Radioactivity
Ionizing radiation

Radioactivity

- Characteristic quality of unstable core of atoms, during which the core decays, forming new core and emitting ionizing radiation

Ionizing radiation

- Radiation, which directly or indirectly ionizes atoms of matter
- Particles : alpha, electrons, positrons, neutrons, protons, mesons
- Photon: gamma, X-rays

Radioactivity

- 1903 Henri Becquerel (1896)
- 1903 Marie Curie-Skłodowski
- 1935 Irène a Frédéric Joliot-Curie

Radioactivity

- Law of conservation of matter and energy
- Law of conservation of electric charge
- Law of conservation of nucleons
- Law of conservation of momentum

Radioactivity – Ionizing Radiation

- Alpha α
- Beta β
- Gamma γ

alpha radiation

- Particles of helium $_2He^4$ (so called helions)
- After the helion is emitted, core loses 2 neutrons and 2 protons
- A new atom core is created, and in the periodic table it is moved two spots to the left

- $_{86}Rn^{222} \Rightarrow {}_{84}Po^{218} + {}_2He^4$

beta radiation

- Formed by of electrons or positrons
- Two types β^+ and β^-
- β^+ decay- unstable nucleus with abundance of protons, proton is transformed to neutron, positron and electron neutrino
- $_{12}Mg^{23} \Rightarrow {}_{11}Na^{23} + e^+ + v_e$
- Weak interaction

beta radiation

- β^- decay - unstable nucleus with abundance of neutrons; neutron is transformed to proton, electron and a electron neutrino

- $_6C^{14} \Longrightarrow {}_7N^{14} + e^- + v_e$

- Weak interaction

gamma radiation

- No nucleus transformation
- Electro-magnetic radiation
- Nucleus emits abundant energy
- Usually accompanies other types of radiation

Natural radioactivity

- Spontaneously transforming nuclei, which can be found in nature

- Heavy elements
- Decay chains

Uranium	^{238}U	^{206}Pb	4n+2
Actinium	^{235}U	^{207}Pb	4n+3
Thorium	^{232}Th	^{208}Pb	4n
Neptunium	^{241}Pu	^{209}Bi	4n+1

Natural radioactivity

- Elements with lighter atoms
  - Created by interaction of cosmic radiation on nitrogen

  - Light elements
    - Tritium
    - Carbon ^{14}C

    - Proton radiation

Artificial radioactivity

- External intervention is needed
  - Particle bombardment
    - Protons
    - Deuterons
    - Alpha particles
    - Electrons (accelerators)
  - Chain reaction

Law of radioactive transformation

$$N_{(t)} = N_o . e^{-\lambda t}$$

$N_{(t)...}$quantity of not yet transformed nucleuses

$N_{o...}$quantity of nucleuses at the time o

λ...transformation constant

t....time

$$\ln \frac{N_t}{N_0} = -\lambda t$$

Activity

- Activity (A)
- Quantity of radioactive transformations in time
- Unit Bq (becquerel; s^{-1})

Transformation half-life

- Characteristic physical quantity
- Time, during which precisely one half of the observed cores decay
- Tf
- Transformation half-life can be seconds or even years long

Half-lives

- Transformation half-life Tf
- Biological half-life Tb – time, during which precisely one half of the observed cores is excluded from an organism
- Efective half-time Tef – time, during which the activity of radionuclide is decreased precisely by one due to the effect of the transformation and the exclusion
- $1/T_{ef} = 1/T_f + 1/T_b$

Interaction of radiation with matter

- Creation of secondary radiation (lower energy)
- Creation of free radicals
- Creation of heat
- Gradual energy loss of primary radiation particles (linear energy transfer)

Interaction of ionizing radiation with matter

- Interactions with electron cloud
- Interaction with nucleus

Interactions of ionizing radiation with electron cloud

- α, β radiation
  - Partial absorbtion of the radiation by matter
  - Electron excitation
  - With higher energy = ionization

