Radiological Sciences @ OUHSC

# Radiation Detection and Measurement

Lecture 1

Chapter 1: Radiation Sources

# Radioactivity

$$\left.\frac{dN}{dt}\right|_{decay} = -\lambda N$$

- where *N* is the number of radioactive nuclei and *λ* is the decay constant

$$1Bq = 2.703 \times 10^{-11}\,Ci$$

$$1Ci = 3.7 \times 10^{10}\,Bq$$

# Specific Activity (sa)

$$sa = \frac{activity}{mass} = \frac{\lambda N}{NM / A_v} = \frac{\lambda A_v}{M}$$

- *M*: molecular weight of sample
- $A_v$: Avogadro's # = 6.02 x 1023 particles/mole
- *λ* = decay constant (= ln 2/ T1/2)

# Carrier Contamination

- radioisotopes tend to be diluted in larger concentrations of stable nuclei; and thus are not carrier-free
- for sources with high self absorption, one requires high specific activity to maximize the number of radioactive nuclei in a given thickness
- high *sa* is acquired from samples with large decay constant

# Energy

- eV is defined as the kinectic energy gained by an electron ($e^-$) by its acceleration through a potential difference of 1V
- for ionizing radiation keV & MeV are the magnitudes of interest
- # of charges accelerates through potential multiplies energy;
- $\alpha^{2+}$ through 1000V = 2 keV
- SI unit is joule [J]; 1eV = $1.602 \times 10^{-19}$ J
- Energy and frequency of quanta (photon)

# Photon Energy

$$E = h\nu$$

- *h* : planck's constant
  - ( 6.626 x 10-34 J·s, 4.135 x 10-15 eV·s)
- $\nu$ : frequency

$$\lambda[m] = \frac{1.240\times10^{-6}}{E[eV]} \Rightarrow \frac{1.240}{E[keV]} = \lambda[nm]$$

# Fast electron sources: $\beta^-$

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \overline{\nu} $$

- *X*, *Y* are the initial and final nuclear species and is the anti neutrino (lepton conservation)
- anti-neutrino and neutrino's have a small interaction probability with matter, we consider them undetectable
- end point is defined: average energy is 1/3 $E_{peak}$



