Chap. 15 – Fast Neutron Detection

All neutron detection relies on observing a neutron-induced nuclear reaction.

The capture cross sections for fast-neutron induced reactions are small compared to those at low energies (in the limit: geometric with resonances).

Two approaches to detect fast neutrons:
– thermalized & capture which only provides a "count"

– Elastic scatter from protons at high energy – observe recoils for ToF techniques.

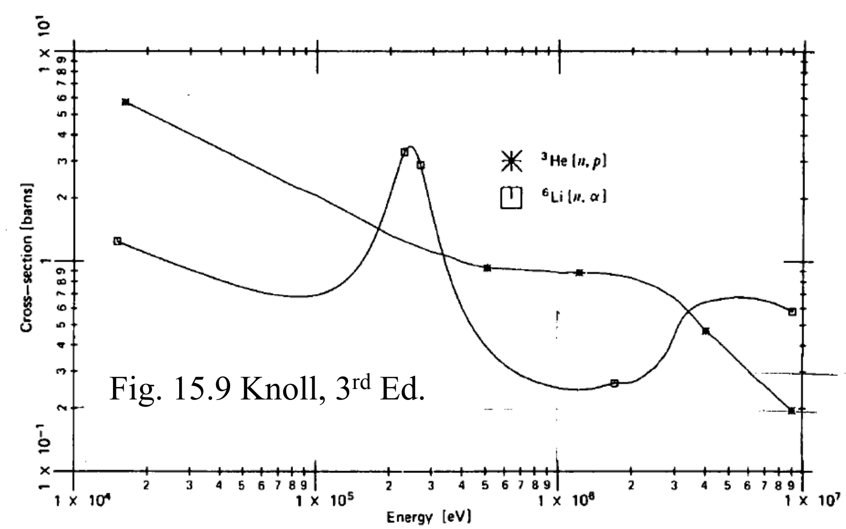
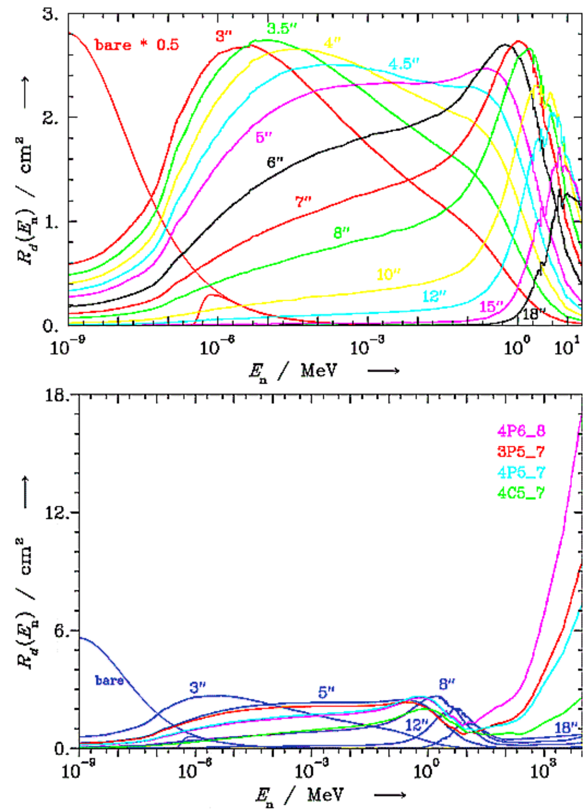


Fig. 15.9 Knoll, 3rd Ed.

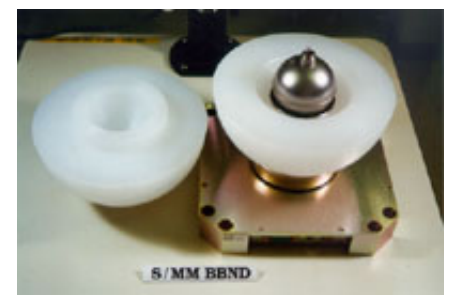
Bonner Spheres – “Counter”

$n + {}^{3}He \rightarrow ({}^{4}He)^{*} \rightarrow p + {}^{3}H$, Q=0.765 MeV



Physikalisch-Technische Bundesanstalt
http://www.ptb.de/en/org/6/65/nemus_details.htm

Moderate neutrons in spheres of different sizes and then detect the neutrons in a proportional counter in the center. Add metal for highest energy neutrons … unfold response to get distribution.

