Production of X-Rays from Linacs

Reference: Metcalfe
Acknowledgements: Joe Hayward – original lecture
History

- **mid-1930’s**: Hansen develops mathematics of microwave resonant cavities
- **1937**: Russell and Sigurd Varian invent klystron (30kW)
- **1936**: British invent magnetron
- **1946**: 45 cm, 0.5 MeV accelerator guide developed by Fry in Britain
- **1946**: 90 cm, 1.7 MeV guide developed by Hansen at Stanford
- **1952**: first stationary linac for radiotherapy at Hammersmith Hospital, London (2 MW magnetron, 3 m guide, 100 cGy/min)
- **1954**: first orientable linac for radiotherapy at Christie Hospital, Manchester
So What Do We Need To Make a Linear Accelerator?

- source of electrons (electron gun)
- accelerator assembly (waveguide)
- source of power to accelerate electrons (magnetron or klystron)
- production of x-rays (target)
Clinical Requirements of Megavoltage Radiotherapy Accelerators

<table>
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<th>Item</th>
<th>Major criteria</th>
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| Precise delivered dose throughout target volume | Flatness of fields—all field sizes.  
                                            | Stability of field flatness versus angles of gantry and beam limiting device  
                                            | Stability of penetrative quality                                               |
| Precise dimensions of target volume     | Spatial precision of machine and radiation beam  
                                            | Spatial precision of position indicators                                       |
| Minimal dose to normal tissue           | Depth to maximum dose  
                                            | Penetrative quality  
                                            | Slope of fall-off of electron depth dose  
                                            | Sharpness of dose profile shoulder  
                                            | Width of penumbra at depth  
                                            | Scatter from beam modifiers.                                               |
| Wide variety of radiation modalities    | Low and high x-ray energies  
                                            | Low to high electron energies  
                                            | Small to large field sizes  
                                            | Rotational therapy                                                           |
| Reliability                             | Minimal unscheduled down time                                                |
| Convenience of patient set up           | Set-up time per field  
                                            | Range and ease of equipment motions  
                                            | Height of isocenter above floor                                                 |
| Moderate time to irradiate, for patient comfort, minimal motion | Dose rate (with beam modifiers)                                               |
| Patient safety                          | Mechanical injury avoidance  
                                            | Radiation injury avoidance                                                     |
Clinac 1800
Linear Accelerator Components
Linear Accelerator Components

- electron gun
- accelerator structures
- klystrons and magnetrons
- magnet systems
- scattering, flattening
- dose monitoring and beam stabilization
Electron Gun

Diode

Triode
Klystron

LOW LEVEL MICROWAVES TO BE AMPLIFIED

FIRST CAVITY (BUNCHER)

SECOND CAVITY (CATCHER)

AMPLIFIED HIGH POWER MICROWAVES

HOT WIRE FILAMENT

CATHODE

ELECTRON STREAM

DRIFT TUBE

ELECTRON BUNCHES

ELECTRON BEAM COLLECTOR

E vs t

a

b

c
Klystron
Magnetron
Travelling Wave Accelerators
Travelling Wave Accelerators
Standing Wave Accelerators
Standing Wave Accelerators
**Typical Pulse Beam Characteristics**

![Diagram showing pulse beam characteristics](image)

- **330 picoseconds**
- **150,000,000 electrons in each packet of pulses**
- **30 picoseconds**
- **10,000 electrons carried in each microwave pulse**
- **5 microseconds**
- **5 milliseconds**
- **15,000 pulses**

Typical microwave pulse sequences involved in linac operation. (Reprinted with permission from: Krieger and Petzold 1989.)
Linac Head Assembly

- X-Ray Target Retractable
- Bending Magnet Assembly
- Electron Orbit
- Primary Collimator
- Flattening Filter
- Scattering Foils
- Dual Ionization Chamber
- Field Defining Light Rangefinder
- Collimators
- Isocenter
Electron Beam Bending

- 90°
- 270°
- 45°
- 112.5°
Electron Beam Bending
Spatial Distribution of X-Rays Around a Thin Target
Target and Flattening Filter

Depth: 10 cm
SSD: 100 cm

Al target
(unflattened beam)

Pb target
(unflattened beam)

Ion chamber current (arbitrary units)

Distance from central axis (cm)
Linac Carousel
Dosimetry and Beam Steering
Beam Steering
Photon Mode

Electron Mode
Electron Dosimetry
Photon Dosimetry

(a) 200 kV
(b) 6 MV
(c) 24 MV

Depth In Water (cm)

Percent Depth Dose

Depth In Water (cm)

100%
90%
80%
70%
60%
50%
40%
30%