APPLICATIONS OF RADIATION IN MEDICINE

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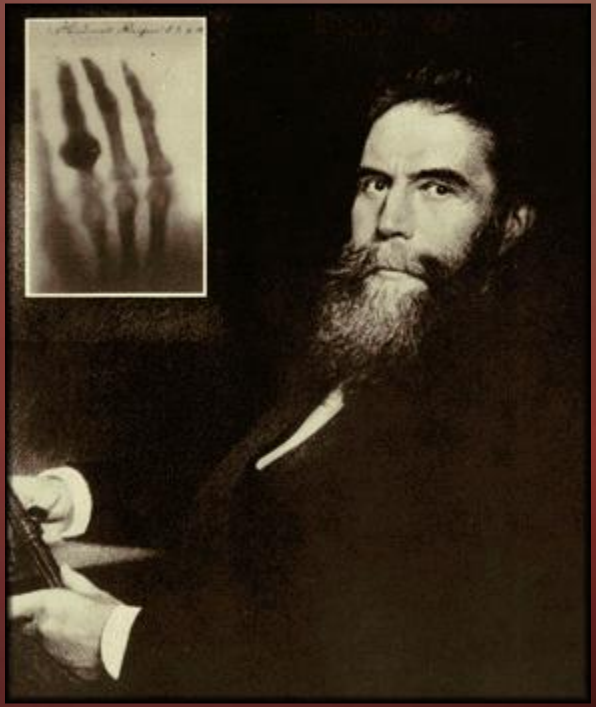
CONTENTS

- Principles of Radiation Therapy
- Radiobiology
- Radiotherapy Treatment Modalities
- Special Techniques
- Nuclear Medicine

X-RAYS

- **1895** Professor Wilhelm Conrad Roentgen discovered x-rays by accident
- Experimented with x-rays using vacuum tubes and saw the could pass through wood, paper, skin etc.
- Took 1st x-ray of his wife's hand using photographic plate
- **1896** Henri Becquerel discovered radioactivity
- **1898** Marie Curie discovered radium
- X-rays widely used as essential diagnostic tool in medicine, but also in cancer treatment



WHAT IS CANCER?

- Cancer describes disease characterised by uncontrolled and unregulated cell division that invades healthy tissues and affect their function
- Cancer can be malignant or benign (do not spread to distant parts)
- Malignant cells can spread locally or to distant parts of the body via the bloodstream or lymphatic system
- Treated with surgery, chemotherapy, radiotherapy, hormone treatments (conventional medicine)or in combination e.g.. Pre or post surgery

PRINCIPLES OF RADIOTHERAPY

- Deliver maximum radiation dose to tumour to achieve cell death whilst minimising dose to neighbouring healthy tissues
- Approximately 50% cancer patients treated with radiotherapy
- Royal College of Radiologists estimates that 40% of all long term cancer survivors owe their cure to radiotherapy
- High doses of radiation needed for tumour control
- Sensitivity of tumour vs. sensitivity of normal tissue= Therapeutic Ratio

PRINCIPLES OF RADIOTHERAPY

- Oncologist will prescribe a dose to the tumour volume (Gray)
- 1 Gy = 1J/kg
- Named after the British physicist Louis Harold Gray
- Treatment is delivered in sessions or fractions
- The time over which the dose is delivered is very important
- Patients may attend treatment for 1 day to up to 7 weeks, depending on the Intent of the treatment
- Radiotherapy given radically (cure) or palliative (symptom relief)

RADIATION INTERACTIONS

- A photon is ***$E = hv$***
- ***h*** is Planck's constant (6.62×10^{-34} J-sec)
- ***v*** is the frequency of the photon
- Frequency is equivalent to the quotient of the speed of light (3×10^{8} m/sec) divided by the wavelength
- High-energy radiations have a short wavelength and a high frequency
- The interaction of a photon beam with matter results in the attenuation of the beam
- Four major interactions occur:

