Beam-Line Components

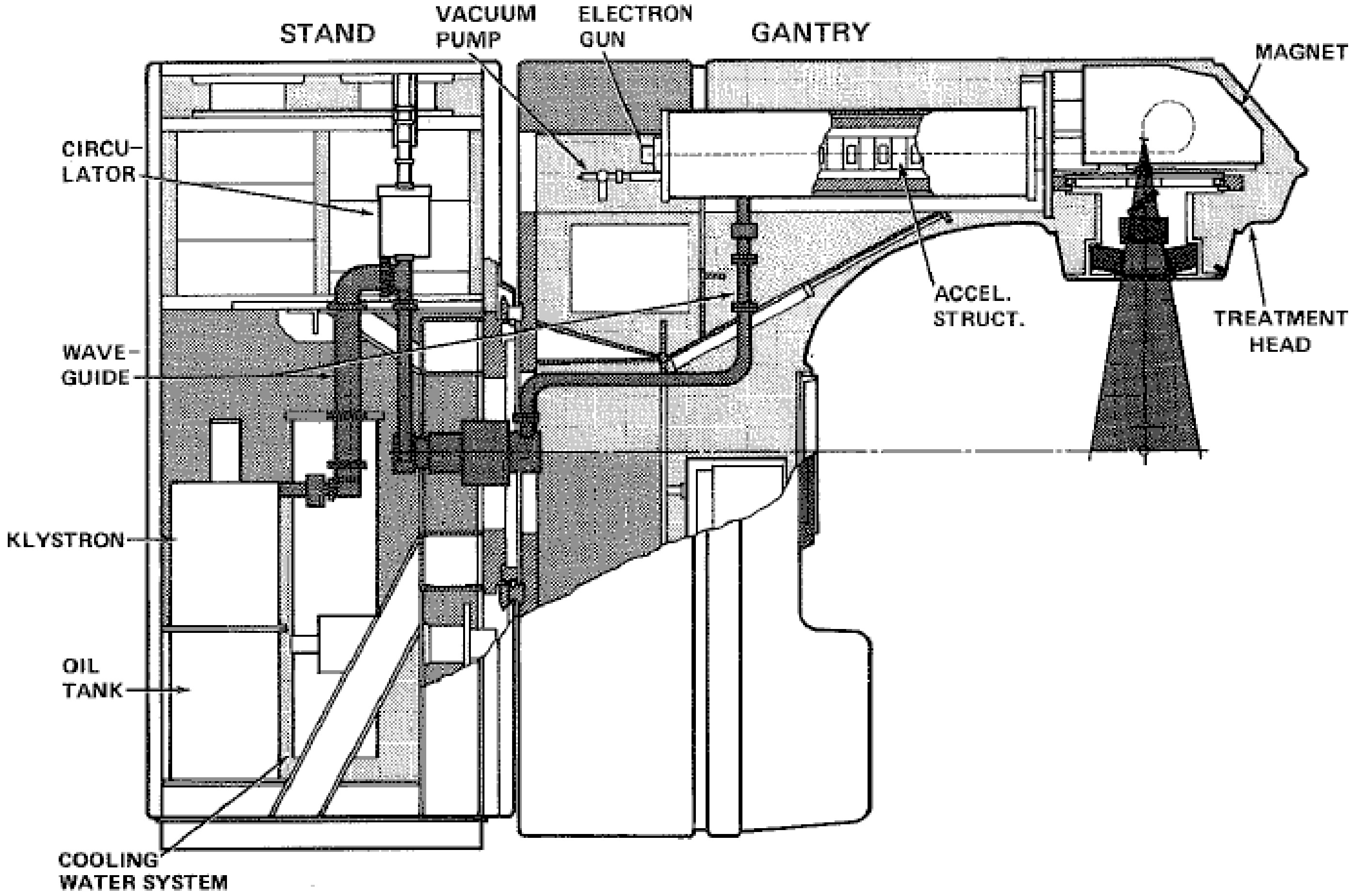


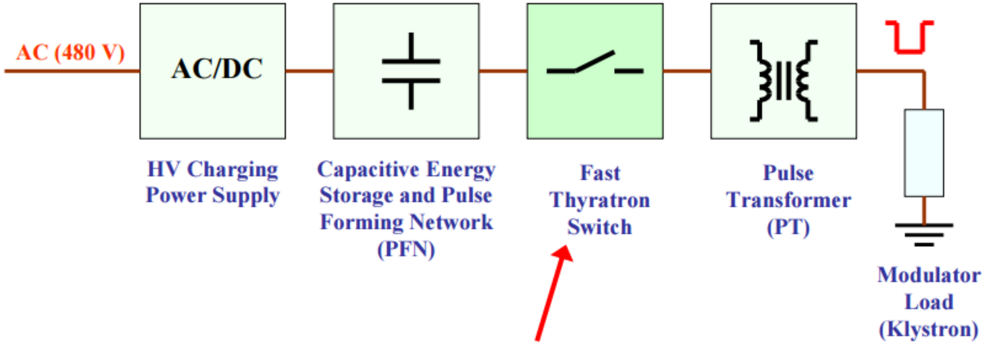
Figure 15. Schematic diagram of a high-energy radiotherapy linac (Clinac 18) identifying major components housed in the stand and gantry.

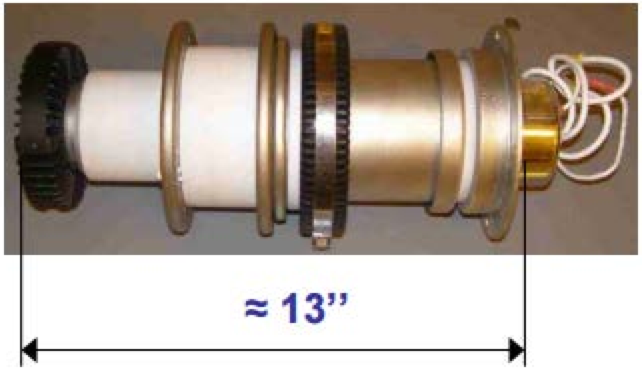
Resources

- Karzmark – Primer on Linear Accelerators
- Karzmark – Medical Electron Accelerators
- Varian Truebeam – Technical Ref Guide
- The Novice's Guide to Electron Linear Accelerators

Modulator

- High Voltage power supply charges the Pulse Forming Network (PFN)
- High current gas-filled tube switch (Thyratron), discharges PFN into the primary Pulse Transformer
- Two AC (50 Hz) voltage sources are used to power filaments of the Accelerator Electron Gun and Microwave Power Source filament





CX1836A thyratrons that are employed in the Linac modulators are Deuterium filled fast switching devices.

Microwave Power Source

1. **Klystron**—a linear series of microwave cavities that sit atop an insulating oil tank and provides a source of microwave power to accelerate electrons;

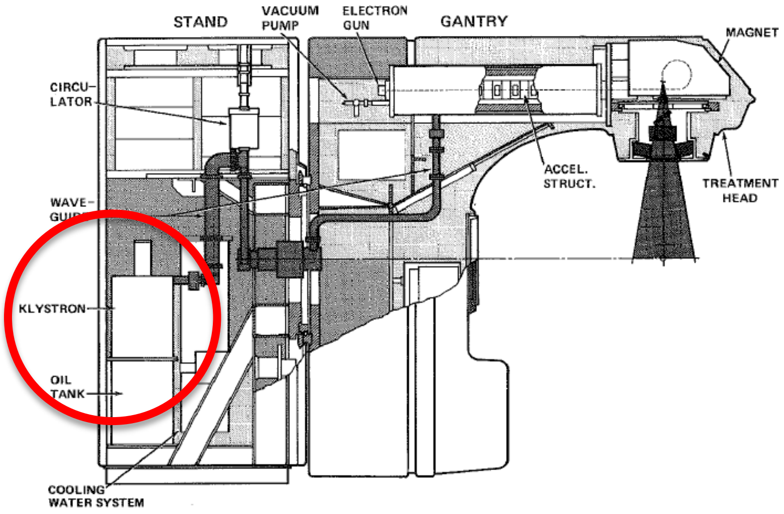
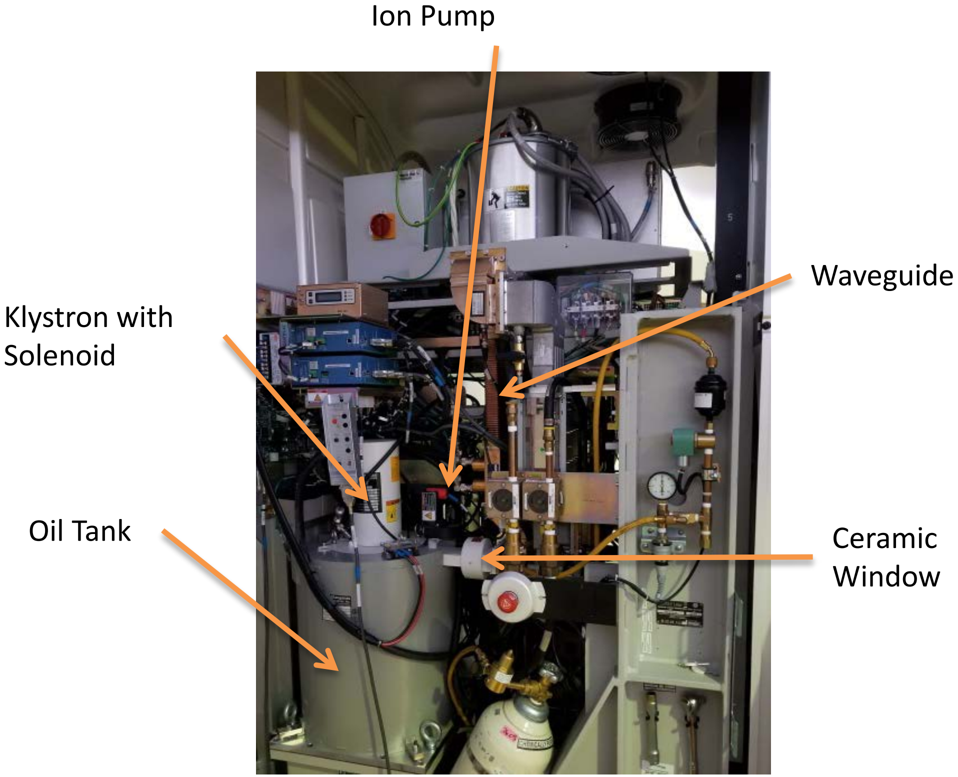


Figure 15. Schematic diagram of a high-energy radiotherapy linac (Clinac 18) identifying major components housed in the stand and gantry.

