Week 13, Lecture 1 – Interaction of Radiation

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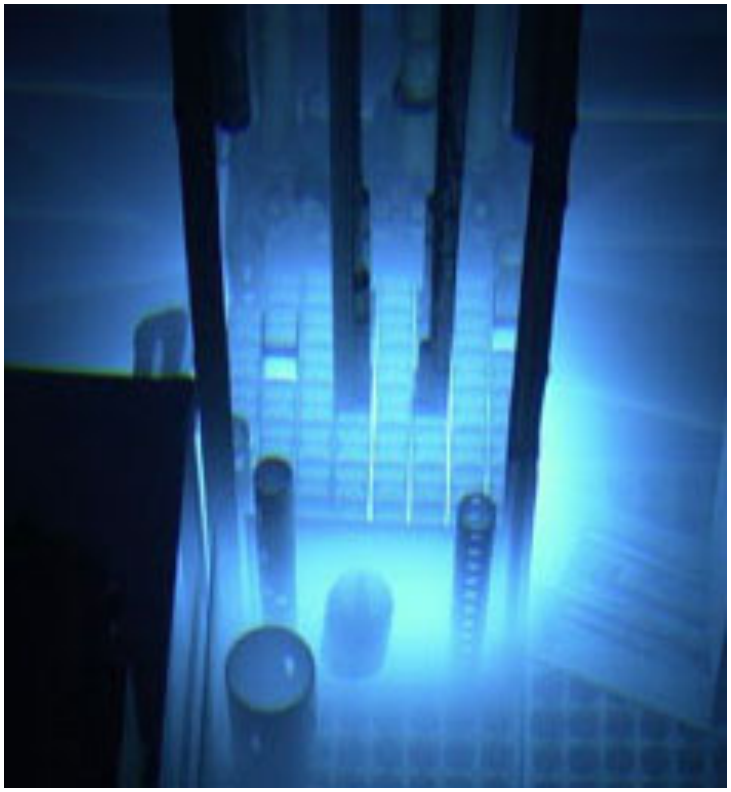
Interaction of Radiation with Matter

-- Penetration/absorption of charged particles
--- heavy ions
--- electrons
-- Penetration/absorption of neutral particles
--- gamma rays
--- neutrons

8th Homework due Today



Radiation Transport at UofM reactor

Classes of Radiation

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	zero mass	“low” mass	“high” mass
Neutral	Gamma rays (photons)	Neutrinos	Neutrons
Charged		Electrons +/-	Massive Charged Particles Muons … Nuclei

“Force”
Electromagnetic
Coulomb
Strong (Nuclear)

Except neutrons, these particles interact *primarily* with the electrons in materials that they enter … we are interested in those that are energetic enough to ionize the materials.

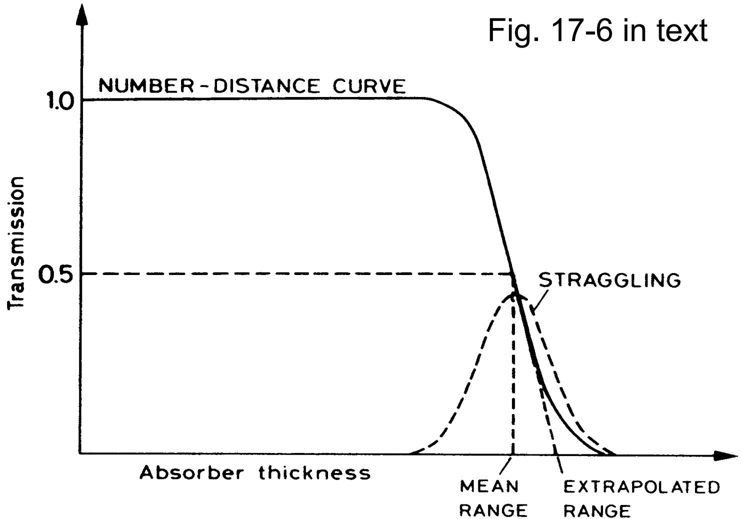
The coulomb interaction has an infinite range, thus charged particles interact with a large number of electrons and a moving charged-particle continuously slows down until it stops. This process creates a host of ion pairs with a variety of excitation energies.
A photon (uncharged) can only “collide” with one electron and the interaction creates a moving electron and a cation essentially at rest.
Finally, neutrons only collide with nuclei and are detected through the secondary products of nuclear reactions.

