide

Automatic Frequency Control



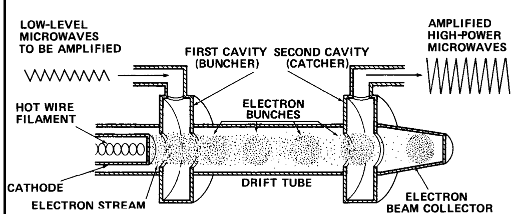
- Thermal expansion and gantry rotation can cause changes in the microwave frequency
- The automatic frequency control (*AFC*) system continuously senses the optimum operating frequency of the accelerator to maximize radiation output
- The microwave output is sampled by a probe in the transmission waveguide and fed into two tuned cavities machined out of copper

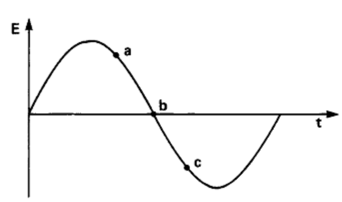
Automatic Frequency Control



- These cavities are tuned to slightly different frequencies, just below and above the desired value
- If the microwave frequency is equal to the desired value, then the signal from the two cavities will be equal
- If the frequency is too high, then the high-frequency cavity will give a larger signal than the low-frequency cavity
- The comparator gives an output voltage to a control motor that turns the magnetron tuner

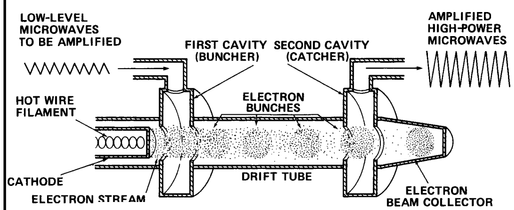
The Klystron

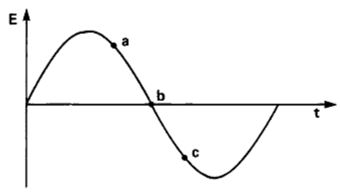




- The Klystron is a microwave amplifier tube
- The primary resonant cavity is excited by the use of a low power microwave oscillator
- This sets up an alternating "E" field across the gap between the left and right cavity walls
- The oscillating "E" field will either accelerate or decelerate the electrons
- A negative voltage pulse is applied to the cathode and an electron beam is injected into the first cavity

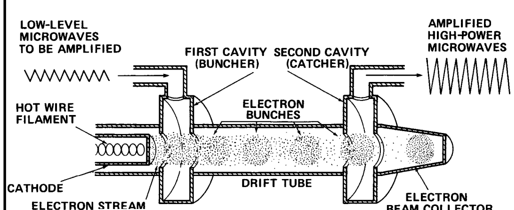
The Klystron

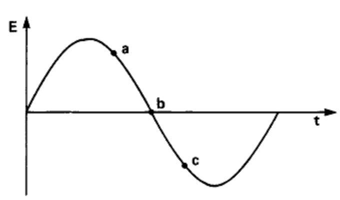




- Electrons that arrive early in the microwave cycle (*between time points a and b*) encounter a retarding "E" Field and are slowed
- Electrons that arriving at point b receive no effect
- Electrons that arrive late in the microwave cycle (*between time points b and c*) encounter an accelerating "E" Field
- This causes the electron stream to form bunches

The Klystron





- The electrons pass along a drift tube that connects the microwave cavities
- A catcher cavity has a resonance at the arrival frequency of the bunches
- As the electrons leave the drift tube and traverse the catcher cavity gap, they generate a retarding "E" field by inducing charge on the ends of the cavity
- Much of the electron's kinetic energy is converted into the "E" field, which creates microwave power

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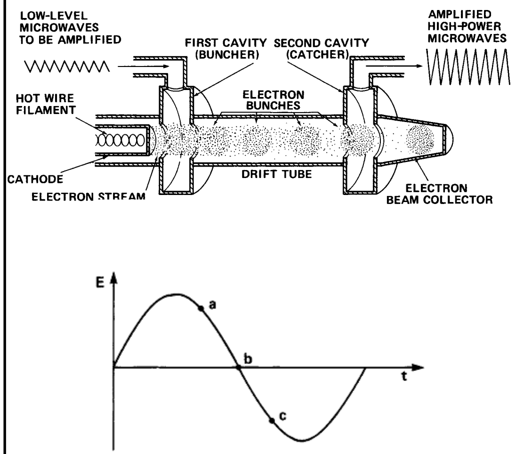
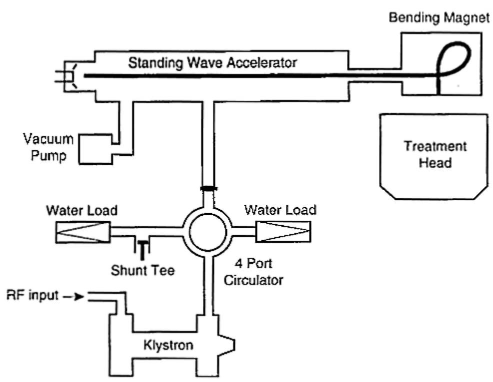
The Klystron



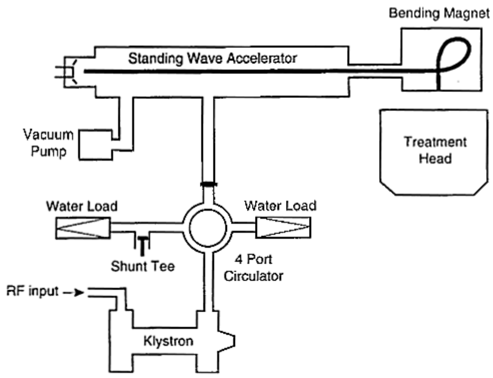
- The residual beam energy that is not converted into microwave power is dissipated as heat in the electron collector
- The beam collector is shielded with lead to attenuate x-rays created by the electron stopping
- The klystron is 1 meter in length and is submersed in an oil tank
- A typical klystron consists of three to five cavities that provide 100,000 : 1 microwave amplification (*5 megawatts of peak power*)

The Waveguides and Circulators



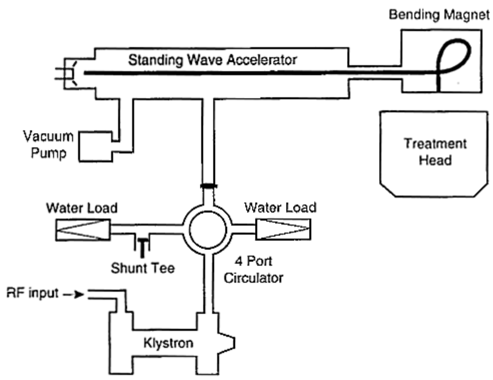
- Microwave power is conveyed from the magnetron or klystron to the accelerating structure by hollow pipes called waveguides
- Waveguides replace traditional electrical wires and cables, which are inefficient in transmitting microwave power
- Waveguides confine microwaves by reflecting them forward off the walls
- They are pressurized with sulfur hexafluoride, which reduces the possibility of electrical breakdown

The Waveguides and Circulators



- Ceramic windows separate the pressurized waveguide from the evacuated klystron and accelerating structure
- A Four-Port Circulator prevents reflected microwave power from returning to the Klystron
- Microwave power enters Port#1 and leaves Port#2
- A mechanical Shunt Tee is used to adjust the microwave power
- A magnetized ferrite strip induces a 180-degree phase change in one of the sections

The Waveguides and Circulators

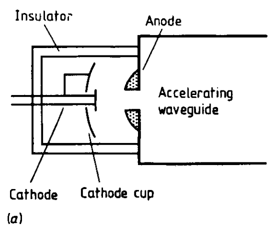


- As such, Microwave power enters Port#2 and leaves Port#3 and continues on the accelerating structure
- Reflected microwave power from the accelerator enter Port#3, and exits in port #4
- The microwave load is then dissipated in using a water cooled lossy dielectric material
- A rotary joint is used to transfer microwave power from the stationary stand to the rotating gantry

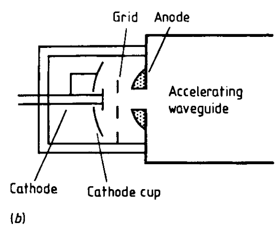
Electron Guns

- The electron gun is a cathode that provides the source of electrons injected into the accelerating structure
- In a diode gun, electrons are thermionically emitted from the cathode and are electrostatically focused into the accelerating structure by the use of curved cathode and anode cups
- The maximum energy to which electrons are accelerated into the accelerator and the dose can be controlled using the gun current

Diode Gun



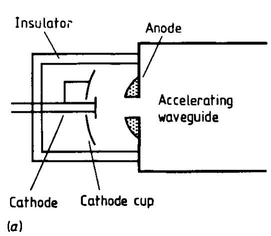
Triode Gun



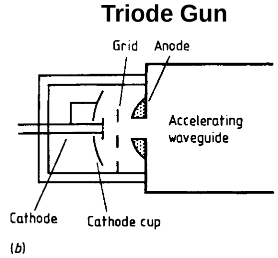
Electron Guns

- The change in gun current between electron and photon treatment mode is about a factor of 100
- Some linear accelerator require regular replacement of the gun, which is removable from the guide
- Other manufactures have the gun welded on the accelerator, which means that the entire guide would need to be replaced in the case of a gun failure

Diode Gun



Triode Gun



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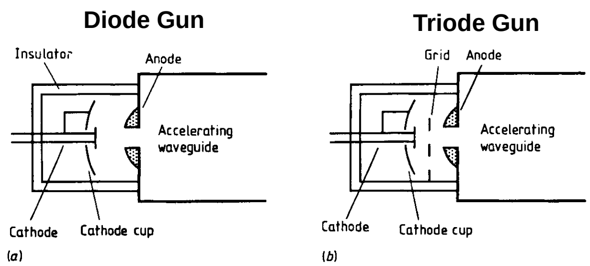
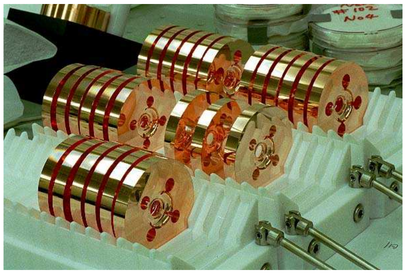
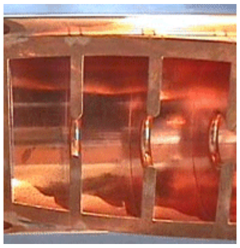
Electron Guns

- A triode gun uses an additional grid to control the electron beam current
- The grid is normally held sufficiently negative to the cathode to cut off the current to the anode
- The grid is used to control the timing and magnitude of the current pulses injected into the accelerating structure



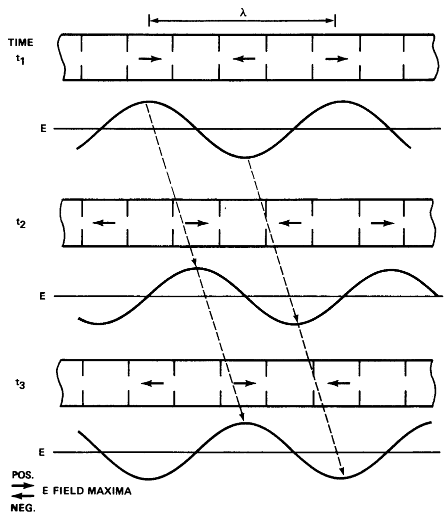
Accelerating Structures





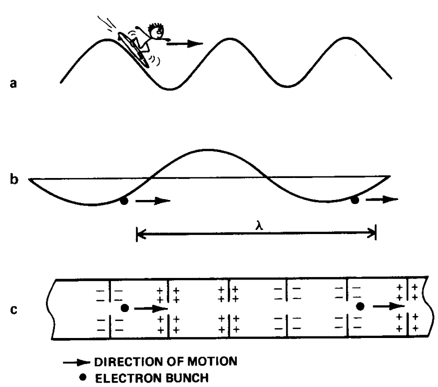
- The microwave cavities of the accelerating structure are made of copper
- Copper is used because of its high heat and electrical conductivity
- The accelerator consists of a series of short cylindrical sections that are assembled in a long sequence and then soldered together in a furnace
- Once fused, the sections become a rigid, vacuum tight structure
- The cavities are then fine tunes by mechanical compression

Accelerating Structures



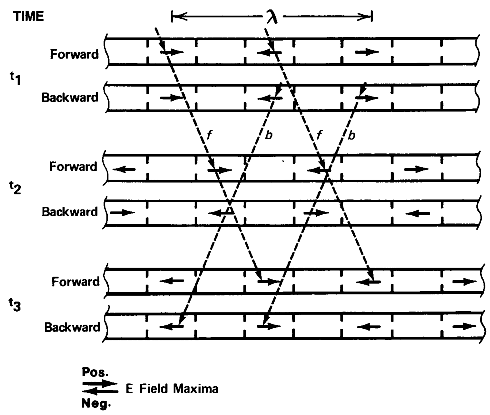
- In a traveling-wave accelerating structure, the "E" field moves from left to right as time progresses
- The solid arrows denote the instantaneous positions of the maximum positive and negative values of the traveling electric wave
- Electrons are accelerated to the right on the negative portions of the "E" Wave
- In any one cavity, the "E" field reverses direction for each half cycle
- The Wave crest moves forward by one cavity

Accelerating Structures



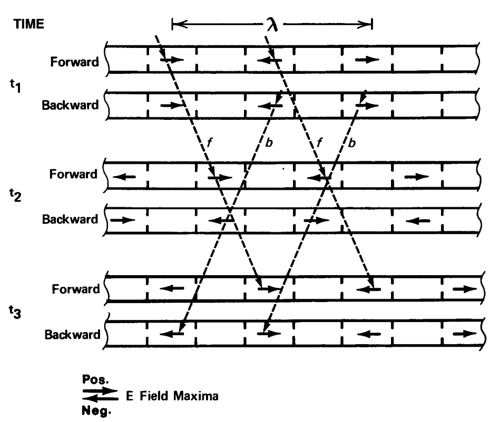
- A surfer rides the forward edge of a water wave, moving in step with the traveling wave
- If the surfer slips back over the crest he/she will bob up and down as the wave passes underneath
- The water particles do not move forward, but the wave travels forward
- Similarly, electrons move forward on the front of the advancing "E" wave
- Power enters the waveguide near the electron gun, and is absorbed at the end of the guide

Accelerating Structures



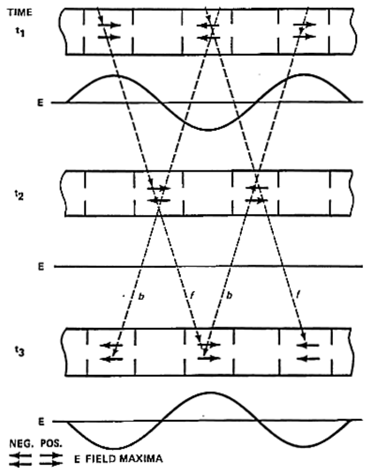
- Most modern day linacs use a standing-wave because the accelerating structure can be shorter
- In a standing wave system, the "E" wave varies in magnitude with time, but the pattern remains stationary along the axis
- The microwave power enters the guides near the middle and is reflected at both ends
- An analogy is the pattern of a violin string fixed at both ends and vibrating up and down

Accelerating Structures



- The advancing incident wave and reflected wave move back and forth inside the accelerating structure about one hundred times during a 5-microsecond pulse
- As described earlier, the circulator prevents reflection to the klystron or magnetron
- The forward wave crest moves to the right by one cavity length
- The effective "E" field is the sum of the forward and backward waves