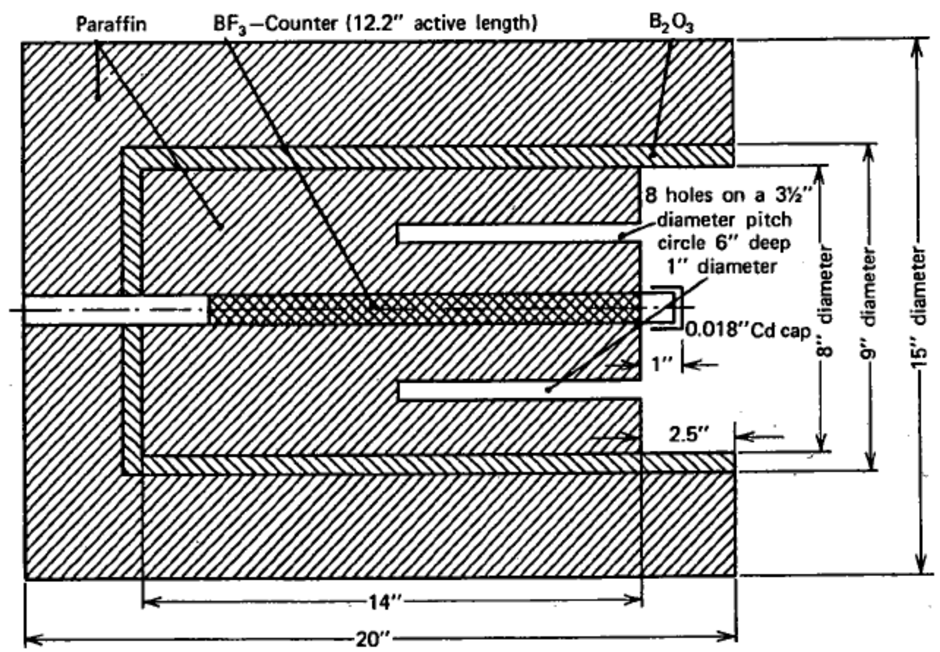


STS-102 Space Shuttle, six spheres, 3He, 6atm

Fast neutron detection: Long Counter

$n + {}^{10}B \rightarrow ({}^{11}B)^* \rightarrow {}^{7}Li^* + {}^{4}He$, Q=2.31 MeV, Branch=94%, target abundance = 19.9%