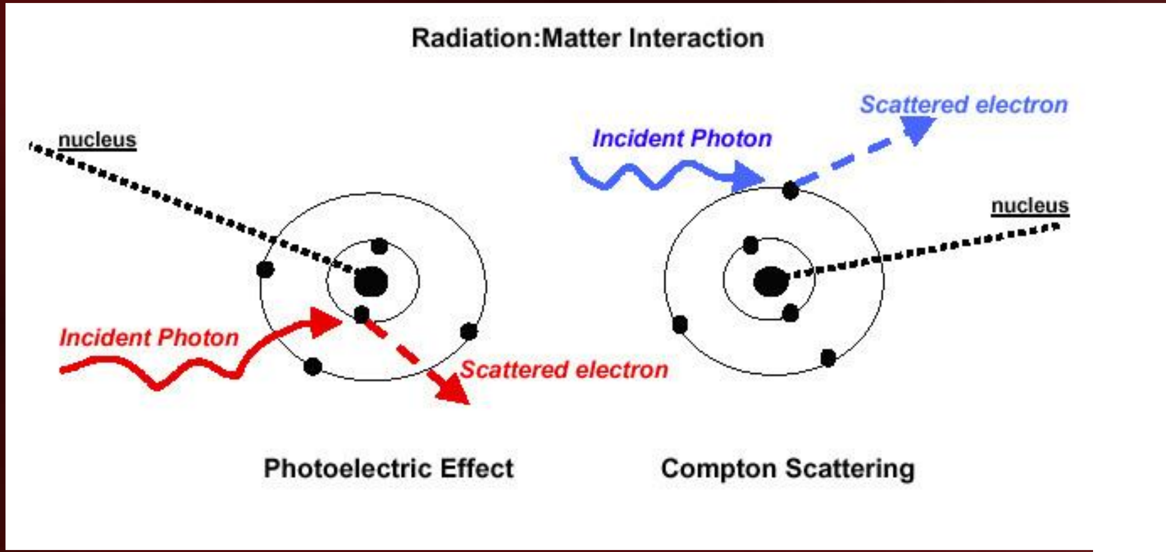
-Compton Scattering

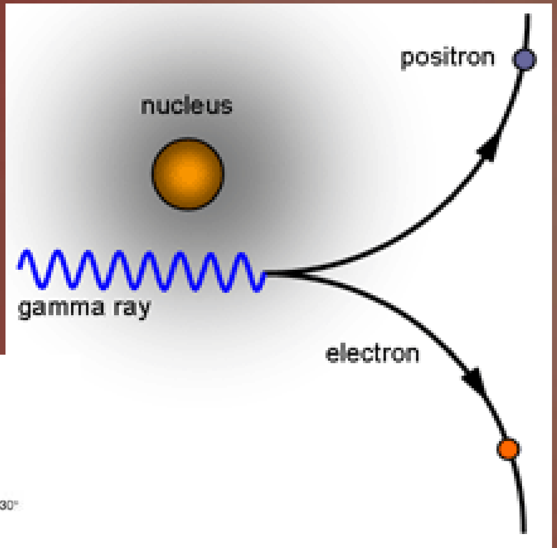
-Thompson Scattering

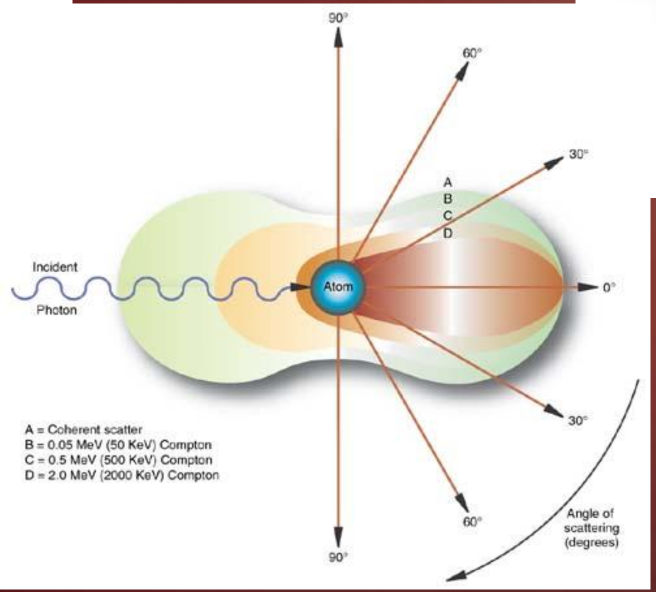
-Photoelectric Absorption

- Pair Production

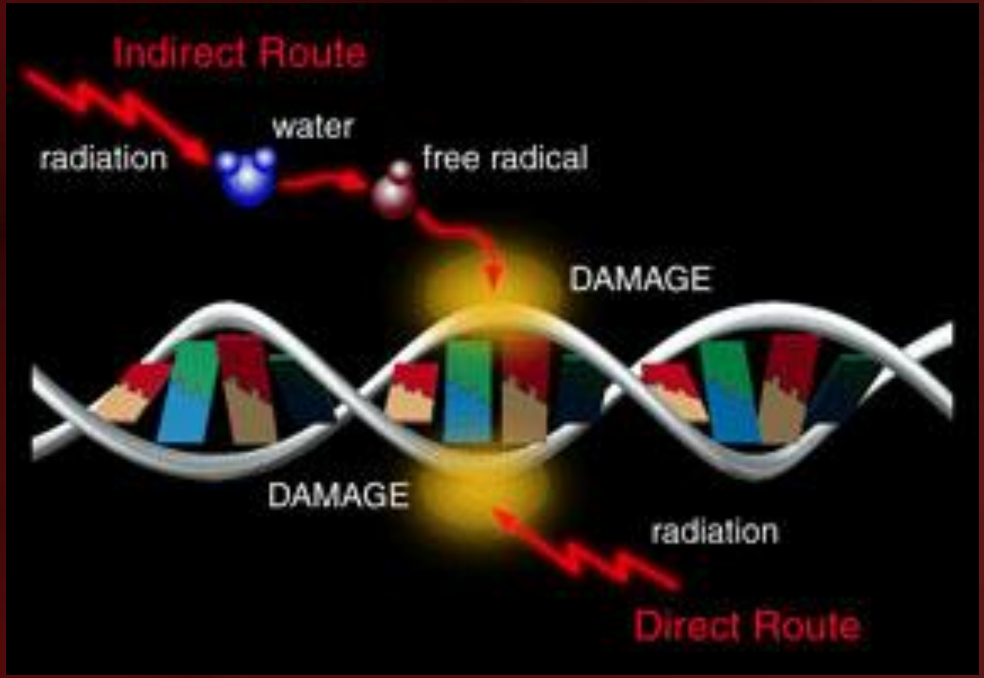
RADIATION INTERACTIONS







RADIOBIOLOGY



- High energy particles collide into a living cell with enough energy they knock electrons free from molecules that make up the cell
- Most damage occurs when DNA(deoxyribonucleic acid) is injured. DNA contains all the instructions for producing new cells
- Ionizing radiation causes damage in two way: 1.**Indirectly** – H2O in our bodies absorbs radiation, produces free radicals which react with and damage DNA strand 2.**Directl**y – radiation collides with DNA molecule, ionizing it and damaging it directly

RADIOBIOLOGY

- Unless repair occurs, the cumulative breaks in the DNA strand will lead to cell death
- Factors affecting cells response to radiation: (4 R's)
  - Reoxygenation
  - Repopulation
  - Repair
  - Redistribution

REOXYGENATION

- Oxygen stabilizes free radicals
- Hypoxic (low O2 content) cells require more radiation to kill
- Hypoxic tumor areas
  - Temporary vessel constriction from mass
  - Outgrow blood supply, capillary collapse
- Tumor shrinkage decreases hypoxic areas
- Reinforces fractionated dosing