Accelerating Structures



- The crests of the sine wave pattern oscillate up and down with the progression of time
- Note that every other cavity in the standing wave structure has a zero "E" Field at it's center at all times
- This is because the forward and backward waves are always equal in magnitude but opposite in direction
- These zero "E" cavities are essential in the transporting of microwave power

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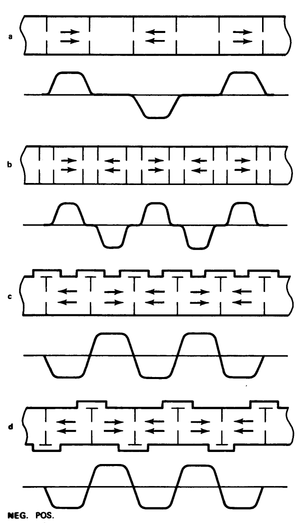
Accelerating Structures



- Because the zero "E" cavities play no role in acceleration, they can be moved off axis
- Every other cavity is shorten in length (*the resonance depends on its diameter, not its length*)
- The coupling cavities can be moved off-axis, and then to alternating sides
- This results in a substantial decrease in the length of the accelerating structure

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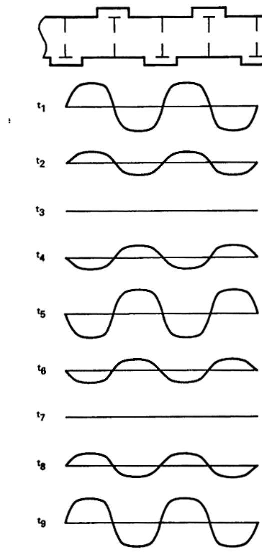
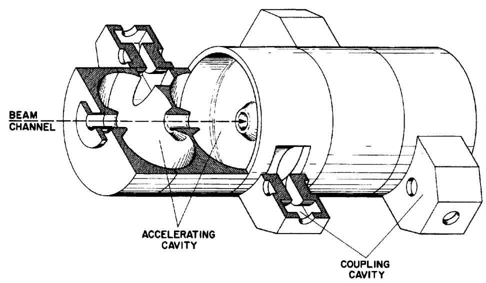
Accelerating Structures



- The filling time of the cavity is 1 µsec of the 4 µsec microwave pulse
- Electrons are captured and bunched in the first few cavities
- The electrons first gain energy by velocity, then by increasing mass once they become relativistic



Energy Switch

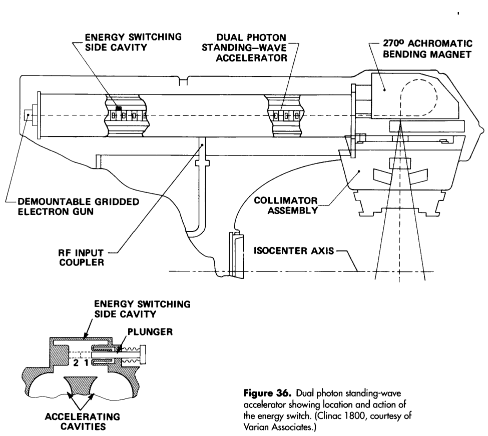


Figure 36. Dual photon standing-wave accelerator showing location and action of the energy switch. (Clinac 1800, courtesy of Varian Associates.)

- Many linear accelerators are capable of producing clinical electron and photon beams of multiple energies
- 4, 6, 8, 10, 15, 18, and 23 MV Photons
- 4, 6, 8, 10, 15, 18, and 23 MV Electrons
- The maximum energy is defined by the accelerator structure length
- The same structure must also be capable of generating lower energies

Energy Switch

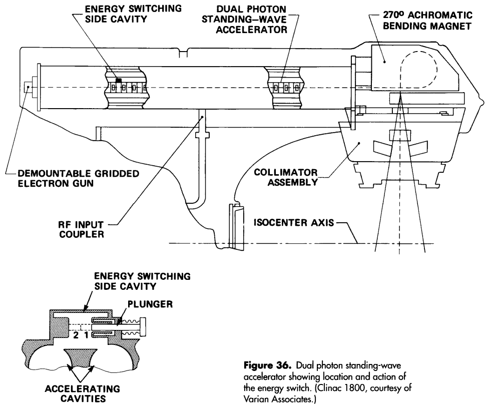


Figure 36. Dual photon standing-wave accelerator showing location and action of the energy switch. (Clinac 1800, courtesy of Varian Associates.)

- The accelerator can produce two photon energies by dropping the magnitude of the "E" field in a subsection of the accelerating structure
- This is achieved using an energy switch located in a side cavity
- In the high energy position, the cavity provides high coupling between the adjacent cavities
- The decreases the coupling when depressed

Energy Switch

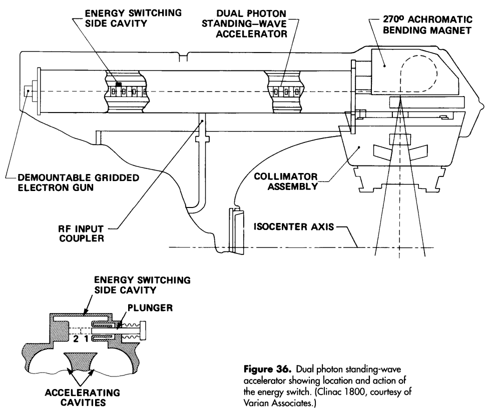
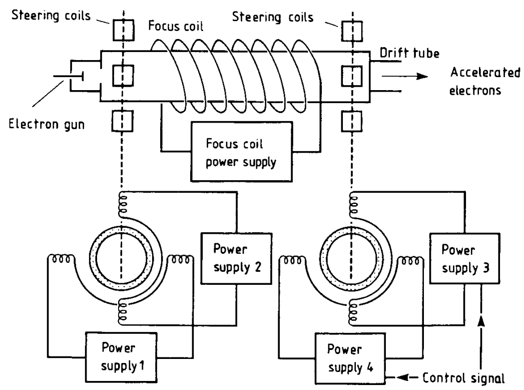


Figure 36. Dual photon standing-wave accelerator showing location and action of the energy switch. (Clinac 1800, courtesy of Varian Associates.)

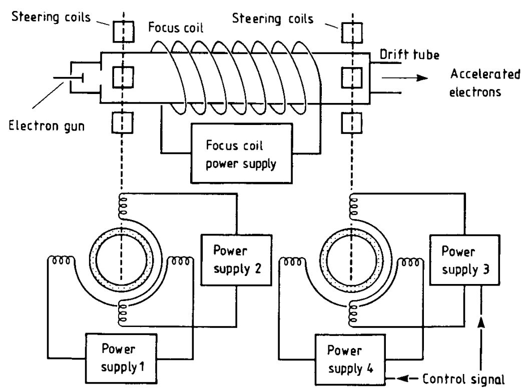
- This creates a lower magnitude "E" field in the accelerating structure after the switch
- In both positions, the high "E" field is maintained in the first section of the accelerator
- Another system uses a high-power microwave circuit
- These systems use a power divider and a phase shifter, which are bulky and employ many moving parts

Beam Steering / Bending Magnet



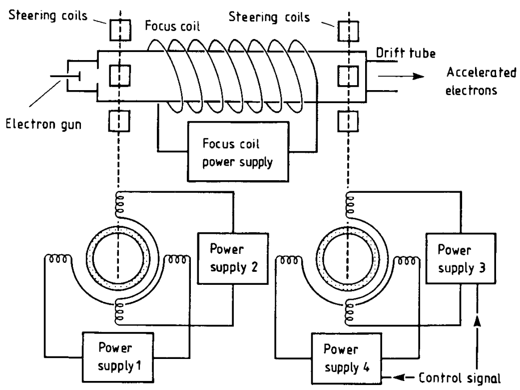
- Electrons passing through the accelerating structure will not travel exactly along the central axis because of minor imperfections and because of external magnetic fields
- The deflection of a 2.5 MeV electron traveling along a 1.5 meter accelerating structure will be deflected by several millimeters due to the Earth's magnetic field
- As a result, the beam must be steered inside the accelerator

Beam Steering / Bending Magnet



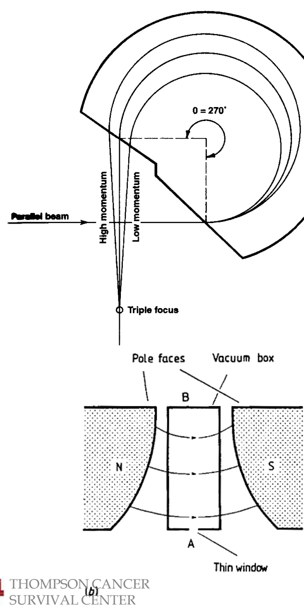
- Beam steering is accomplished using two orthogonal dipole formed by pairs of beam steering coils
- Coils near the electron gun are used to steer the beam immediately after injection into the accelerator
- The electron gun may be misaligned relative to the accelerator
- Coils at the high energy end are used to correct for deflections

Beam Steering / Bending Magnet



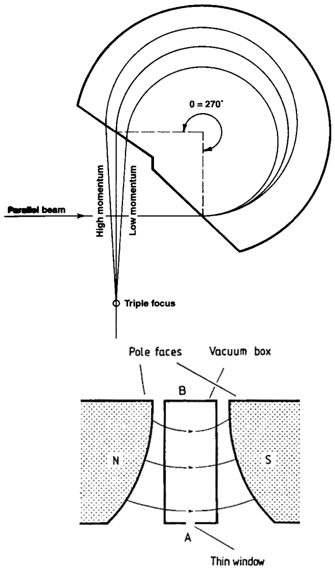
- Beam steering at the gun end can be preset to a constant value
- Failure to set the steering fields to optimal values can result in loss of beam as all the electrons inadvertently strike the accelerator walls
- The high-energy beam steering must be performed dynamically as the accelerator rotates relative to the magnetic fields that cause the deflection

Beam Steering / Bending Magnet



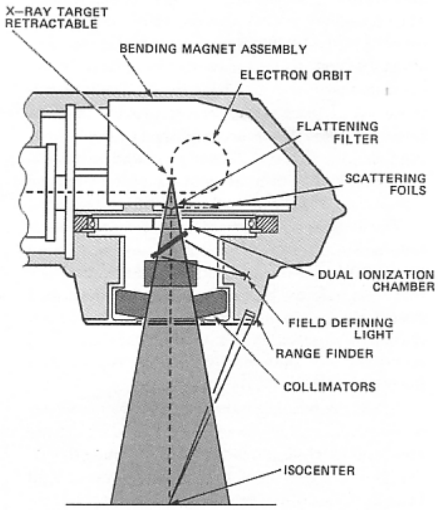
- The electron beam leaving the accelerating structure may enter an evacuated bending magnet system
- The electrons are deflected magnetically so that they strike a target (*for x-ray treatment*) or exit the head through a thin window (*for electron treatment*)
- The bending magnet deflects the electron beam by 270-degrees
- This magnet design provides focusing for the spread of the energies in the beam
- A 90-degree deflection will defocus and spread the beam

Beam Steering / Bending Magnet



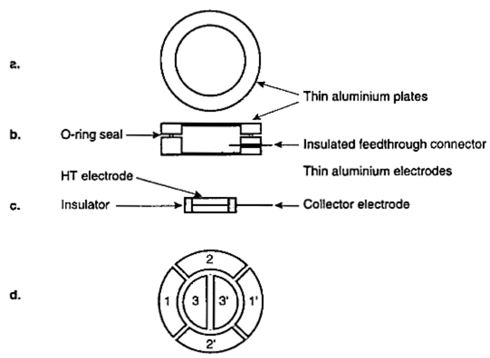
- As an electron penetrates into the magnetic field, it will follow a path whose curvature depends on its energy
- Lower energy electrons are deflected through a loop of smaller radius
- Higher energy electrons are deflected through a loop of higher radius
- During the first half of the orbit, the electrons disperse
- During the second half of the orbit, the electrons converge to emerge from the deflecting field at the same point traveling in the same direction

Linac Head



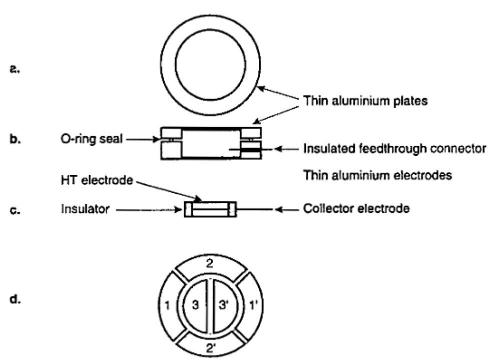
- The head of the gantry contains the bending magnet, target (*and scatter foil*), flattening filter, ionization chambers, beam collimators, and field defining lights
- The target and flattening filter are used to create a clinical x-ray field
- The scattering foil is used for clinical electron treatments

Dose Monitoring / Feedback



- Small changes in the operating conditions, performance, and ambient conditions can have a significant effect on the radiation produced
- It is therefore necessary to monitor the output consistency to control the radiation beam in terms of energy, dose distribution, flatness, and symmetry
- This is normally achieved using transmission ionization chambers located in the head of the gantry

Dose Monitoring / Feedback



- The chambers must be thin in relation to the radiation beam being monitored so that they cause minimum perturbation of the beam
- The ion chamber consists of multiple parallel plates (*typically 0.1-mm thick*)
- The plates create an electrode that is used to indirectly measure dose
- The chambers are typically segmented to measure dose in different parts of the beam

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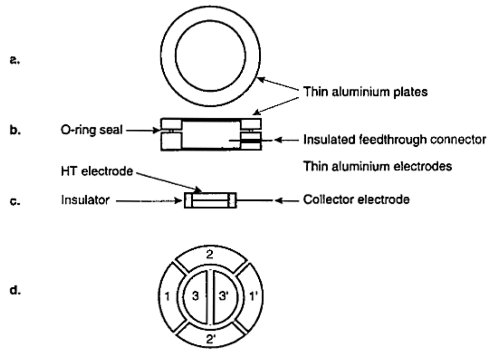
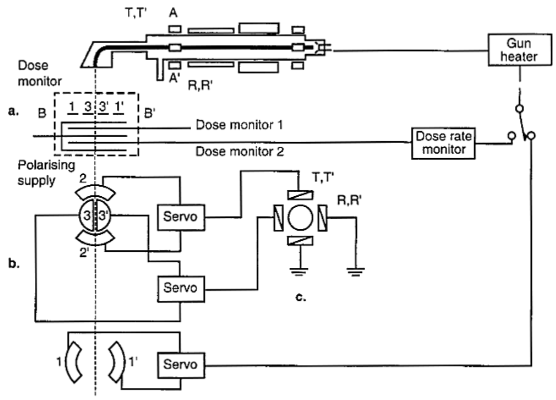
Dose Monitoring / Feedback



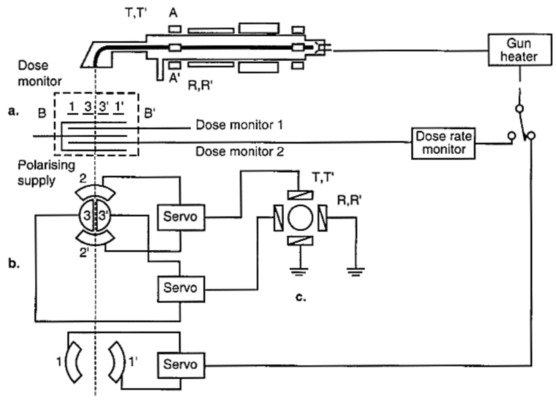
- The voltage between the two electrodes is typically 300V
- The signal from an ion chamber depends on the amount of gas between the electrodes
- The distance between the plates must be mechanically stable
- The chambers are also sealed to prevent changes due to temperature and pressure
- These systems are typically stable of many years, however chambers can leak