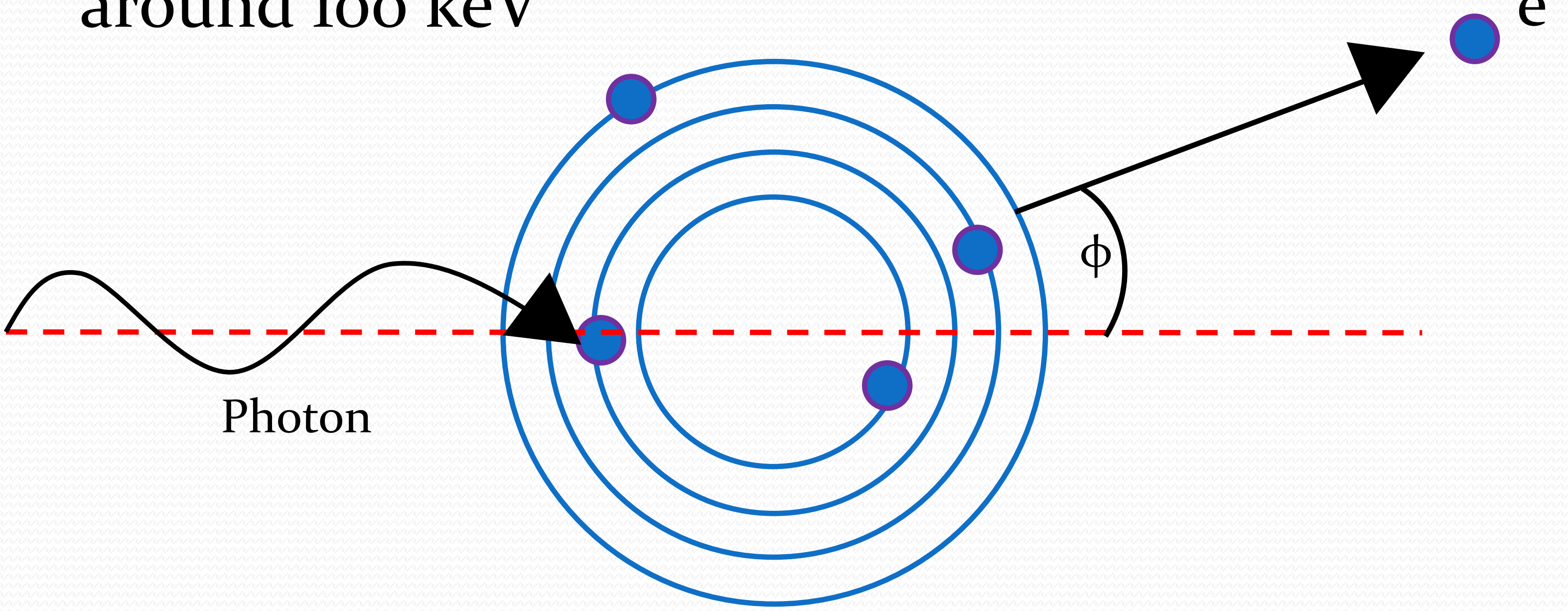
- α – excitation, ionization
- β – excitation, ionization, electron scattering, braking radiation

Interactions of ionizing radiation with electron cloud

- γ radiation interacts indirectly
  - Fotoelectric effect
  - Compton effect
  - Creation of electron – positron pairs