$\rightarrow {}^{7}Li + {}^{4}He$, Q=2.79 MeV, Branch=6%



*

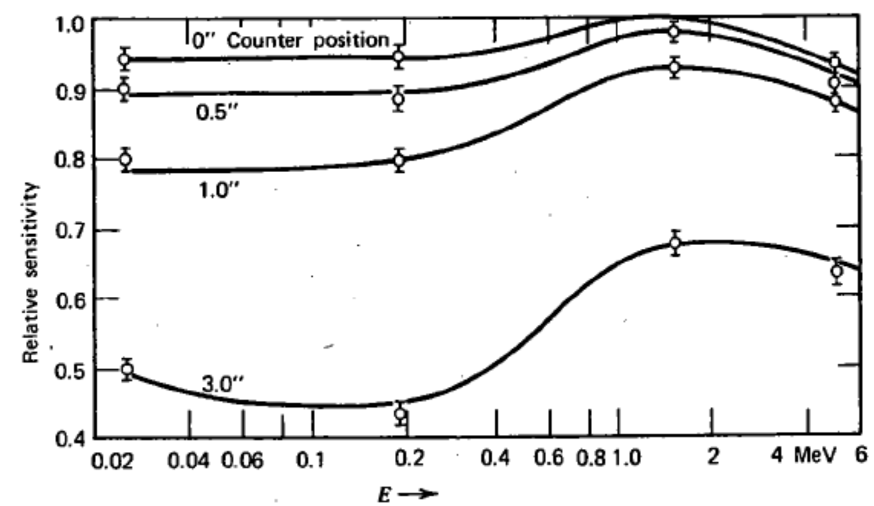
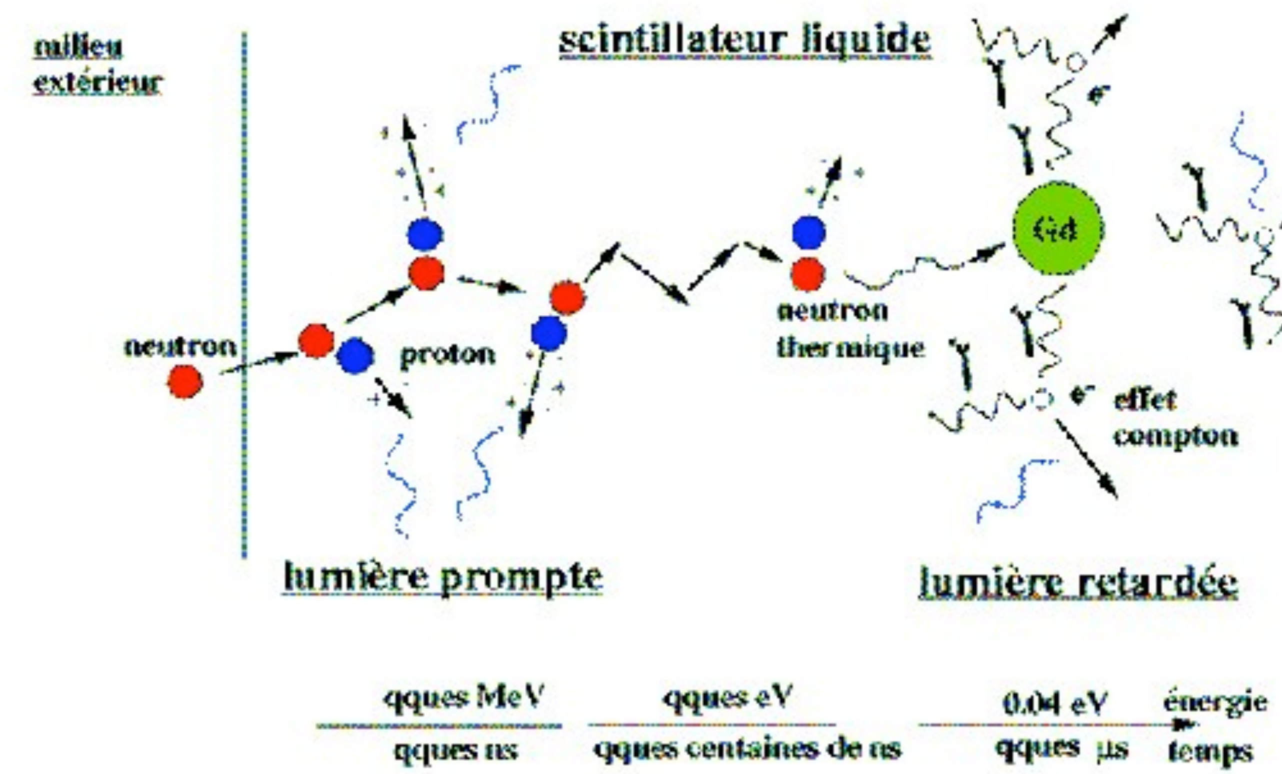


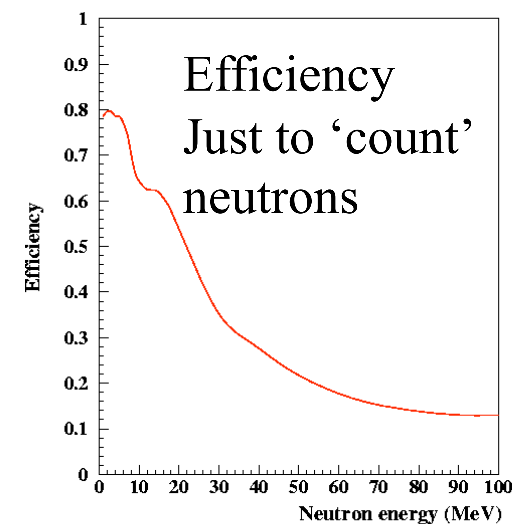
Fig. 15.6 Knoll, 3rd Ed.