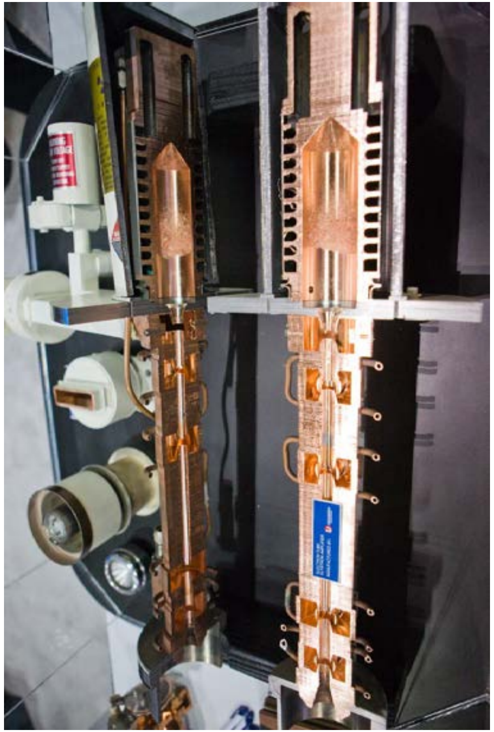


TRUEBEAM WW

Klystron

Microwave Amplifier

- Invented by Russell and Sigurd Varian at Stanford in 1937, with W.W. Hansen
- Low power microwave input – low MW oscillator source
- Electrons travelling from cathode to anode are bunched in first cavity oscillating from input RF
- Oscillations induced in catcher cavity from passing electron bunches
- Deceleration of bunches results in power amplification



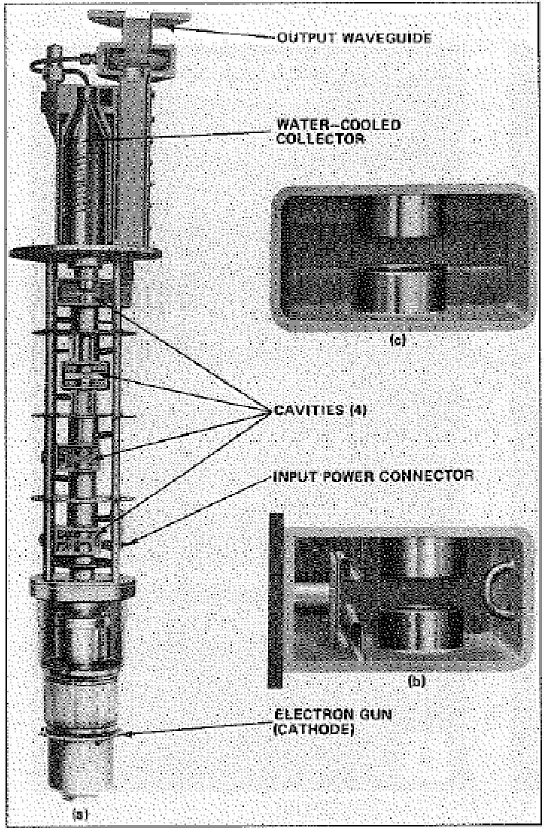
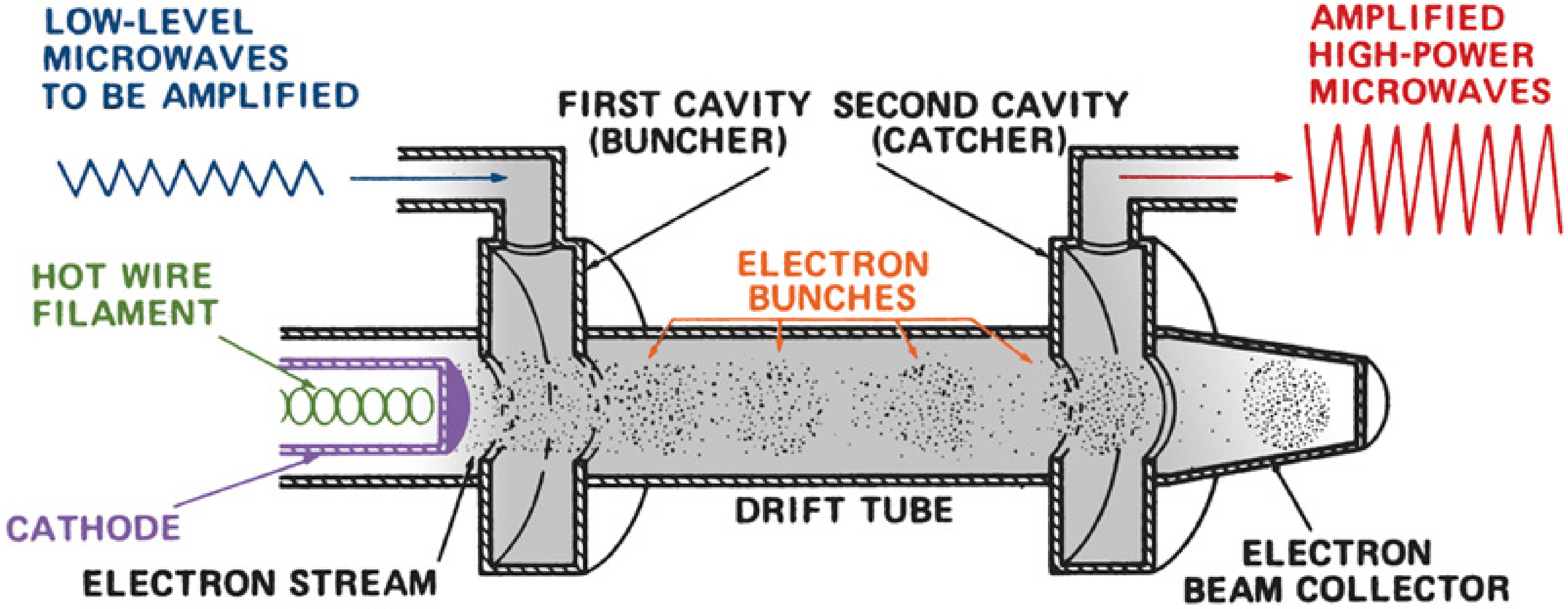


Figure 20. (a) Cutaway four-cavity klystron, similar to that employed in the Clinac 18. Views (b) and (c) are cutaway individual cavity sections. (b) Enlarged view of the bottom cavity, the input power coupling loop is on the right and a fine-tuning device is on the left. (c) Enlarged view of cavity number three; the fine-tuning device has been cut away in this view.

Klystron



LOW-LEVEL MICROWAVES TO BE AMPLIFIED
FIRST CAVITY (BUNCHER)
SECOND CAVITY (CATCHER)
AMPLIFIED HIGH-POWER MICROWAVES
HOT WIRE FILAMENT
ELECTRON BUNCHES
CATHODE
ELECTRON STREAM
DRIFT TUBE
ELECTRON BEAM COLLECTOR

Klystron

The klystron solenoid provides the necessary magnetic field to keep the klystron electron beam well-collimated and working at maximum efficiency. The klystron solenoid power supply, programmed to a constant value, provides a set level of current for the klystron focusing coil.

TABLE 5-3 · Clinac 1800, (VA8252) klystron operating parameters

Mode	Low mode	High mode	Unit
Frequency	2856 ± 2.5	2856 ± 2.5	MHz
Peak output power	3.0	5.5	MW
Peak beam power	7.5	11.5	MW
Gain at saturation	47	50	dB
Load VSWR	1.2	1.2	
Beam pulse width	5.8	5.8	μs
Repetition rate (max)	360	180	Hz
Peak beam voltage	110	127	kV
Peak beam current	72	92	A
Heater voltage	7.5	7.5	Vr.m.s.
Heater current	30 ± 3	30 ± 3	Ar.m.s.
Warm-up time	10	10	min
Efficiency	43	53	%