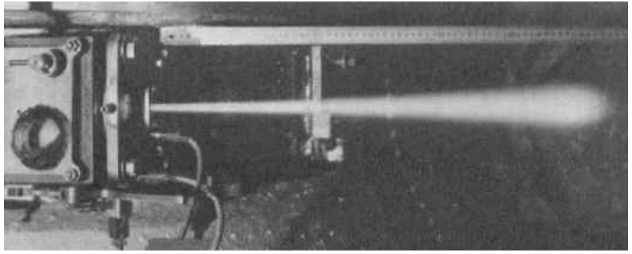
E.g, solid Silicon:

Interaction of massive C.P. with Matter –1–

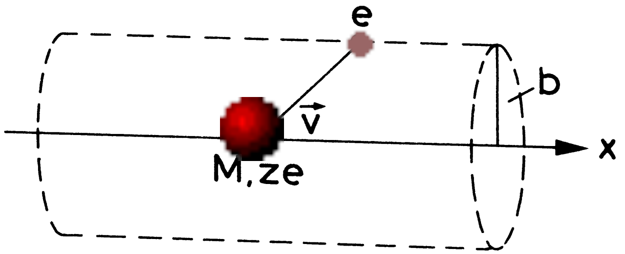
The massive particles can be expected to interact with the electrons in the bulk material but the very large ratio of masses (m_p/m_e ~ 1800) means that the ions will travel on straight lines until the end, continuously slow down, and finally stop at some point after a huge number of interactions.

Fig. 17-6 in text





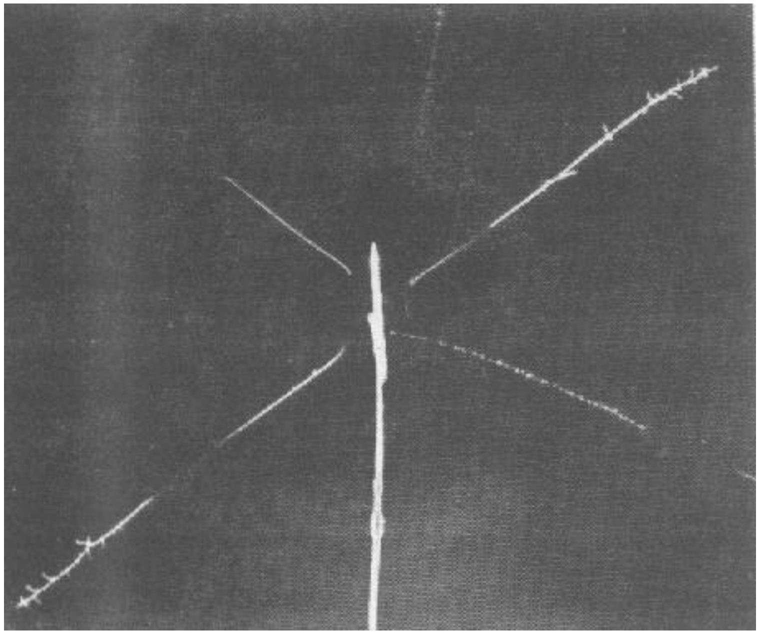
Deuterons in air from:
A.K. Solomon, "Why Smash Atoms?" (1959)

