Radiation Detection and Measurement

Lecture 2

Chapter 1: Radiation Sources

Sources of electromagnetic radiation: Beta Decay

- Includes β^-, β^+ (positron) and electron capture (competes with β^+)
- γ's are emitted after particulate radiation, where daughter nucleus is left in an excited state
- γ's are quasi-mono energetic and have a defined energy equal to the difference between the excited and stable states
- General transition reactions

Sources of electromagnetic radiation: Beta Decay

$$\beta^- : n \rightarrow p^+ + e^-$$

$$\beta^+ : p \rightarrow n + e^+$$

$$ec : p + e^- \rightarrow n$$

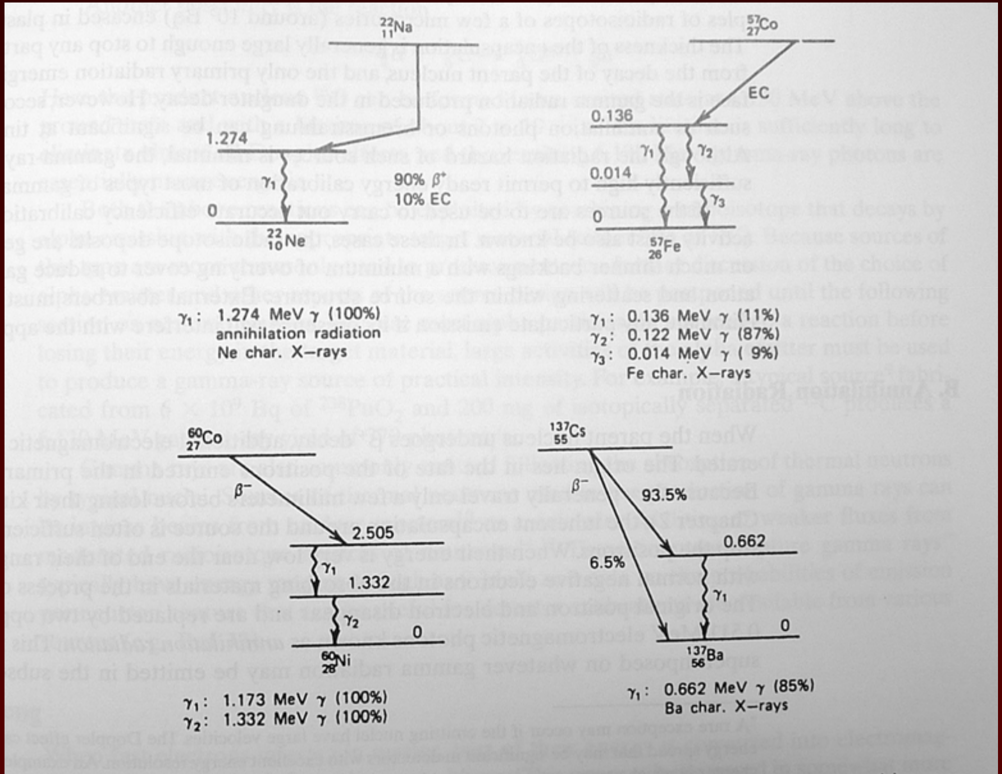

Figure 1.5 Decay schemes for some common gamma reference sources. Only major transitions are shown. The energies and yields per disintegration of X- and gamma rays emitted in each decay are listed below the diagram. (Data from Lederer and Shirley.[1])

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Sources of electromagnetic radiation: Annihilation

- after a β^+ decay, the β^+ particle will only travel a short distance (small MFP)
- when low on T the β^+ will find an electron and the two will combine to form two γ's with E = 511 keV each
- thus there is a threshold on β^+ emission of 1.2 MeV (to allow for both photons)

Sources of electromagnetic radiation: following a nuclear reaction

- i.e. $^{4}_{2}\alpha + ^{9}_{4}Be \rightarrow ^{12}_{6}C^{*} + ^{1}_{0}n$
- the de-excitation of $^{12}_{6}C^{*}$ will be in the form of a γ
- also found after the absorption of thermal neutrons

Sources of electromagnetic radiation: bremsstrahlung

- produced when fast electron interact with matter
- fraction of energy converted to brems is proportional to the energy of the electron
- a monoenergetic group of electron produce a spectrum of γ's
- found in x-ray tubes, β particles, electrons in accelerators, cosmic rays