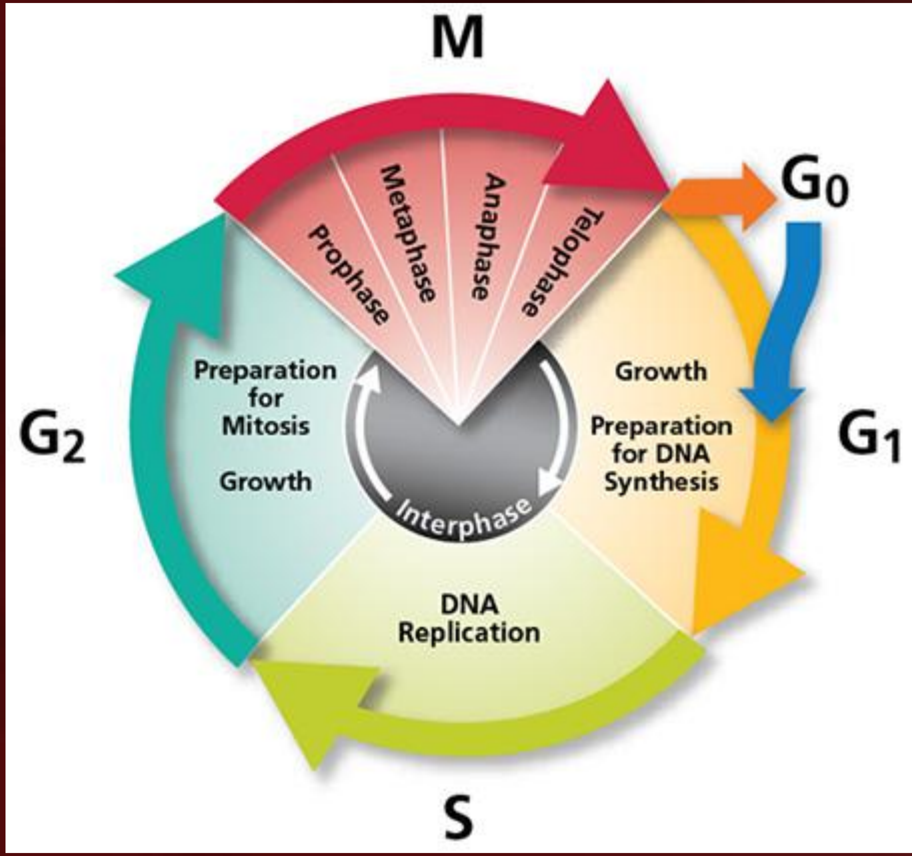
REPOPULATION

- Rapidly proliferating tumors regenerate faster e.g.. mucosa cells
- Determines length and timing of therapy course
- Regeneration (tumor) vs. Recuperation (normal)
- Reason for accelerated treatment schedules

REPAIR

- Sub lethal injury – cells exposed to sparse ionization fields, can be repaired
- Cell death requires greater total dose when given in several fractions
- Most tissue repair in 3 hours, up to 24 hours
- Allows repair of injured normal tissue, potential therapeutic advantage over tumor cells

REDISTRIBUTION



CELL CYCLE

- Cell cycle position sensitive cells
- S phase – radio resistant
- G_2 phase delay = increased radio resistance
- Fractionated XRT redistributes cells
- Rapid cycling cells more sensitive (mucosa, skin)
- Slow cyclers (connective tissue, brain) spared

RADIOTHERAPY TREATMENT MODALITIES

- **Teletherapy**: use of sealed radiation sources at an extended distance i.e. x-rays, electrons (ionized particles), beta or gamma radiation
- **Brachytherapy:** use of small sealed radiation sources over a short distance ie.caesium or iridium
- **Internal Isotope Treatment**: administration of radioactive isotope systemically (around body, via bloodstream)
- **Particle Therapy**: radiation treatment with Neutrons or Protons

TELETHERAPY

- External beam radiotherapy the most common form of treatment in clinical use
- Range of energies available:

- Superficial Machines (50-150 kV);1cm depth

-Orthovoltage Machines (200-300kV) , 3cm depth

-Megavoltage Machines (4-20MV) , deep seated tumours e.g. Linear Accelerator

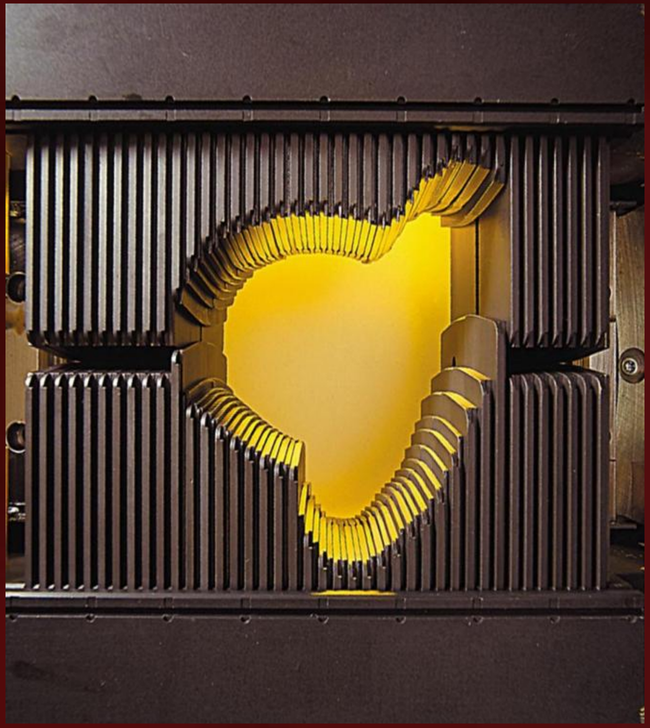
TELETHERAPY

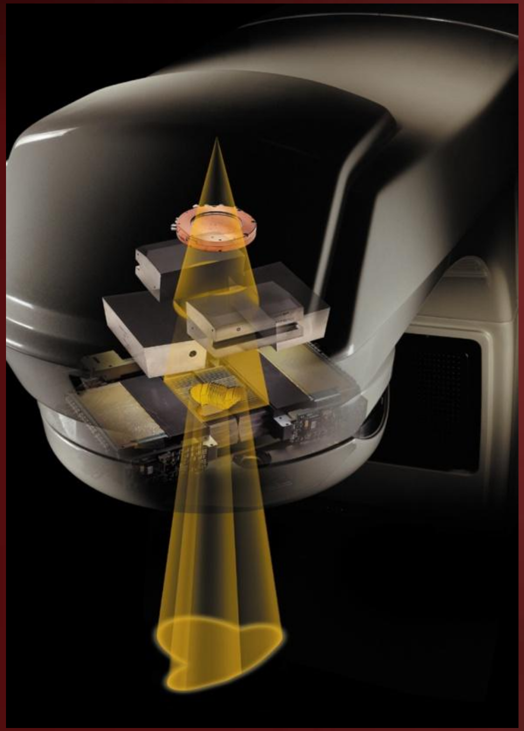
- Linear Accelerator is large stationary x-ray tube
- Contains microwave technology that accelerates electrons through a wave guide'
- When electrons hit a heavy metal target, x-rays are produced
- Various collimator systems in the gantry (head of the machine) shape the beam on it way out
- Change collimator systems to the shape of the tumour volume