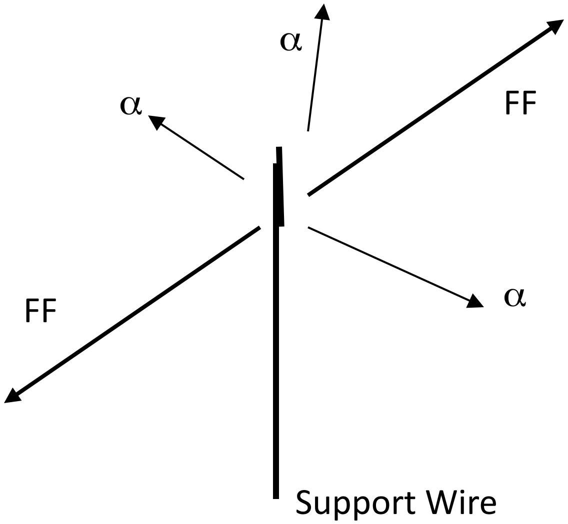


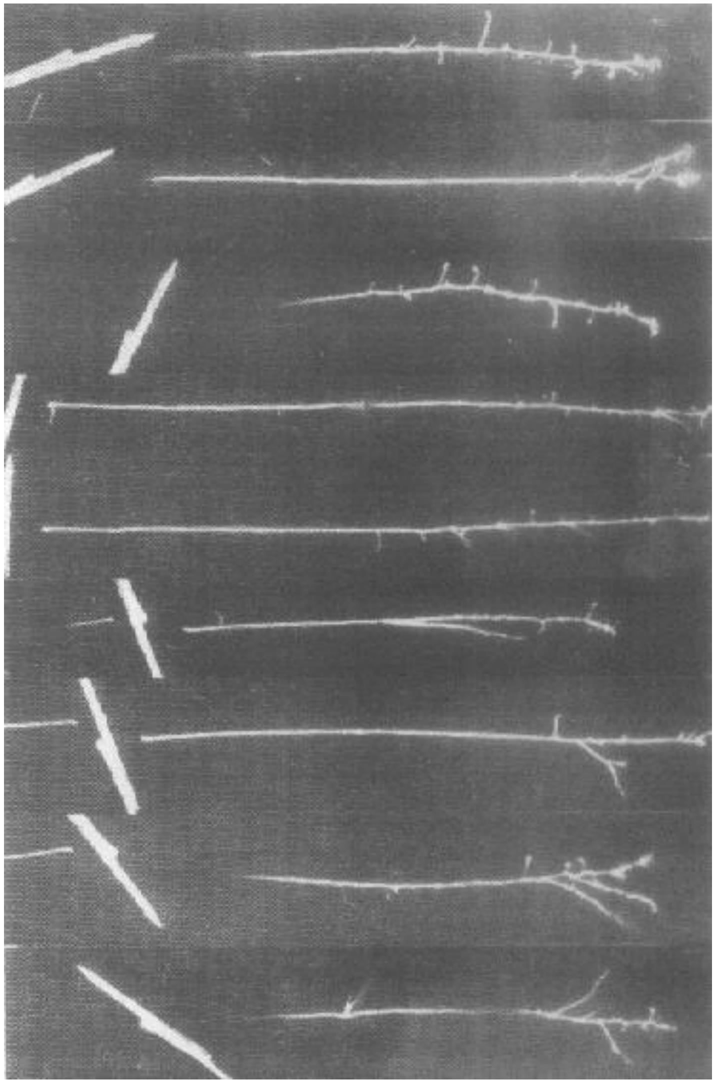
Similar to Fig. 17-2 in text

We can expect that the ion <u>intensity</u> remains essentially constant with depth until the end of the range when the ions all come to rest. On the other hand the kinetic energy of the ion will drop continuously in tiny increments until it stops. In a single collision the energy lost: $\Delta E(b) = [\ \mathrm{Impulse}(b)\ ]^2 / m_e$

Cloud Chamber Images of ^{252}Cf (α & FF)







From: http://www.lateralscience.co.uk/cloud/diff.html

Interaction of massive C.P. with Matter –2–

Rate of energy loss, dE/dx, for a heavy charged particle is called the stopping power and it is made of three terms. The electronic stopping is the most important, the nuclear reaction part is generally very small, and the nuclear-atomic part is only important at the end of the range (misnomer in my opinion).

$$\frac{-dE}{dx} = S_{electronic} + S_{\substack{nuclear\\reaction}} + S_{\substack{nuclear\\atomic}}$$

Bethe-Bloch Eq.

$$\frac{-dE}{dx} = S_{elecronic} = 4\pi r_e^2 m_e c^2 \left(\frac{q^2}{v^2}\right) Z_{Tar}\rho_{Tar}\left(\ln\left[\frac{2m_e c^2\beta^2}{I_{Tar}}\right] - \ln[1-\beta^2] - \beta^2\right)$$