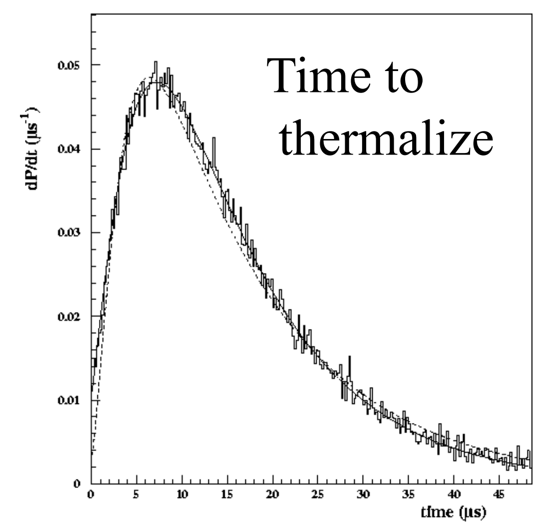
NSCL Bucket neutron detectors use BF_3 (1" diameter, 4" long, 400Torr) in a parafin filled container.

Gd-loaded Liquid Scintillator – "Counter"

n + ^{157}Gd → (^{158}Gd)* → ^{158}Gd + γ , Q~8 MeV , target abundance = 15.6% (255k barns)

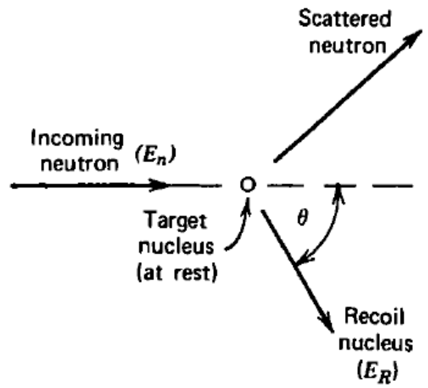






"ORION" detector at GANIL , similar to "superBall" at NSCL (both decommissioned)

Fast Neutron Detection: Scattering



$$\frac{E_R}{E_n} = \frac{4A}{(1+A)^2} Cos^2\theta_{lab} \quad \text{max at } \theta_{lab} = 0^o$$

Tgt	A	$4A/(1+A)^2$
^{1}H	1	1
^{2}H	2	8/9=0.889
^{4}He	4	16/25=0.64
^{12}C	12	48/169=0.284