Radiological Sciences @ OUHSC

# Fast electron sources: β-

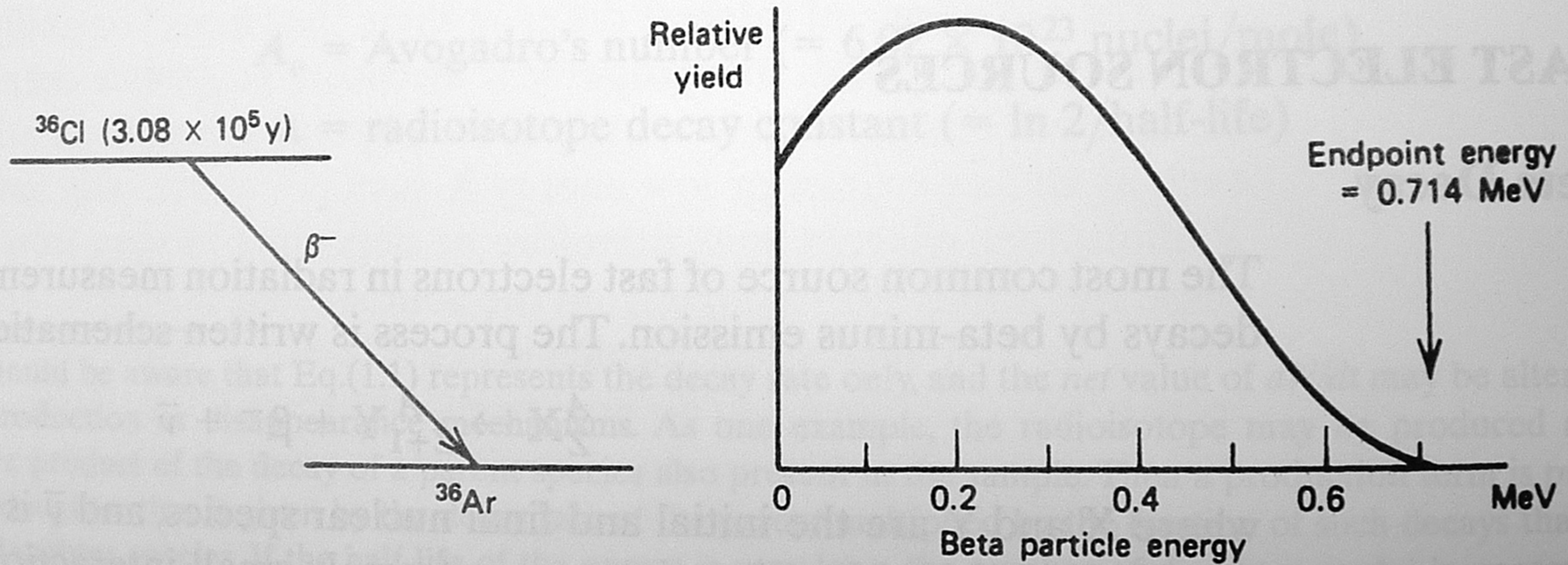



**Figure 1.1** The decay scheme of $^{36}$Cl and the resulting beta particle energy distribution.

# Fast electron sources: Internal Conversion (IC)

$$E_{e^-} = E_{ex} - E_b$$

- starts with de-excitation of parent species (often $\beta^-$ decay), nucleus
- emission of $\gamma$-particle ($E_{ex}$) which interacts with an internal shell electron through transfer
- the electron then is ejected at $E_{e-}$ where $E_b$ is the binding energy of the shell

I.B. Rutel

# Fast electron sources: Auger electron

- similar to IC only the energy originates from the electron shells not the nucleus
- a preceding process leaves a vacancy
- the resulting x-ray may leave the atom or transfer energy to outer electron, x-ray is characteristic and monochromatic
- the release of the outer electron is an Auger electron

# Heavy Charged Particle Sources: Alpha Decay

$$ {}_{N}^{A}X \rightarrow {}_{N-2}^{A-4}Y + {}_{2}^{4}\alpha $$