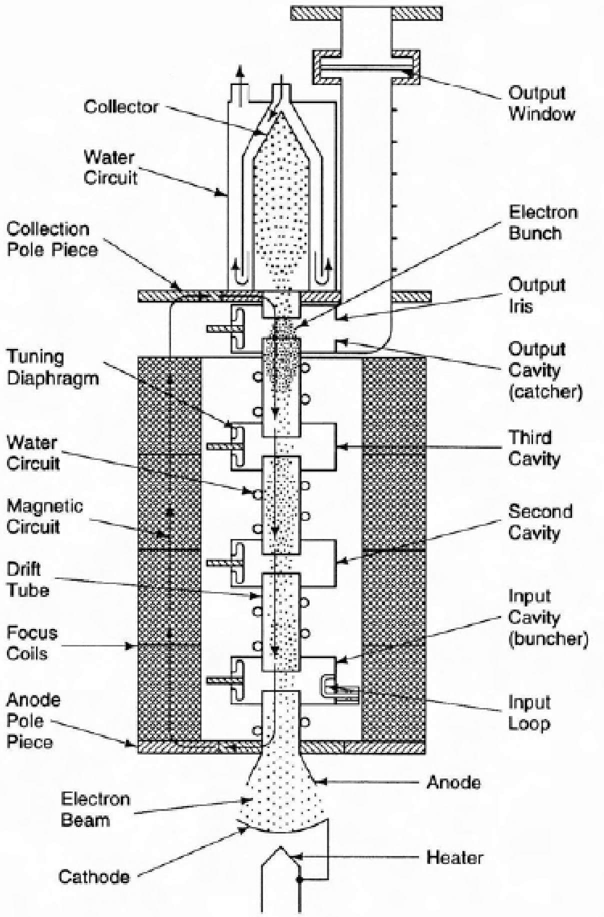


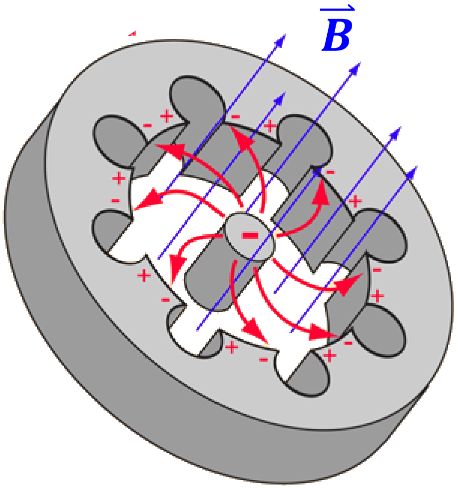
FIGURE 5-6 · Schematic cross section of a high power four-cavity klystron.

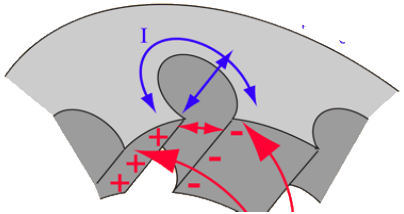
Amazing Klystron video: https://www.youtube.com/watch?v=Fvud81pYGOg

Magnetron

Microwave Generator

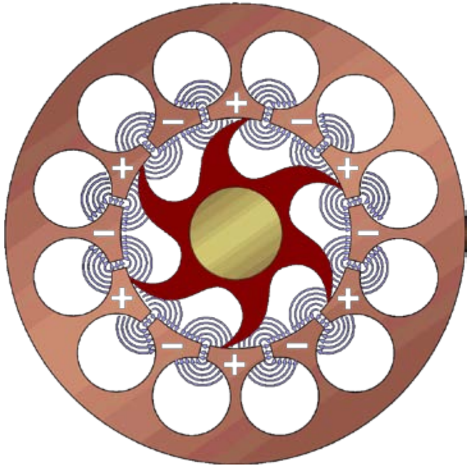
- Electrons accelerate from central cathode to anode in trajectories curved by the magnetic field
- Resultant oscillating electric fields + magnetic field result in electrons forming space charge spokes
- High power microwaves (up to ~5 MW)
- Small size allows mounting directly on gantry - Tomotherapy



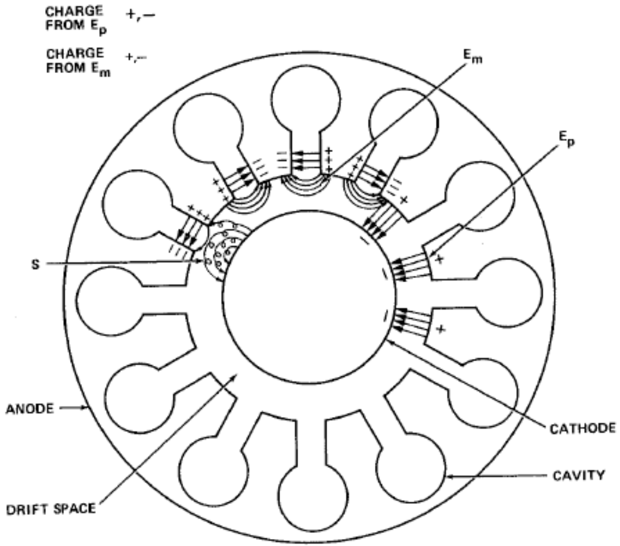


e-

Magnetron



- Copper anode block with resonant cavities
- Central cylindrical coaxial cathode - Thermionic emission of electrons
- Microwave oscillations in cavities caused by currents induced electrostatically by moving electrons
  - Frequency determined by structure dimensions (thermal expansion, sagging)
  - Plunger can be used to slightly vary frequency (AFC)
- Electrons circulate and are bunched due to acceleration/deceleration at oscillating cavity mouths
  - Form space charge clouds like spokes
  - Increases amplitude of oscillations
  - Peak power determined by electron emission and applied voltage (up to 5 MW)
- Coupled to rectangular waveguide (TM mode)



Microwave System Comparison

Magnetron

- Microwave Generator
- Used in lower energy linacs (4-8 MeV)
  - Lower peak power (2-5 MW)
- Smaller - Can mount on gantry
- Lower operating voltage (~50 kV)
- Less expensive, Less stable
- Temperature Dependent
- Shorter life (2000 hr / 1 yr)

Klystron

- Microwave Amplifier
- Used in higher energy linacs
  - Higher peak power (5-20 MW)
- Requires RF input
- Larger/Bulkier
  - Must be in gantry stand, requiring rotating joint in waveguide
- Higher operating voltage (~100+ kV)
- Frequency more stable
- Oil tank insulation
- Longer life (10,000 hr / 5 yr)

Microwave System Comparison

TABLE 5-4 · Comparison of S Band magnetron and klystron

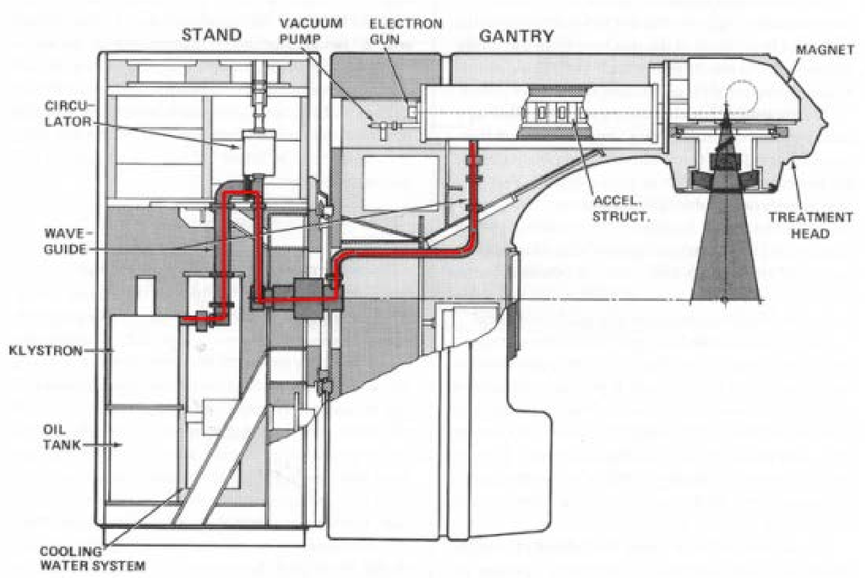
	Magnetron	Klystron
Function	Oscillator	Amplifier
Output power	Low (3 MW)	High (7 MW)
Life	Short (2000 h)	Long(10,000 h)
Cost	Low	High
Magnet	Permanent	Electromagnet
Operation	Moving	Stationary
Voltage	Low (45 kV)	High (140 kV)
Insulation	Potting	Oil tank

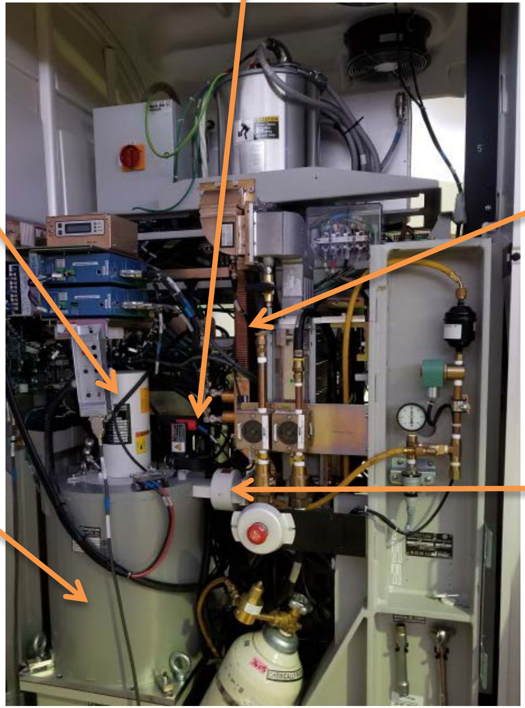
TABLE 3-2 · Microwave frequency bands and frequency range of each band.

