Detectors

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Main reference on radiation detectors:
Glenn F KNOLL, *Radiation Detection and Measurement*

Neutron Detectors

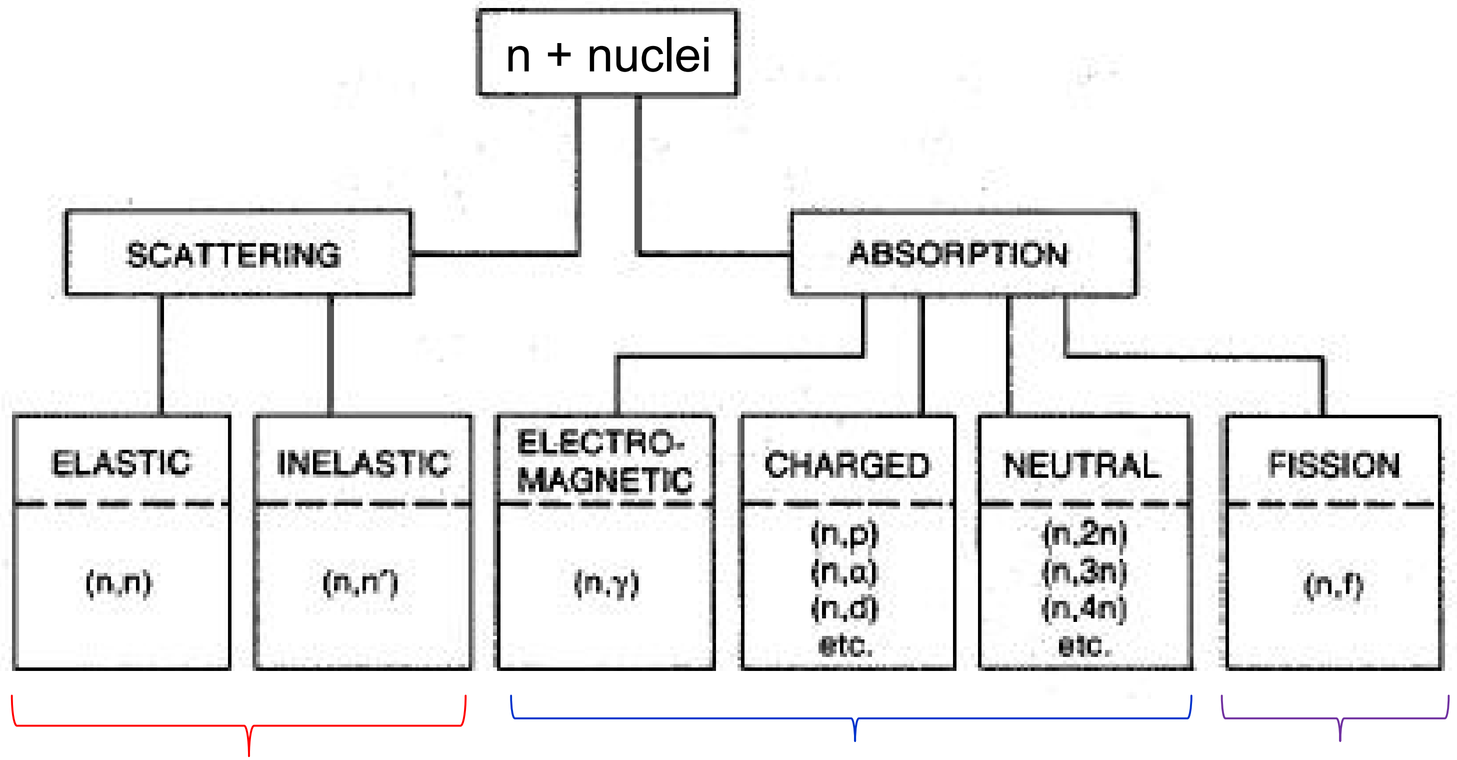
- How does one "detect" a neutron?
  - Can't directly detect slow neutrons
    —they carry too little energy
  - Need to produce some sort of measurable quantitative (countable) electrical signal
- Need to use nuclear reactions to convert neutrons into charged particles
- Then one can use some of the many types of charged particle detectors
  - Gas proportional counters and ionization chambers
  - Scintillation detectors
  - Semiconductor detectors

Challenges in neutron detection

- Neutrons have no charge: they do not produce ionizations or excitations in matter directly; neutrons are difficult to stop.
- Background : main component gamma-rays; discrimination against gamma-rays is not easy.
- High detection rates are often required: usually neutron detectors are used in a regions of high neutron (and gamma-ray) flux
- Cross-sections of neutron reactions on which neutron detectors can be based decrease with increasing neutron energy $\Rightarrow$ fast neutrons with high efficiency is particulary difficult

Interaction of neutrons with matter

- No electric charge → no electromagnetic interaction (or too weak)
- Only strong interaction with the nuclei



used for **fast** neutrondetection

used for **slow** neutron detection

fast and slow neutrondetection

Principles of neutron detection: reaction-based detectors

Neutrons are detected through nuclear reactions that produce charged particles:

$$\text{Target Nucleus} + \text{neutron} \rightarrow \begin{cases} \text{recoil nucleus} \\ \text{protons} \\ \text{alpha particles} \\ \text{fission fragments} \end{cases}$$

Some requirements:

- High cross section (→ high efficiency)
- High Q-value (→kinetic energy of the reaction products ~independent of small energy of the slow neutron; easier discrimination against gamma-rays)
- Ideally, all the energy of the reaction products should be absorbed in the detector

Slow Neutron Detection

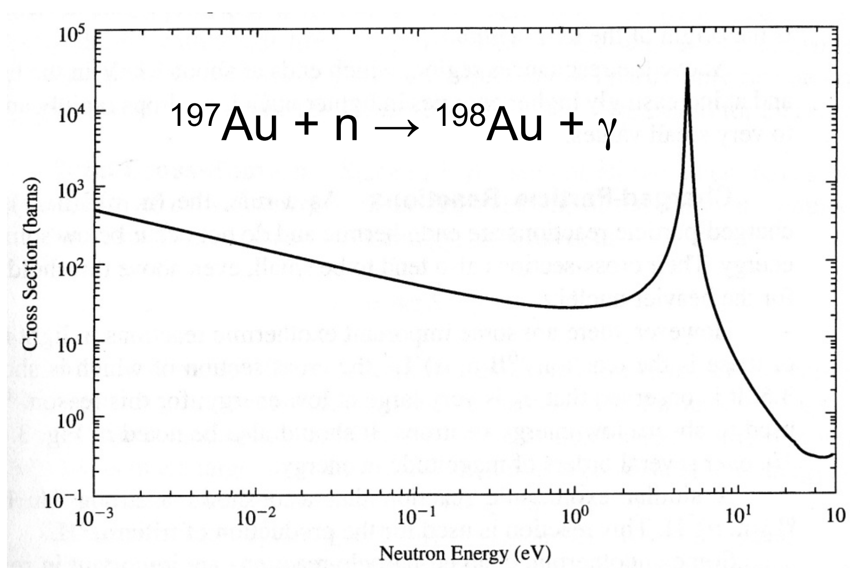
- Cross-section for elastic (potential) scattering : $\sigma_e = 4\pi R^2$
- Cross-section for capture reaction follows characteristic 1/v dependence for low neutron energies
- The form can be derived from Breit-Wigner resonance lineshape (single level resonance formula), e.g. neutron capture and capture-independent gamma-ray emission (radiative capture):