- *α* particles appear in quasi mono energetic groups
- these groups are produced due to the requirement of conservation of angular momentum between wave functions for the initial and final nuclei
- generally, this leaves the daughter nuclei in some excited state, where a $\gamma$ decay will shortly follow to de-excite the daughter to the ground state
- this requirement produces a unique Q value and thus several peaks, characterized by Q

# Heavy Charged Particle Sources: Alpha Decay Energy

$$m_x c^2 = m_{x'} c^2 + T_{x'} + m_\alpha c^2 + T_\alpha$$

$$(m_x - m_{x'} - m_\alpha) c^2 = T_{x'} + T_\alpha = Q$$

CE

$$p_\alpha = p_{x'}$$

CM

Assume E~5 Mev (non-relativistic), so $T=p^2/2m$

$$2m_\alpha T_\alpha = 2T_{x'} m_{x'}$$

$$T_{x'} = T_\alpha (m_\alpha / m_{x'})$$

$$T_\alpha = Q - T_{x'} = Q - T_\alpha (m_\alpha / m_{x'})$$

$$T_\alpha = Q / (1 + m_\alpha / m_{x'})$$

I.B. Rutel

Radiological Sciences @ OUHSC

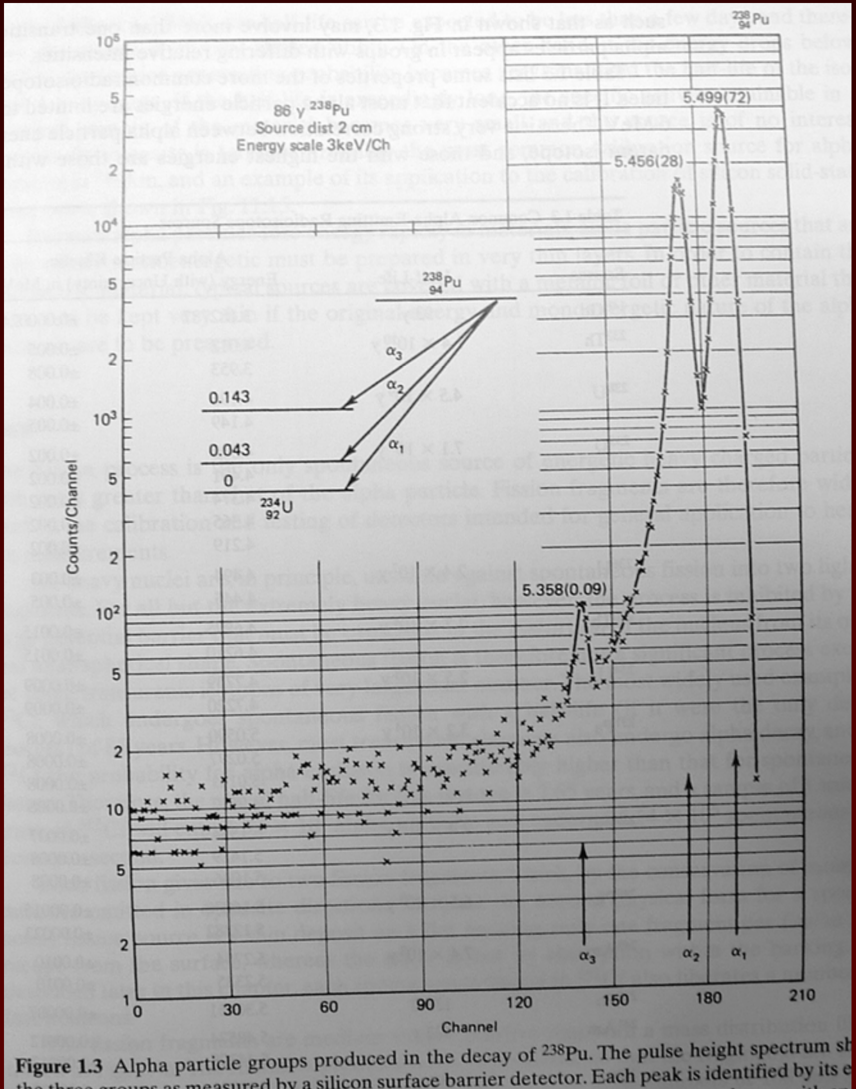
# Heavy Charged Particle Sources: Alpha Decay Energy