Frequency band	Frequency (GHz)	Wavelength (cm)	Center frequency (GHz)
L band	0.39–1.55	76.9–19.3	1.30
S band	1.55–5.20	19.4–5.8	3.00
C band	3.90–6.20	7.7–4.8	5.45
X band	6.20–10.90	5.8–2.8	9.38
K band	10.90–36.00	2.8–0.8	24.00
Q band	36.00–46.00	0.8–0.7	34.80
V band	46.00–56.00	0.7–0.5	50.00
W band	56.00–100.00	0.5–0.3	80.00

Transmission Waveguide

2. **Waveguide**—which conveys this power to the accelerator structure in the gantry;
3. **Circulator**—a device inserted in the waveguide to isolate the klystron from microwaves reflected back from the accelerator;

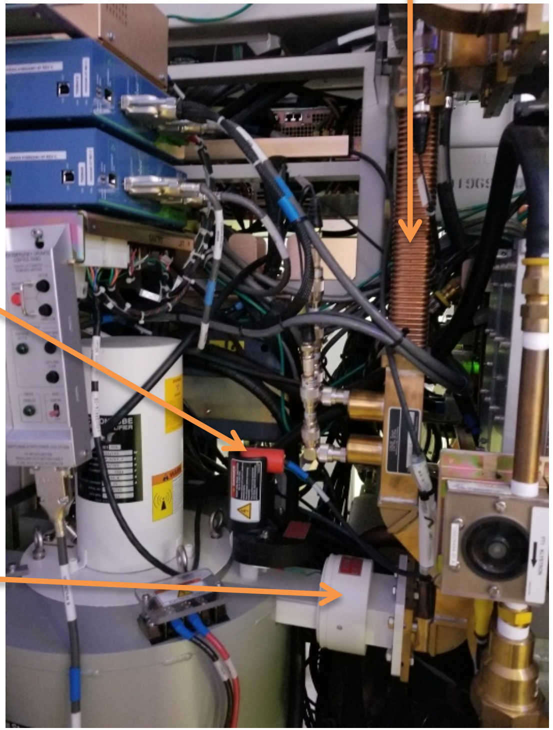




TRUEBEAM WW

Transmission Waveguide

- Waveguide filled with pressurized Sulfer Hexafluoride as an insulator, prevents arcing
- Ceramic window interfaces between Klystron vacuum and pressurized gas of Waveguide, transparent to microwaves
- Conveys power to accelerator structure more efficiently than traditional electrical wires / cables



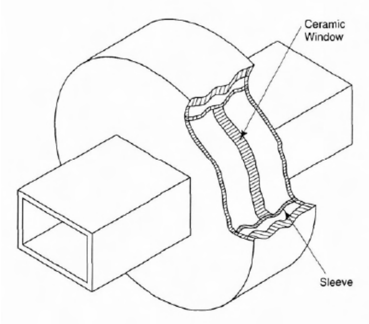
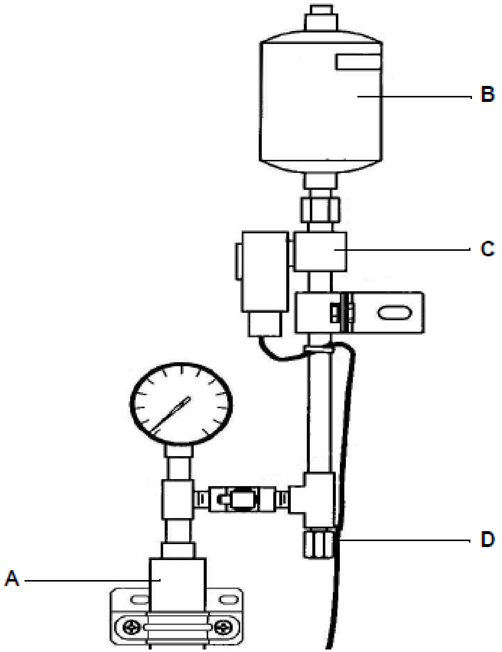


FIGURE 5-19 · Cut away view of pill-box type rf window.

Chapter 12 SF_6 Gas System

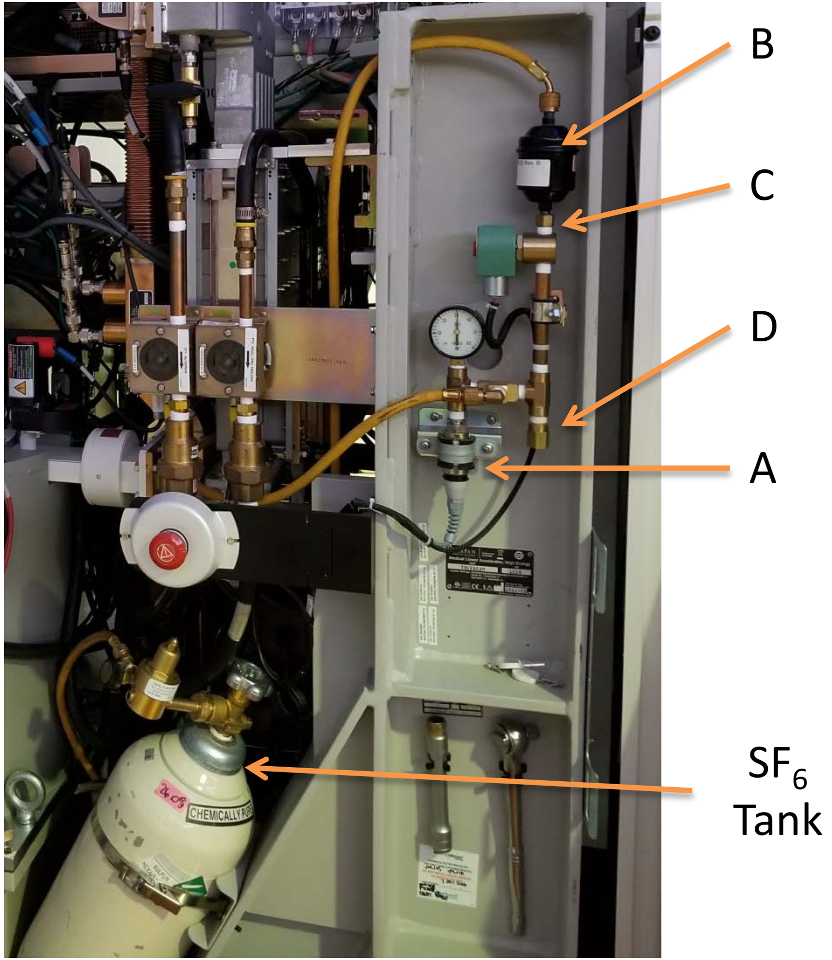
The accelerator waveguide in the Stand is filled with pressurized, dielectric sulfur hexafluoride (SF_6) gas. SF_6 gas is an electrical insulator that is used to protect waveguide components when arcing occurs.

The SF6 gas system (Figure 51) consists of a filter, a pressure sensor, and relief and solenoid valves.



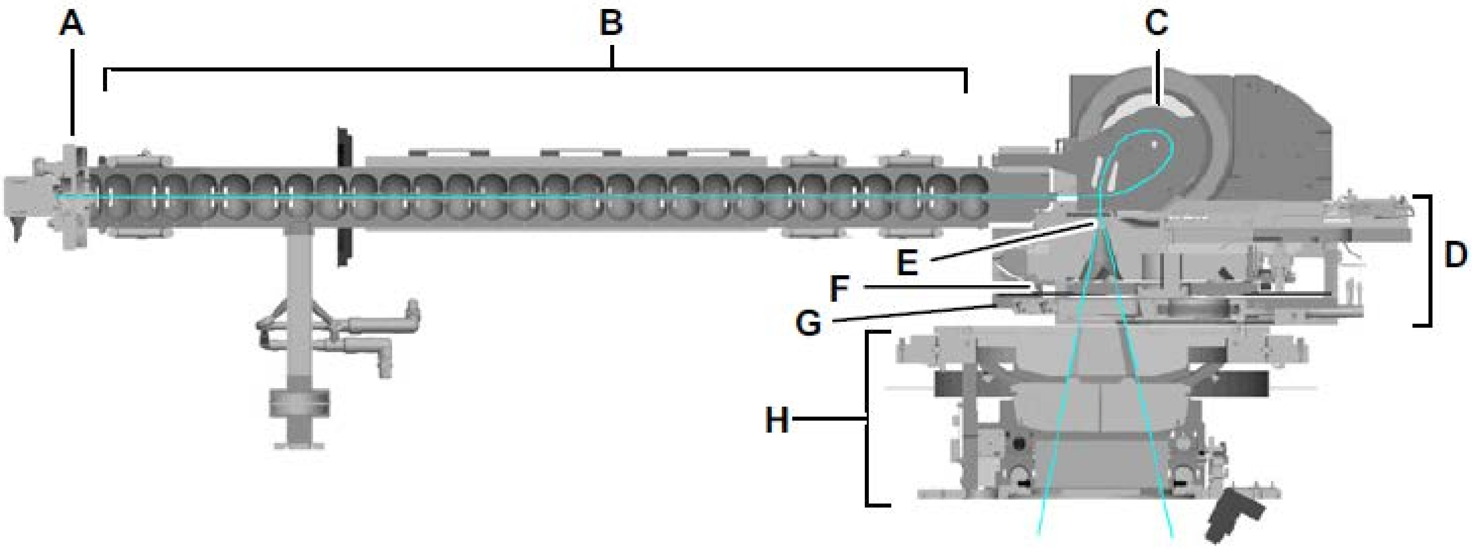
A Pressure sensor. **B** Filter. **C** Solenoid valve. **D** Pressure relief valve.

Figure 51 SF_6 Gas System



TRUEBEAM WW

Beam Generation



A Gun. B Accelerator. C Bend magnet. D Carousel.
E Target. F Foils and filters. G Ion chamber H Collimator.