Dose Monitoring / Feedback



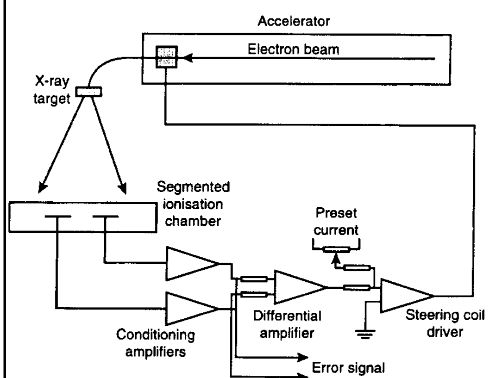
- Beam uniformity depends on delivering the electron beam accurately on the target do that it's focal spot is aligned with the flattening filter
- The ion chambers are divided into three pair, each providing signal relevant to a different dosimetric attribute
- Reading are taken during treatment delivery and adjustments are made dynamically using a servo system

Dose Monitoring / Feedback



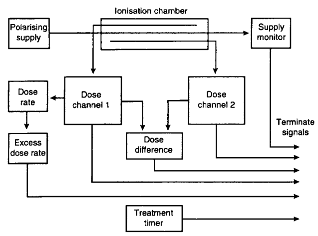
- Chamber pair 1 monitors the energy dependence from the bending system has the greatest effect in the outer portion of the beam
- Chamber pair 2 monitors the position of the beam as it enters the bending magnet
- Chamber pair 3 monitors the position of the beam in the transverse direction
- The same (*or additional chambers*) are used to monitor the output of the beam

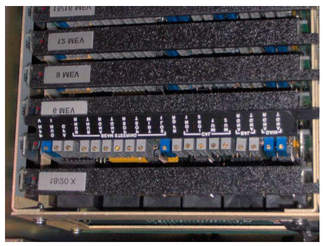
Dose Monitoring / Feedback



- The position of the focal spot on the target is controlled using orthogonal pairs of beam steering coils
- The currents in the coil operate at preset values based on the electron energy
- The output from the ion chamber pairs are preset to give equal signals when the beam is uniform
- These signals form the input to a differential amplified (*or comparator*) whose output is the signal for the beam steering servo

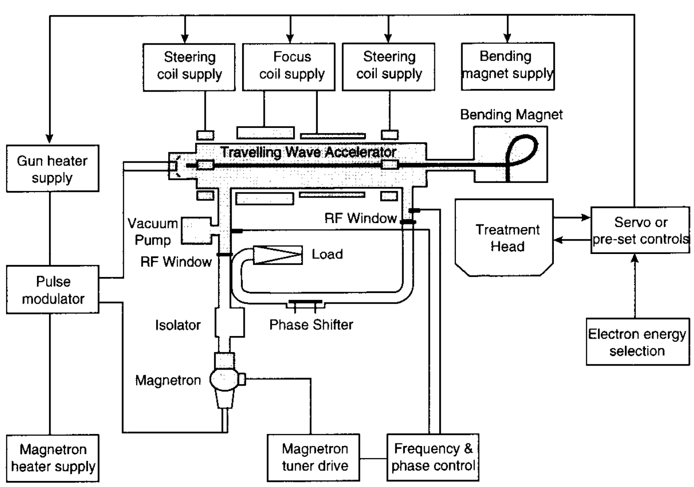
Dose Monitoring / Feedback





- The current collected in the ion chamber is proportional to the number of photons passing through the chamber per unit time
- If the current is proportional to the dose rate, then the total charge collected during an irradiation will be proportional to the dose
- The analogue ion chamber current is divided into pulses using an integrator
- The absorbed dose corresponding to each pulse is referred to as a MONITOR UNIT

System Overview



Superficial Therapy

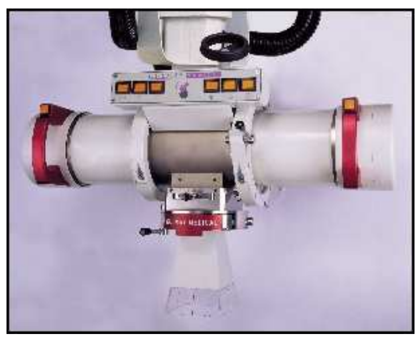
Superfical treatments are x-rays used for therapy in the 50 to 150 kV energy range

- Skin cancer and tumors no deeper than 5-mm can be treated with superficial therapy
- Aluminum filters are used to harden the beam to the desired amount
- The degree of beam hardening is measured with Half-Value Layer (*HVL*), with typical HVLs ranging from 1-8 mm of aluminum
- Treatments use cones or applicators that are generally 2-5 cm in diameter
- Lead cutouts are tailored to fit the treatment area, and the cone lies directly on the patient surface

Orthovoltage Therapy

Orthovoltage treatments are x-rays used for therapy in the 150 to 500 kV energy range

- The types of tumors treated with Orthovoltage units include skin, mouth, and cervical carcinoma (*with the use of cones inserted into the patient*)
- Much like superficial units, Orthovoltage units use filters designed to achieve HVLs from 1 to 4 mm Cu
- The penetrating depth depends on the kV and the filter, but is usually 2 to 3 cm

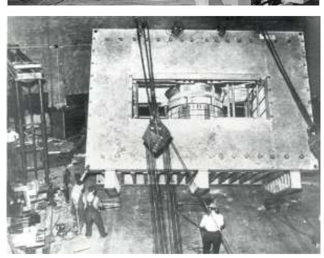


Orthovoltage Therapy

- Orthovoltage units are still popular in many clinics and hospitals
- They are a reliable alternative to electrons in the treatment of superficial skin lesions
- Some clinicians prefer the Orthovoltage unit because of its beam characteristics, especially for small field sizes
- However, most Orthovoltage equipment is older compared to modern linear accelerators

Betatron

- A betatron is a particle accelerator developed by Donald Kerst at the University of Illinois in 1940 to accelerate electrons
- The first betatron accelerated electrons to an energy of 2 MeV
- Electrons from a tungsten filament are injected with an energy of about 50 keV into a torus-shaped vacuum tube
- The torus is mounted between the pole of an electromagnet, which is energized by an alternating voltage oscillating between 50 and 180 Hz
- This alternating current in the primary coils accelerates electrons in the vacuum around a circular path



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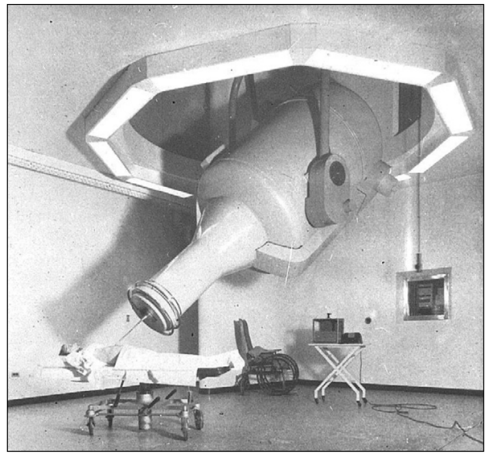
Early Linear Accelerators

In the 1950's the first linacs began treating patients

- Some of the early systems were built using the principles of the resonant transformer
- These systems were acceptable for the production of orthovoltage quality x-rays
- However, the bulky insulation required or megavoltage levels rendered the equipment somewhat unsuitable for clinical use



A 4 MeV resonant transformer unit

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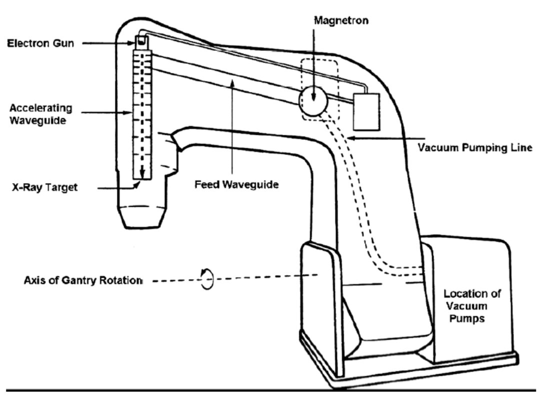
Early Linear Accelerators



- 4 MeV Orthotron (*circa 1950*) were isocentrically mounted, however with limited angular movement

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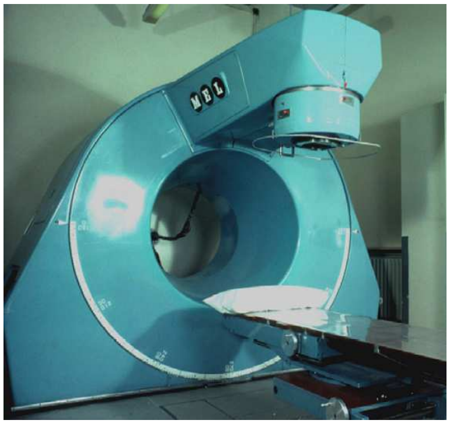
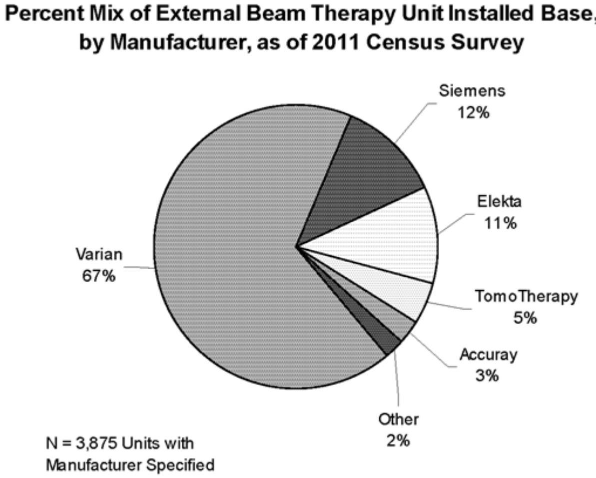
Early Linear Accelerators

In the 1960's the accelerating structures were positioned horizontally in the gantry

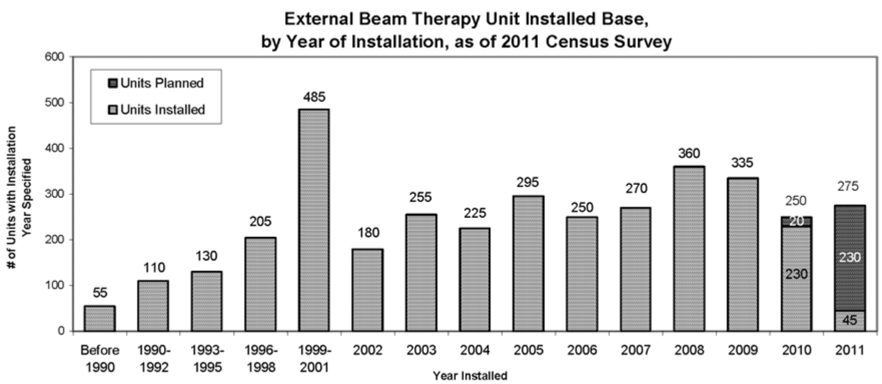
- The beam was deflected magnetically before striking the target
- In addition, the vacuum pump was positioned within the moving structure
- The MEL machine achieved the objective of full isocentric rotation with the center of rotation at a manageable height (*120–130 cm)* above the floor



Linac Manufacturer



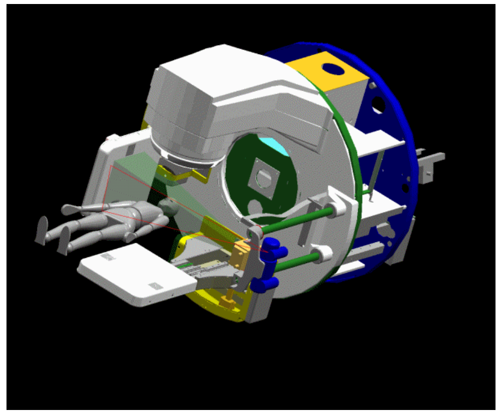
Linac Age



Elekta *Synergy*

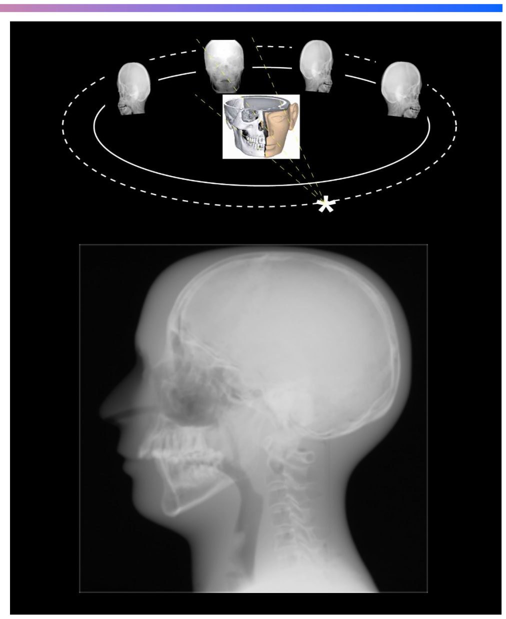
Elekta *Synergy*

- Equipped with a 80 Leaf MLC (1-cm width)
- Travelling wave guide
- Mounted on a drum based gantry
- Microwave systems are easily accessible behind a false wall
- Ability to acquire cone-beam CT



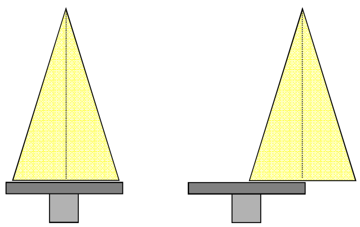
Elekta *Synergy*

- Cone-Beam datasets are created from a series of radiographic exposeures that are aquired at regular angular intervals as the gantry is rotated through a specified range (*typically 180 or 360 degrees*)
- Projections are weighted and filtered in one dimension
- The resulting images are interpolated at 4X resolution and stored for sampling during backprojection



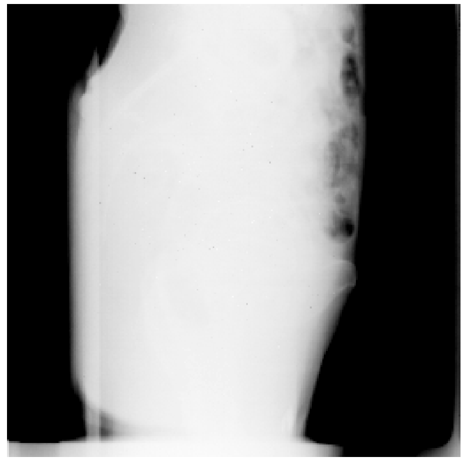
Elekta *Synergy*

- The reconstruction FOV is limited to a cylinder 26.5-cm in diameter and 26.6-cm in height
- A 48-cm reconstruction FOV can be created by offsetting the detector 7.6-cm with respect to the central axis