$$\sigma_{capture} = \pi \lambda\!\!\!^{-2} \frac{\Gamma_n \Gamma_\gamma}{(E - E_R)^2 + (\Gamma/2)^2}$$

$E << E_R; \Gamma_n \approx v; \lambda\!\!\!^- = \hbar/mv$: E_R Resonance energy

Primary decay is γ emission and independent of neutron $\Rightarrow \Gamma \approx \Gamma_\gamma$

$$\Rightarrow \quad \sigma \propto \frac{1}{v}$$



Commonly Used Neutron Reactions

$n + {}^{3}He \rightarrow ({}^{4}He)^{*} \rightarrow p + {}^{3}H$, Q = 0.765 MeV, target abundance ~ 1.4x10^{-4} % (5.3 kb) — (n,p)

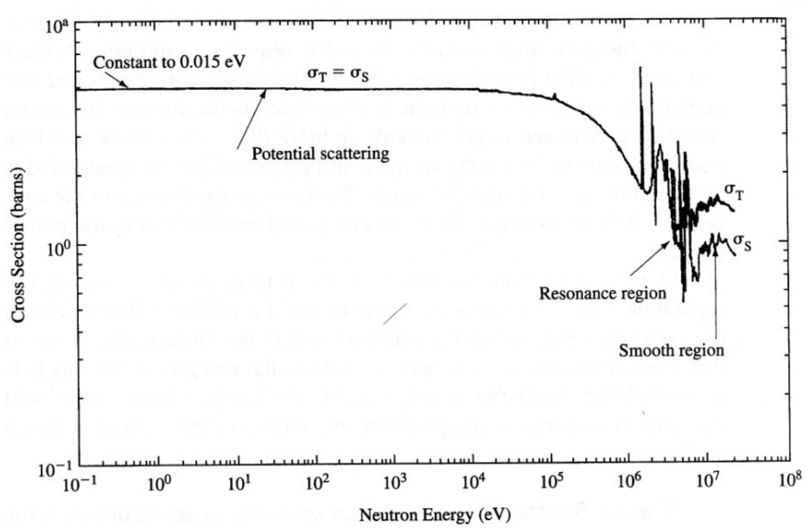
$n + {}^{6}Li \rightarrow ({}^{7}Li)^{*} \rightarrow {}^{4}He + {}^{3}H$, Q = 4.78 MeV, target abundance ~ 7.5% (940 b) — (n,α)

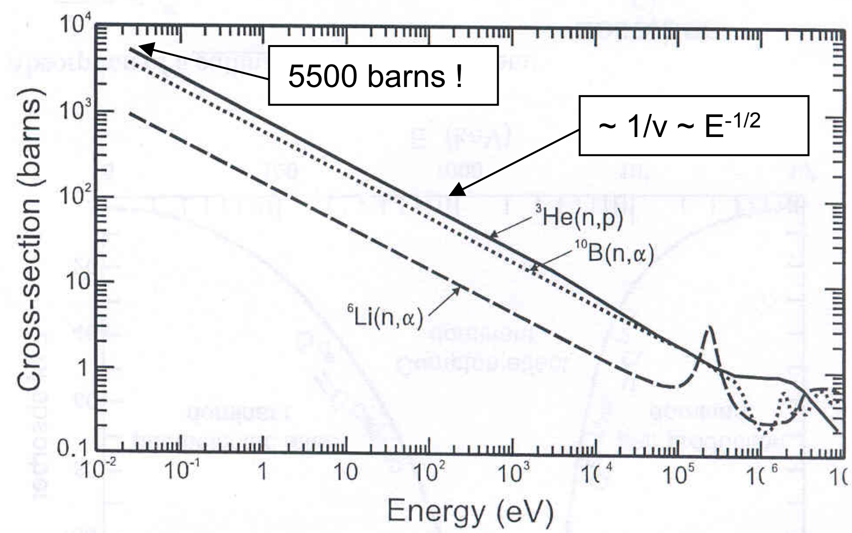
$n + {}^{10}B \rightarrow ({}^{11}B)^{*} \rightarrow {}^{7}Li^{*} + {}^{4}He$, Q = 2.31 MeV, 94% branch, nat. abund. ~20 % (3.8kb) — (n,α)
$\rightarrow {}^{7}Li + {}^{4}He$, Q = 2.79 MeV, 6% branch