$$\frac{-dE}{dx} \propto K\frac{Aq^2}{E}$$

Eq. 17-14 in text

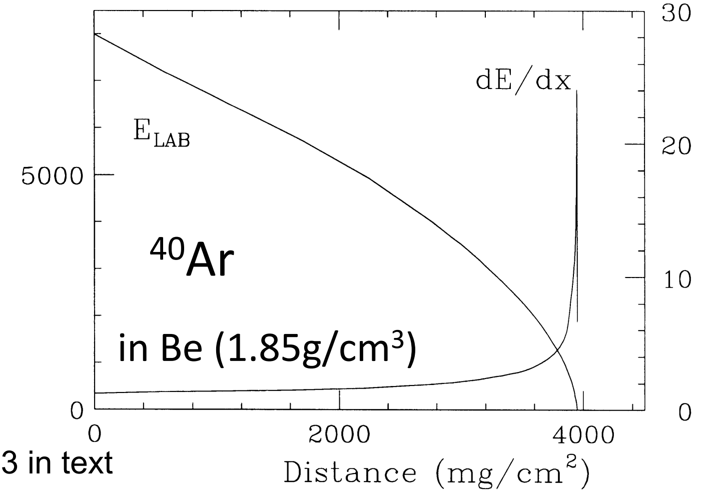


Fig. 17-3 in text

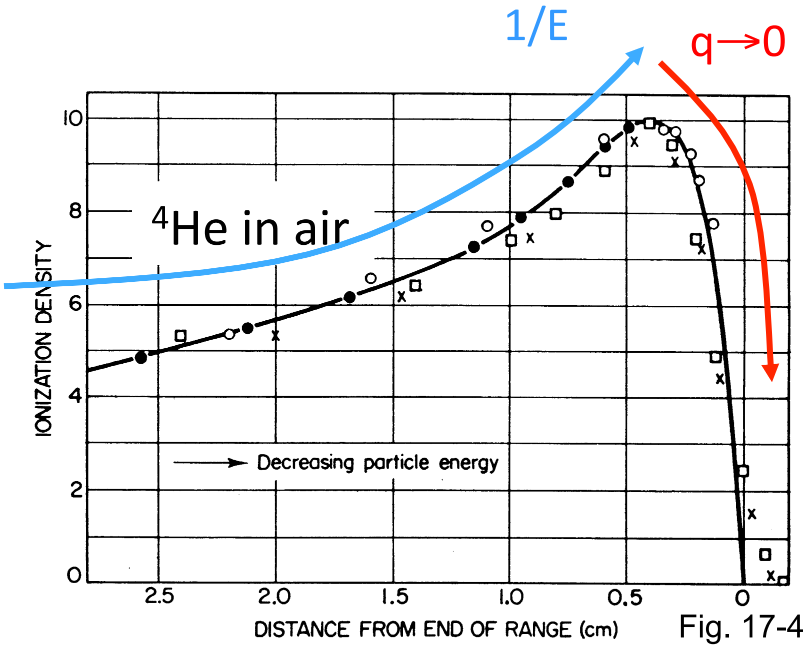


Fig. 17-4 in text

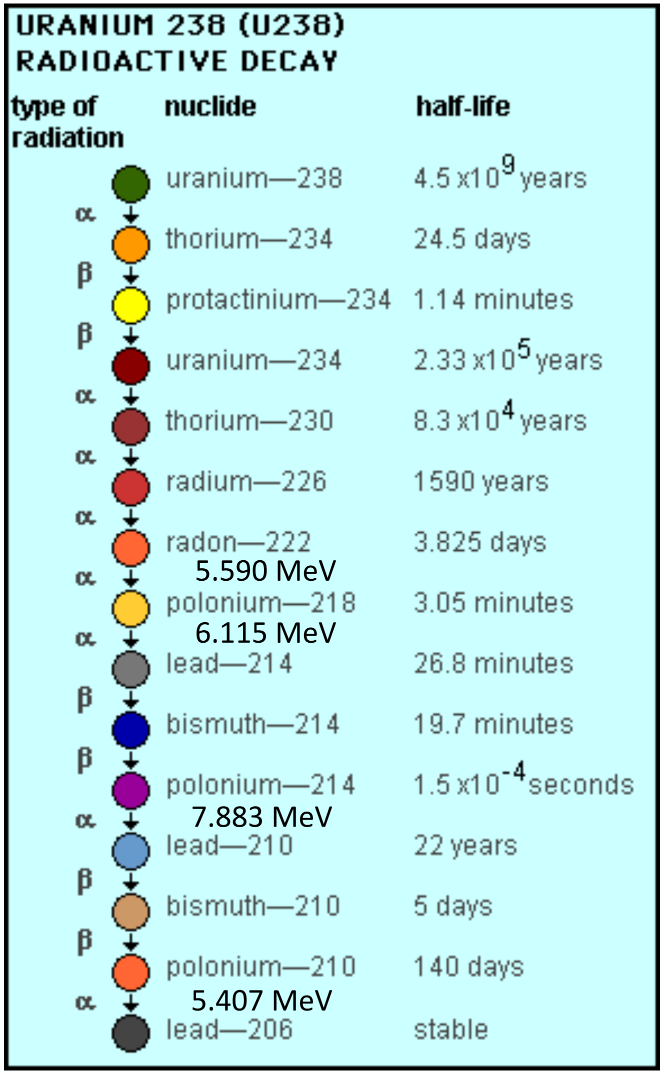
Example of Energy-loss & Range

Consider the problem of a Rn atom that starts in the air and decays inside a person's lung.