Sources of electromagnetic radiation: bremsstrahlung

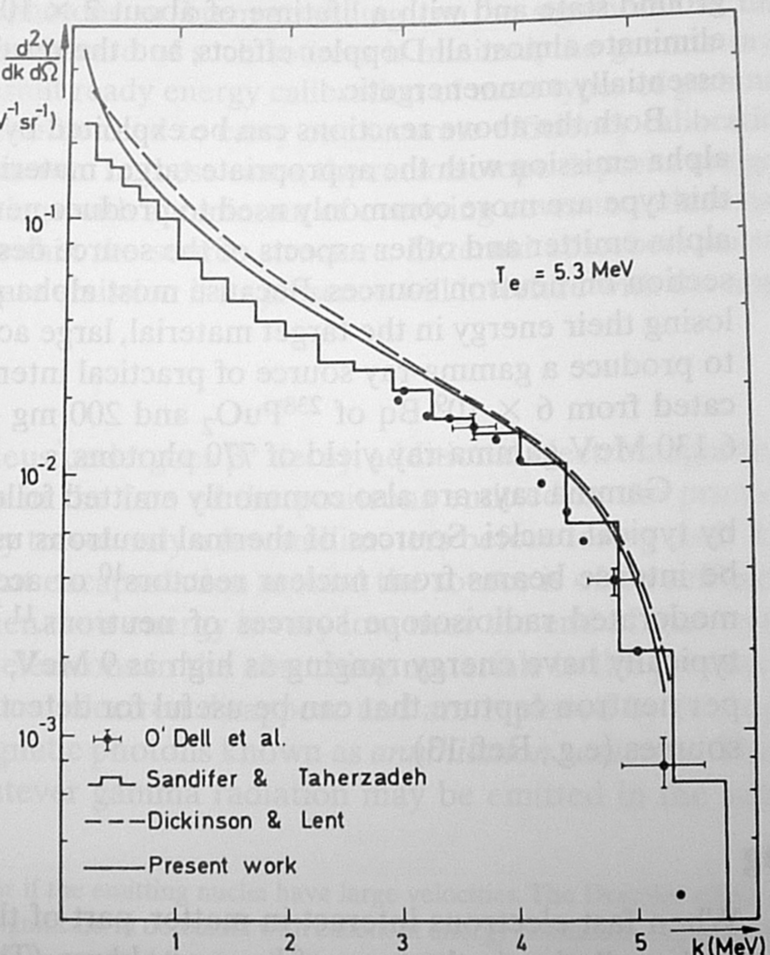

Figure 1.6 The bremsstrahlung energy spectrum emitted in the forward direction by 5.3 MeV electrons incident on a Au-W target. A 7.72 g/cm^2 aluminum filter also was present. (From Ferdinande et al.[14])

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Sources of electromagnetic radiation: bremsstrahlung