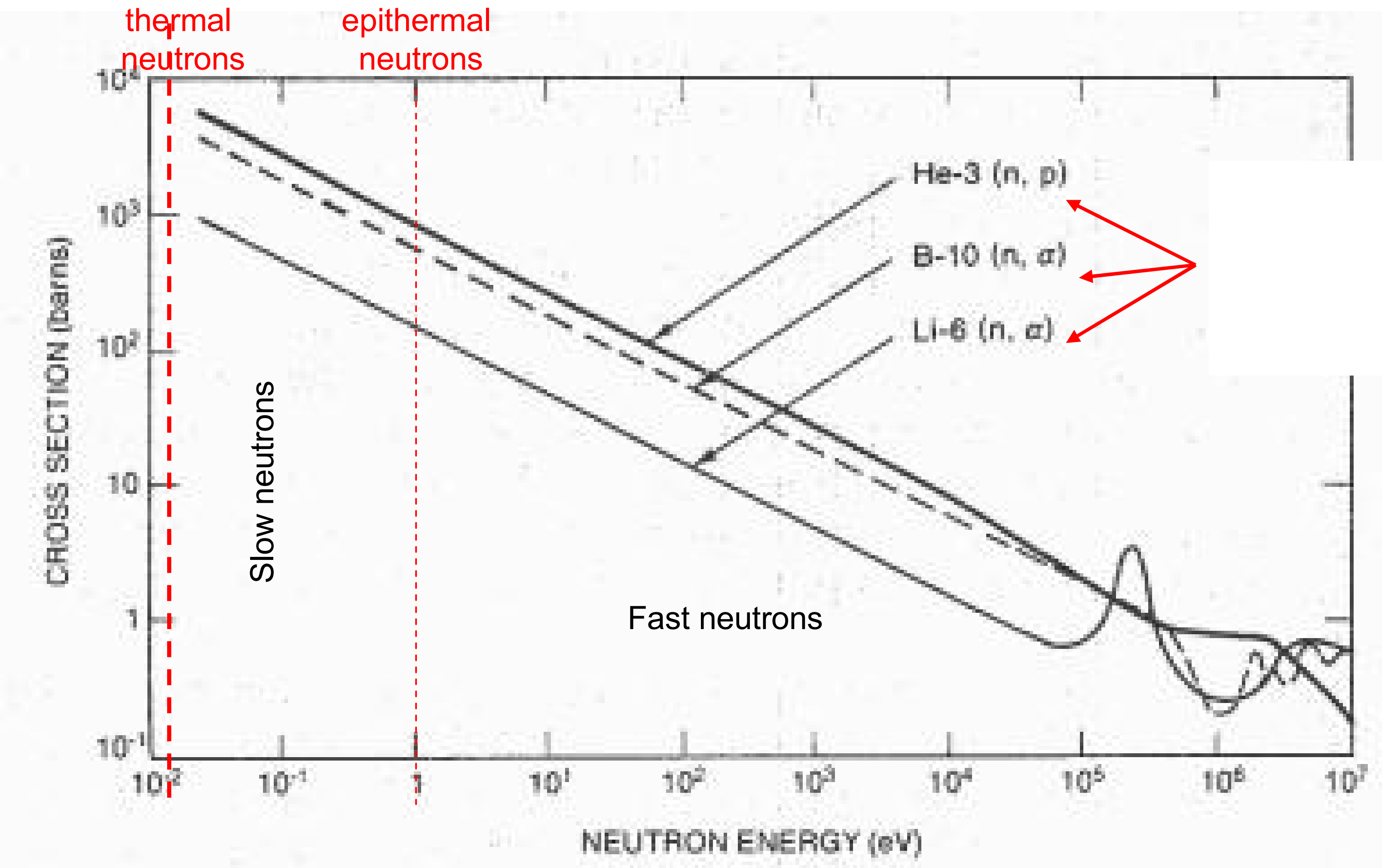
$n + {}^{113}Cd \rightarrow ({}^{114}Cd)^{*} \rightarrow {}^{114}Cd + \gamma$, Q ~ 8 MeV, target abundance ~ 12% (21 kb) — (n,γ)

$n + {}^{157}Gd \rightarrow ({}^{158}Gd)^{*} \rightarrow {}^{158}Gd + \gamma$, Q ~ 8 MeV, target abundance ~ 16% (255 kb) — (n,γ)

$n + {}^{235}U \rightarrow ({}^{236}U)^{*} \rightarrow$ (fission fragments), Q ~ 200 MeV, target abundance ~ 0.7% — (n,f)