TELETHERAPY

- Patient lies on a moveable couch beneath the machine and lasers in the room used to align the patient into the correct position
- Gantry is able to move 360 degrees around the patient delivering beams of radiation from different angles
- Kilovoltage arms (Kv source + Image intensifier) on Varian Linac for Image Guided Radiotherapy: Verification of treatment e.g. IMRT

MULTI-LEAF COLLIMATORS



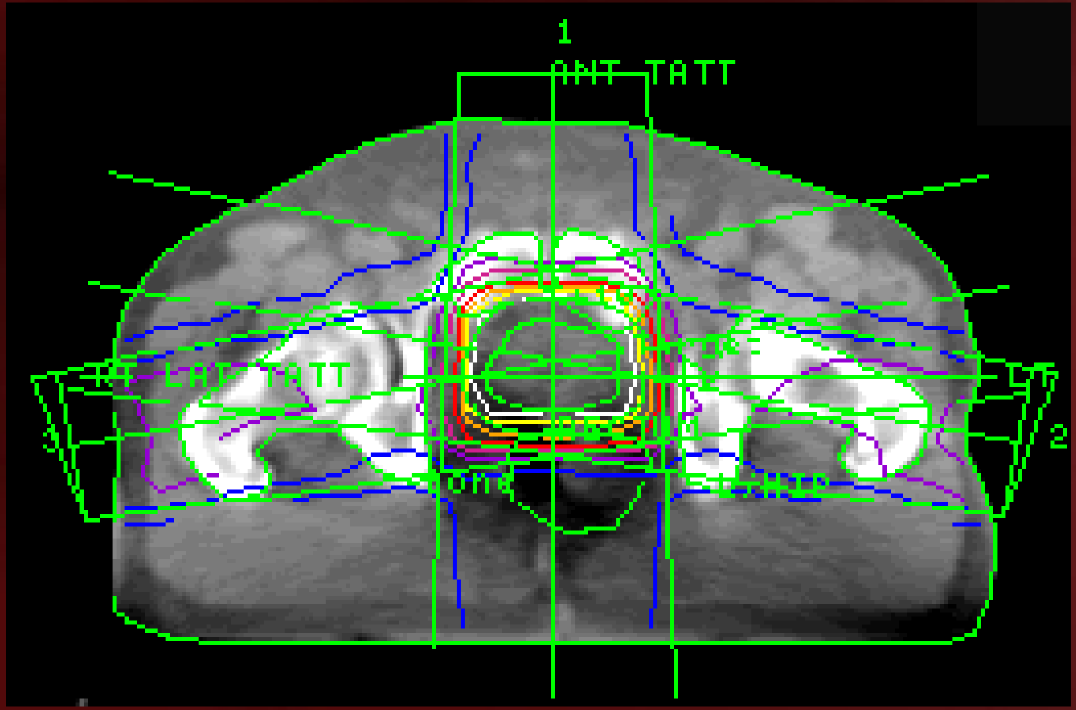


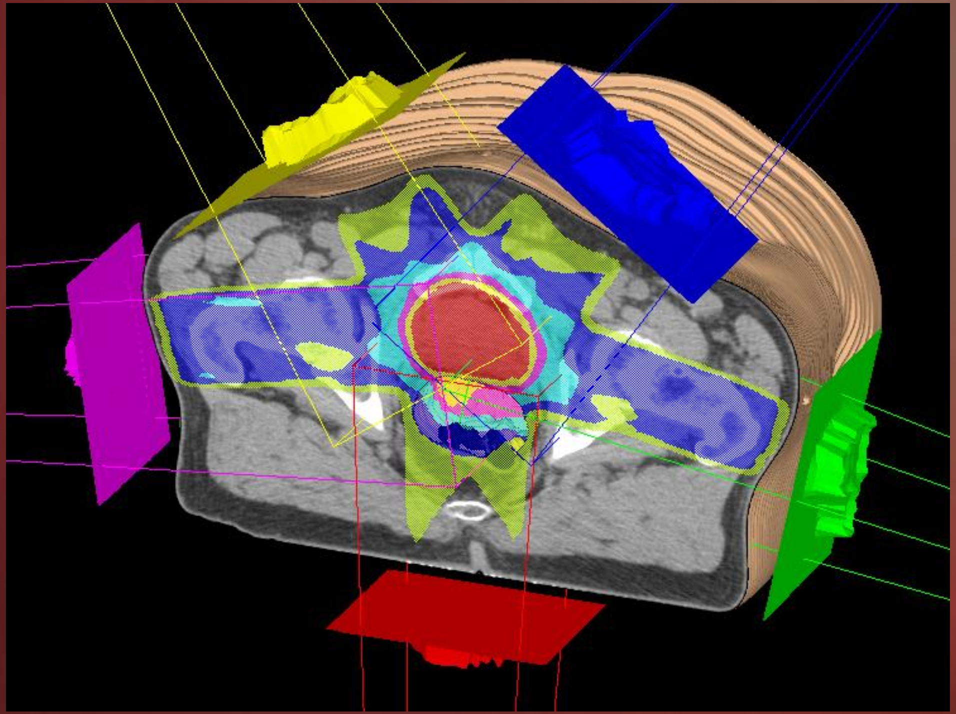
- 40 pairs of tungsten leaves mounted external to the treatment head
- Each leaf transmits 1% of the beam
- Additional attenuation achieved with back up collimators
- These together reduces beam transmission of 0.5% of the primary bean