(4n+2 Natural Radioactivity Series)

Lung is mostly water…

Text has Range in Si …



URANIUM 238 (U238)
RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium—238	4.5×10^{9} years
α	thorium—234	24.5 days
β	protactinium—234	1.14 minutes
β	uranium—234	2.33×10^{5} years
α	thorium—230	8.3×10^{4} years
α	radium—226	1590 years
α	radon—222	3.825 days
α 5.590 MeV	polonium—218	3.05 minutes
α 6.115 MeV	lead—214	26.8 minutes
β	bismuth—214	19.7 minutes
β	polonium—214	1.5×10^{-4} seconds
α 7.883 MeV	lead—210	22 years
β	bismuth—210	5 days
β	polonium—210	140 days
α 5.407 MeV	lead—206	stable

Bragg's Rule

$$\frac{R_1}{R_2} = \frac{\rho_2}{\rho_1}\frac{\sqrt{A_1}}{\sqrt{A_2}}$$

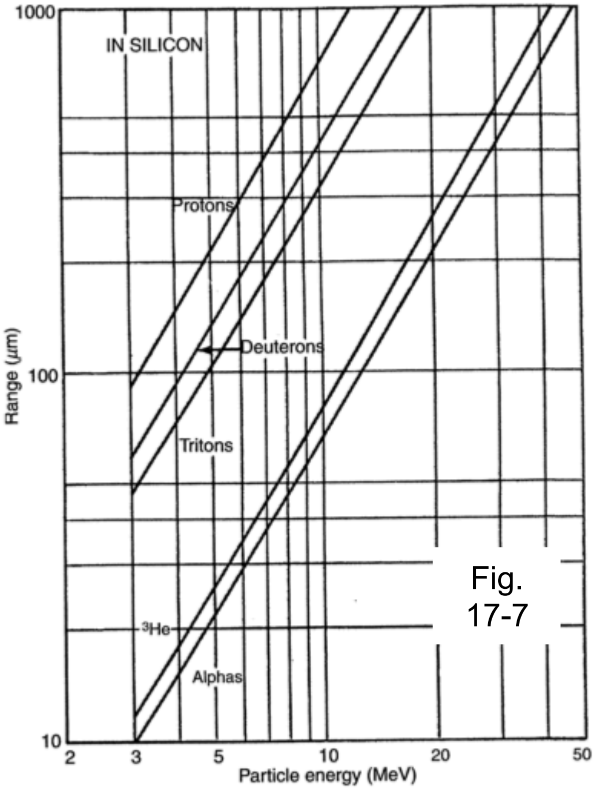


Fig. 17-7

http://learn.genetics.utah.edu/content/begin/cells/scale/

Interaction of e's with Matter –1–

Rate of energy loss, dE/dx, for fast electrons (+ or -) is made of only two terms. The electronic stopping is the most important, the second term is a radiative term due to Bremsstrahlung that is most important for high energies and high Z materials. The electronic term is similar to the Bethe-Bloch formula but the experimental situation for e- is complicated due to scattering by identical particles and the fact that the electrons are relativistic ($m_e c^2$ = 0.511 MeV).