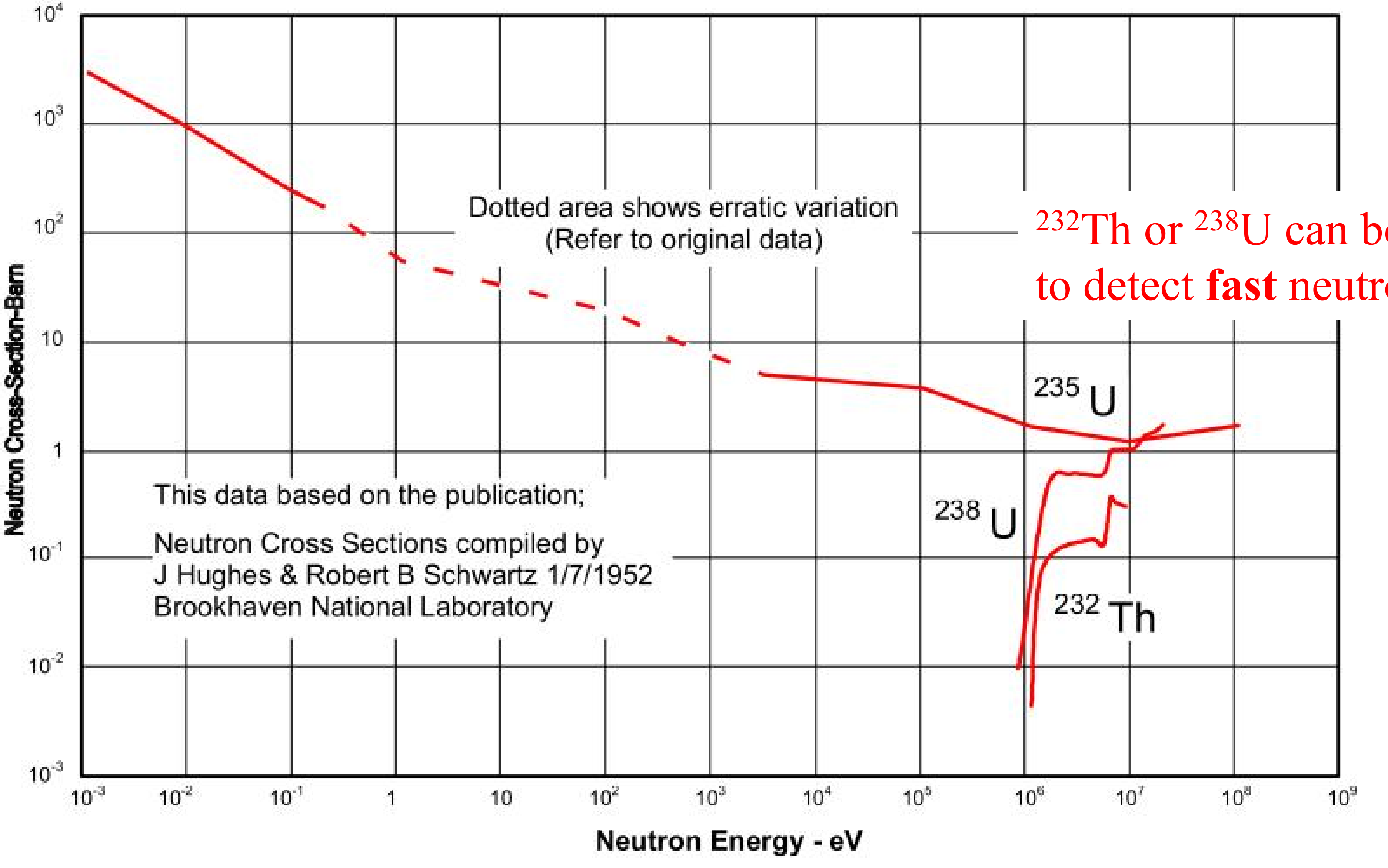






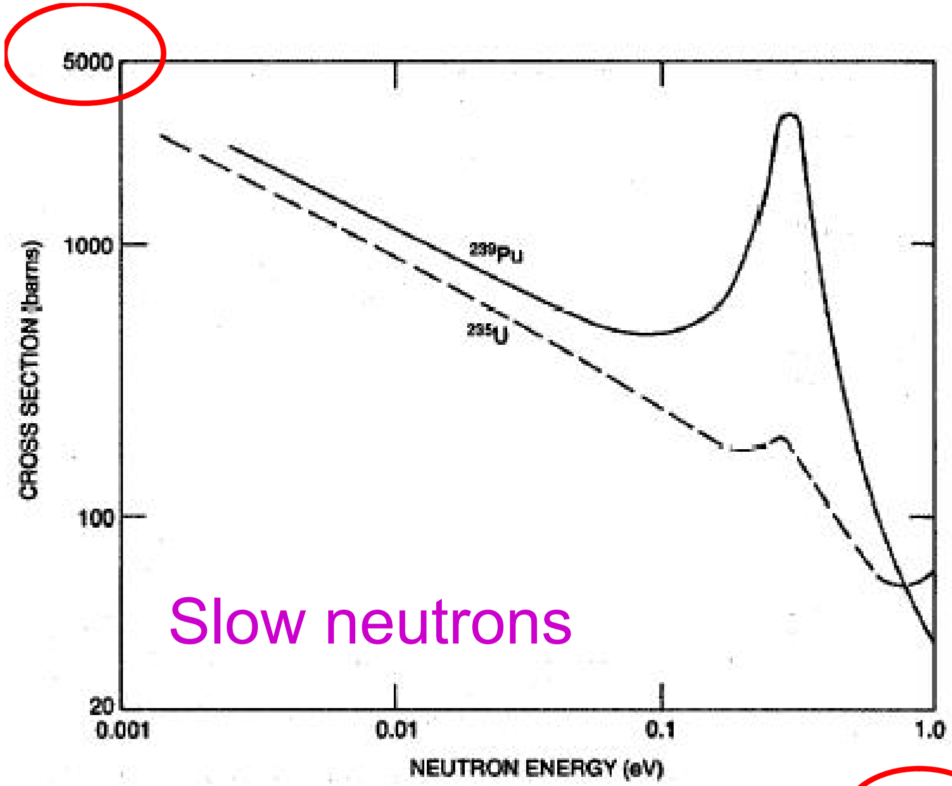
Cross section vs neutron energy for some reactions of interest in neutron detection (G. Knoll)