IMRT

- A form on conformal RT where the intensity of the radiation field varies across the treatment field: achieved by varying the position of the leaves during treatment
- Require multiple non uniform beams to achieve desired plan
- 2 Methods: Step and Shoot or Dynamic
- 3D treatment requires online imaging
- Reliable Immobilisation

CONVENTIONAL RT VS. IMRT





BRACHYTHERAPY

- Brachytherapy is the use of sealed radioactive sources placed either on or within a site involved with a tumour.
- 3 Types: Mould Treatment- superficial tumours
- Intracavitary Treatment e.g.. Cervical treatment using Iridium-192/Caesium-137
- Interstitial Treatment e.g. radioactive gold seeds/ grains for prostate cancer

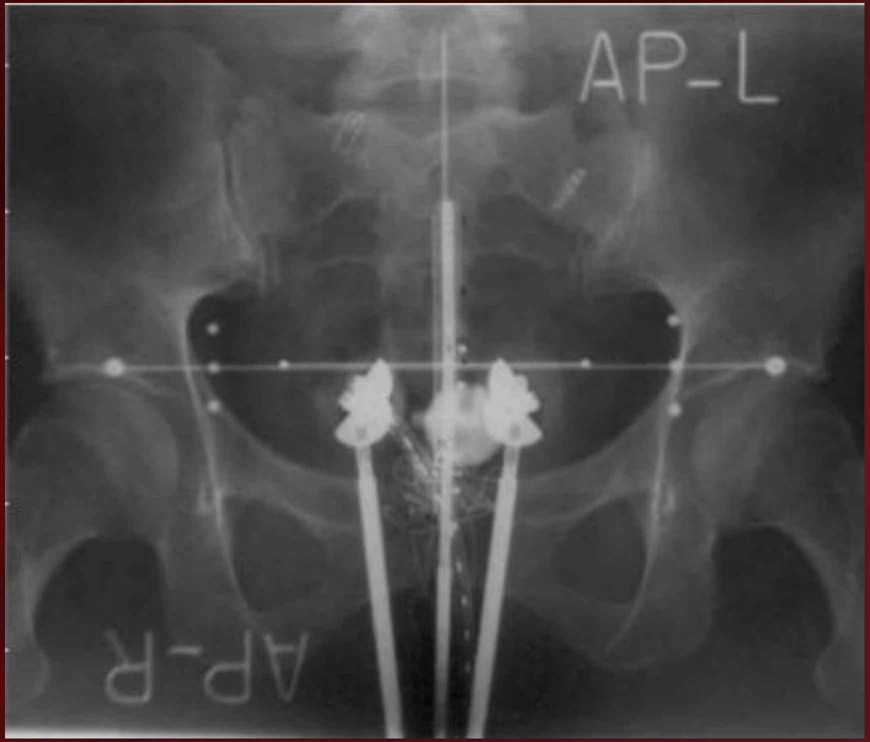
BRACHYTHERAPY

Radio isotope	No. of Isotopes	E of Gamma Rays	Half-life	Other Emissions	Cost	Physical State	Stability of daughter product	Specific Activity
Cobalt60	Two Photons	1.17 MeV 1.33 MeV	5.27 years	Beta Particles	Relatively Cheap	Flaky Solid	Nickel-Stable	High
Iridium-192	Range	0.296 to 0.605 MeV	74 years	Beta Particles	Relatively cheap	Solid	Plantinum-stable	High
Caesium	Single Photon	0.662 MeV	30 years	Beta Particles	Relatively Cheap	Solid	Barium-stable	Moderate
Radium-226	Range	0.118-2.43 MeV	1620 years	Beta +Alpha particles	High	Putty-like solid	Long line of radioactiv edaughter products.	High

BRACHYTHERAPY

- Aferloading Machine
- Designed to reduce dose to staff
- Method whereby empty source containers are placed into a body tissue/cavity and the radioactive sources are loaded at a later time
- More time ensuring accurate position
- Radiograph /CT of inert sources
- Sources are delivered remotely with the patient in the theatre room and staff at console area
- Treatment complete, retracted
- Patient does not remain radioactive
- Short hospital visits/ outpatient appointments