Figure 23 Accelerator and Beam Diagram

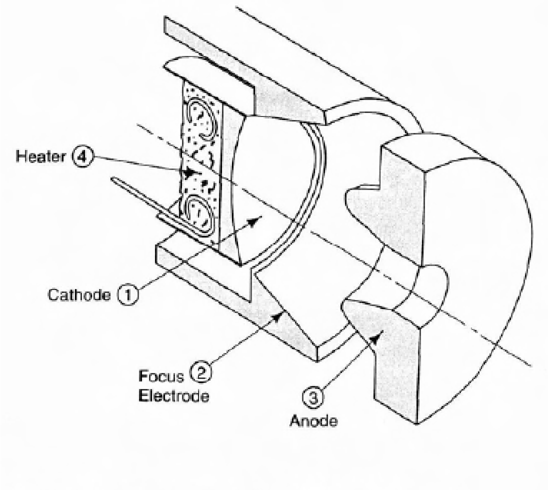
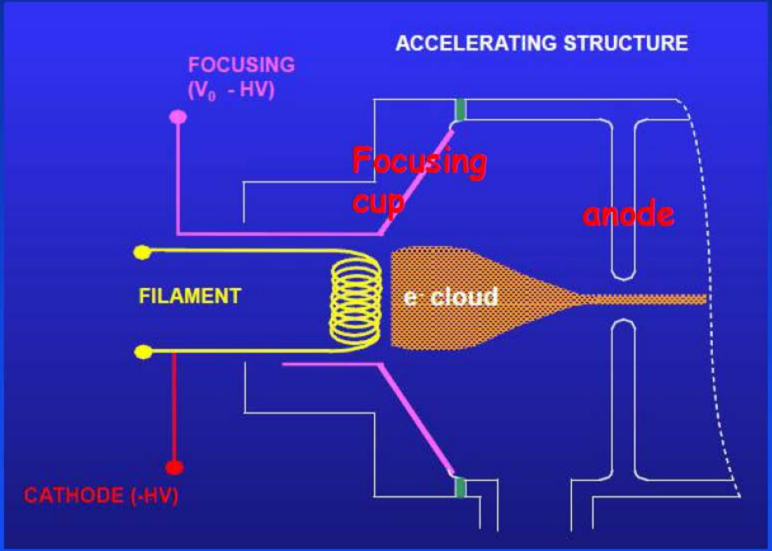


FIGURE 4-1 · Cross-sectional view of a diode electron gun.

Electron gun – Diode gun



- Electrons are emitted through **thermionic emission** from hated filament
- **Accelerated** toward perforated anode by an electrostatic field (**50 KV→0.4 c**)
- Focusing cup is used to **concentrate** the electron pencil beam
- **Synchronized** with RF microwave to enter accelerator waveguide

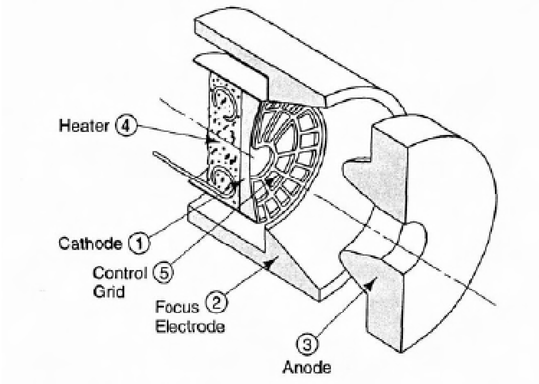
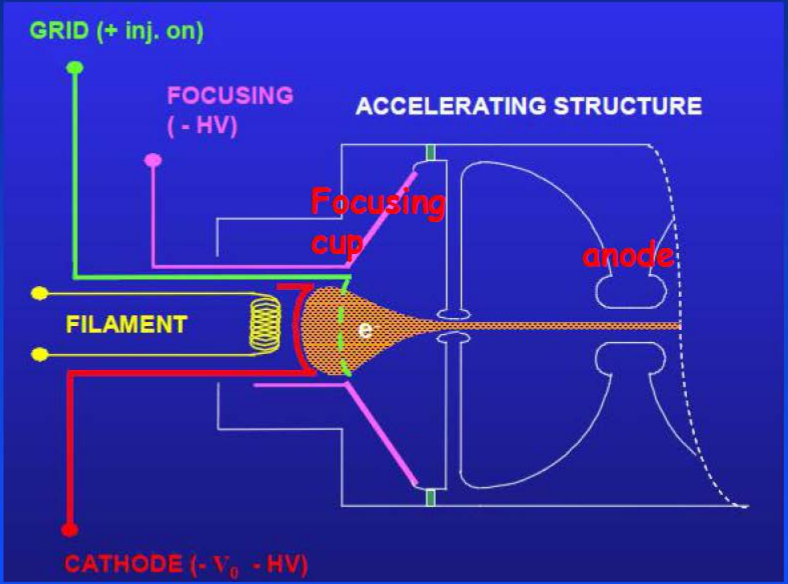
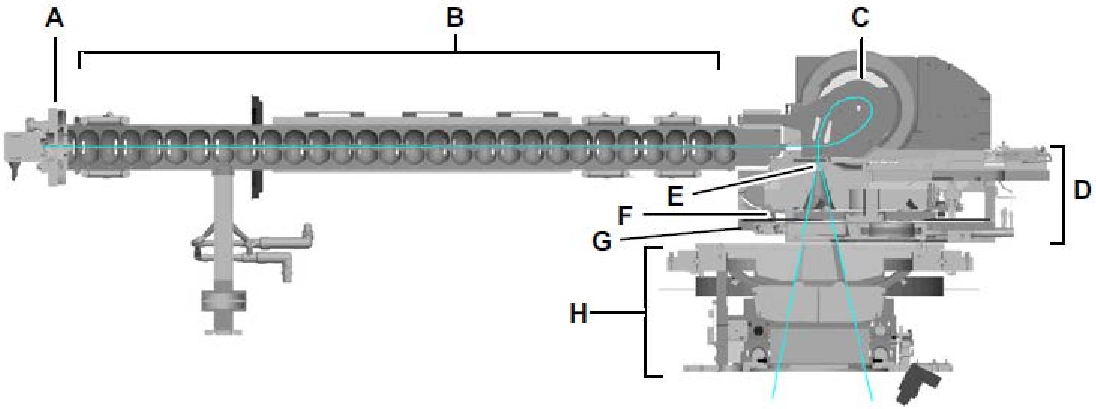


FIGURE 4-2 · Cross-sectional view of a triode electron gun with control grid.

Electron gun – Triode gun



- Grid with negative potential to hold off e^- beam; a slight delay to allow the waveguide to fill in RF power and stabilize
- Synchronized with RF microwave (achieved through grid)
- Independent regulation of cathode and grid



A Gun. **B** Accelerator. **C** Bend magnet. **D** Carousel.
E Target. **F** Foils and filters. **G** Ion chamber **H** Collimator.

Figure 23 Accelerator and Beam Diagram

Accelerator Structure

- Activating the plunger and switches from high coupling to low coupling
- f

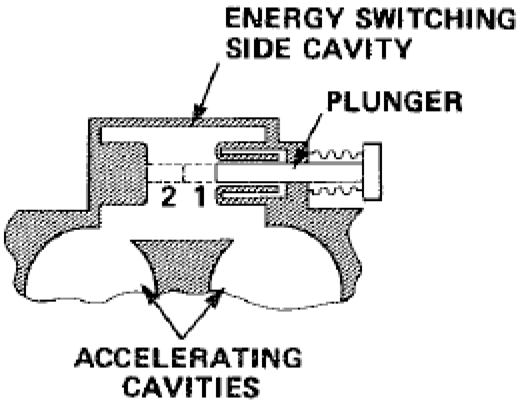
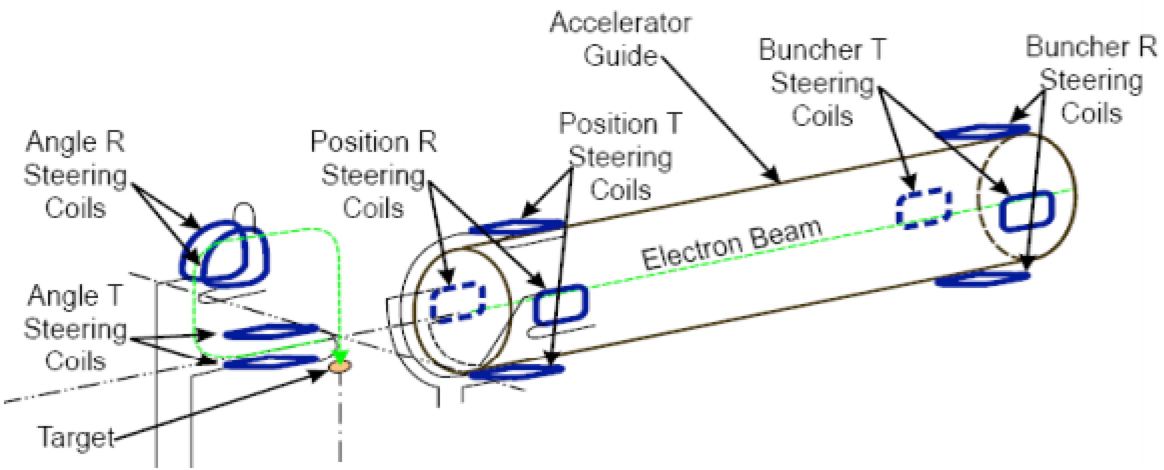