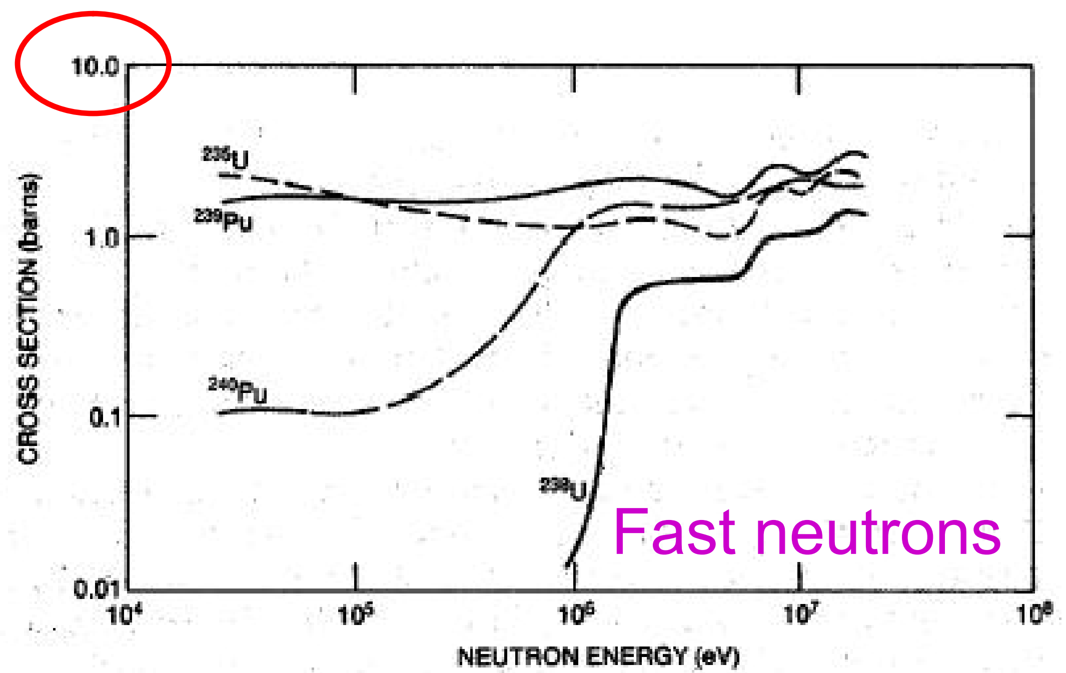
Neutron –Induced Fission Reactions



^{232}Th or ^{238}U can be used to detect **fast** neutrons

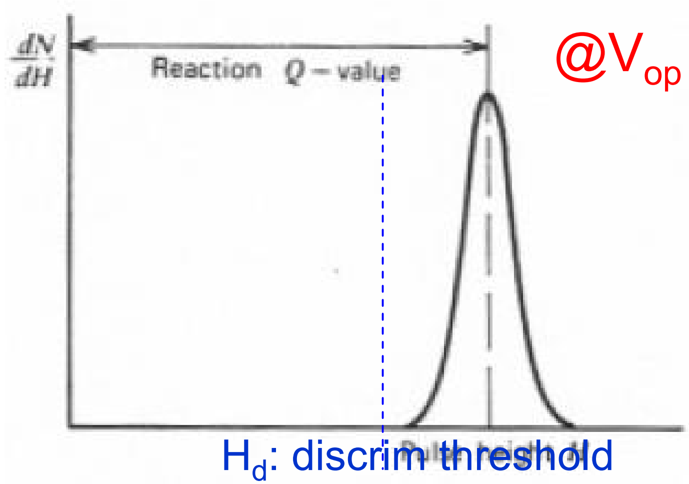
More on fission cross-sections

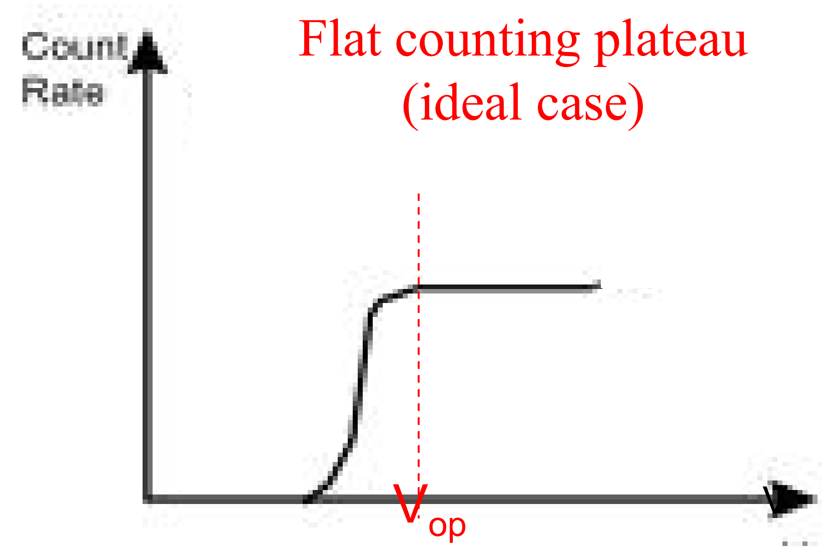




Principles of neutron detection: reaction-based detectors

Ideally, for a reaction-based detector and for **$E_n << Q$:**





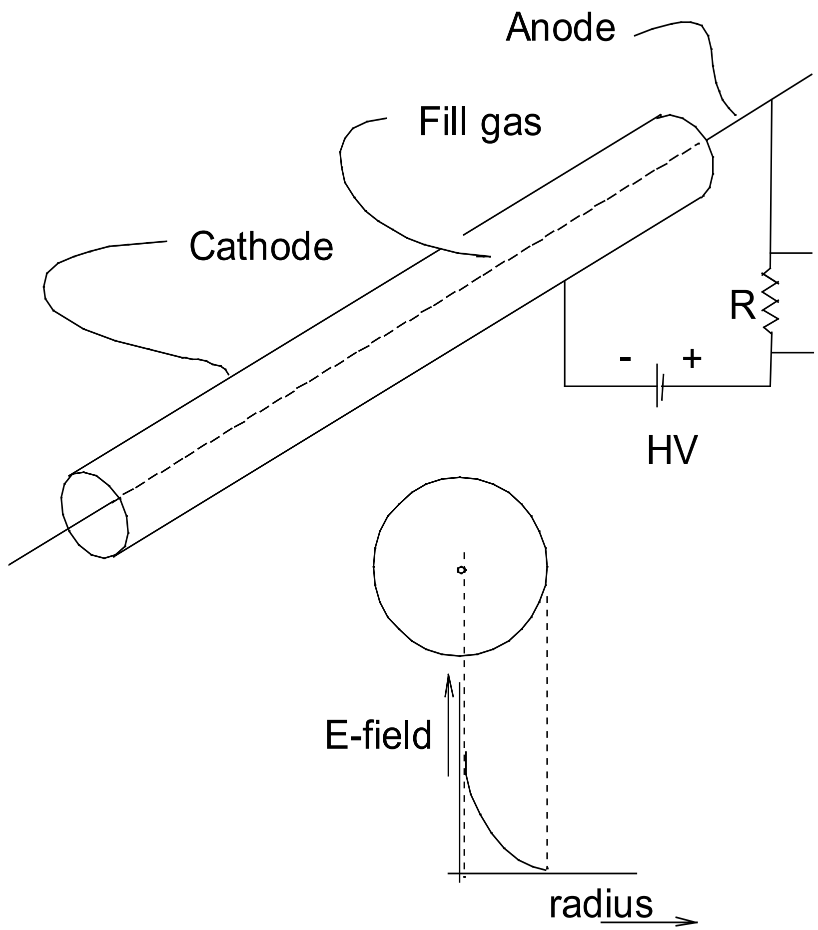
NOTE : **spectrum does not give any information on the energy of the incident neutron**

Large Q → better discrimination between neutrons and gammas (pulses due to γs not represented)

Flat plateau allows stable counting operation

Gas Detectors

Gas Proportional Counter



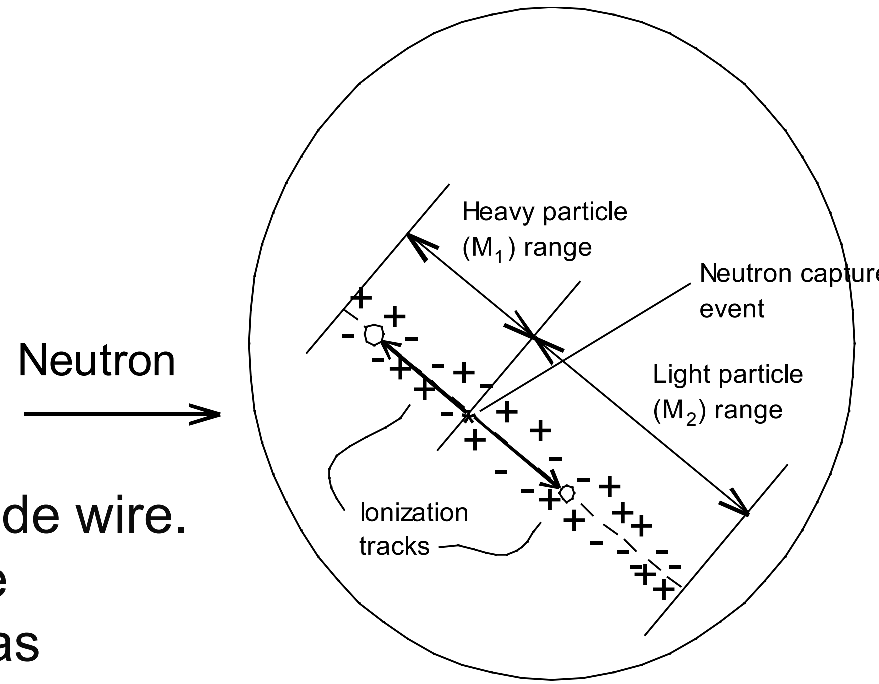
$$n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.76\,MeV$$

$$\sigma = 5333\,\frac{\lambda}{1.8}\quad \text{barns}$$

~25,000 ions and electrons (~4´10^{-15} coulomb) produced per neutron

Gas Detectors

Ionization tracks in proportional counter gas



Electrons drift toward the central anode wire. When they get close, they accelerate sufficiently between collisions with gas atoms to ionize the next atom. A *Townsend avalanche* occurs in which the number of electrons (and ions) increases the number many-fold, about x10^3. Separation of these charges puts a charge on the detector, which is a low-capacitance capacitor, causing a pulse in the voltage that can be amplified and registered electronically.