$$\therefore T_\alpha = Q/(A/A-4) = Q(A-4)/A$$

Typically, the alpha carries ~98% of the energy, although 2% of 5 MeV = 100 keV in the recoil nucleus

The nucleus can then escape from surface and continue to radiate

# Heavy Charged Particle Sources: Alpha Decay Spectrum




I.B. Rutel

# Heavy Charged Particle Sources: Spontaneous Fission

- this will only occur when Q > 0, thus there is free energy from the charge in rest mass and promotes a spontaneous reaction
- this is not significant, except in the transuranic isotopes with a large mass #
- this process of fracturing results in fragments of medium weight positive ions with a mass distribution shown in fig 1.4a
- fragments fall into clusters of “light group” (~ 108) and “heavy group” (~143)
- Fragments also have T with a bimodal distribution where higher T is associated with lighter group and lower T with heavy group.

# Heavy Charged Particle Sources: Spontaneous Fission

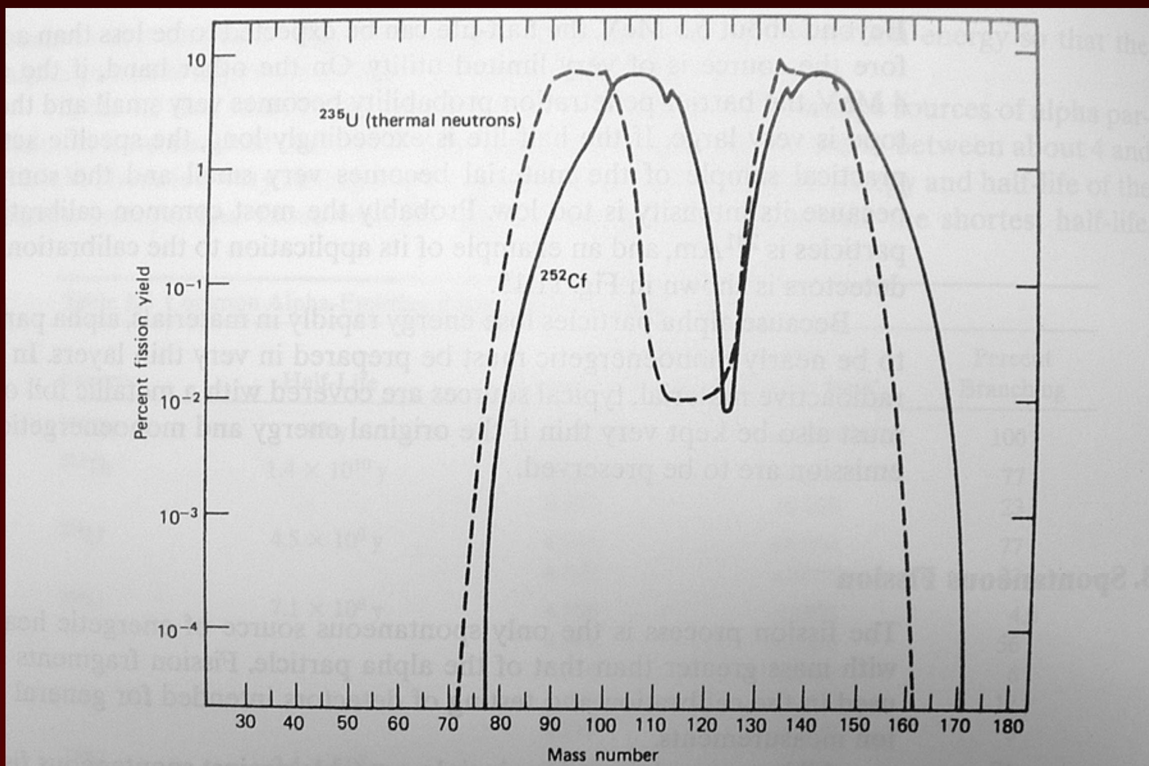



**Figure 1.4*a*** The mass distribution of $^{252}$Cf spontaneous fission fragments. Also shown is the corresponding distribution from fission of $^{235}$U induced by thermal neutrons. (From Nervik.[4])

- Mass distribution for $^{235}$U and $^{252}$Cf

# Heavy Charged Particle Sources: Spontaneous Fission

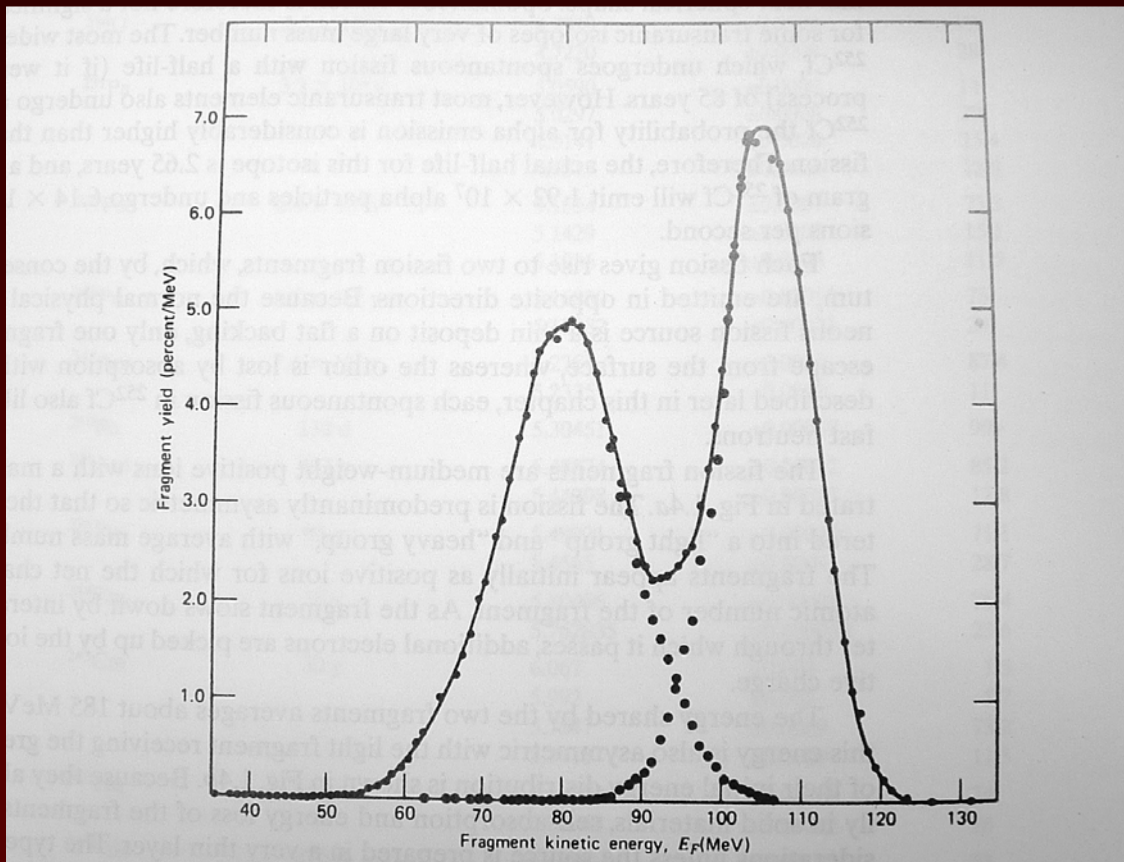



**Figure 1.4*b*** The distribution in kinetic energy of the $^{252}$Cf spontaneous fission fragments. The peak on the left corresponds to the heavy fragments, and that on the right to the light fragments. (From Whetstone.[5])

- Kinetic energy distribution for 252Cf



Radiological Sciences @ OUHSC