Interactions of ionizing radiation with electron cloud

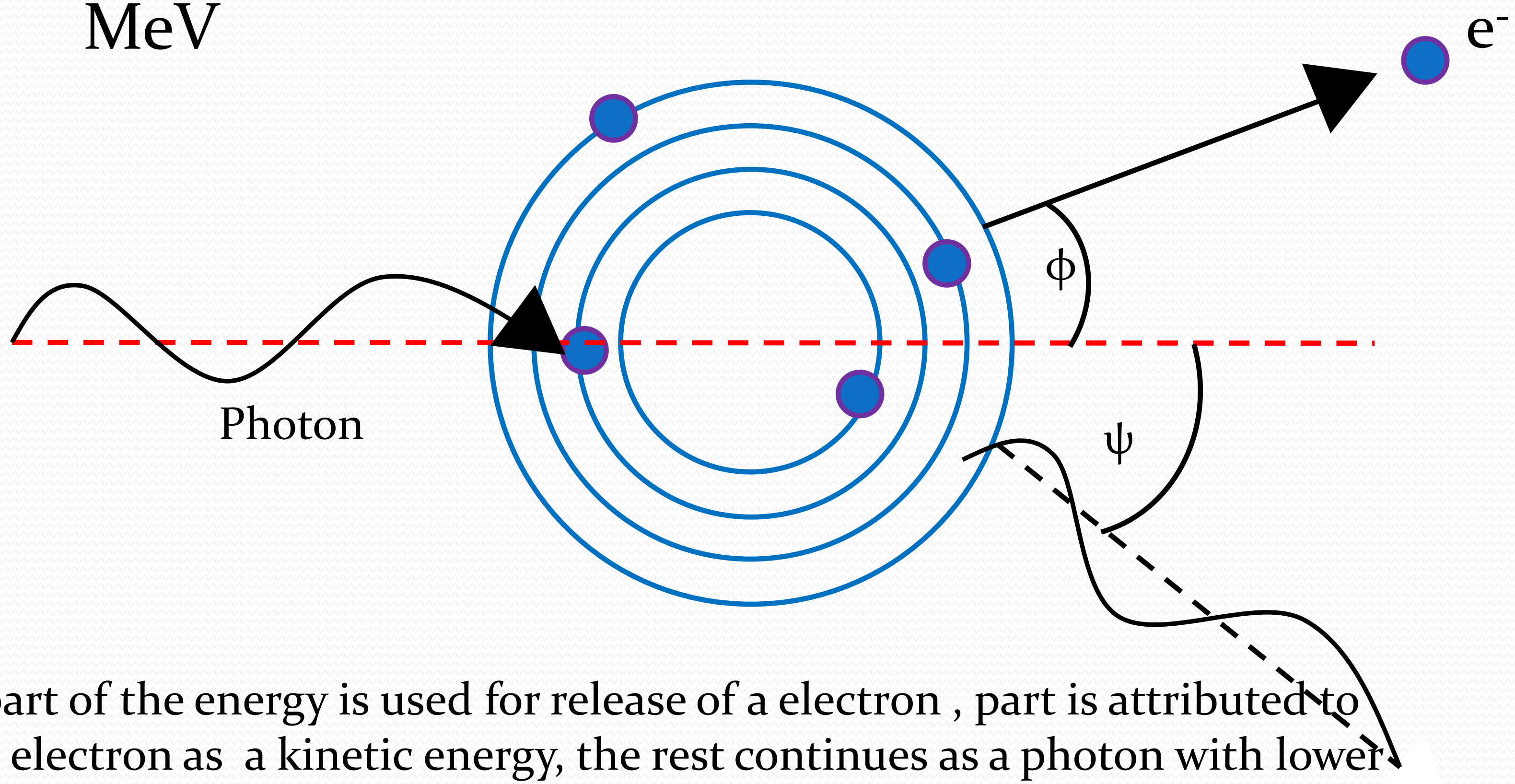
- γ radiation – fotoelectric effect– energetic values around 100 keV



A part of the energy is used for release of a electron and the rest is attributed to the electron as a kinetic energy