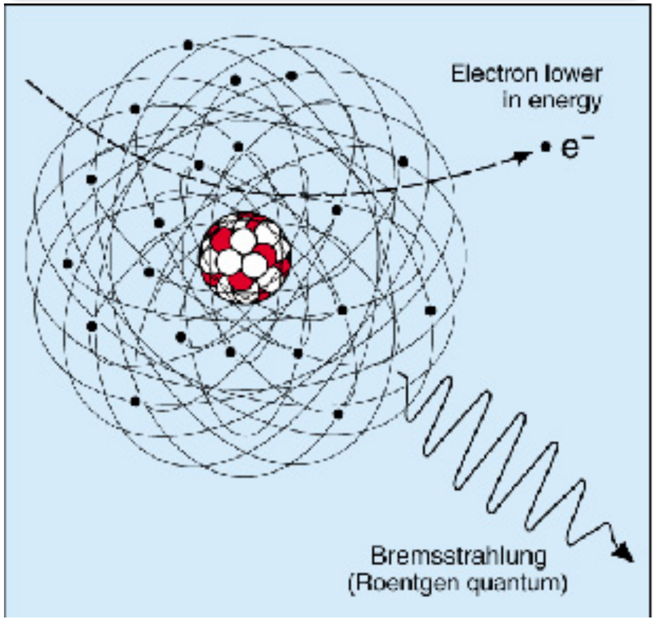
$$\left(\frac{-dE}{dx}\right)_e = S_{electronic} + S_{radiative}$$

$$\frac{S_{radiative}}{S_{electronic}} \approx \frac{T + m_e c^2}{m_e c^2} \frac{Z}{1600} \rightarrow \frac{3Z}{1600} \; at \; T = 1 \; MeV$$

$$\frac{S_{radiative}}{S_{electronic}} \approx \frac{TZ}{700}$$

For a 1 MeV electron the ratio Rad/Elec ~ 3Z/1600 which is a small contribution even for Pb or U targets.

What's wrong with this picture??



http://www.euronuclear.org/info/encyclopedia/bremsstrahlung.htm

Interaction of e’s with Matter –2–

Even monoenergetic electrons do not have a sharp range distribution

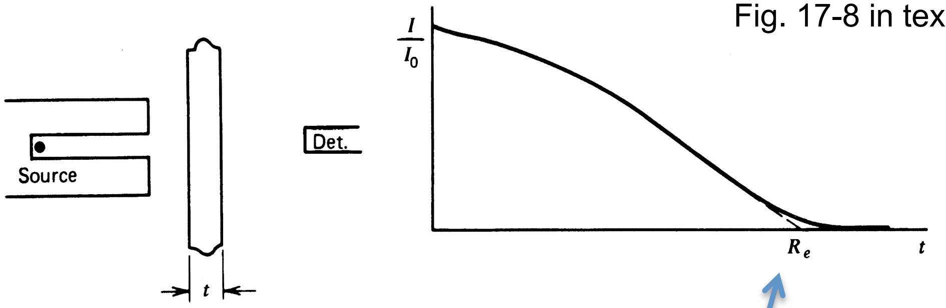


Fig. 17-8 in text

Q: What is the range for a 1 MeV electron in a solid?

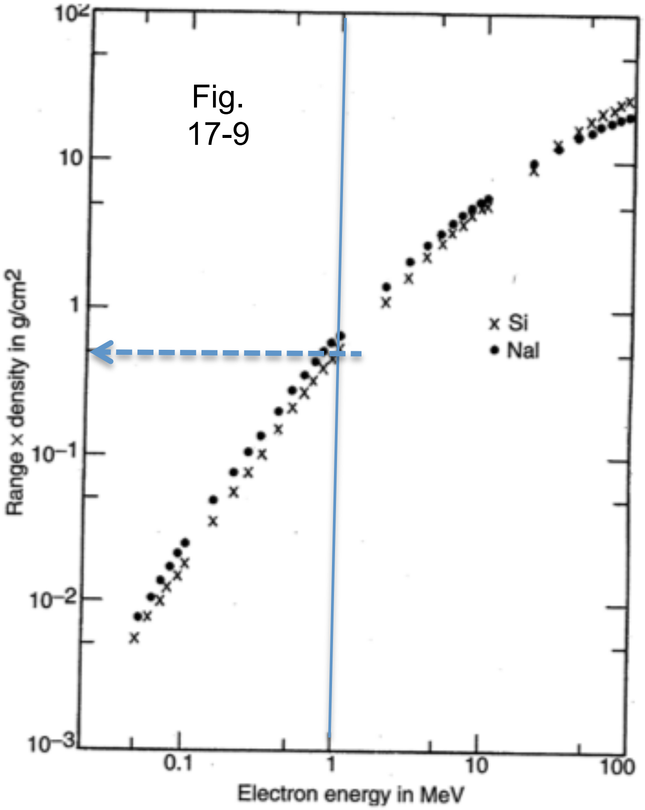


Fig. 17-9

N.B. the range distribution for a beta source will be approximately exponential due to the folding of the Fermi intensity distribution with the range distribution.