BRACHYTHERAPY

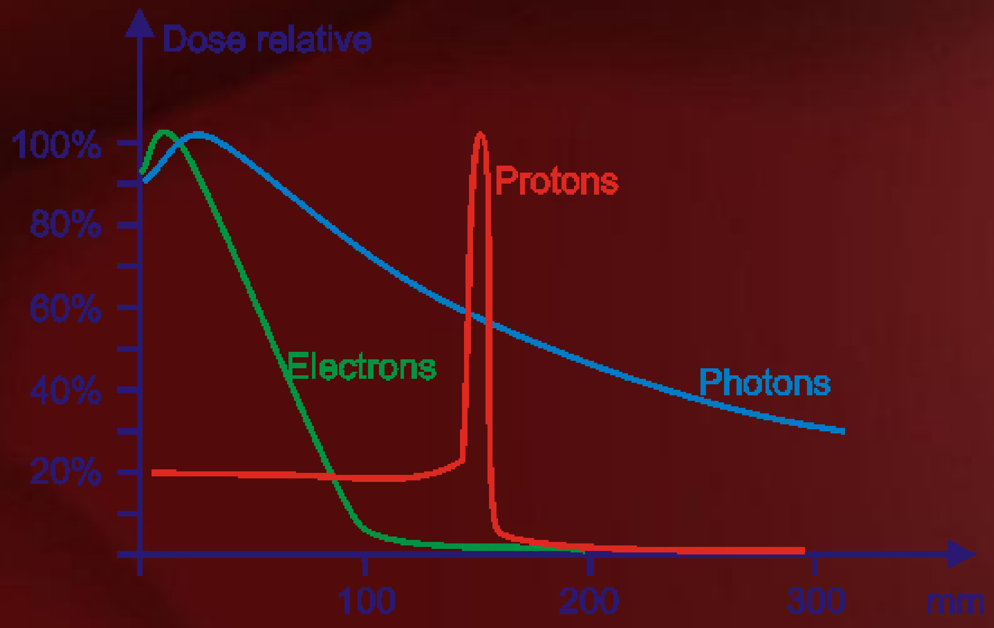


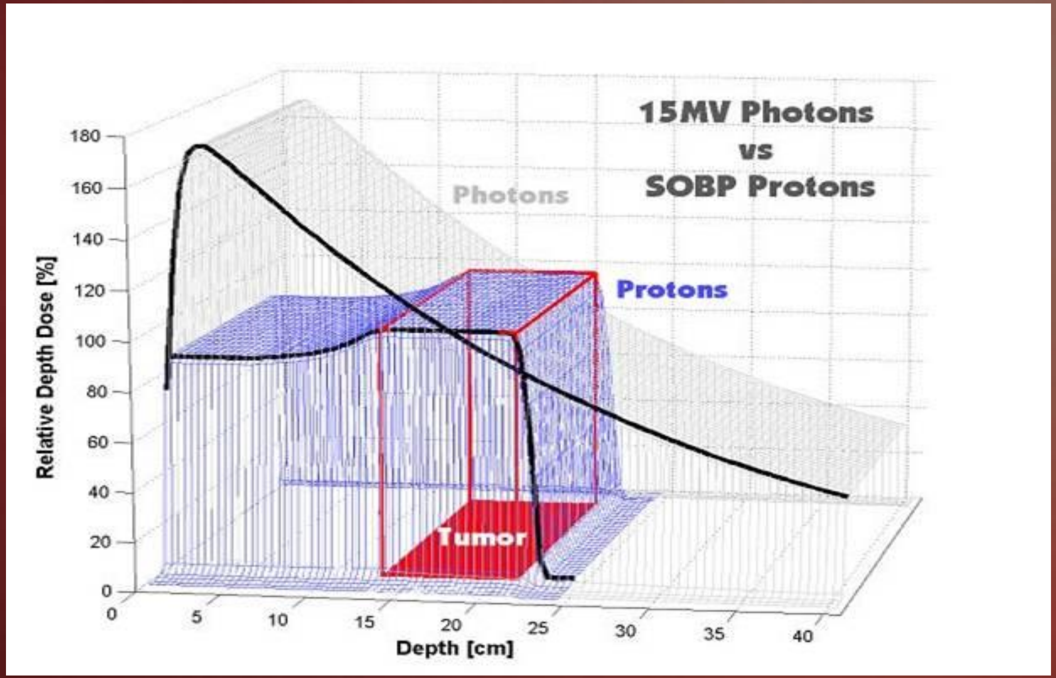
- Very steep dose rates around source
- High dose rate to the tumour and adjacent tissue and low dose further out to normal tissue
- Fewer side effects

PARTICLE THERAPY

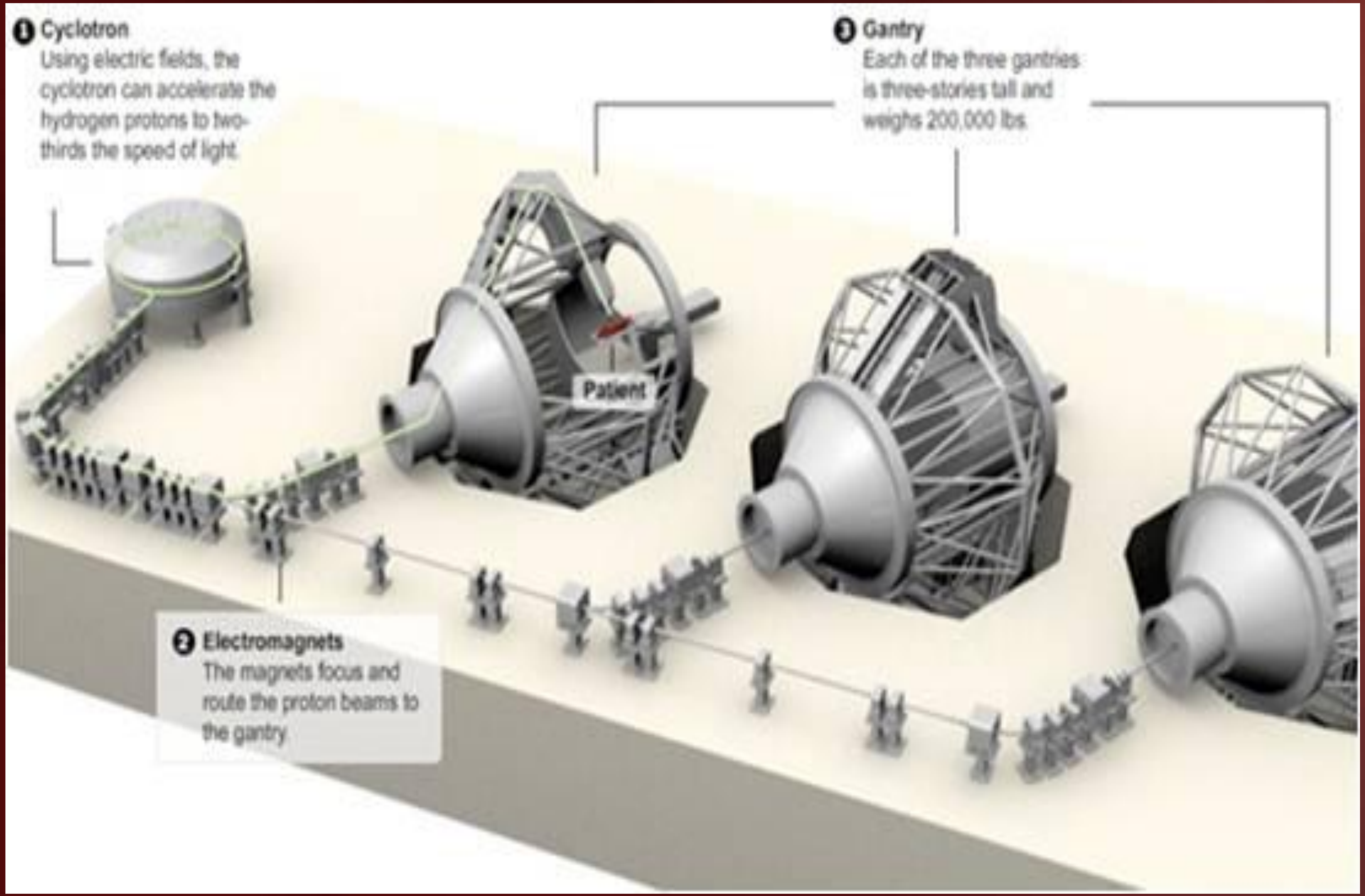
- High LET i.e. higher biological damage along its track or highly focused deposit of radiation (Bragg Peak)
- **Neutrons** :
  - Downside: not selective for cancer cells, therefore more damaging to normal tissue
  - Severe late side effects
  - EU + USA
- **Protons:** +highly localised, high peak in their beam, use of absorbing materials and manipulation of the beam=
- Similar action to x-rays
- Useful for inaccessible tumours i.e. of the eye, pituitary,
- Limitation: cost and technology required
- Use EU, USA and 1 centre in Clatterbridge in UK