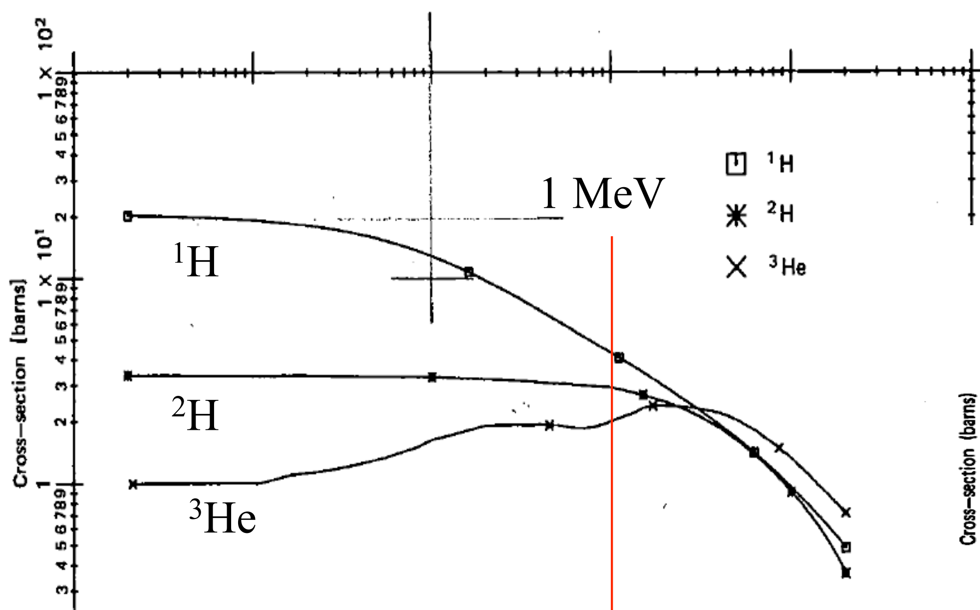
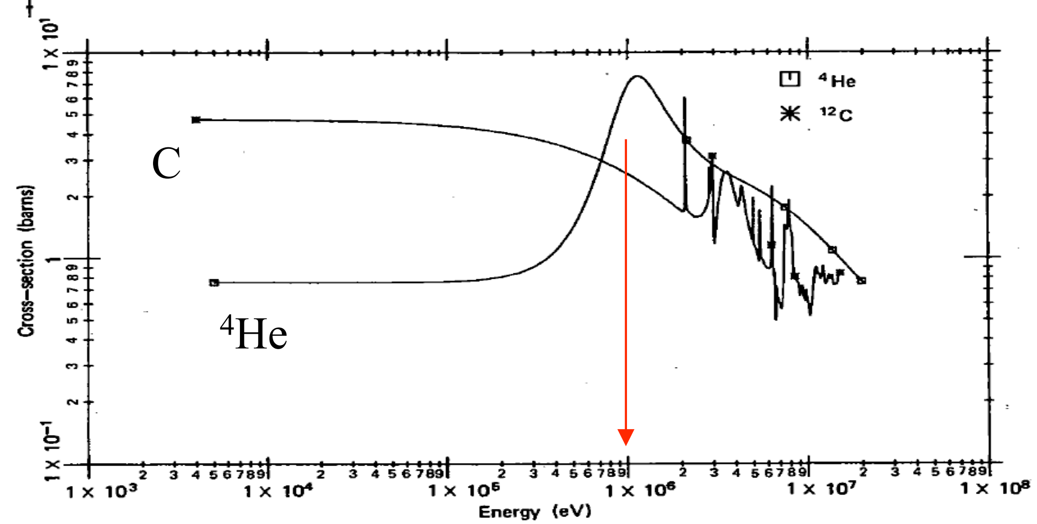
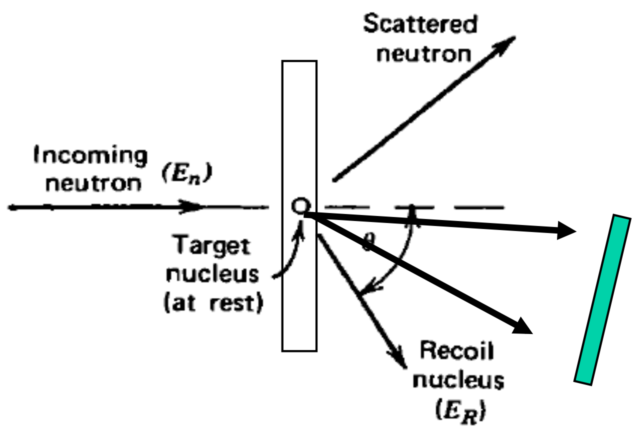


Fig. 15.15 Knoll, 3rd Ed.



Fast Neutron Detection: Absorption

MICHIGAN STATE UNIVERSITY



Proton-radiator telescope: Target allows protons to escape. Target thickness has to be consistent with the $\Delta E/\Delta\Theta$ of the recoil angular distribution.