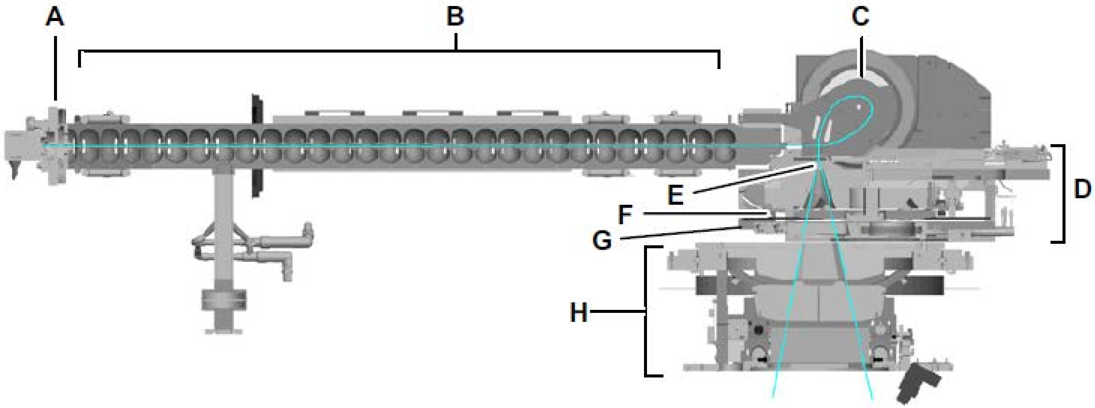
TABLE 4-3 · General comparison of TW and SW accelerators

	TW accelerator	SW accelerator
Shunt impedance	Low	High
Isolator or circulator	Not needed	Needed
Maximum accelerating beam current	High ~2 A	Low ~0.5 A
Tuning sensitivity	High	Low
Input coupler design	Complex	Simple
Buncher design	Rather complex	Simple
Spectrum sensitivity on accelerating field	Low	High
Coupler	Dual	Single
Coupler position	First and last	Any

Steering Coils

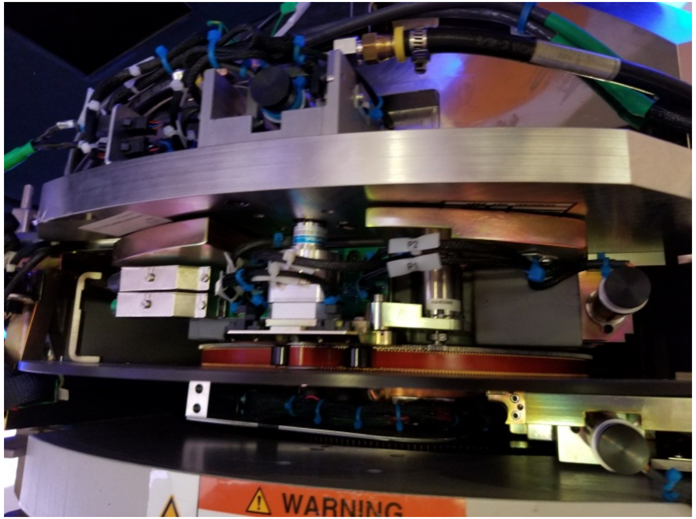


The accelerator solenoid focuses the electron beam as it travels the length of the accelerator structure. The accelerator solenoid power supply provides a programmed level of current to the accelerator focusing coil for each energy level.



A Gun. **B** Accelerator. **C** Bend magnet. **D** Carousel.
E Target. **F** Foils and filters. **G** Ion chamber **H** Collimator.

Figure 23 Accelerator and Beam Diagram



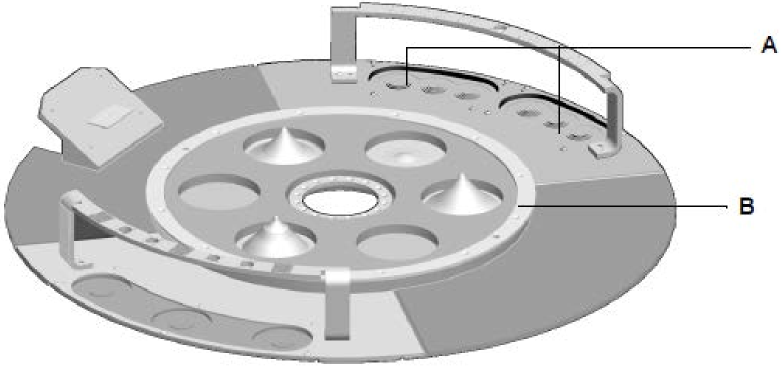
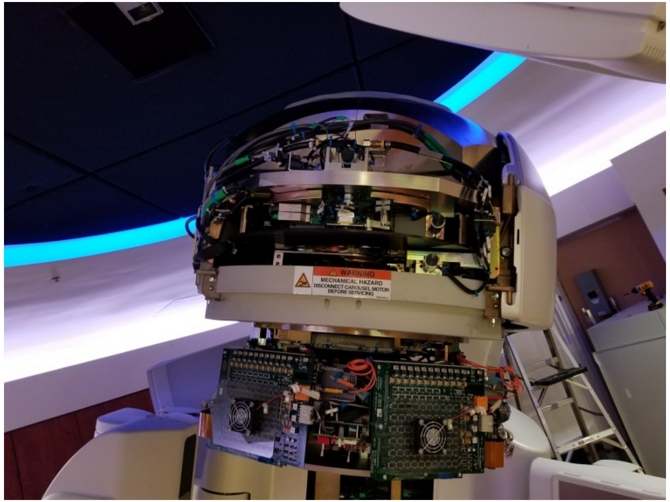
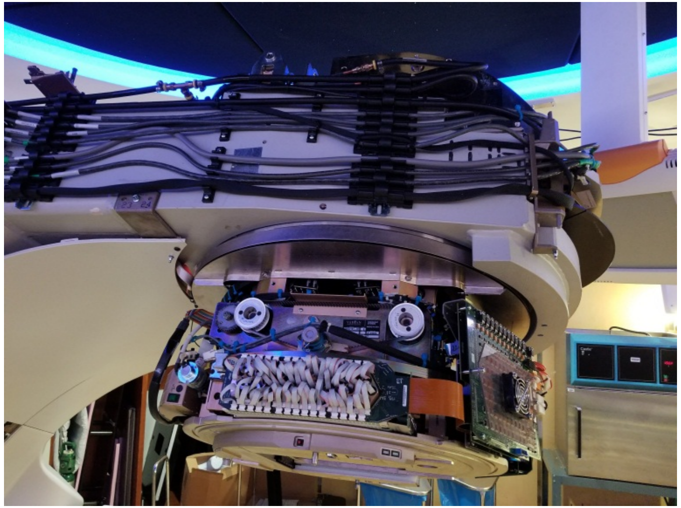


Figure 25 Foils (A) and Filters (B)





Carousel Y-Stage

The BGM-POS node positions the carousel Y-stage axis, providing longitudinal motion for the carousel. The Y-stage axis drive (Figure 26) moves the target out of the way when electron mode energies are used; positions foils and filters; and adjusts the field light mirror for proper focus.

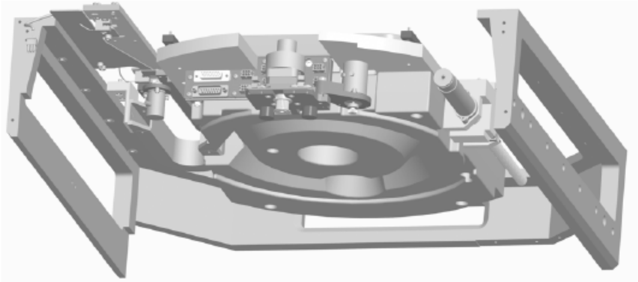
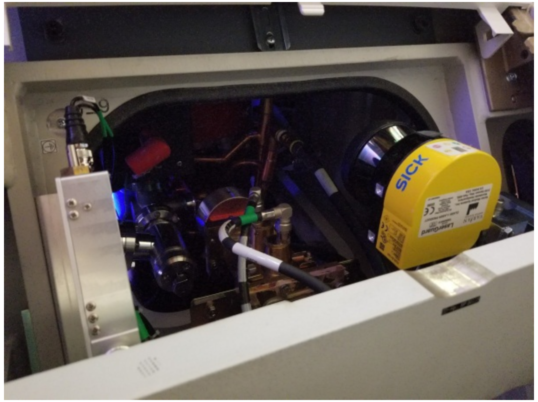