PROTON TREATMENT





PROTON RADIOTHERAPY



Disadvantages

- Set up proton facility
- Cost(11/2 times more that LA)
- Training
- Problems with breakdown :1 accelerating structure
- Demands on immobilisation

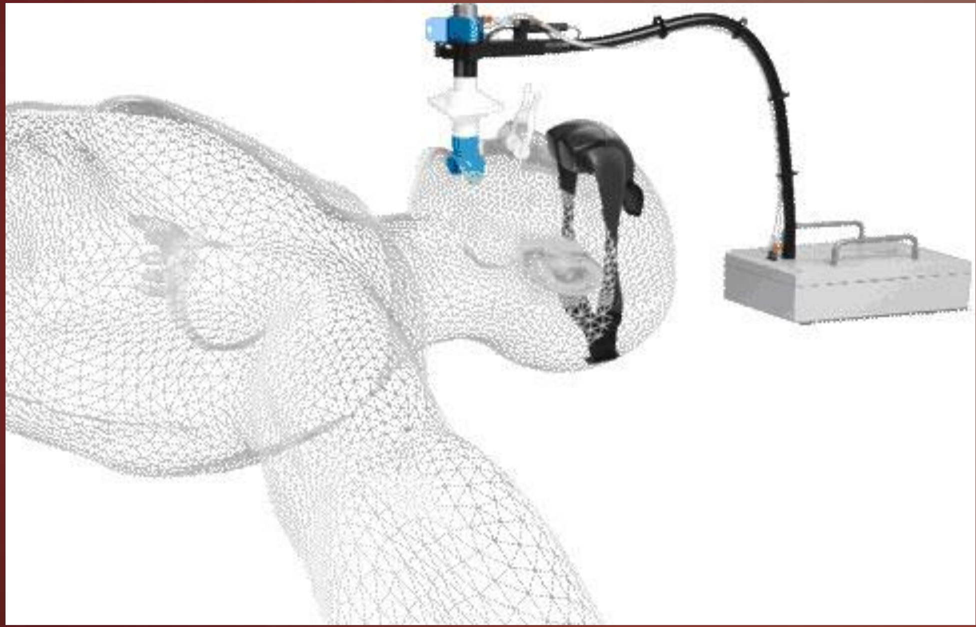
SIDE EFFECTS OF RADIOTHERAPY

- Acute Effects: Those which occur early (within the first few weeks to 3 months of treatment)
- Non-permanent/ Reversible
- Long term side effects are those that occur months after completion of a course of treatment
- Permanent/ Irreversible
- Most patients will experience a skin reaction and fatigue
- Side effects depend on the what area is being treated
- Management requires skills of Multi-disciplinary Team

SPECIAL TECHNIQUES

Respiratory Gating

- Lung and Gastrointestinal tumours
- Track breathing and location of tumour
- Used with IMRT



SPECIAL TECHNIQUES

- <u>Gamma Knife Radiosurgery</u>
- Malignant and benign conditions of the brain
- Patient fitted with an aluminium head frame with approximately 200 apertures through which radioactive cobalt-60 sources are focused at the target
- Area to be treated mapped out using MRI,CT,PET and angiography
- High dose can be delivered to the exact shape of the tumour with highly focused radiation beams, accurate to 0.5mm

SPECIAL TECHNIQUES

<u>Total Body Irradiation</u>

- Blood related cancers e.g. Leukaemia
- Part of a preparative regime for bone marrow transplant
- Used in conjunction with chemotherapy to destroy the patient s immune system and prevent rejection by the donor bone marrow cells
- Total body irradiation, shielding of lung to prevent lung damage
- Using a standard Linear Accelerator with extended distance to encompass entire patient in radiation field

RADIOTHERAPY DEPARTMENT

Tomotherapy

- Combination of two technology systems: Spiral CT scanner and Intensity Modulated Radiotherapy
- Treatment delivered slice by slice therefore the entire volume can be treated at once (rather that multiple beams)
- Cone beam capacity to take CT image prior to treatment for treatment matching to exact location of tumour
- Typical prostate treatment takes 3-5 minutes vs. 12-15 Linac
- 6 centres in UK