Gas-filled detectors for neutron flux measurement

Regime of operation (i.e. with or without charge amplification)	Ionization chambers Proportional counters

Mode of operation (i.e.wether they measure the integrated current or individual pulses)	DC (current mode) AC (pulse mode)

Primary nuclear process in which the detection rely	Nuclear reaction	^{3}He(n,p)	Q=765keV
		^{10}B(n,α)	Q=2310 keV
		Fission (e.g. ^{235}U)	
	Elastic scattering (e.g., ^{4}He and CH_4)		

The ^{3}He Proportional Counter

- n + ^{3}He → p + ^{3}H, Q = 764 keV (^{3}H = triton (t))
- Assume E_n<<Q; Q = E_p + E_t; Momentum conservation:

$$m_p v_p = m_t v_t$$

$$\Rightarrow \sqrt{2E_p m_p} = \sqrt{2E_t m_t}$$

$$\Rightarrow E_p = \frac{m_t}{m_p} E_t = \frac{m_t}{m_p}(Q - E_p)$$

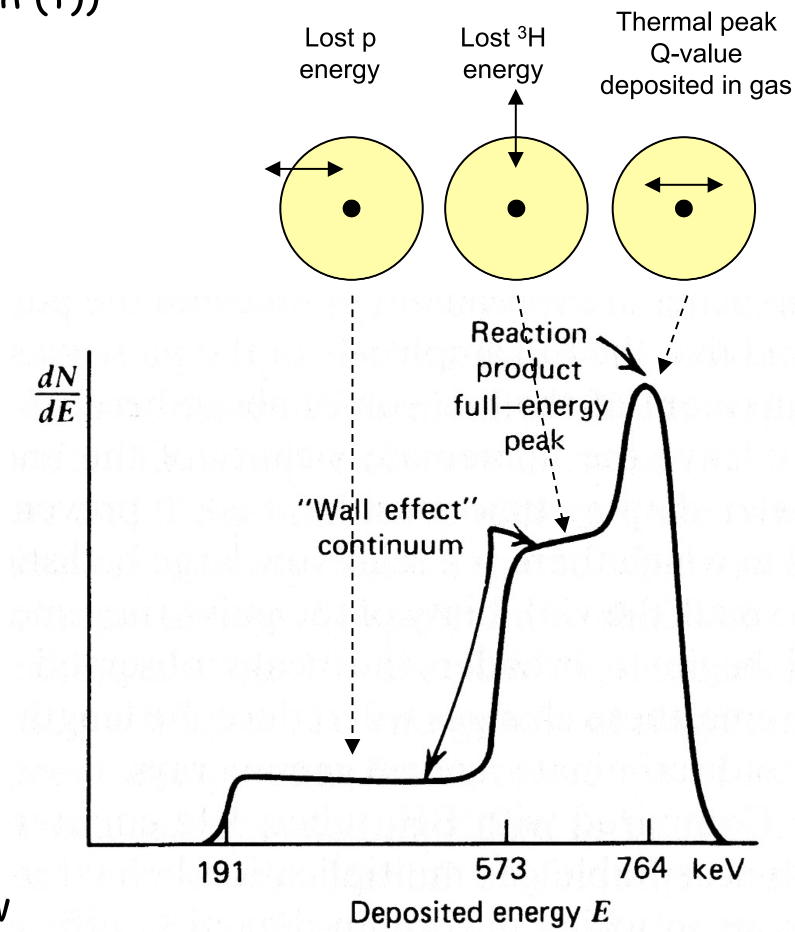
$$\Rightarrow E_p = \frac{m_t}{m_p + m_t} Q$$

⇨ E_p = 573 keV; E_t = 191 keV

⇨ Range R in Si: R_p ~ 6μm, R_t ~ 5μm

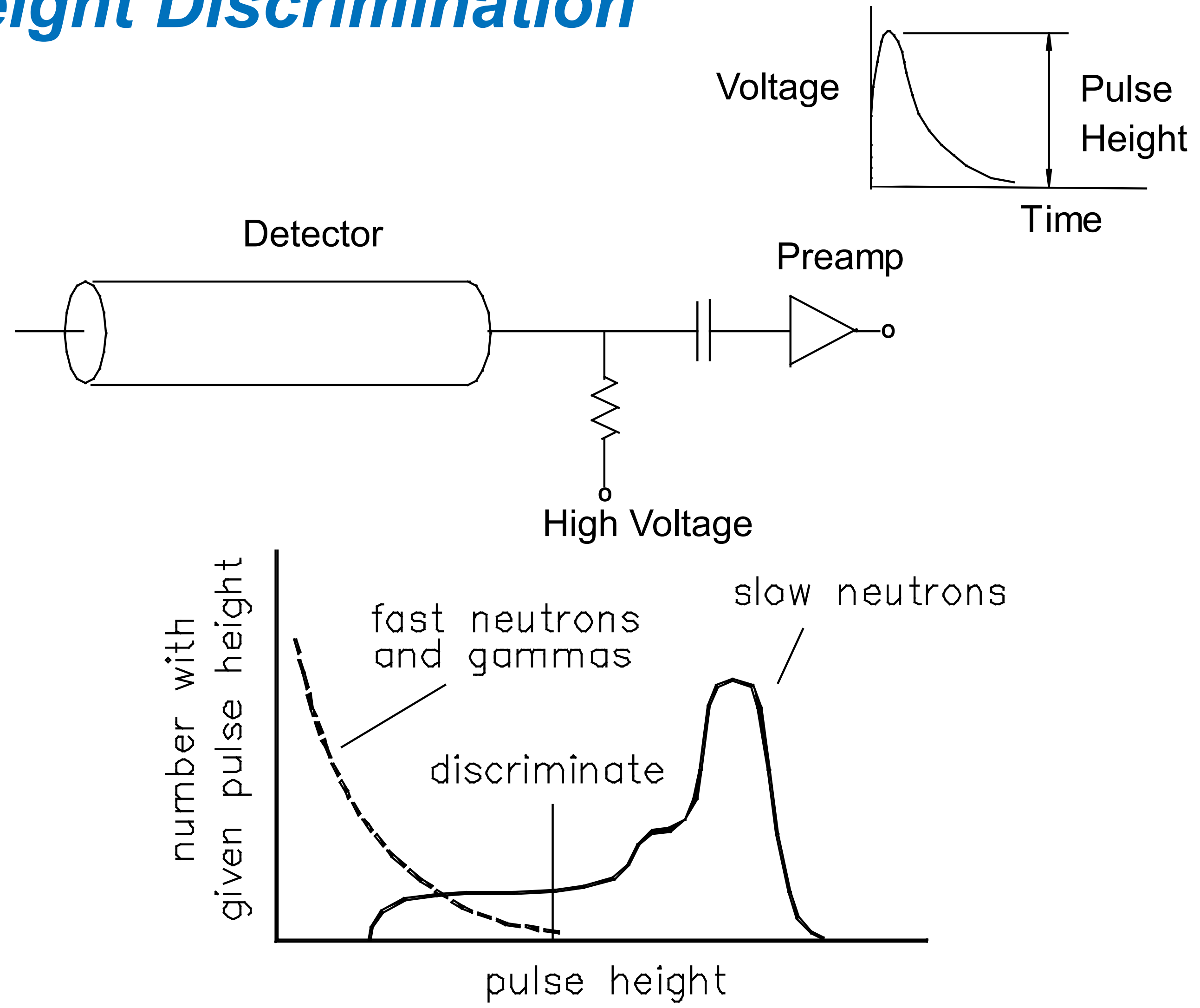
⇨ Ranges in gas ~1000 x range in solid ~ few mm's (Rρ ~ 0.25 mg/cm^2 for α in He gas)