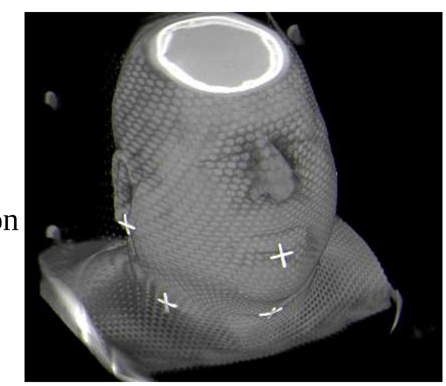
26.6 cm FOV with 180-degree rotation

48 cm FOV with 360-degree rotation

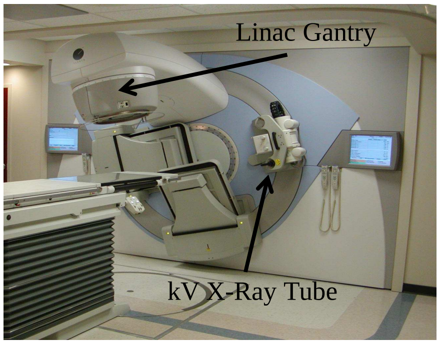


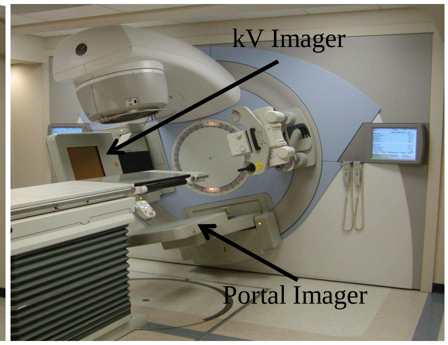
Elekta *Synergy*

- Short acquisition time
  - *Up to 250 slices per minute (in one gantry rotation)*
  - *Independent of the number of reconstructed slices*
- Cone Beam has isotropic resolution
  - *Same resolution in every direction*
  - *Ideal for volume registration*
  - *Reconstruction in arbitrary planes; coronal, sagittal, oblique*



Elekta *Synergy*





Imaging Arms Retracted

Imaging Arms Extended

Elekta *Infinity*

- Similar to the Synergy
- 160 Leaf MLC (5-mm width)

Elekta *Versa HD*

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Elekta - *Financials*

Cash Flow All numbers in thousands

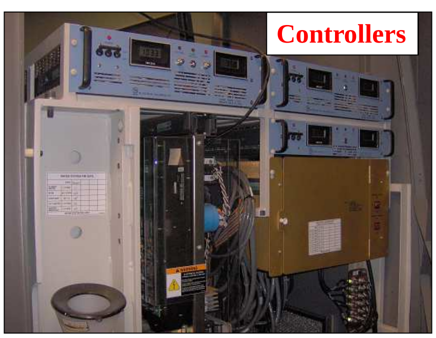
Period Ending	4/30/2017	4/30/2016	4/30/2015	4/30/2014
Net Income	**125,000**	**137,000**	**552,000**	**1,148,000**
Operating Activities, Cash Flows Provided By or Used In				
Depreciation	275,000	308,000	276,000	242,000
Adjustments To Net Income	-	-	-	-
Changes In Accounts Receivables	158,000	350,000	532,000	-843,000
Changes In Liabilities	-	-	-	-
Changes In Inventories	231,000	80,000	27,000	-189,000
Changes In Other Operating Activities	662,000	31,000	-35,000	615,000
Total Cash Flow From Operating Activities	**1,819,000**	**1,170,000**	**1,823,000**	**1,275,000**
Investing Activities, Cash Flows Provided By or Used In	**$236M**			
Capital Expenditures	-141,000	-187,000	-297,000	-234,000
Investments	**$18M**	-	-	-
Other Cash flows from Investing Activities	-	-	-	-
Total Cash Flows From Investing Activities	**-792,000**	**-786,000**	**-1,144,000**	**-777,000**
Financing Activities, Cash Flows Provided By or Used In				
Dividends Paid	-	-	-	-
Sale Purchase of Stock	-	-	-	-
Net Borrowings	-	-	-	-
Other Cash Flows from Financing Activities	-627,000	-589,000	-662,000	-544,000
Total Cash Flows From Financing Activities	**-55,000**	**-1,303,000**	**186,000**	**-888,000**
Effect Of Exchange Rate Changes	138,000	-72,000	153,000	70,000
Change In Cash and Cash Equivalents	**1,110,000**	**-992,000**	**1,018,000**	**-320,000**

1 SEK (Swedish Krona) = 0.13 USD

Varian *21EX*

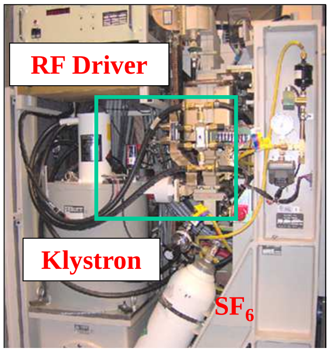
- Analog to Digital System
- Standing Wave Guide with Triode Electron Gun
- Klystron Driven
- 4 to 23 MV photons (2)
- 4 to 20 MeV Electrons (5)
- 100 to 1000 MU/min
- 0.5 x 0.5 to 40.0 x 40.0-cm
- 120-Leaf MLC
- Electronic Portal Imager

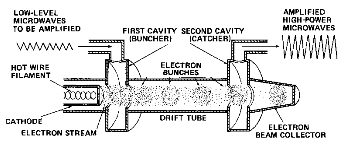
Varian *21EX*

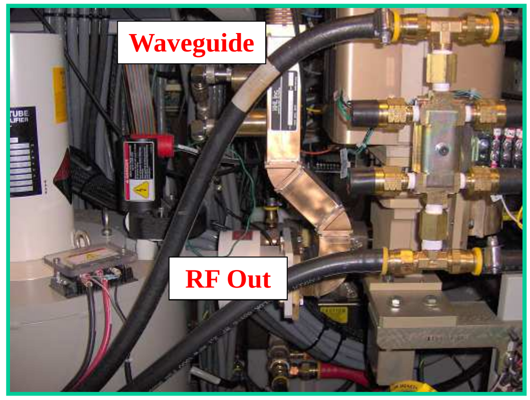


Right Side Gantry Stand

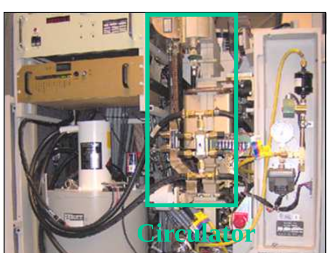
Varian *21EX*

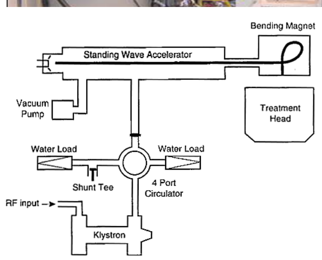


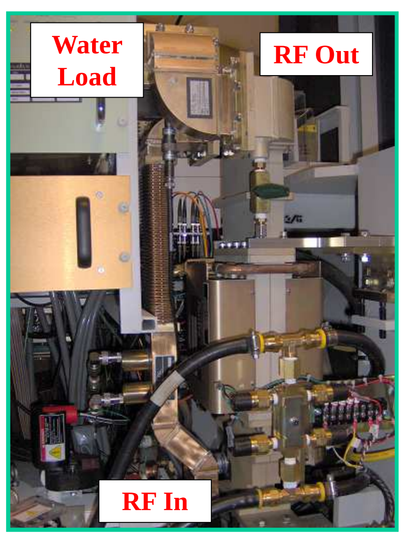




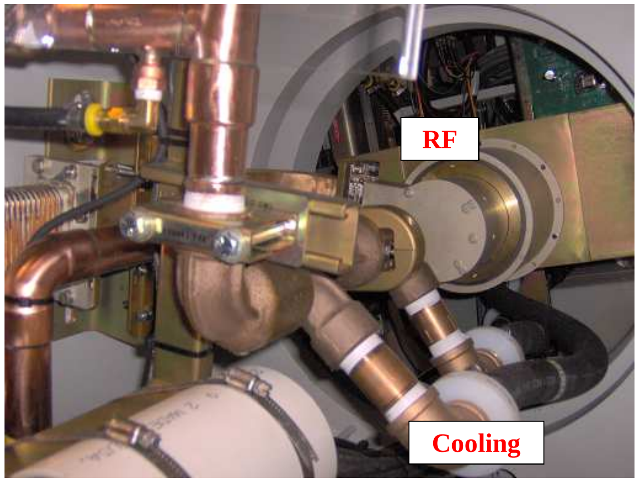
Varian *21EX*





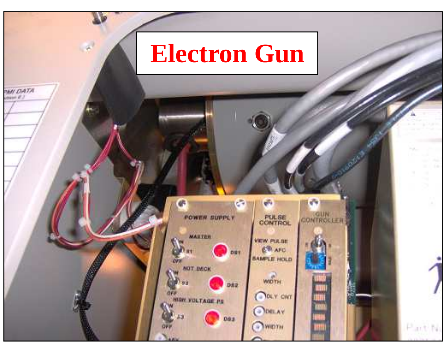


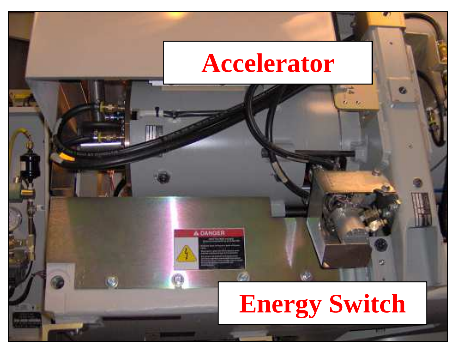
Varian *21EX*

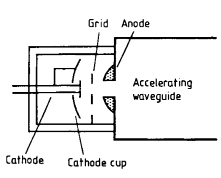


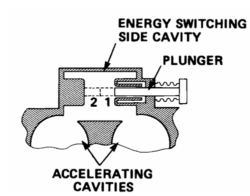
Rotating Junction

Varian *21EX*

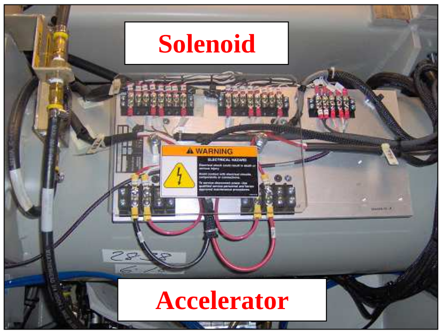


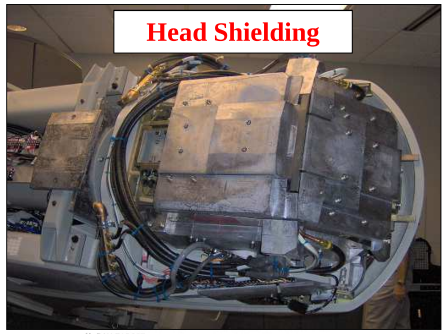


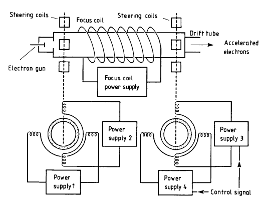


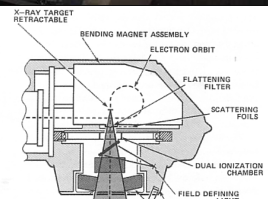


Varian *21EX*









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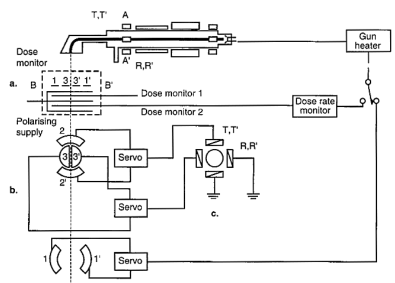
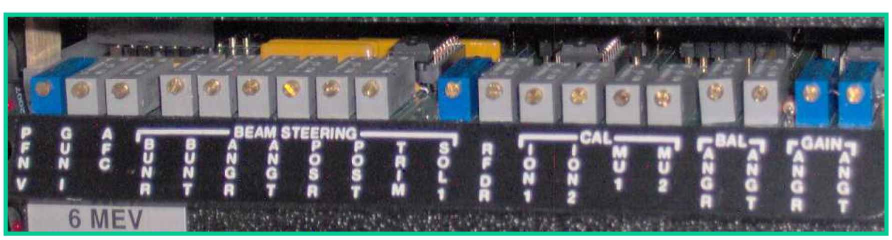
Varian *21EX*





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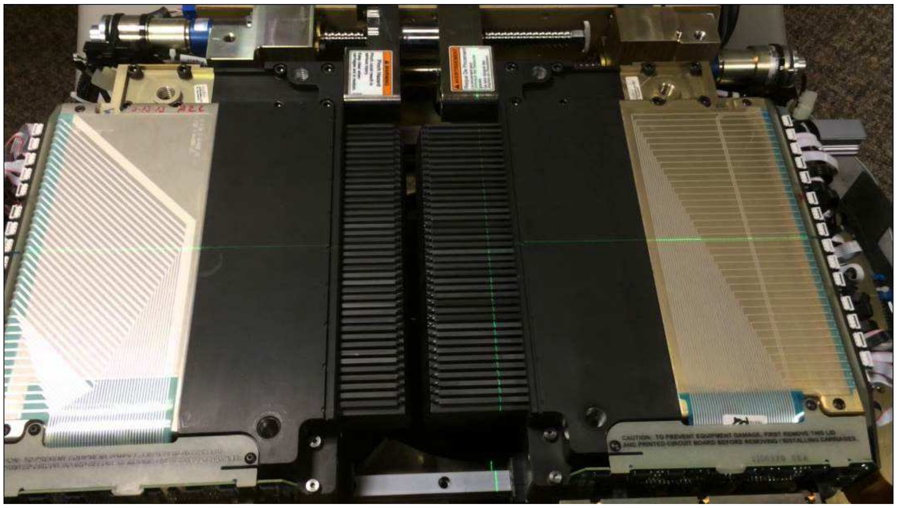
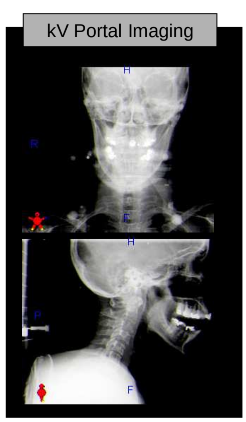
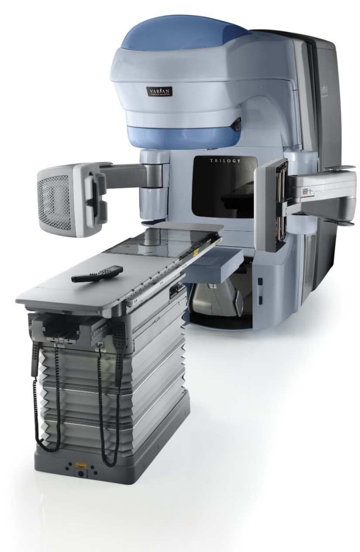
Varian *21EX*



Varian *21iX / Trilogy*

- Similar to the 21EX with On-Board Imaging
- *Robotic Arms* allow kV Cone-Beam CT, kV CT and Fluoroscopy





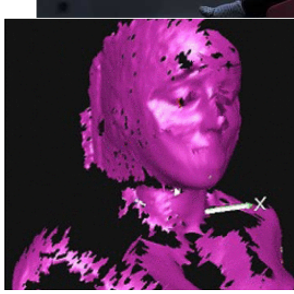
Varian *TrueBeam*

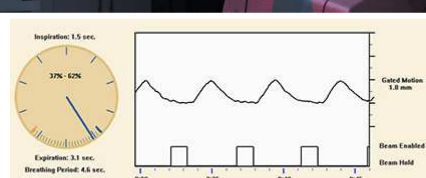
- Varian's First Digital Platform
- Three Photon Energies
- Advanced Imaging