Figure 26 Y-stage Axis


SICK

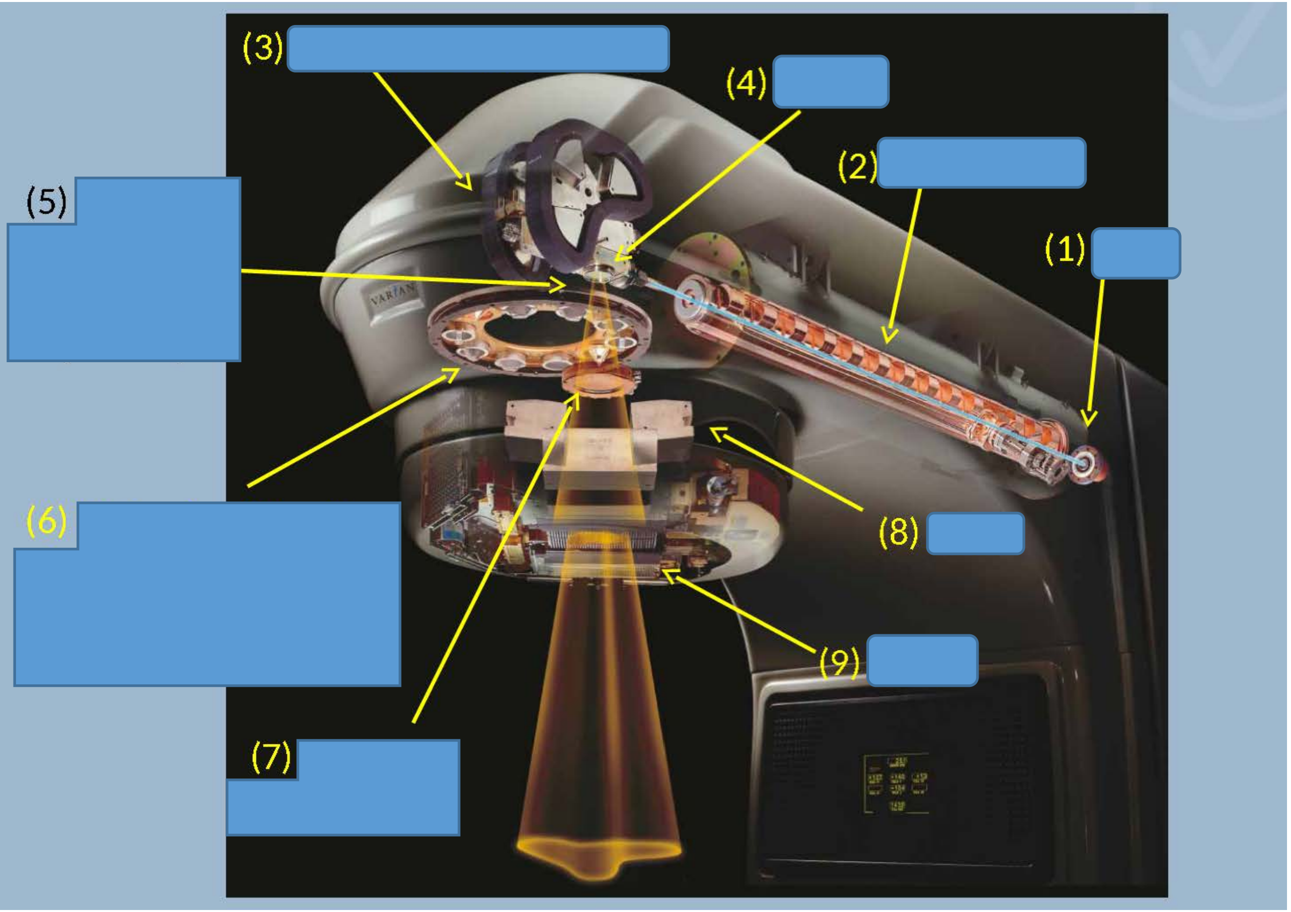
SICK

SICK


CAUTION
Heavy Object.
Lift with help.

MLC

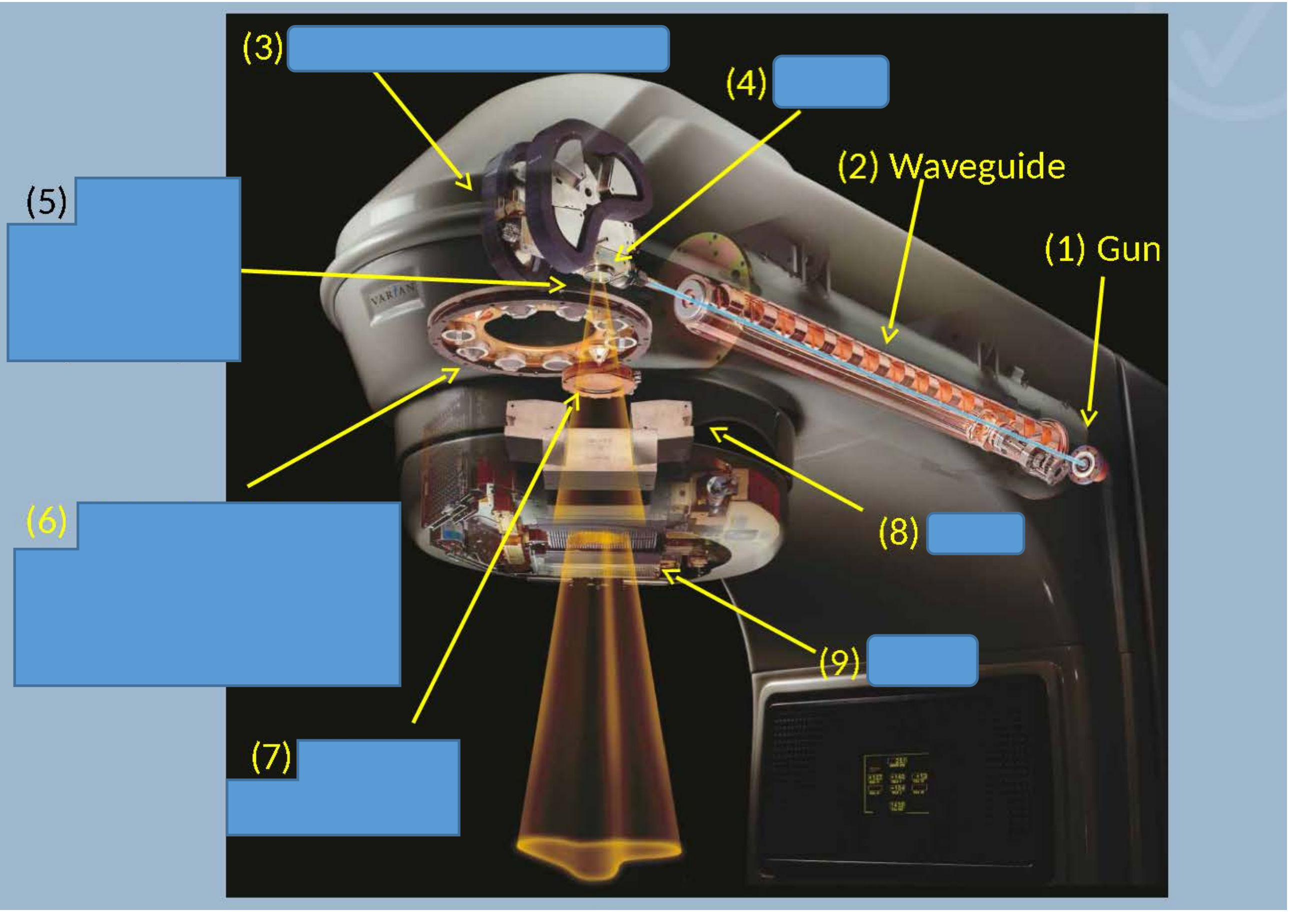
- TG-50: Basic Applications of Multi-Leaf Collimators

QUIZ!



1. Electron gun
   - Generates electrons through **thermionic emission**.
   - Injects pulses of electrons to electron accelerator.

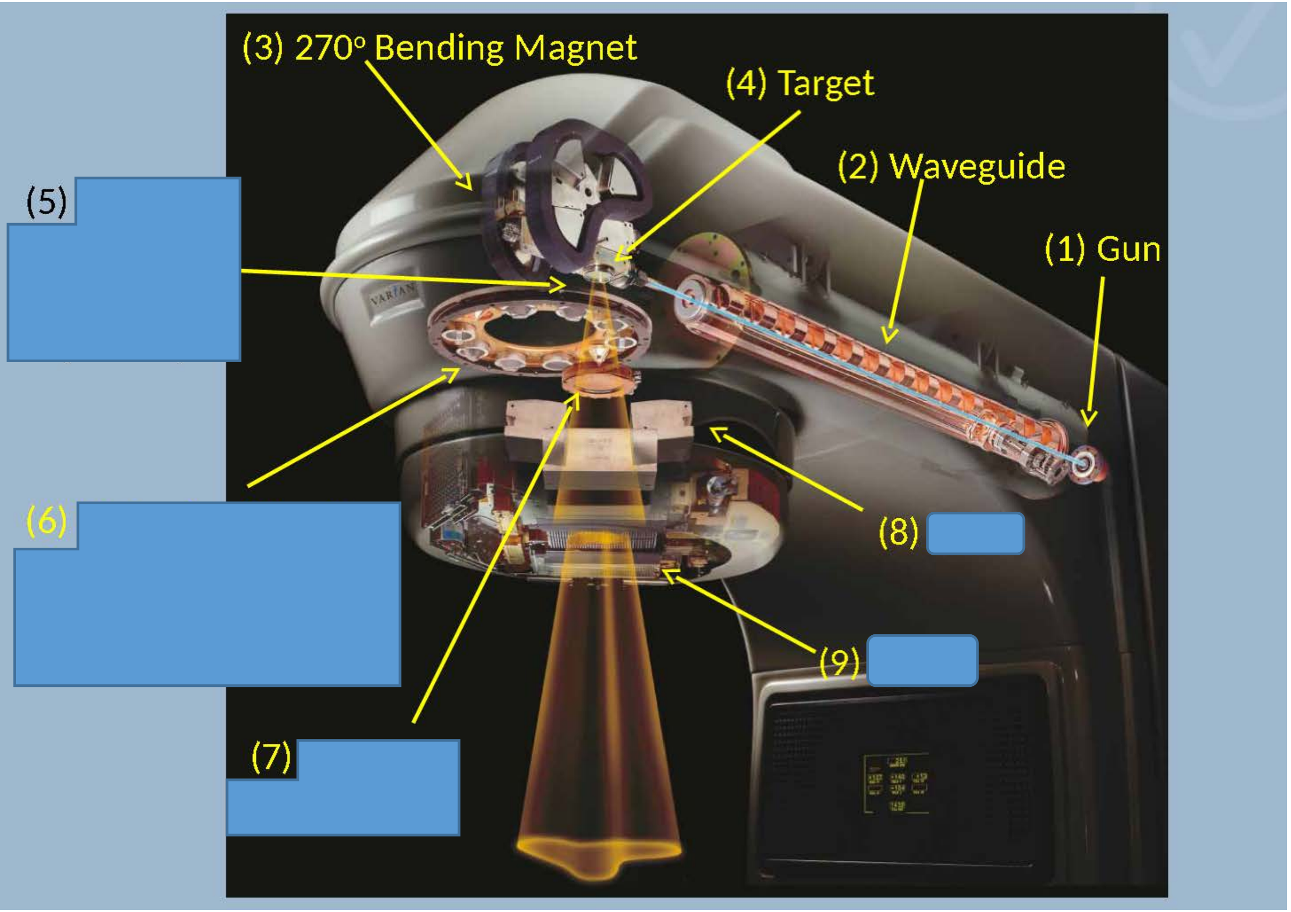
2. Accelerating waveguide
   - Either traveling or standing wave; standing is shorter
   - **3000 MHz** (**S band**)
   - CyberKnife, Tomotherapy = operates at **9000 MHz (X band)**
   - Powered by either magnetron (<=6MV - Tomo) or klystron (>6MV).