20 MeV n .. Scatters and gives protons

10 MeV p in CH_2 .. dE/dx ~30MeV/ g/cm^2

$Ep = En \,Cos^2\theta$ $\quad \Delta Ep = Ep(\theta) - Ep(0)$

$\Delta Ep = En[1 - Cos^2\theta]$

$\Delta Ep = En\, Sin^2\theta$ (~3% for 0-10^o)

Energy loss must be less than change with angle

$\Delta x \sim \Delta Ep / (dE/dx) = 0.03 * 20MeV / 30\ MeV/\ g/cm^2$

$\Delta x \sim 0.02\ g/cm^2$

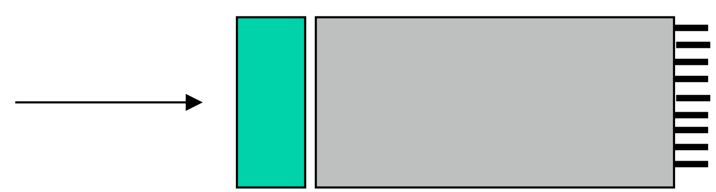
Efficiency is set by thickness

$n\,\Delta x \sim (2*6x10^{23} / 14)\ 0.02 = 1.7x10^{21}\ /cm^2$

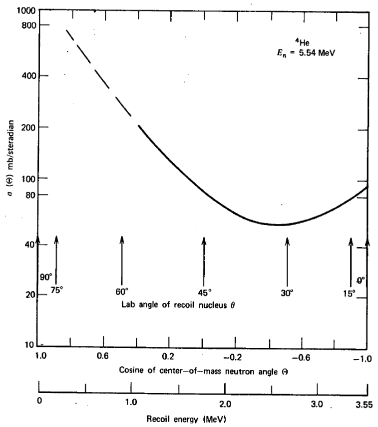
$\sigma(E{=}20\ MeV) = 0.4\ b$

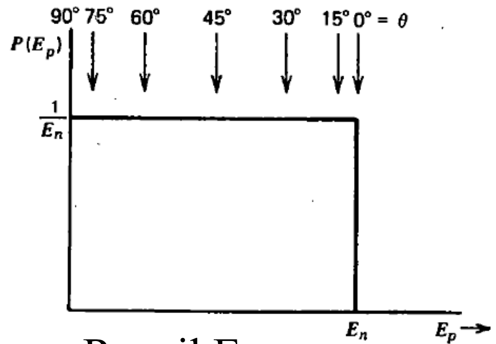
$\varepsilon = 1 - e \wedge(-n\,\Delta x\,\sigma) = 7x10^{-4}$

Give up! Use a thick plastic scintillator .. 10 cm ε~0.2



Fast Neutron Detection: Scattering Pulse Height



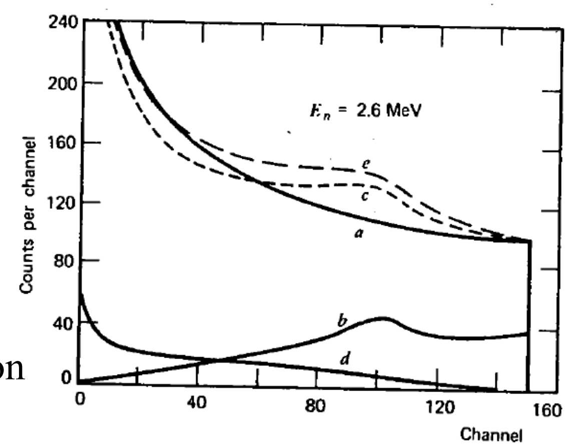


Recoil Energy

^{12}C(n,n') cross section has a modest angular distribution .. Small energy dependence on recoil angle. The ^{1}H(n,n') distribution is flat.