Varian *TrueBeam*

Varian *TrueBeam*

Varian *TrueBeam*



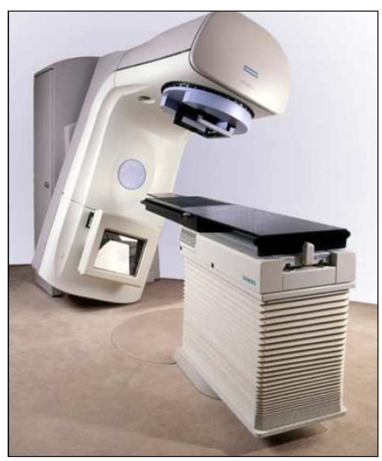


Varian *Financials*

Period Ending	9/30/2016	10/2/2015	9/26/2014
Net Income	**402,300**	**411,500**	**403,700**
Operating Activities, Cash Flows Provided By or Used In			
Depreciation	79,800	68,500	62,500
Adjustments To Net Income	31,300	54,200	70,800
Changes In Accounts Receivables	-168,300	-79,400	-74,500
Changes In Liabilities	30,500	64,100	33,100
Changes In Inventories	-27,700	-41,600	-43,300
Changes In Other Operating Activities	8,000	-8,200	-3,300
Total Cash Flow From Operating Activities	**356,300**	**469,600**	**449,000**
Investing Activities, Cash Flows Provided By or Used In			
Capital Expenditures	-80,400	-91,400	-89,600
Investments	-8,100	-24,900	-12,600
Other Cash flows from Investing Activities	-20,700	-94,600	-30,900
Total Cash Flows From Investing Activities	**-109,200**	**-210,900**	**-133,100**
Financing Activities, Cash Flows Provided By or Used In			
Dividends Paid	-	-	-
Sale Purchase of Stock	-411,700	-347,300	-536,800
Net Borrowings	167,100	58,600	-68,800
Other Cash Flows from Financing Activities	-5,100	-600	-800
Total Cash Flows From Financing Activities	**-245,800**	**-276,700**	**-595,500**
Effect Of Exchange Rate Changes	-3,300	14,200	11,000
Change In Cash and Cash Equivalents	**-2,000**	**-3,800**	**-268,600**

Siemens *Primus/Oncor*

- Fully Digital System
- Standing Wave Guide
- Klystron Driven
- 4 to 23 MV photons (2)
- 4 to 20 MeV Electrons (5)
- 100 to 600 MU/min
- 0.5 x 0.5 to 40.0 x 40.0-cm
- MLC
- Electronic Portal Imager



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Siemens *Artiste*

2D Mega-Voltage Portal Imaging
- Max Field of View: 40 cm

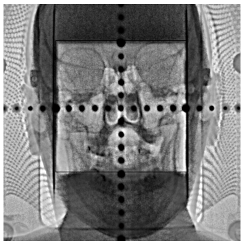
3D Mega-Voltage Cone Beam
- Extended FOV up to 27x40 cm

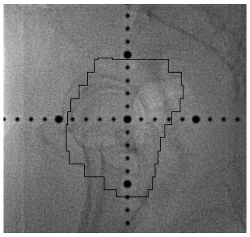
- The Artiste is Siemen's newest line of image-guided linear accelerator

Siemens *Artiste*

- The Artiste is Siemen's newest line of image-guided linear accelerator

2D Mega-Voltage Portal Imaging





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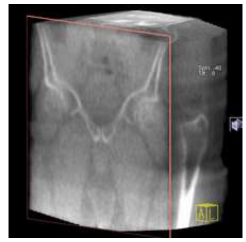
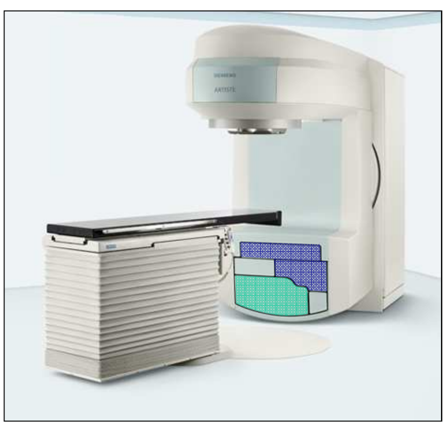
Siemens *Artiste*

- The Artiste is Siemen's newest line of image-guided linear accelerator

3D Mega-Voltage CBCT Imaging



Siemens *Artiste*

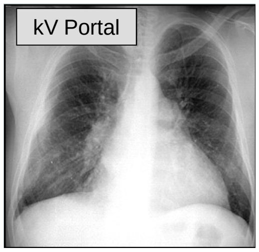


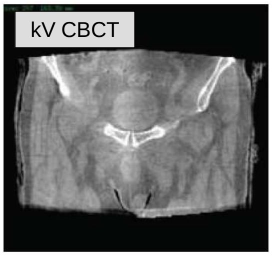
- The Artiste is Siemen's newest line of image-guided linear accelerator

2D Kilo-Voltage Portal Imaging
- Fluoroscopy prior to treatment
- Motion Verification

3D Kilo-Voltage Cone Beam Imaging
- Extended FOV: 28x50 cm

Siemens *Artiste*





- The Artiste is Siemen's newest line of image-guided linear accelerator

Siemens – *Radiotherapy*

Siemens to end linac sales

December 22, 2011
by Brendon Nafziger , DOTmed News Associate Editor

SIEMENS medical

Siemens Healthcare said it is leaving the linear accelerator business to concentrate on modalities with higher margins.

By the end of the year, Siemens will no longer sell new linacs. However, the company will still service and maintain its current install base. The company, whose headquarters is in Erlangen, Germany, makes the Artiste, Primus and Oncor systems.

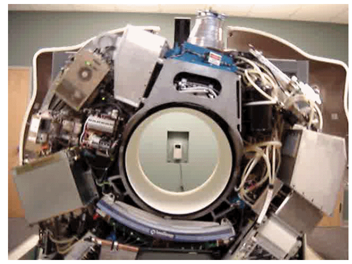
Leaving linacs

Kraemer said the decision to quit the linacs business comes out of a recently launched initiative, Agenda 2013, which looks to maintain profitability, in part, by focusing investments in areas the company believes are going to do well over the next two years, such as emerging markets, entry-level technology and next-generation IT architecture.

"We see cost pressure already today, but you don't have to be a wizard to see that cost pressure certainly will increase," Kraemer said.

With linacs, he said his company was faced with a choice: invest heavily in linacs to create a "leapfrog technology" that would put the firm in a leading position, or invest the same amount of money in something else to get better results. The company opted for the latter, he said.

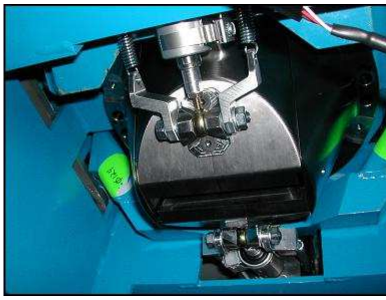
TomoTherapy *HI-ART*



TomoTherapy *HI-ART*

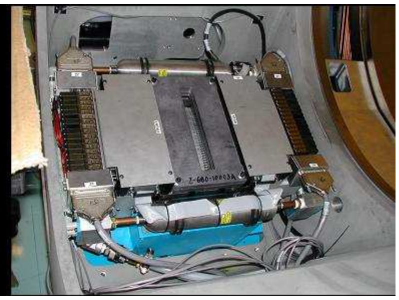
TomoTherapy *HI-ART*

TomoTherapy Primary Collimator



- Independent Primary Jaws in the Superior - Inferior Direction
- Symmetric or Asymmetric Slice Thickness Ranging from 6-mm to 5-cm

TomoTherapy MLC



- 64 Binary MLC leafs in the Lateral Direction (6.25-cm Width at Isocenter)
- 10-cm Thick Interspersed Tungsten leafs
- Divergent Design with Interlocking Tongue-and-Groove
- Less Than 25 msec Transit Time

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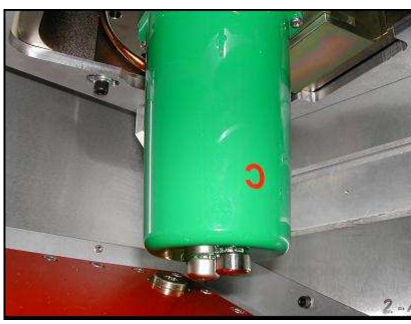
TomoTherapy *HI-ART*

EV2 (English Electric) Magnetron



- 3 MW Peak Output Power
- Energy Changed by Adjusting Magnetron Current from 105 Amps to 75 Amps and changing the Magnetron Magnet Current

Solid State Modulator (SSM)

- Solid State Technology replaces Conventional Line Modulator
- 50 to 60 kV High Voltage Pulses to the Magnetron

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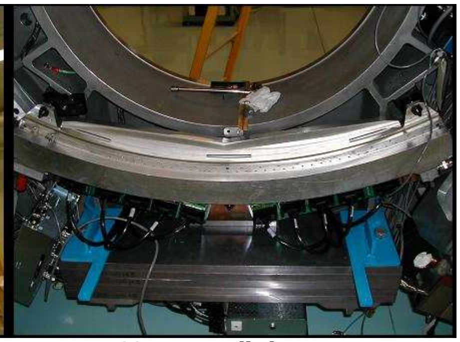
TomoTherapy *HI-ART*

Siemens 6 MV Linear Accelerator

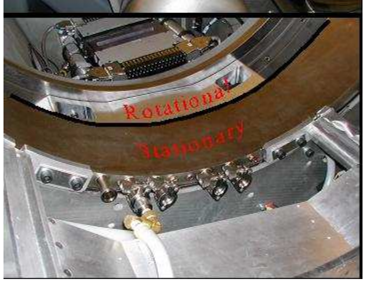
- Treatment Nominal Acceleration Potential: 3.6 MV (6 MV Max)
- MVCT Nominal Acceleration Potential: 2.6 MV (6 MV Max)

Xenon CT Detector Array



- 738 Xenon Filled Detectors
- 0.73 mm Width at Isocenter
- 35-cm Max Field of View
- 1mm^3 Resolution
-

TomoTherapy *HI-ART*



- Rotational Water and Air Cooling System
- Rotating Close Loop Water System Mounted on the Backside of the Gantry
- Cooling Water is Passed through Heat Exchanger
- Heat is Dumped into the Air through Cooling Fans
- Chilled Air (62 Degrees F) is Blown into the Base of the Gantry
- Warm Air is Blow out the Top of the Gantry with Fans

TomoTherapy goes Public

TomoTherapy IPO opens at $24 a share

By -
May 9, 2007, 8:54am CDT **Updated** May 9, 2007, 3:29pm CDT

An initial public offering of shares of TomoTherapy Inc., a Madison developer of targeted radiation treatment systems, jumped more than 26 percent higher than its proposed $19 per share pricing at the open of trading Wednesday.

Shares of TomoTherapy opened on the Nasdaq National Market at $24 a share and hit an early high of $24.73. Shares were priced Tuesday at $19 per share in filings with the U.S. Securities and Exchange Commission, higher than the $15 to $17 price set in earlier filings.

Shares closed at $22.67 Wednesday on volume of 10.67 million shares.

TomoTherapy's shares trade under the symbol TTPY. The company has registered to sell 10.6 million shares of stock at $19 per share. Other shareholders will sell 1.14 million shares.

TomoTherapy Inc. expects to receive net proceeds from the offering of approximately $185 million, the firm said in a press release late Tuesday.

Accuray to buy TomoTherapy for about $277 million

Reuters Staff

1 MIN READ

(Reuters) - Accuray Inc (ARAY.O) said it will acquire TomoTherapy Inc TOMO.O, a smaller rival in the radiation therapy system market, for about $277 million in a cash and stock deal.

TomoTherapy shareholders will get $4.80 per share, a premium of about 31 percent to the stock's closing price on Friday.

The deal comprises $3.15 per share in cash and 0.1648 share of Accuray common stock for each TomoTherapy share.

The companies expect the deal, approved by both the boards, to close in the second quarter or the beginning of the third quarter of 2011.

The combined revenue of the companies in 2010 exceeded $400 million, they said.

Accuray sees the acquisition to add to its earnings per share beginning July 1, 2012.

Accuray *Models*

The TomoHDA™ System offers the ultimate flexibility in treatment delivery, enabling unrivaled dose conformality, faster treatments and faster concurrent treatment planning.

TomoEDGE™ spares more normal tissue while enabling increased throughput and unprecedented quality. It can help practices expand by providing efficient care to patients with difficult-to-treat tumors that are outside the capability of conventional radiation therapy systems.

The TomoHD™ System combines both TomoHelical™ and TomoDirect™ into a single, comprehensive solution that efficiently handles clinical indications of any complexity with ease. This integrated solution enables accurate and efficient treatment of tumors anywhere in the body.

The TomoH™ System is the gold standard for image-guided IMRT treatment delivery – it maximizes both conformality and target dose uniformity. CTrue™ image guidance provides daily 3D CT target localization and enables margin reduction while sparing healthy tissue. The ultra-fast, binary MLC enables unprecedented intensity modulation.

All are variants of the original HI-ART System

Accuray *Radixact*

More efficient.
Treat more patients.

More effective.
Deliver more precise treatments.

More versatile.
Expand your clinical capabilities – treat every patient, from the routine to the most complex.

Accuray *Financials*

Cash Flow All numbers in thousands

Period Ending	6/30/2017	6/30/2016	6/30/2015
Net Income	**-29,579**	**-25,504**	**-40,209**
Operating Activities, Cash Flows Provided By or Used In			
Depreciation	25,947	27,146	29,255
Adjustments To Net Income	15,741	15,923	16,149
Changes In Accounts Receivables	-15,732	16,994	-7,172
Changes In Liabilities	-3,316	5,400	-197
Changes In Inventories	7,675	-10,502	-21,094
Changes In Other Operating Activities	-1,116	1,468	8,859
Total Cash Flow From Operating Activities	**-380**	**30,925**	**-14,409**
Investing Activities, Cash Flows Provided By or Used In			
Capital Expenditures	-5,031	-8,066	-10,445
Investments	23,187	16,328	14,134
Other Cash flows from Investing Activities	-333	-333	-333
Total Cash Flows From Investing Activities	**17,823**	**8,262**	**3,689**
Financing Activities, Cash Flows Provided By or Used In			
Dividends Paid	-	-	-
Sale Purchase of Stock	3,786	3,849	6,555
Net Borrowings	-56,905	-1,774	-1,774
Other Cash Flows from Financing Activities	-1,419	-2,832	-660
Total Cash Flows From Financing Activities	**-54,538**	**-757**	**5,895**
Effect Of Exchange Rate Changes	197	-1,006	-5,757
Change In Cash and Cash Equivalents	**-36,898**	**37,424**	**-10,582**

Accuray *Financials*

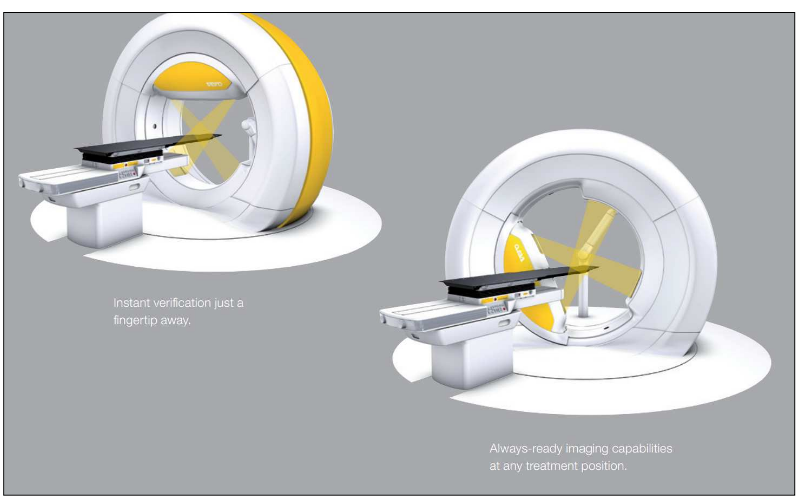
4.10 -0.05 (-1.20%)

As of 12:05PM EDT. Market open.