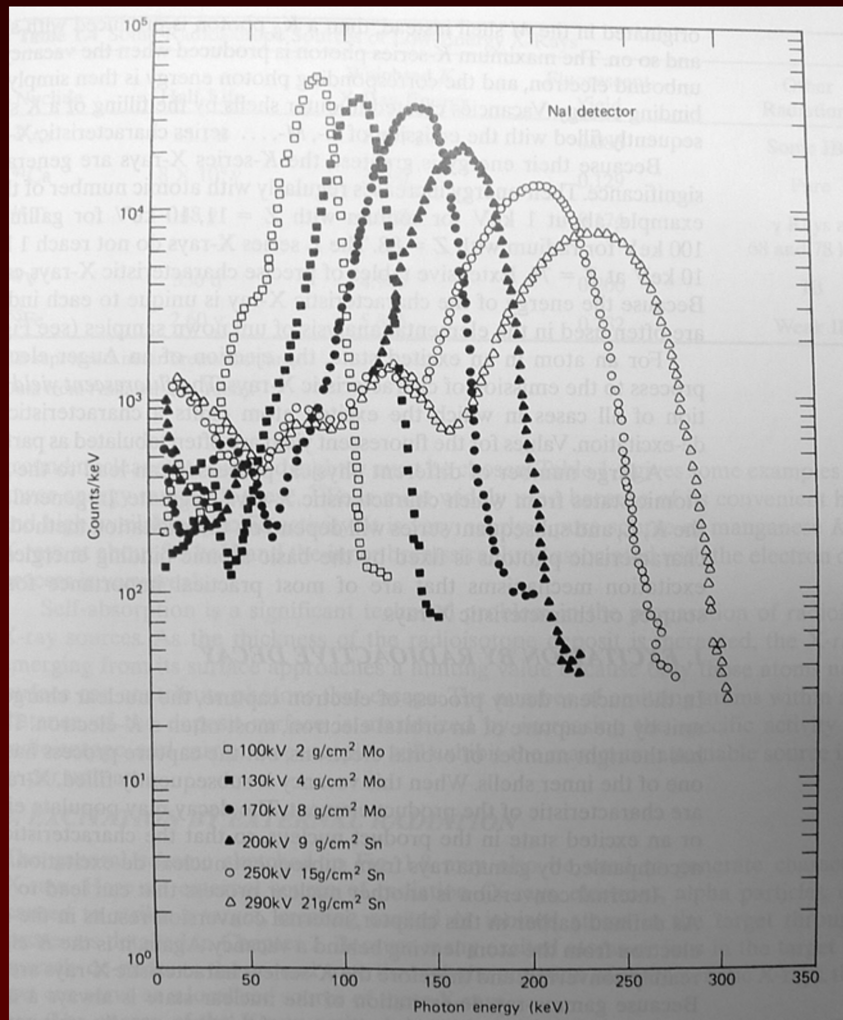

Figure 1.7 Examples of measured pulse height spectra [using a NaI(Tl) scintillator] after filtrat an X-ray tube output using the indicated absorbers and tube voltages. (From Storm et al.[15])

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Sources of electromagnetic radiation: characteristic x-rays

- classified by the shell with a vacancy being filled in spectroscopic notation
- i.e. K_α is the energy emitted from a vacancy filled in the K shell from an electron in the L shell
  - K_β would be an electron from the m shell
  - L_α is a vacancy filled in the L shell from an electron in the M shell, etc.
- X_α will have less energy than X_β (higher shell, more E)
- Fluorescent yield is the fraction of all cases in which the excited atom emits a characteristic γ in its de-excitation

Characteristic x-rays: Excitation by radioactive decay

- E.C. : the nucleus captures an electron (generally a K shell) leaving a K shell vacancy
- I.C. : the nucleus emits energy which ejects an electron, leaving a vacancy
- Table 1.4 lists some low energy x-ray sources

Characteristic x-rays: Excitation by external radiation

- an external radiation strikes a target creating ionized atoms (sources; x-rays, electron, α^{2+})
- target will determine energies of characteristic radiation, low Z- soft, high Z- harder
- In all cases the energy of the sources must exceed the energy of the γ's you are trying to produce.
- X-ray fluorescence: where x-ray gammas interact with the target (generally through photoelectric absorption) and emit a characteristic x-ray of the target
- α^{2+} particles are a convenient way to excite a target and keep the spectrum relatively free of brems. contamination, since they tend to not decay through electron modes and have little γ contributions of their own, see table 1.5 for the branching ratios of two common sources ^{210}Po & ^{244}Cm.