Interactions of ionizing radiation with electron cloud

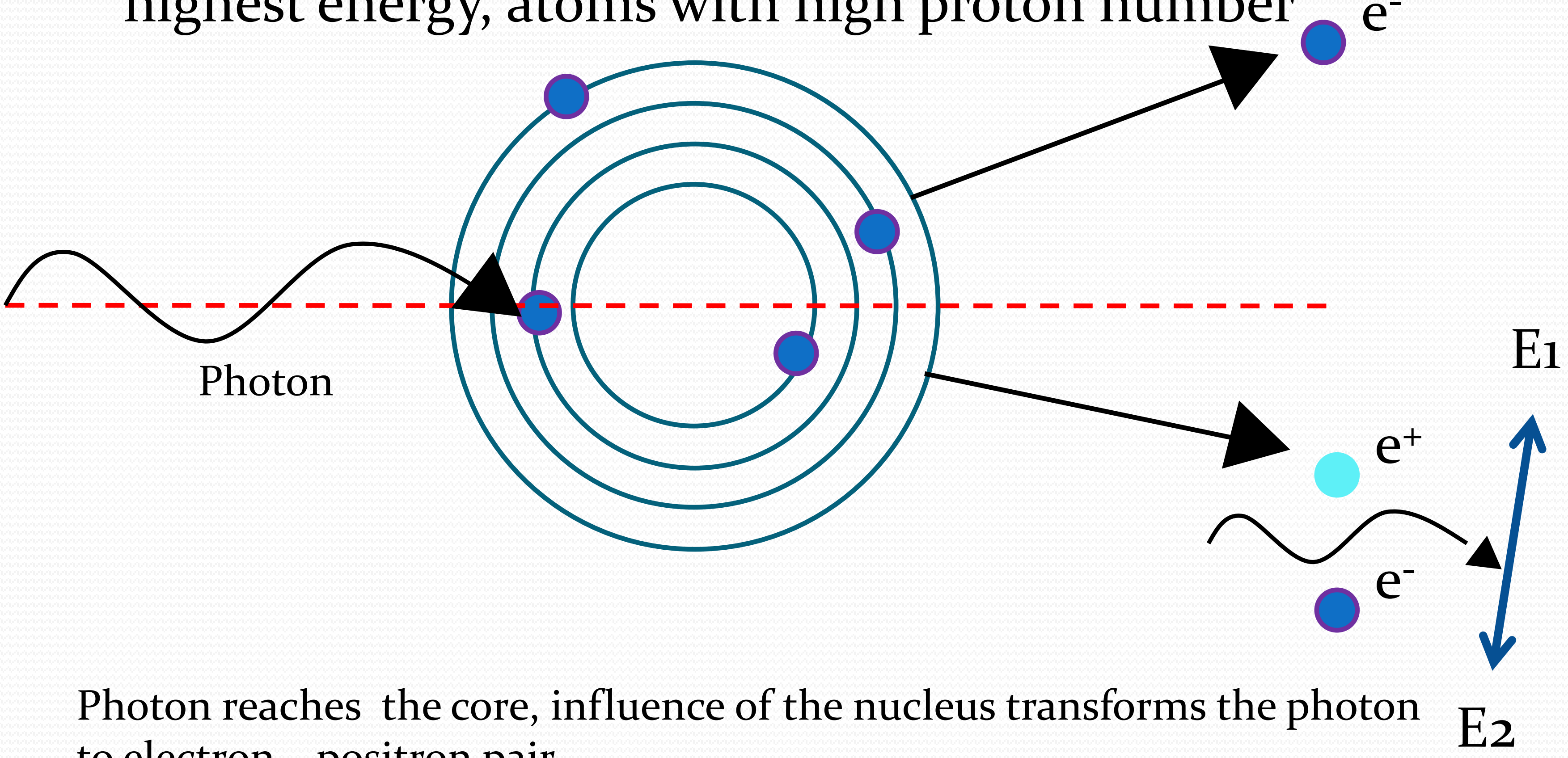
- γ radiation – Compton effect – higher energy 0,5 to 5 MeV



A part of the energy is used for release of a electron , part is attributed to the electron as a kinetic energy, the rest continues as a photon with lower energy

Interactions of ionizing radiation with electron cloud

- γ radiation – formation of electron – positron pairs – highest energy, atoms with high proton number



Photon reaches the core, influence of the nucleus transforms the photon to electron – positron pair

Interaction with nucleus

- Collision with target nucleus – transmutation – new element, can be stable
- α particles – synthetic reactions; natural alpha particles may react only with nuclei of light atoms

- Neutron radiation – less energy required, neutrons do not have to overcame potential barrier
  - Indirect ionization ((n, γ) new isotope is formed)

Interaction with nucleus

- Proton radiation ((p,n), (p,d), (p, γ) or deuterons ((d,p) (d,n))
- γ radiation – photo nuclear reaction; affected nucleus loses nucleons (n, 2n, p, α) energy of the radiation must be high enough to knock out a particle

Biological effects of ionizing radiation

Biological effects of ionizing radiation

- Phases
  - Physical
  - Physically – chemical
  - Chemical
  - Biological

Interaction with biological material

- 1) Direct effect
  - Direct cell absorption
  - Damaged or changed function
  - Tissue with low water content