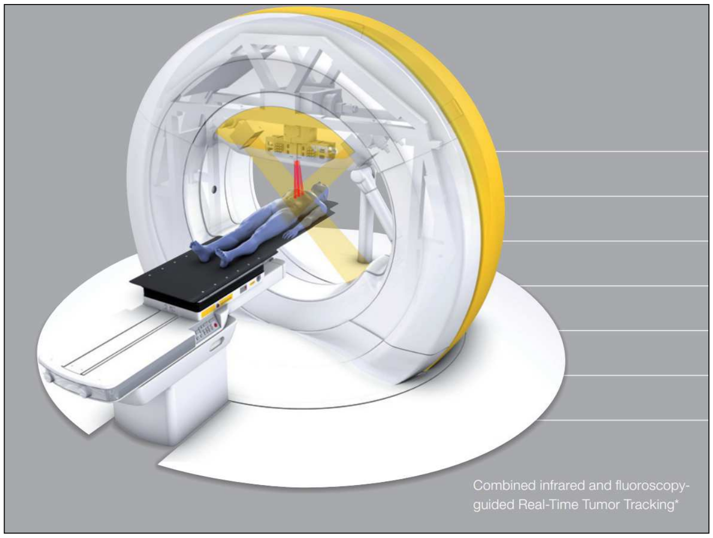
Summary | Conversations | Statistics | Profile | Financials | Options | Holders | Historical Data | Analysts

Previous Close	4.15	Market Cap	343.36M
Open	4.15	Beta	2.12
Bid	4.10 x 8400	PE Ratio (TTM)	-11.42
Ask	4.15 x 8100	EPS (TTM)	-0.36
Day's Range	4.10 - 4.20	Earnings Date	Oct 25, 2017 - Oct 30, 2017
52 Week Range	3.60 - 6.39	Dividend & Yield	N/A (N/A)
Volume	105,558	Ex-Dividend Date	N/A
Avg. Volume	476,380	1y Target Est	6.66

BrainLab Vero



BrainLab Vero



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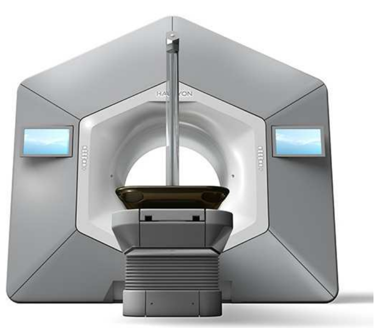
Varian *Halcyon*



Gantry: linear-drive ring motor with 100-cm bore

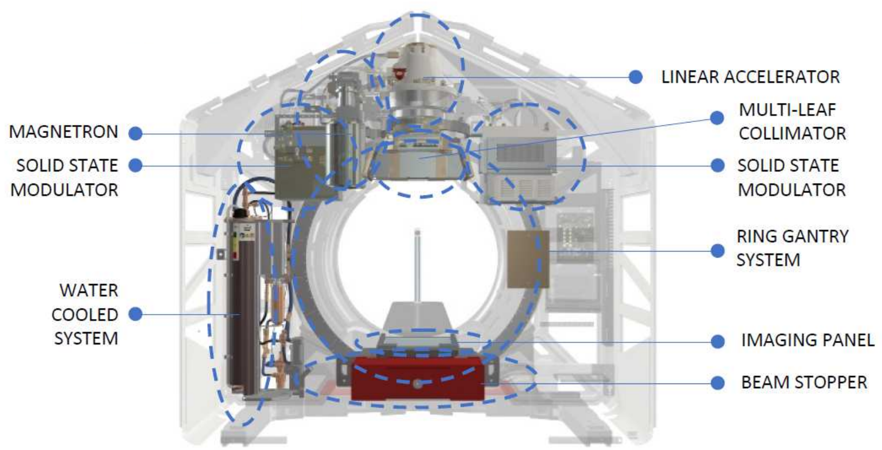
Stand: Small footprint, no modulator cabinet, and built-in beam stopper

Beam: 6-MV FFF @ 800 cGy/min

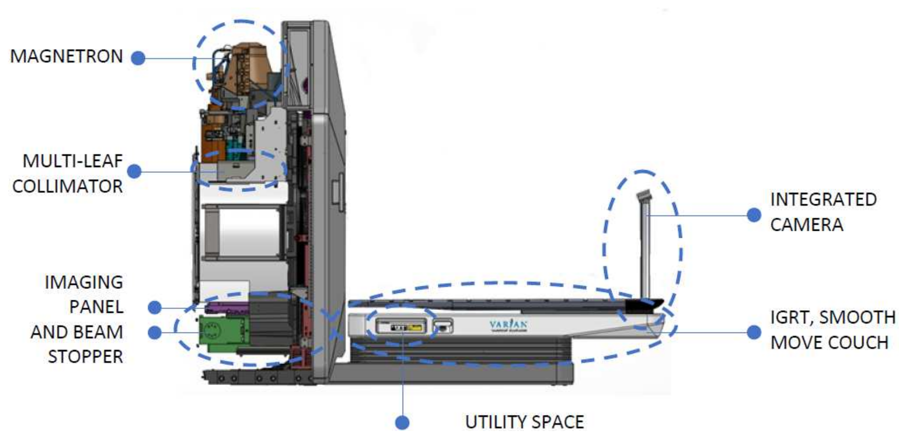
Collimation: New patented dual-layer MLC

Imaging: 100% IGRT with 15 second MV CBCT

Varian *Halcyon*



Varian *Halcyon*



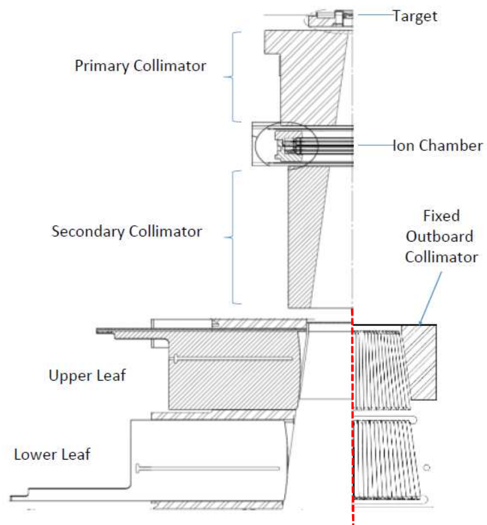
Varian *Halcyon*

<u>Multileaf Collimator</u>

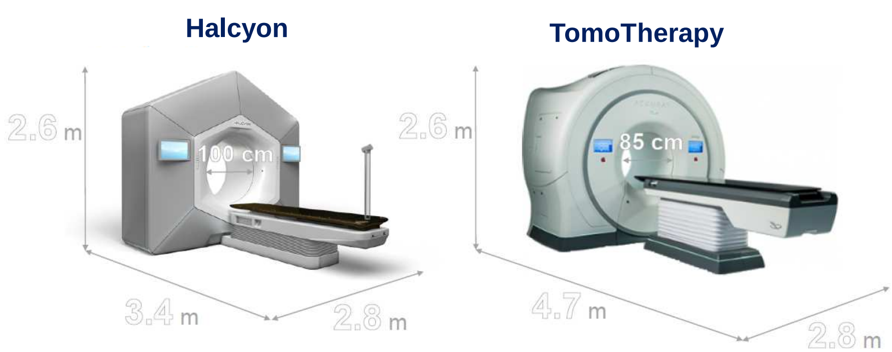
- No jaws, large clearance
- Staggered upper/lower leaves
- 16 cm of tungsten in leaves
- 100% overtravel
- Low Transmission (0.01%)

<u>Imaging System</u>

- 43 cm x 43 cm high-efficiency MV panel
- 7 seconds acquisition for MV/MV pair: 28 x 28 cm (max)
- 15 seconds acquisition for MV CBCT: 26 x 26 cm length (max)

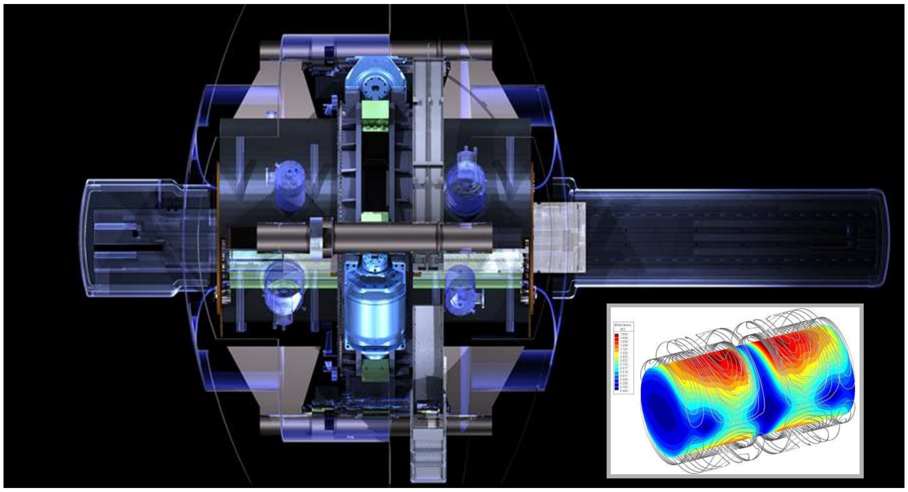


Varian *Halcyon*

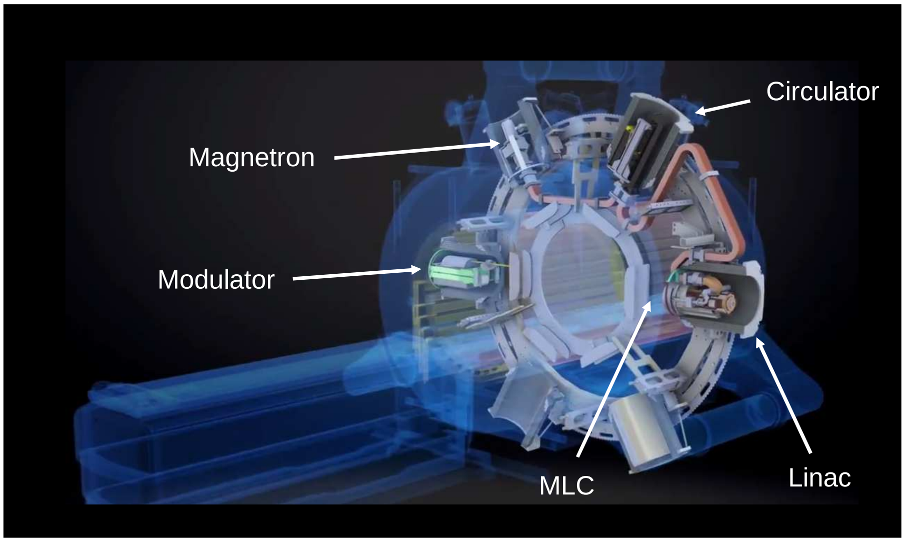


ViewRay

ViewRay – Cobalt System



ViewRay – Linac System



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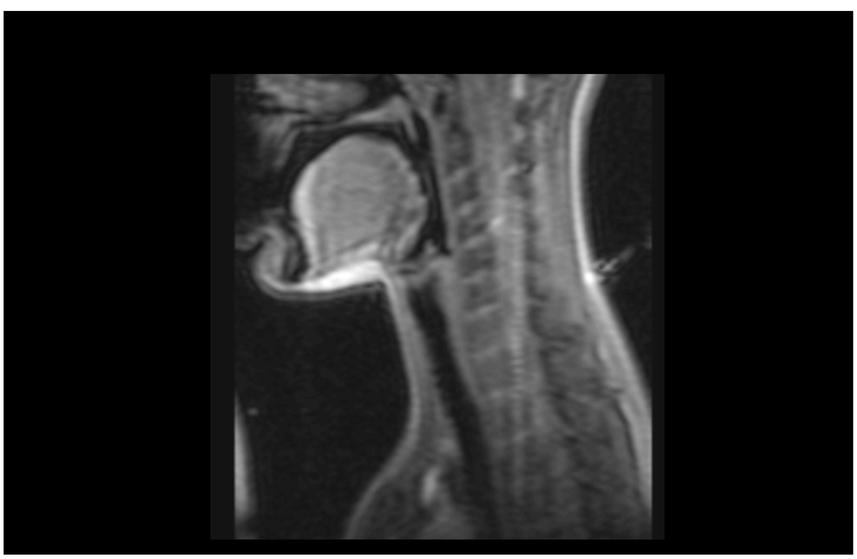
ViewRay -Imaging



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ViewRay

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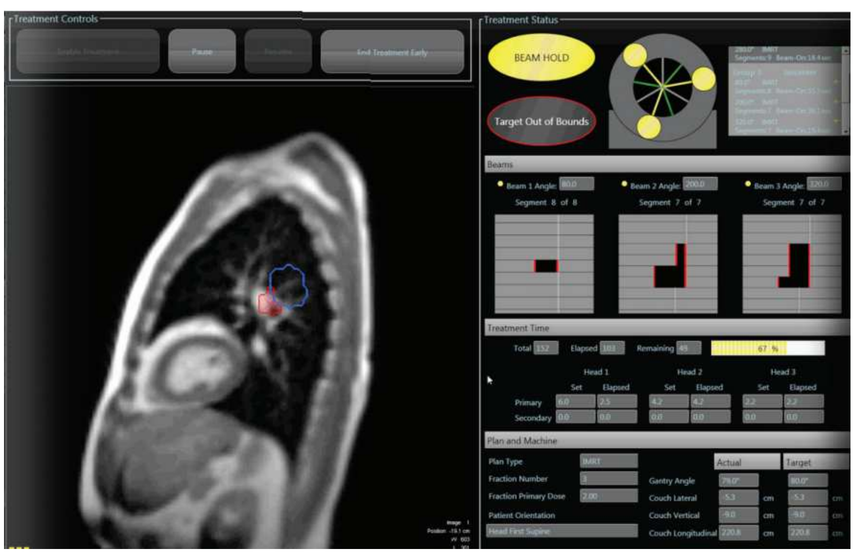
ViewRay



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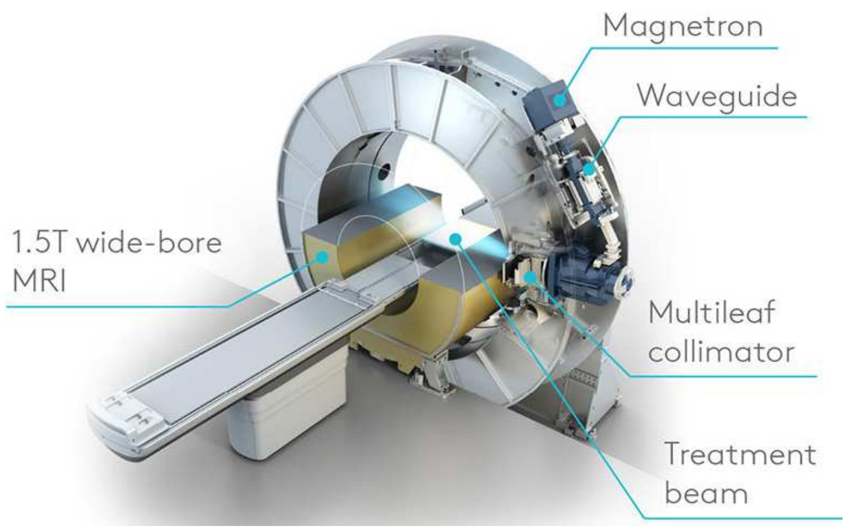
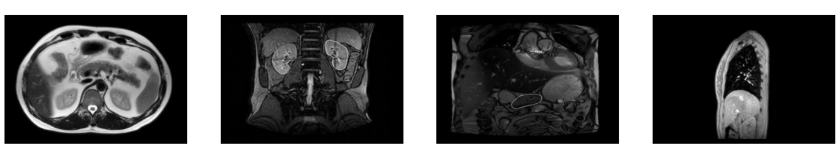
Elekta - *Unity*