Combine and fold with scintillator light output

2.6 MeV neutron
1"x1" stilbene



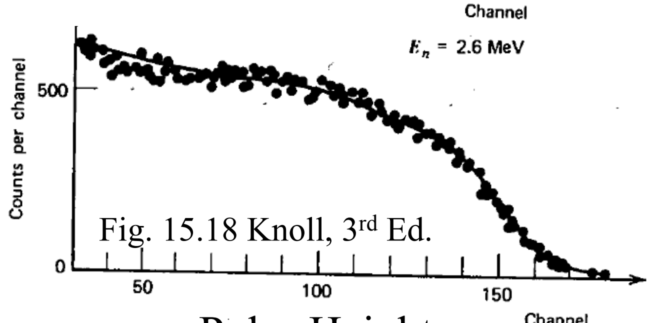


Fig. 15.18 Knoll, 3rd Ed.

Pulse Height

Set threshold

NE213 into 1.9cm x10cm

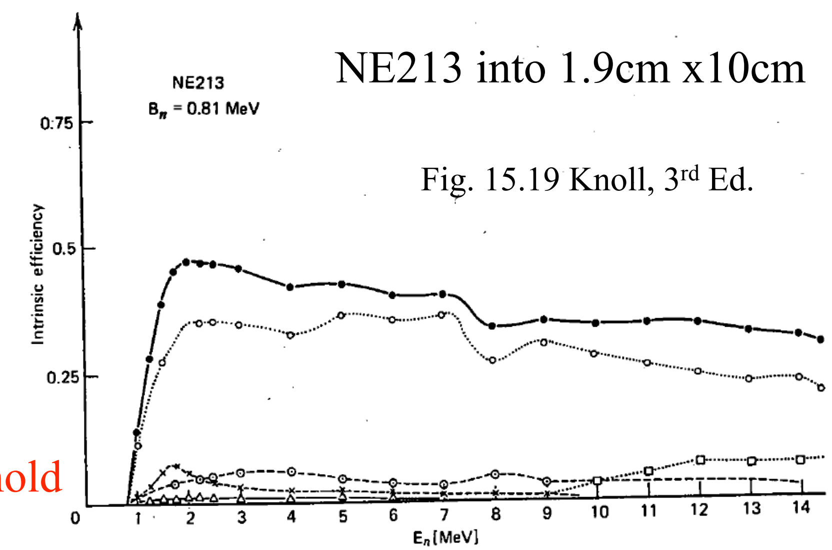
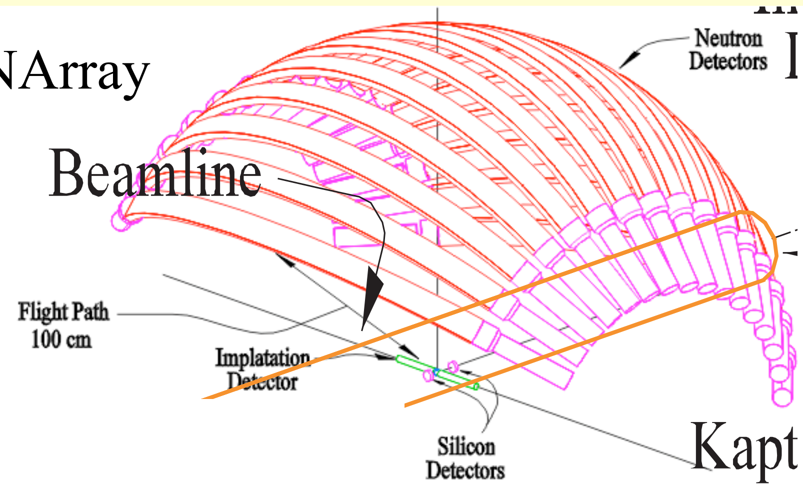


Fig. 15.19 Knoll, 3rd Ed.