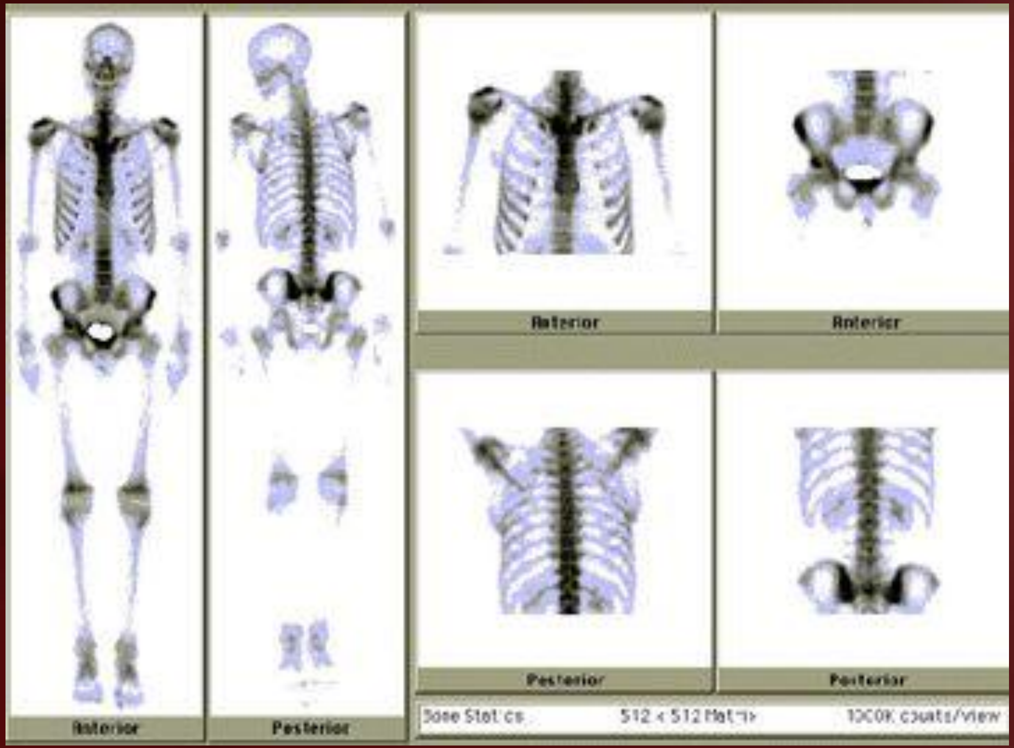
NUCLEAR MEDICINE

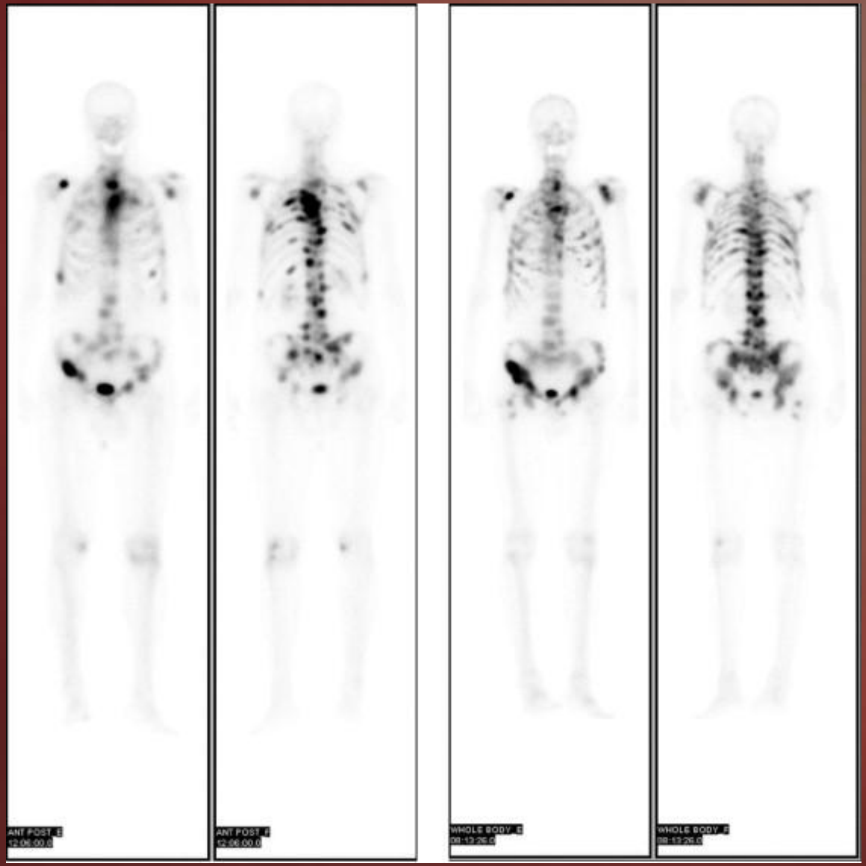
- Nuclear Medicine is the clinical application of unsealed radiation source
- Diagnostic, Localisation, Treatment
- Radiopharmaceutical : pharmaceutical is chemical substance that will selectively seek out the tumour cells that you want to locate. A radionuclide is added that will not interfere with the uptake
- Administered in-vitro or in-vivo (ingestion, inhalation, intravenous)
- Diagnostic: a gamma camera will show up hot spots (areas appear dark due to higher uptake of radiopharmaceutical, i.e.. With good blood supply or greater metabolic activity or appear as a cold spot=less activity

TECHNETIUM-99MM

- Half life is the time it takes for half the nuclei in an atom to decay
- Effective half life
- 1 / Teff =1/ Tphysical + 1/ Tbiological
- Tc 99M= T ½ =6 hours
- Short half life=scanning procedure data collected quickly low dose to patient
- Extracted by kidneys in Urine
- Unit of measurement in mCi
- 1mCI=37MBq

BONE SCAN TC-99M





NUCLEAR MEDICINE

- Treatment:
- Hyperthyroidism-Iodine-131
- Ablation therapy for carcinoma of the thyroid- Iodine-131
- Bone pain palliation- Stontium-89
- Treatment for Polycythaemia Ruba Vera -32P Sodium phosphate
- Non-Hogkins Lymphoma- Radioactive Monoclonal Antibodies-

NUCLEAR MEDICINE

Disadvantages:

- Radiopharmaceuticals used in treatment have a longer half life
- Longer in-patient stays in isolation
- Radiation exposure to staff
- Minimal family visits
- Expensive
- Long term effects -leukaemia

MEDICAL PHYSICS

- Physics continues to play a vital role in advancing radiotherapy
- Installation and commissioning of new equipment
- Maintenance and Quality Assurance checks of equipment – safe and fit for purpose
- Dosimetry and planning
- Radiation Protection and safety
- Work closely with the oncologists and radiation therapists in designing, planning and executing accurate and safe delivery of radiation treatments for our patients