Elekta - *Unity*



ViewRay - *Financials*

Cash Flow All numbers in thousands

Period Ending	12/31/2016	12/31/2015	12/31/2014
Net Income	**-50,636**	**-44,995**	**-33,800**
Operating Activities, Cash Flows Provided By or Used In			
Depreciation	4,373	2,393	1,466
Adjustments To Net Income	5,201	6,531	904
Changes In Accounts Receivables	-3,370	74	-650
Changes In Liabilities	13,687	4,502	13,040
Changes In Inventories	-2,065	-2,413	-3,279
Changes In Other Operating Activities	4,654	-5,941	-5,150
Total Cash Flow From Operating Activities	**-28,156**	**-39,849**	**-27,469**
Investing Activities, Cash Flows Provided By or Used In			
Capital Expenditures	-7,031	-4,151	-2,003
Investments	-	-	-
Other Cash flows from Investing Activities	-212	6	-600
Total Cash Flows From Investing Activities	**-7,243**	**-4,145**	**-2,603**
Financing Activities, Cash Flows Provided By or Used In			
Dividends Paid	-	-	-
Sale Purchase of Stock	13,948	39,664	4,731
Net Borrowings	15,000	15,000	9,941
Other Cash Flows from Financing Activities	-	-	-
Total Cash Flows From Financing Activities	**28,930**	**53,532**	**14,672**
Effect Of Exchange Rate Changes	-	-	-
Change In Cash and Cash Equivalents	**-6,469**	**9,538**	**-15,400**

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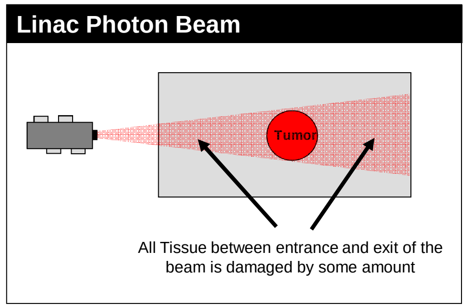
Proton Therapy

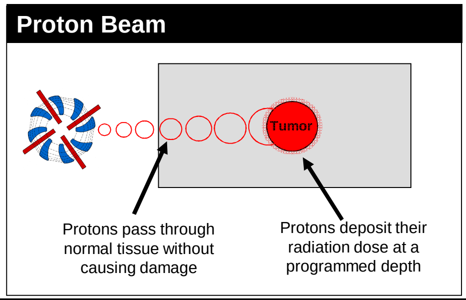
- Proton beam therapy is a form of external beam radiotherapy that uses proton ions instead of photons or electrons
- Protons are simply a hydrogen atom with the electron removed
- However, protons have a mass that is 1,836 times larger than the electrons that are accelerated in conventional radiation therapy linacs
- As such, the equipment used to generate proton treatment beams is much larger and vastly more expensive than conventional linear accelerators

A single proton treatment gantry weighs 150 tons and is eleven meters (36 ft) in diameter

Clinical Rational

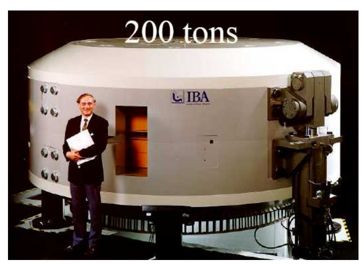
- Proton therapy surpasses intensity modulated radiation therapy (IMRT) and stereotactic radiosurgery (SRS)
- Photons and electrons produced by linacs cause damage to tissue between the entrance and the exit of the beam
- In contrast, protons will pass through normal tissue without cause damage until the proton reaches a programmed depth
- Like a depth charge, the proton “explodes” at the programmed depth of the tumor
- This means that normal tissue in front and behind the tumor receive little to no radiation damage

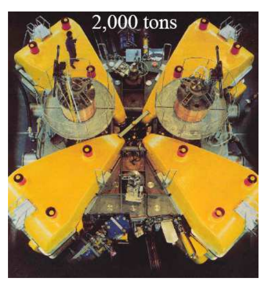




Cyclotrons

- A cyclotron has constant magnetic field magnitude and constant rf frequency
- Beam energy is limited by relativistic effects, which destroy synchronization between particle orbits and rf fields
- Therefore, the cyclotron is useful only for ion acceleration
- The virtue of cyclotrons is that they generate a continuous train of beam micropulses
- Cyclotrons are characterized by large-area magnetic fields to confine ions from zero energy to the output energy





Cyclotrons

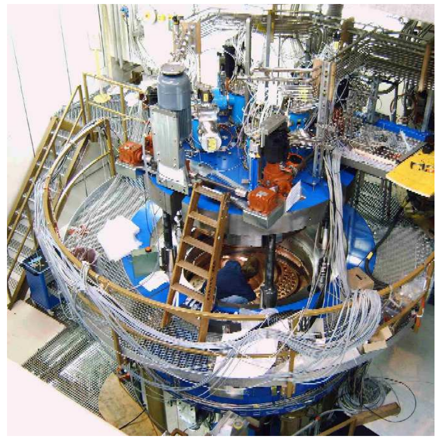
- Superconducting cyclotrons have shaped iron magnet poles that utilize focusing techniques
- The magnetizing force is supplied by superconducting coils, which consume little power
- Superconducting cyclotrons are typically compact machines because they are operated at high fields, well above the saturation level of the iron poles
- In this situation, all the magnetic dipoles in the poles are aligned; the net fields can be predicted accurately

Cyclotrons

- The 3m diameter Cyclotron has been optimized for beam delivery with pencil scanning
- The system produces a DC beam with a 100% duty factor for scanning
- The system uses a deflector plate at cyclotron center to rapidly turn the proton beam on and off
- The intensity of the beam can be modulated in the order of 100 ms time scale

Cyclotrons

- The system uses and internal ion source (*PIG*) that contains hydrogen gas
- A pill-box design is used that allows fast and easy access by automatic jacking system of the pole caps.
- Low temperature superconducting coils are enclosed in cryostat, with all other parts warm
- Trim rods are located at two radii for beam centering and excitation of precession for extraction
- The system uses four Dees (D-shaped metal structures)



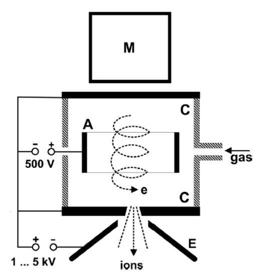
Cyclotrons

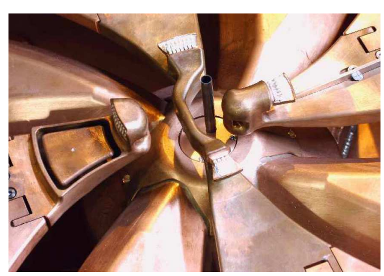
Beam Energy	250 MeV
Extracted Current	500 nA
Momentum spread	± 0.2%
Number of turns	650
Extraction efficiency	> 80%
Intensity modulation	> 10% in 100 µs
Outer diameter	3.1 m
Height	1.6 m
Weight	90 t
RF Frequency	72.8 MHz
RF Power	120 kW

Cyclotrons

Internal Ion Source

- A Penning Ion Generator (*PIG*) is a high-voltage, low pressure ($\geq 10^{-4}$ *Torr)* glow discharge
- Electrons oscillation between two cathodes (C) inside an anode tube (A)
- The plasma ions are extracted through a cathode boring or anode-tube slit
- The advantages of the PIG design is that it is compact in design and reliable in operation,
- However, the system has low energy and gas efficiencies and is susceptible to cathode sputtering





Synchrocyclotron

- The synchrocyclotron is a precursor of the synchrotron, and represents an early effort to extend the kinetic energy limits of cyclotrons
- Synchrocyclotrons have a constant magnetic field with geometry similar to the uniform-field cyclotron
- The main difference is that the rf frequency is varied to maintain particle synchronization into the relativistic regime
- Synchrocyclotrons are cyclic machines with a greatly reduced time-averaged output flux compared to a cyclotron

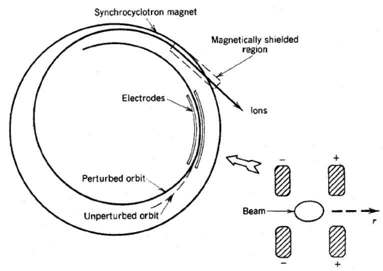
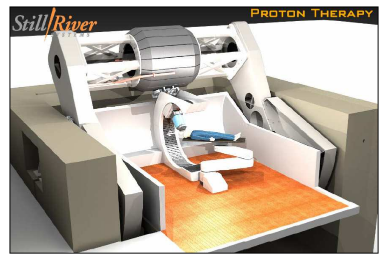
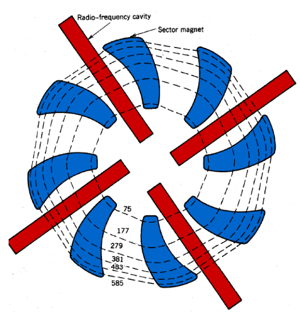


Figure 15.11 Beam extraction from a synchrocyclotron by a pulsed radial electric field.



Synchrotron

- Synchrotrons are the present standard accelerators for particle physics research, but are rarely used in radiation therapy
- Both the magnitude of the magnetic field and the rf frequency are varied to maintain a synchronous particle at a constant orbit radius
- The constant-radius feature is very important; bending and focusing fields need extend over only a small ring-shaped volume which minimizes the cost of magnets



Energy Selection System (ESS)

- The Cyclotron produces a fixed proton energy of 250 MeV
- The Energy Selection System is used to change the energy of the proton beams, which controls the depth at which the protons will release their energy in the patient

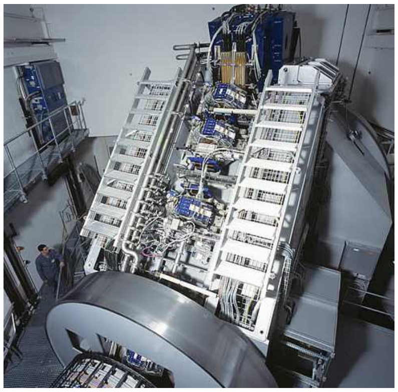
Proton Beamline

- Proton facilities like require long beamlines between the individual therapy stations
- The beam is guided through vacuum tubes to the therapy site using magnetic lenses to continually focus the beam (*otherwise the protons would disperse*)
- The following box-shaped device is a magnet that constitutes a beam switch: it can direct the beam left to the first gantry

Two magnets colored in blue and beige are located downstream and they act as a magnetic lens

Proton Gantry (Backside)

- The gantry is a steel structure weighing 150 tons, measuring eleven meters in diameter that can be rotated 360° about its horizontal axis
- The protons enters the gantry and are deflected upwards by bending magnets and then returned vertically into the axis of rotation
- Because the gantry can rotate about its own axis, the patient and tumor can be irradiated from all directions



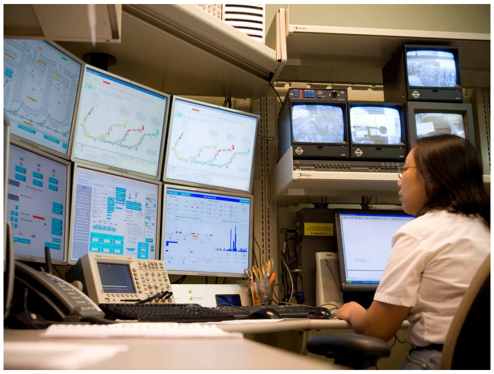
Treatment Nozzle

- The nozzle is the device connected to the end of the tube emitting the beam of protons and used to deliver protons to the patient
- The nozzle is mounted near to the patient so that the proton beam can be transported in the vacuum without scatter for as long as possible
- The nozzle contains two small pairs of bending magnets that deflect the beam in two dimensions, in one direction away from the gantry axis and in the other in parallel to the gantry axis
- This provides targeting with the scanning system in two of the three dimensions

Cyclotron Operations

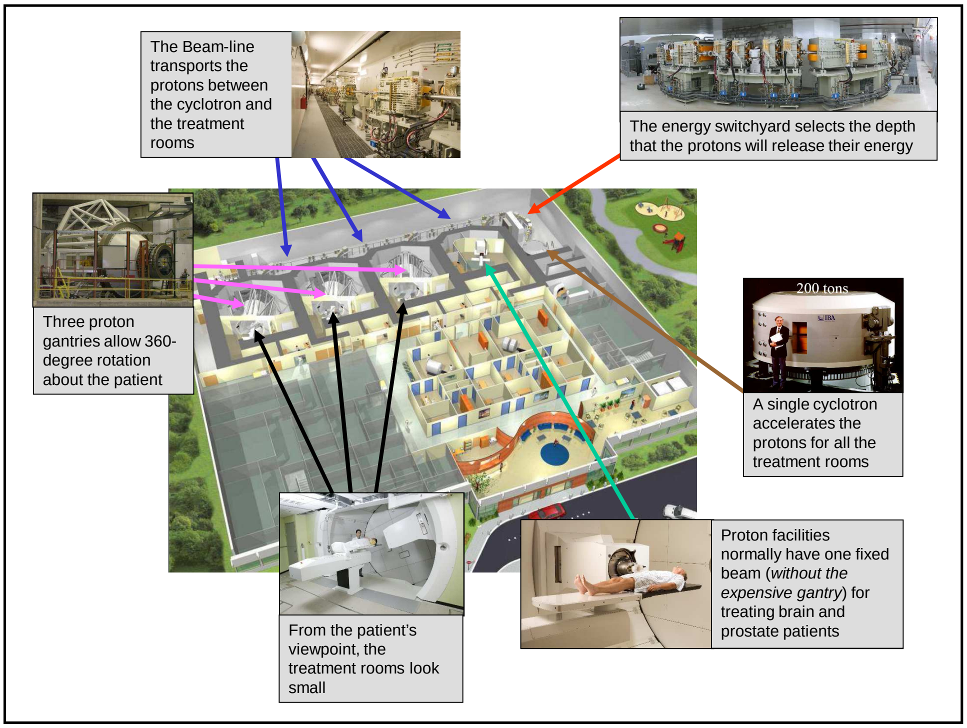
Cyclotron Operations

- Proton beam therapy centers require a team of up to 20 physicists and engineers to maintain the system's cyclotron
- There are typically 30+ therapists that treat patients from 6-am to 11-pm
- The cyclotron is controlled 24 hours per day by this team in a central control room
- Annual operating costs for a proton beam therapy facility exceeded $14 million



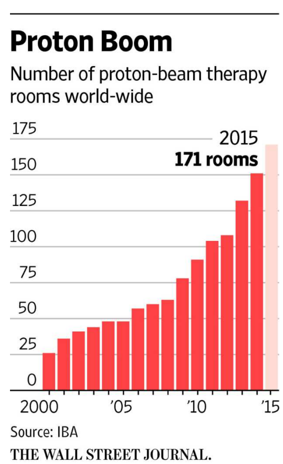
Patient Volumes

- Since U.S. hospitals first opened proton beam therapy centers in 1990, demand has ballooned, creating three-month-long wait lists for patients who travel regionally and even nationally for the treatment
- While reimbursement is currently favorable Medicare reimburses approximately $21,500 per case, and private insurer rates begin at about $36,000 per case future rates may not be as generous