Interaction with biological material

- 2) Indirect effect (radical theory)
  - Radiation splits electron pairs (creation of radicals)
  - Water radiolysis

excitation (*) $H_2O \rightarrow H_2O^* \rightarrow H\cdot + \cdot OH$ most toxic

ionization $H_2O \rightarrow H_2O^+ + e^-$

$H_2O^+ \rightarrow H^+ + \cdot OH$

$e^- + H_2O \rightarrow H_2O^- \rightarrow H\cdot + OH^-$

$e^- + O_2 \rightarrow O_2\cdot$

Interaction with biological material

- 2) Indirect effect (radical theory)

Radical reactions

$H\cdot + H_2O \rightarrow H_2 + \cdot OH$

$H\cdot + H\cdot \rightarrow H_2$

$OH + \cdot OH \rightarrow H_2O_2 \rightarrow H_2O + O$

$H\cdot + O_2 \rightarrow HO_2\cdot$

$H\cdot + HO_2\cdot \rightarrow H_2O_2$

Interaction with biological material

- 2) Indirect effect (radical theory)
  - Creation of reactive molecules H_2, H_2O_2...
  - Cells with high oxygen uptake are the most sensitive

Biological effects of ionizing radiation

- Of biggest concern is **damage to DNA**

- Damage of organism on several levels:
  - Molecular level
    - Molecular changes, lowering or loss of function
  - Subcellular level
    - Disruption of metabolical pathways
  - Cell level
    - Reduction of cell population

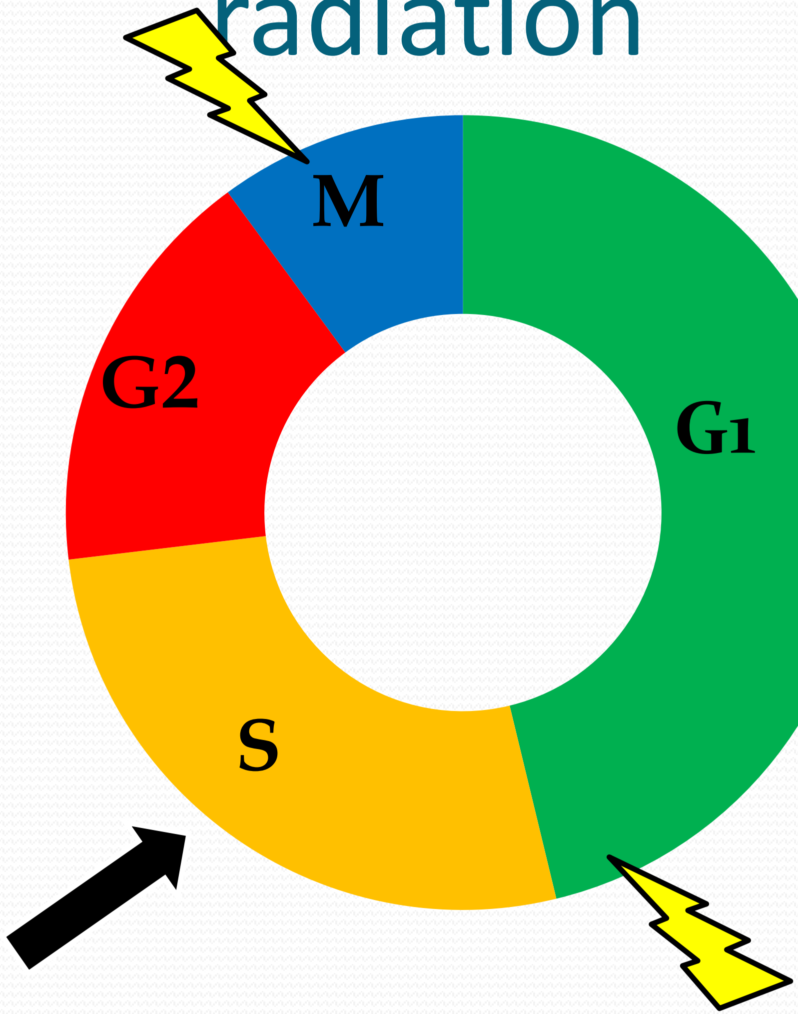
- => changes of the whole system

Biological effects of ionizing radiation

- Proliferating cells can experience these degrees of ionizing radiation damage:

- Temporary stoppage of proliferation
- Loss of proliferation
- Cell death

Biological effects of ionizing radiation



Damage by Ionizing radiation

- Stochastic effects – no threshold
  - Somatic effects (irradiated individual)
  - Hereditary (progeny)
  - Mutation
  - Probability of adverse effect is a linear function of dose (tumors)

Damage by Ionizing radiation

- Deterministic effects
  - Threshold
  - Acute radiation syndrom

Therapy of acute radiation syndrome

- Decontamination
- Iodine
- Contamination of GIT - laxatives
- Nausea and vomiting = more than 1,5 Gy
- Supporting therapy:
  - Antiemetics
  - Antibiotics
  - Infusions, blood cells
- Causal
  - Recovery of haematogenesis– cytokines, stem cells transplantation

Dosimetry

Dosimetry

- Exposure X – charge, which is gained by 1 kg of absorbing material (air) during passage of ionizing radiation ($C.kg^{-1}$)

- Exposure speed – exposure in time ($C.kg^{-1}.s^{-1}$)

- Absorbed dose – energy absorbed by 1kg of material; unit G – Gray ($J.kg^{-1}$)

$$D = \frac{E}{m}$$

Dosimetry

- Equivalent dose (H)
  - Represents effect on health

Gamma, x-ray, electron	Q = 1
Neutron	Q = 10
Alpha radiation	Q = 20

- H = D.Q.
  - Q = quality factor desribing the biological effect of the radiation
- unit sievert (Sv)

Detection of ionizing radiation

- Not detectable by human senses
- Detectors
  - Ionization
  - Excitation
  - Effects on photographic emulsion

Detection of ionizing radiation

- Ionization detectors
  - Based on ionization of gas in measuring chamber => gas becomes conductive, electric current can be then measured by electrodes

  - Ionization chamber
    - Static – measurement of radiation (exposition)
    - Impulse – measurement of radiating particles

  - Geiger –Muller tube

Detection of ionizing radiation

- Scintilation detectors
  - Some materials can excite their atoms in presence of ionizing radiation, followed by deexcitation => emitting photons – flashes (scintilation) NaI(Tl)
  - Emitted photon falls on photomultiplier = increasing the signal
  - Scintigraphs, gammacameras

Detection of ionizing radiation

- Photographic detection methods
  - Ionizing radiation causes blackening of photographic emulsion with intensity directly proportional to dosage
  - Personal film dosimeter

Protection against ionizing radiation

- Protection by time
- Protection by distance
- Protection by shading– lowers radiation exponentially

- Protection against contamination
  - Contamination external x internal

- Limits (workers vs standard population)

Ionizing radiation in therapy

Ionizing radiation in therapy

- Open emitters (radioactive drugs)
  - Free molecules for administration to human organism
  - Metabolic pathways
- For example: ^{131}I , ^{99}Te
  - examination of thyroid
  - Selective uptake
- $^{99m}TcO_4^-$ replaces ^{131}I, clean γ radiator with low energy, short half-life = better safety
- ^{99m}Tc-DMSA (DimercaptoSuccinic Acid)

  ^{99m}Tc-pentetreotid - examination of thyroid
- ^{18}F – cholin: prostate - PET/CT imaging
- ^{18}F – deoxyglucose (DFG): glucose metabolism - PET/CT imaging
- XOFIGO® - ^{223}Ra dichloride – prostate carcinoma metastasis in bones
- ^{111}In-Cl: antibodies tagging
- ^{111}In-pentetreotid : GIT tumors, feocytochroma, ganglioneuroma

Ionizing radiation in therapy

- Encased emitters
  - Radionuclides are encased in metal casing
  - Needles for application to tumours
  - Casings for insertion to body cavities
  - Insertion to organs (brachyotherapy)