The wall effect



Wall effect depends on tube dimensions and gas pressure

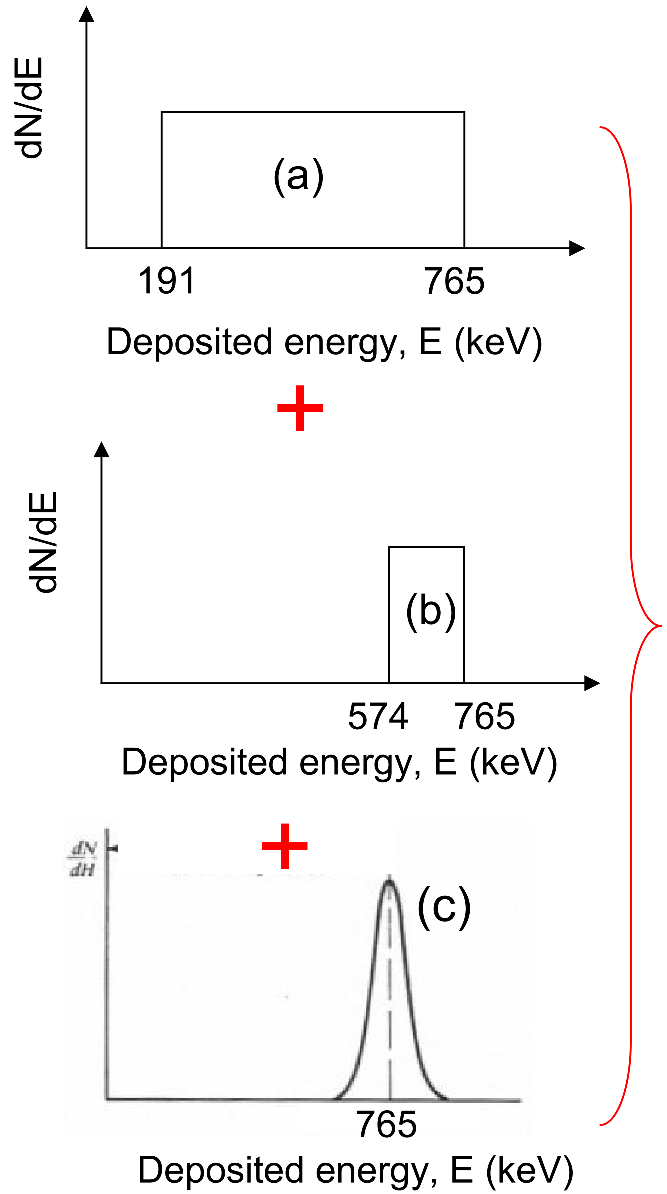
Pulse Height Discrimination

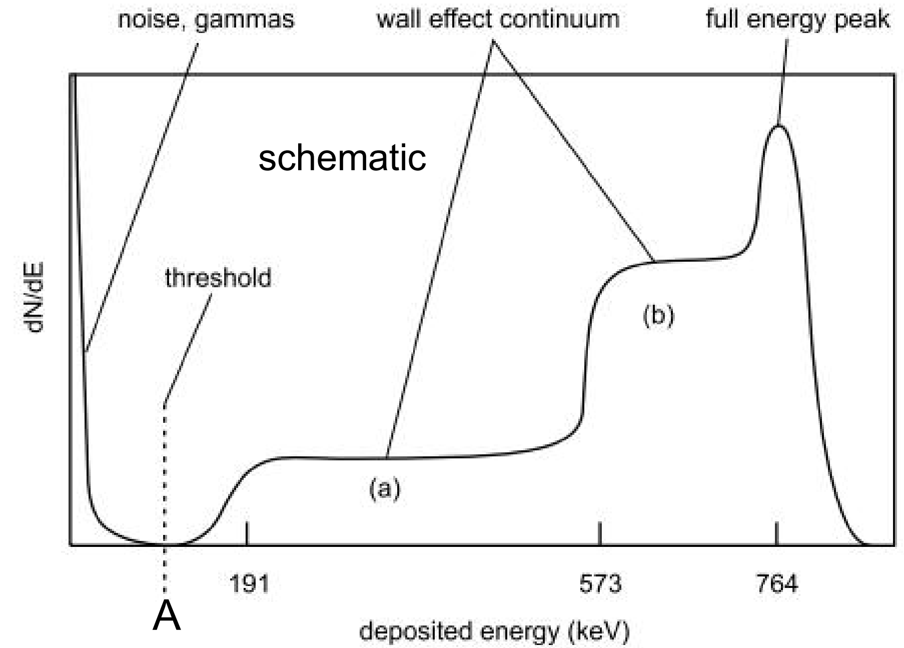


Pulse Height Discrimination-cont'd

- Can set discriminator levels to reject undesired events (fast neutrons, gammas, electronic noise).
- Pulse-height discrimination can make a large improvement in background.
- Discrimination capabilities are an important criterion in the choice of detectors (^{3}He gas detectors are very good).

^{3}He counters: n/γ discrimination





- Spectrum depends on size and geometry detector
- γ interactions produce small amplitude pulses that can be eliminated by amplitude discrimination
- For counting purposes, the threshold should be set around A

MAPS Detector Bank (at ISIS)

Sizes of Proportional Counters

- PCs come in many sizes.
  - Diameters from ~ 5. mm to 50 mm.
  - Fill gas pressures are highest for small diameters, up to 40 atm, and lowest for large diameters 2.~ 3. atm.
  - Lengths vary from cm to meters; the longer detectors, up to about 3. m long, are typically those of larger diameter.