Proton Therapy Market (1995-2013)

- As cost drops, many health systems are taking a second look at proton therapy
- Several factors have historically made providers hesitant to invest in proton therapy
  1. There is a lack of randomized controlled trials that have shown that proton therapy improves patient outcomes
  2. The equipment used for proton therapy initially carried a price tag of between $120 and $200 million
- However, many facilities are struggling because they don't offer protons as part of a wider spectrum of cancer treatments



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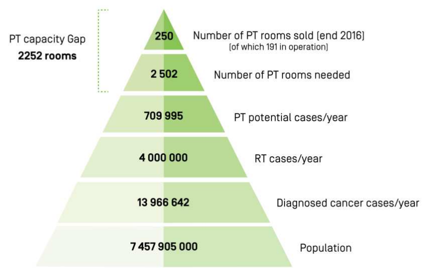
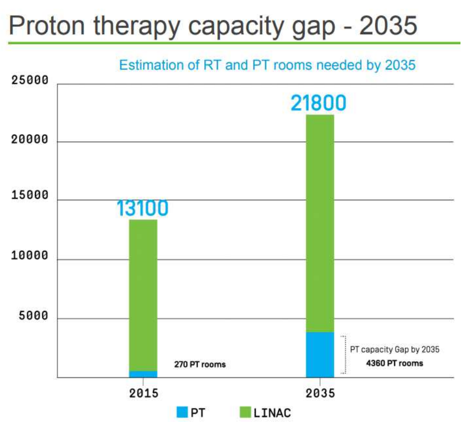
Proton Therapy Market (2015-2035)





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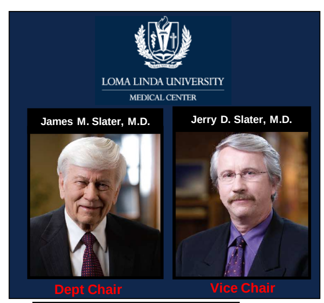
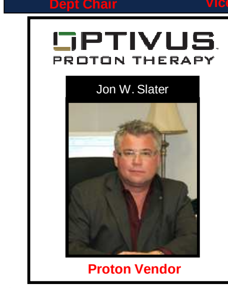
Optivus Proton Therapy

- James M. Slater, MD first became the Chair of the Radiation Oncology Department at Loma Linda University Medical Center (LLUMC) in 1970
- Jerry D. Slater, MD was recruited by his father in 1987 to become Vice-Chair of the Loma Linda Radiation Oncology Department
- In 1988, James M. Slater made a formal proposal to the Loma Linda Board of Directors in 1988 to develop the world's first hospital-based proton therapy center in conjunction with Fermilab
- Congress appropriated $8.5 million for the facility and, in another session, granted an additional $11.1 million through the Department of Energy.
- Engineers from Fermilab began designing the proton therapy system, including James M. Slater's son Jon W. Slater
- Jon W. Slater and David Nusbaum created Optivus Proton Therapy, Inc., that supplied Loma Linda with its proton therapy system





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Optivus Proton Therapy

- In April 1988, ground was broken on the campus of Loma Linda University Medical Center for the proton facility, and the first patient was treated in 1990
- In 2001, Jerry D. Slater succeeded his father and became the Department Chairs of the Radiation Oncology Department, while James M. Slater became the Vice Chair
- In 2008, the Loma Linda Proton Center was renamed the James M. Slater Proton Center
- For over 20 years, the proton center was directed and managed by James and Jerry Slater, while Jon Slater's Optivus was the exclusive proton equipment vendor and service provider

OPTIVUS
PROTON THERAPY

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Optivus Proton Therapy

- Optivus' proton therapy platform was the first proton system to receive FDA approval (1990)
- By virtue of Optivus' long tenure at Loma Linda, Optivus has accumulated lengthy experience in designing, building, and operating proton beam technology
- Optivus has also pioneered image-guided and intensity modulated proton therapy, although the latter has not yet been used in daily clinical practice
- Despite its experience at Loma Linda and continued innovation, however, Optivus remains a single-site vendor
- No other facility has yet installed or publicly signed on its equipment
- So what's the solution if you can't get anyone to buy your equipment after 20 years…

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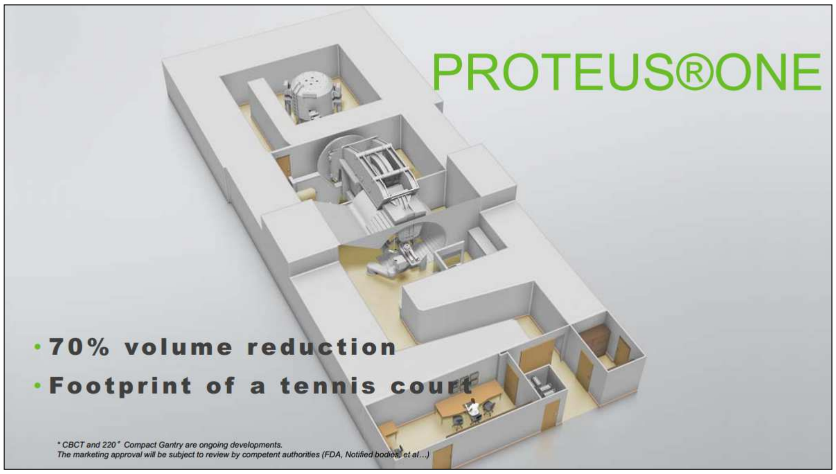
IBA Proteus One



IBA Proteus One

Cost < $25 Million

- First US install at Willis Knighton Cancer Center
- FDA Approved July 2014
- Installed and Accepted Sept 2014
- The first patient received Image Guided Intensity Modulated Proton Therapy (IMPT) treatment on September 9th, 2014
- In 2014 and 2015, a total of 66 contracts for new treatment rooms
- Imaging with Cone Beam CT or orthogonal imaging

IBA - *Financials*

Cash Flow All numbers in thousands

Period Ending	12/31/2016	1/1/2016	12/31/2014	12/31/2013
Net Income	**24,000**	**61,000**	**24,000**	**-1,000**
Operating Activities, Cash Flows Provided By or Used In				
Depreciation	3,000	2,000	2,000	2,000
Adjustments To Net Income	-	-	-	-
Changes In Accounts Receivables	-10,000	-9,000	-1,000	-13,000
Changes In Liabilities	-	-	-	-
Changes In Inventories	-53,000	15,000	-11,000	22,000
Changes In Other Operating Activities	-1,000	-37,000	-7,000	-13,000
Total Cash Flow From Operating Activities	**-17,000**	**45,000**	**15,000**	**7,000**
Investing Activities, Cash Flows Provided By or Used In				
Capital Expenditures	-9,000	-2,000	-3,000	-2,000
Investments	-	-	-	-
Other Cash flows from Investing Activities	-	-	-	-
Total Cash Flows From Investing Activities	**48,000**	**6,000**	**2,000**	**6,000**
Financing Activities, Cash Flows Provided By or Used In				
Dividends Paid	-	-	-	-
Sale Purchase of Stock	-	-	-	-
Net Borrowings	-	-	-	-
Other Cash Flows from Financing Activities	59,000	1,000	2,000	-7,000
Total Cash Flows From Financing Activities	**-39,000**	**-6,000**	**-8,000**	**-28,000**
Effect Of Exchange Rate Changes	-	-1,000	-1,000	-1,000
Change In Cash and Cash Equivalents	**-7,000**	**45,000**	**8,000**	**-17,000**

1 EUR = 1.2 USD

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IBA - *Financials*

$33.65

28.04 -0.11 (-0.39%)

At close: 5:35PM CEST

Summary | Conversations | Statistics | Profile | Financials | Options | Holders | Historical Data | Analysts

Previous Close	28.15	Market Cap	818.93M
Open	28.53	Beta	0.27
Bid	39.60 x 15000	PE Ratio (TTM)	71.53
Ask	40.00 x 39500	EPS (TTM)	0.39
Day's Range	27.60 - 28.53	Earnings Date	N/A
52 Week Range	19.80 - 56.94	Dividend & Yield	0.00 (0.00%)
Volume	138,217	Ex-Dividend Date	2016-05-13
Avg. Volume	205,152	1y Target Est	35.48

1 EUR = 1.2 USD

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IBA - *Financials*

UPDATE 3-IBA shares dive as Belgian proton therapy group flags slower growth

Reuters Staff 4 MIN READ

* Cuts sales and margin outlook for 2018 and 2019

* Blames project delays and increased competition

* Shares lose a third of their value (Adds CFO comments)

By Alan Charlish

Aug 24 (Reuters) - Belgian proton therapy specialist Ion Beam Applications (IBA) lost a third of its $1 billion market value on Thursday as it cut revenue and margin guidance for 2018 and 2019, blaming project delays and increased competition.

IBA - *Financials*

Million USD	Elekta	Varian	Siemens	Accuray	ViewRay	IBA
Market Cap	4290	9820	N/A	385	349	829
Annual Revenue	1400	3200	N/A	141	22	394
Total Assets	2700	2600	N/A	406	49	457
Current Liabilities	1800	1600	N/A	360	92	276
Cash Flow	236	356	N/A	-0.3	-28	-20

Mevion S250

- Founded in 2004, Mevion is a closely held private company headquartered in the Boston metropolitan area
- Super-compact 20 ton synchrocyclotron mounted on gantry (*compared to > 200 tons for conventional cyclotron*)

Mevion S250

- First unit delivered to Siteman Cancer Center in St Louis in October 2011
- FDA approved in June 2012
- First patient treatment in 2013
- Pencil Beam in 2017
- 6 Sites Operational
- 3 Site Under Installation
- 21 Purchase Contracts

Cost < $20 Million

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Protom International

Radiance 330

- Private Company Founded in 2008
- First system installed McLaren Health in Flint, MI, starting in 2010
- Scheduled to open in 2012
- Synchrotron based system delivered in 2014
- FDA approved in March 2014
- Acceptable testing started in Nov 2014

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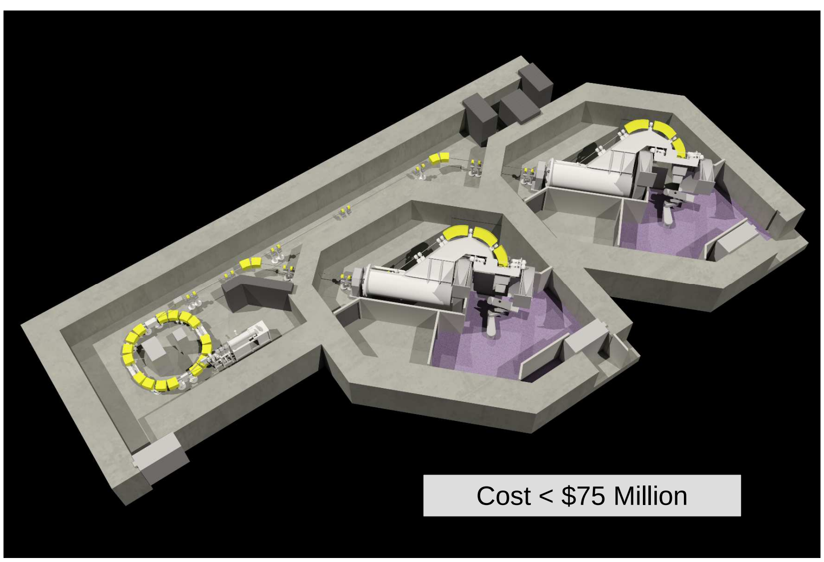
Protom International



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Protom International

ProTom files for bankruptcy protection
By AuntMinnie.com staff writers

June 4, 2015 -- Proton therapy developer ProTom International has filed for bankruptcy protection in a U.S. court, according to an article in Dow Jones' *Daily Bankruptcy Review*.

ProTom will be auctioned off on July 21, after filing a bankruptcy petition on May 12. The firm was trying to finish its first proton therapy project, for McLaren Health Care in Michigan, when it made the filing, according to the article.

ProTom markets the Radiance 330 proton therapy system.

BANKRUPTCY
ProTom Defers Auction After Drawing Only One Bid
Katy Stech
Updated July 27, 2015 5:35 p.m. ET

Motion for Asset Sale Approved for ProTom International, Inc.
Aug 24 15

The US Bankruptcy Court approved the sale of substantially all the assets of ProTom International, Inc. on August 24, 2015. As per the order, debtor has been authorized to sell substantially all its assets to Michaelson Capital Special Finance Fund, LP for the purchase consideration of $10.18 million of credit bid, $2 million in cash, aggregate cure payment of $2.03 million, assumption of certain liabilities and series A preferred amount, as per the agreement dated August 20, 2015. Buyer will pay aggregate cure amount excess of $0.47 million to the debtor upon closing. Under the series A preferred amount, buyer will either pay $1 million in cash or will pay common stock of the entity formed by the acquisition of assets of the debtor. Michael Venditto of Reed Smith LLP acted as legal counsel for the buyer.

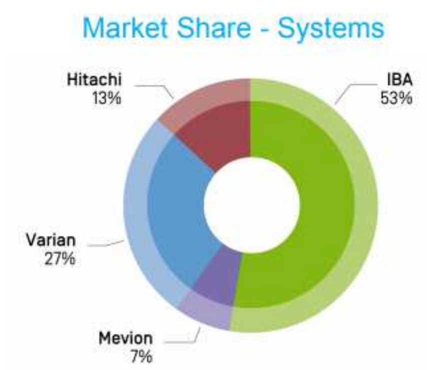
ProNova Solutions

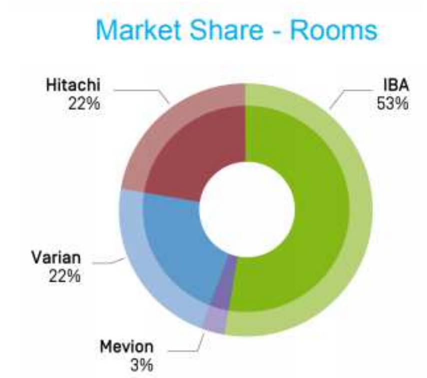
SC360

- Company Founded in 2012
  - *1st Est Treatments in 2015*
- Installation of 1st Gantry begins in Knoxville in Sept 2013
- Sumitomo Heavy Industries Cyclotron Delivered in Sept 2014
- New Factory Opened in June 2015
- Layoffs in Nov 2015
  - *FDA Approved Dec 2016*
  - *No Patients Treated*
  - *No Systems Sold outside of ProVision*

Cost < $50-75 Million

Proton Therapy Orders - 2016





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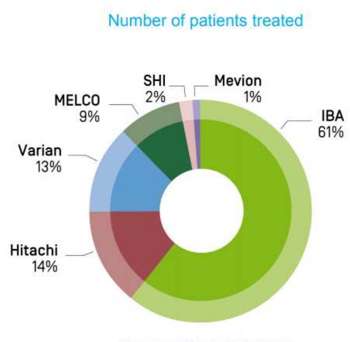
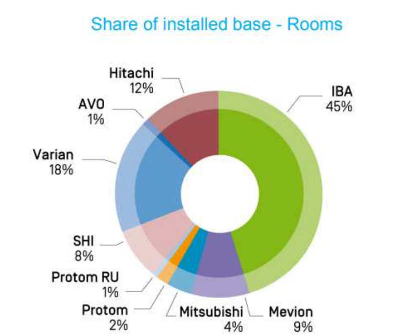
Proton Therapy Treatments- 2016





Total accumulated: 250 rooms

Including commercial PT rooms at end 2016

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Questions

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