  - Teletherapy (= irradiation from distance)
  - ^{90}Sr, ^{60}Co, ^{137}Cs

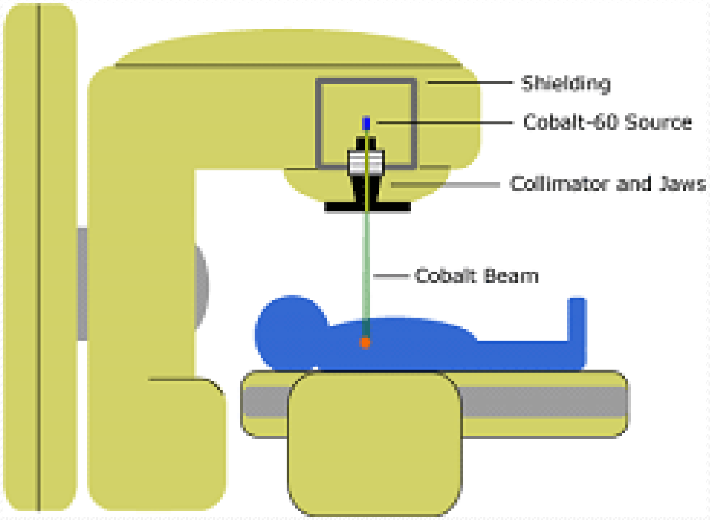
Ionizing radiation in therapy

Radiotherapy

- Selection of appropriate radiation device
  - Localization, dimension, radiosensitivity
- Tumor x healthy tissue
- Calculation of correct dose
- Radiation field

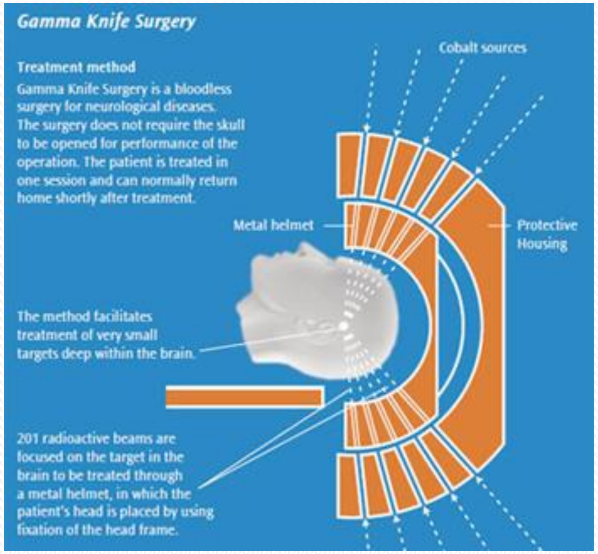
Ionizing radiation in therapy

- Cobalt (^{60}Co) and cesium(^{137}Cs) irradiators
  - depth radioteletherapy



Ionizing radiation in therapy

- Gamma knife – Lars Leksell 1951
  - Radiosurgery
  - Source of radiation: ^{60}Co
  - Gamma knife contains hundreds of radiation sources, rays meet in a focus => restricted lesion



Ionizing radiation in therapy

- Betatron – electron accelerator
  - Acceleration in magnetic field
- Linear accelerator– electron accelerators
  - Acceleration in electric field
- Usage
  - Accelerated particles themselves
  - Capturing of the radiation on wolfram tablet– creation of hard gamma radiation

Ionizing radiation in therapy

- Proton therapy
  - Cyclotrons – proton accelerators
  - Acceleration by ever changing electric field
  - Spiral trajectory (influenced by magnetic field
  - Proton therapy is less damaging to healthy tissue

Ionizing radiation in therapy

- Contraindication
  - Disintegration of tumour
  - Terminal conditions
  - Cachexia
  - Anemia

X-Ray

X-ray

- 1895 Wilhelm Conrad Röntgen

- Similar character as gamma radiation
- Can have similar energy or wavelenghts
- Gamma is from nucleus
- X-ray is energy coming from changes in electron cloud

X-Ray

- Characteristic X-ray
  - Fast electrons hit a metal electrode => handing over energy to electron in metal atom => excitation, ionization => return to former energetic level = emitting the characteristic X-Rays
- Braking (deceleration) X-Ray
  - Electrons passing by a target (atom) are slowed down, their trajectory changes, abundant energy is emitted in form of braking X-Ray

Usage

- Skiascopy
- Skiagraphy
- Computing tomography (CT)