3. Bending magnet
   - 270^{o} design (**achromatic**)
   - Focus the beam;
     Angle
     Position
     Energy

4. Target
   - Converts electrons to bremsstrahlung photons
   - Conversion efficiency is on the order of **1% (1-20%??)**
   - Made of high-Z materials (good for bremsstrahlung process)
   - Usually some **tungsten alloy***

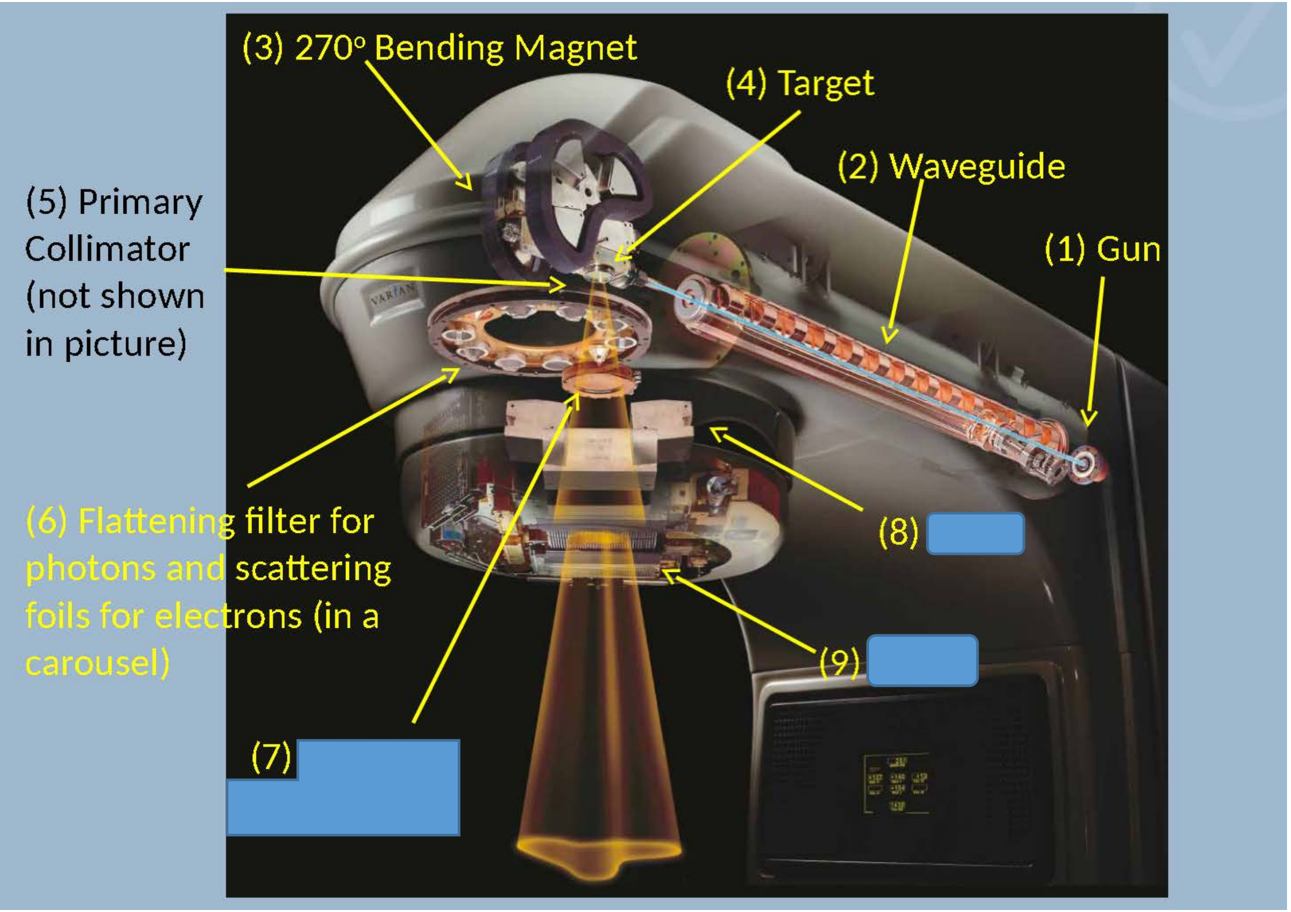
*lower E uses higher Z target while higher E uses lower Z target



5. Primary collimator
   - Collimates the beam coming out of target to a **circular beam**
   - Minimizes side leakage to **0.1%**

6A. Flattening filter (for photons)
   - **Cone shaped** to reduce beam fluence at center
   - Should not use high-Z material because it changes spectrum
   - Usually made of medium-Z material, usually **aluminum**
   - Creates flat beam at specific depth, usually **10 cm**

6B. Scattering foils (for electrons)
   - **Each electron energy** has its own foil
   - Could be 1 or 2 layers (one for scattering, one for flattening)

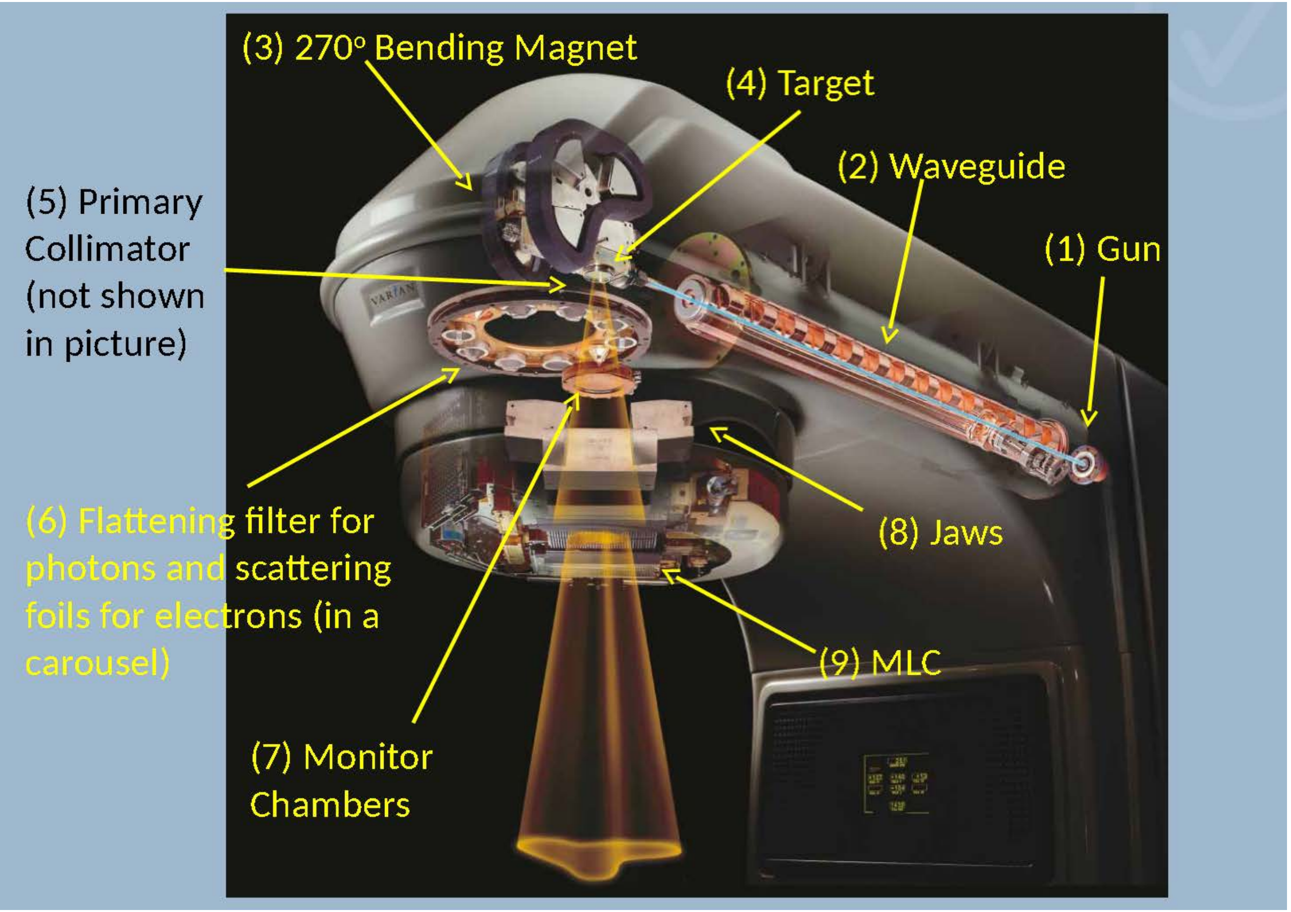


7. Monitor chambers
- There are two layers (for MU1 and MU2)
- Each one has 5 leads (center, ±X, ±Y) for output and symmetry*.

*positioned AFTER the flattening filter.

8. Jaws
- The higher the jaw position, the larger its penumbra
- Leakage max should be less than **2%** by IEC. Usually **<0.5%**.

9.MLC
- Leakage should be less than 5%.
- Usually <1% (intraleaf) and 1-2% (interleaf)



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