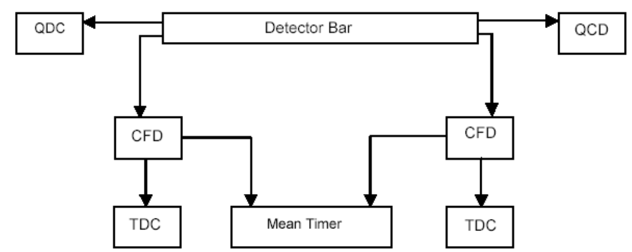
Fast Neutron Detection: Arrays

DNArray



$$E = \frac{m}{2}v^2 = \frac{m}{2}\left(\frac{L}{t}\right)^2 \qquad E_n \ll m_o c^2$$

$$\frac{dE}{dt} = \frac{-mL^2}{t^3} \rightarrow \frac{dE}{dt} = \frac{-2E}{t} \rightarrow \frac{dE}{E} = \frac{-2dt}{t}$$



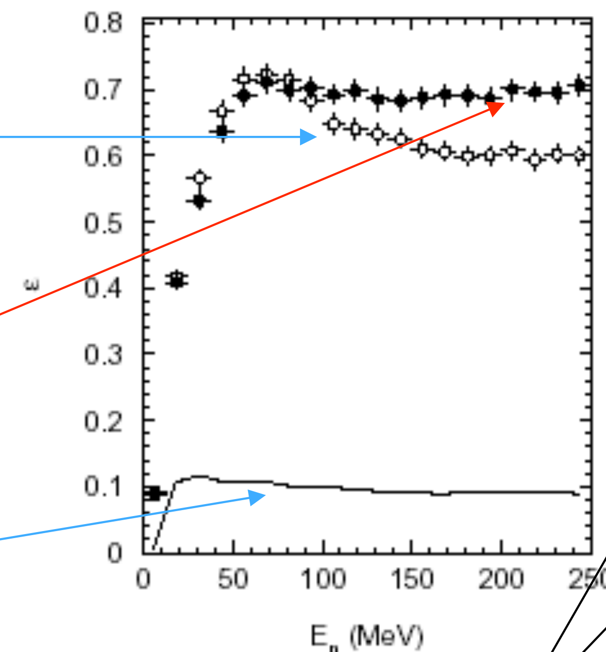
MoNA plastic scintillator

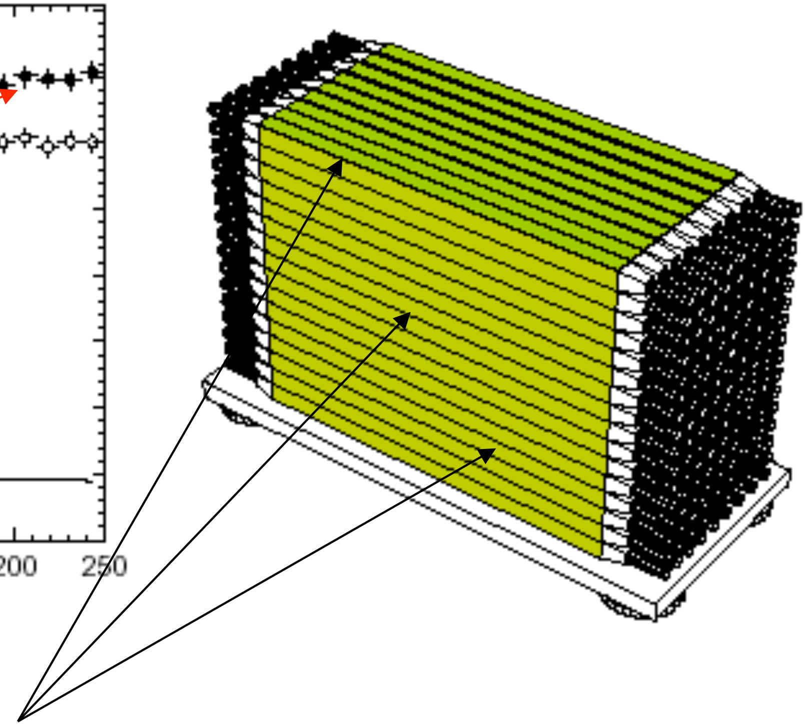
Ten layers – plastic scint.

Add Iron converter layers

NSCL "neutron wall"

One layer of liquid scint.





Estimate the number of photons reaching the end of a MoNA slat from the interaction of a cosmic ray muon passing through the midpoint of the slat. The attenuation length of the slats was found to be 4.2m, the slats are 200x10x10 cm^3, are made from BC-408 scintillator and are readout on the long ends.