Characteristic x-rays: Excitation by external radiation

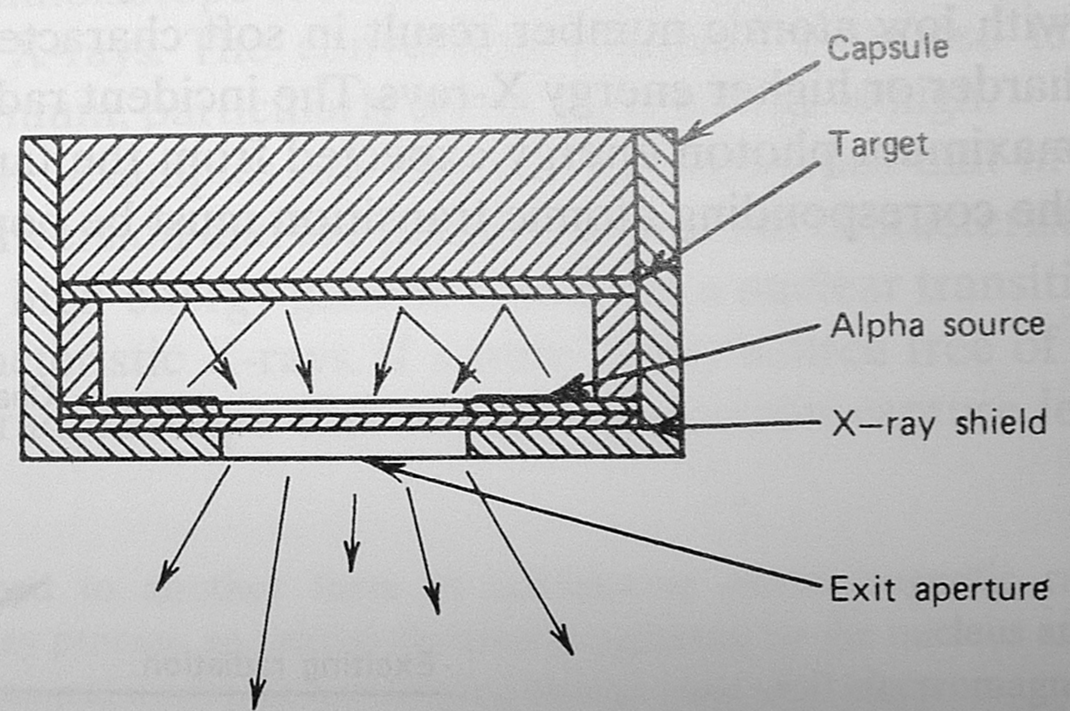

Figure 1.9 Cross-sectional view of a compact source of characteristic X-rays wh
ticle excitation of a target. (From Amlauer and Tuohy.[17])

Sources of electromagnetic radiation: synchrotron

- energetic electron are bent into circular orbits, where the change in momentum (direction changes) causes the beam to lose some energy during each cycle.

- Allows for highly mono- chromatic beams, with monochromators, with a wide energy range ~ eV-10^4 eV

Neutron sources: spontaneous fission

- most common is ^{252}Cf producing ~ 3.8 neutrons on average and 9.7 γ's
- the spectrum of neutrons is governed by:

$$\frac{dN}{dE} = E^{1/2} e^{-E/T}$$, with T = 1.3 MeV

Neutron sources: radioisotope (α,n) sources

- (α,n) refers to the incident particle & resultant particle in this case $\alpha^{2+} + X \rightarrow Y + {}_{0}^{1}n$
- ${}_{2}^{4}\alpha + {}_{4}^{9}Be \rightarrow {}_{6}^{12}C + {}_{0}^{1}n$, this reaction produces a maximum neutron yield (irradiating Be with α) , Q value = +5.71 MeV
- All the α emitters of practical interest are actinide elements and a stable metal of the actinide can be formed by MBe_{13}, where M is the actinide element
- this metallurgical combo allows the α's to interact with the Be nucleus without intermediate energy loses

Neutron sources: radioisotope (α,n) sources

Table 1.6 shows the characteristics of several MBe_{13} sources

- ^{239}Pu/Be is the most widely used but ^{241}Am/Be is an alternative
- when used for calibration, caution must be taken to account for impurities which may have shorter $T_{1/2}$, and α emitting daughters; this may lead to an increase in the n yield

Neutron sources: photoneutron sources

- Photoneutron emitters are sources that emit neutrons after absorbing γ's

$$ {}^{2}_{1}H + h\nu \rightarrow {}^{1}_{1}H + {}^{1}_{0}n \qquad Q = -1.66 \text{ MeV} $$

$$ {}^{9}_{4}Be + h\nu \rightarrow {}^{8}_{4}Be + {}^{1}_{0}n \qquad Q = -2.226 \text{ MeV} $$

- Having (-Q) means hv ≥ Q to allow the reaction

Neutron sources: photoneutron sources

- For γ's with more than this minimum, the energy of the neutron can be calculated from:

$$E_n(\theta) \cong \frac{M(E_\gamma + Q)}{m+M} + \frac{E_\gamma[2mM(m+M)(E_\gamma + Q)]^{1/2}}{(m+M)^2}\cos\theta$$

Where

θ is the angle between the γ and n

E_γ is the γ energy

M is the mass of the recoil nucleus x c^2

m is the mass of the neutron x c^2

Neutron sources: reactions from accelerated particles

$$D - D: {}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n$$ Q = 3.26 MeV

$$D - T: {}_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n$$ Q = 17.6 MeV

There are a number of the other charged particle reactions with (-Q's), but these require an accelerator to allow the reaction.

Aside: This is one of the only ways to get (^{3}He) which is important for cooling applications