Detection efficiency

$$\varepsilon = 1 - exp(- N\,\sigma\,d)$$

Approximate expression for low efficiency:

$$\varepsilon = N\,\sigma\,d$$

Here:

s = absorption cross section (energy dependent)
N= number density of absorber
d= thickness

$N = 2.7x\ 10^{19}\ cm^{-3}$ *per atm for a gas at 300 K.*
For 1-cm thick ^3He at 1 atm and "thermal" neutrons,
$\varepsilon = 0.13$.

The BF_3 slow neutron detector

$n + {}^{10}B \rightarrow ({}^{11}B)^*$

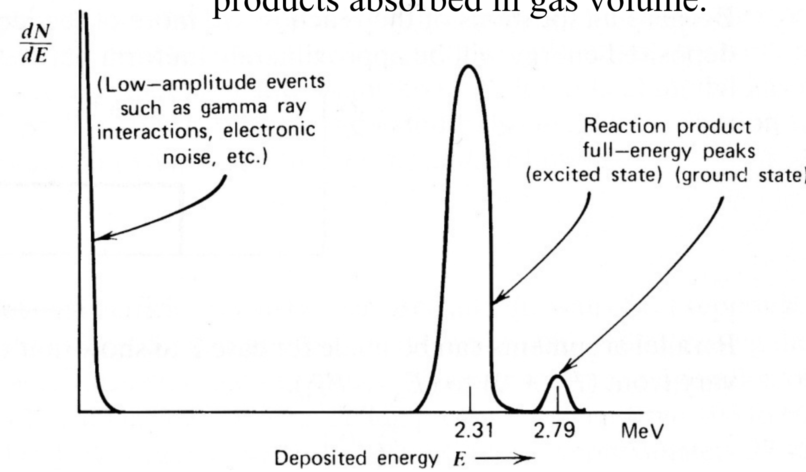
$\rightarrow {}^{7}Li^* + {}^{4}He$, Q = 2.31 MeV [94%]

K.E. 0.84 MeV + 1.47 MeV

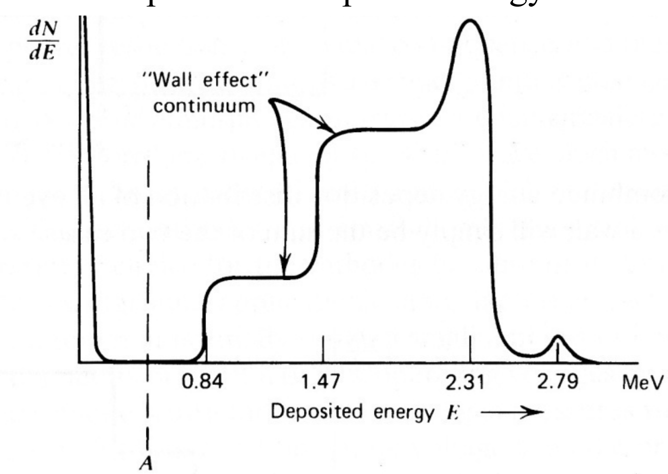
$\rightarrow {}^{7}Li + {}^{4}He$, Q = 2.79 MeV [6%]

- BF_3 gas, enriched to >90% of ^{10}B
- Operated as proportional or G-M counter
- However, recombination and formation of negative ions require lower pressure P < 1atm
  - Range of α-particles ~ 10 mm
  - Pronounced wall effect
- As in ^3He tube, spectrum reflects response of detector, NOT neutron energy

"Ideal" response: large tube, all reaction products absorbed in gas volume.



Obs. response due to partial energy loss in tube walls



BF_3 counters:
P ~ 0.5 – 1 atm
2000 – 3000 V
M ~ 100-500

BF_3 proportional counters

$^{10}B(n,\alpha)$ reaction is employed in BF_3 proportional tubes where BF_3 gas is the neutron converter and the detector medium simultaneously.

•The BF_3 gas is enriched in ^{10}B (up to more than 90%) to increase the sensitivity to neutrons (natural B has ~20% ^{10}B)

•The range of 2.31 MeV alpha-particle @ 1 atm: ~1 cm

wall effect: not all energy deposited in gas

BF_3 counters: properties

- Wall effect are reduced by making the detector larger or rising BF_3 pressure
- Small tubes are acceptable as long as a clear counting plateau is maintained.
- Detection efficiency decreases as neutron energy increases (1/v behavior of cross section)
- Aging (degradation of performance after ~10^{10}-10^{11} counts)

- At high flux, multiple γ pulses in short time succession may give a net pulse large enough to be mistaken for a neutron pulse

BF_3 proportional counter construction and operation parameters

- Construction material: often aluminium (it has low neutron interaction cross-sections)

- Gas: as BF_3 is not ideal as proportional counter gas, a mixture of Argon + BF_3 is often used → neutron efficiency decreases but sharper peaks → more stable counting plateau

- Gas pressure: ~ 500-1500 torr in order to get a good performance as a proportional gas.

- Geometry: cylindrical; typical anode ϕ~0.1 mm; typical cathode: a few cm.

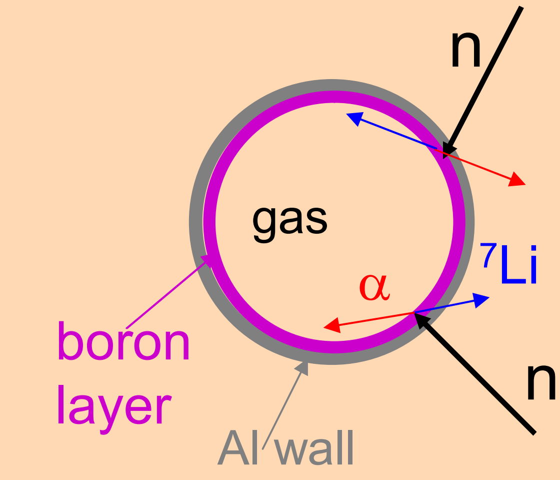
- Operating voltages: typically 2000-3000V; higher pressure or larger anode wires require higher applied voltages.

Boron-lined detectors

- Boron deposited on the inner surfaces of the chamber is the target material for conversion of the neutrons into a ^{7}Li and an α ($^{10}B(n,\alpha)^{7}Li$);

- ^{7}Li or α (not both) enter the chamber.

- As ^{7}Li or α are charged, they are detected in the gas filling the detector



Schematic ilustrating the operation principle of a boron-lined detector

- α-range in boron is ~1mg/cm^{2} $\Rightarrow$ boron plating should be thin $\Rightarrow$ the neutron detection efficiency (~10%) is lower in ^{3}He or BF_3 counters.

Boron-lined Proportional Counters

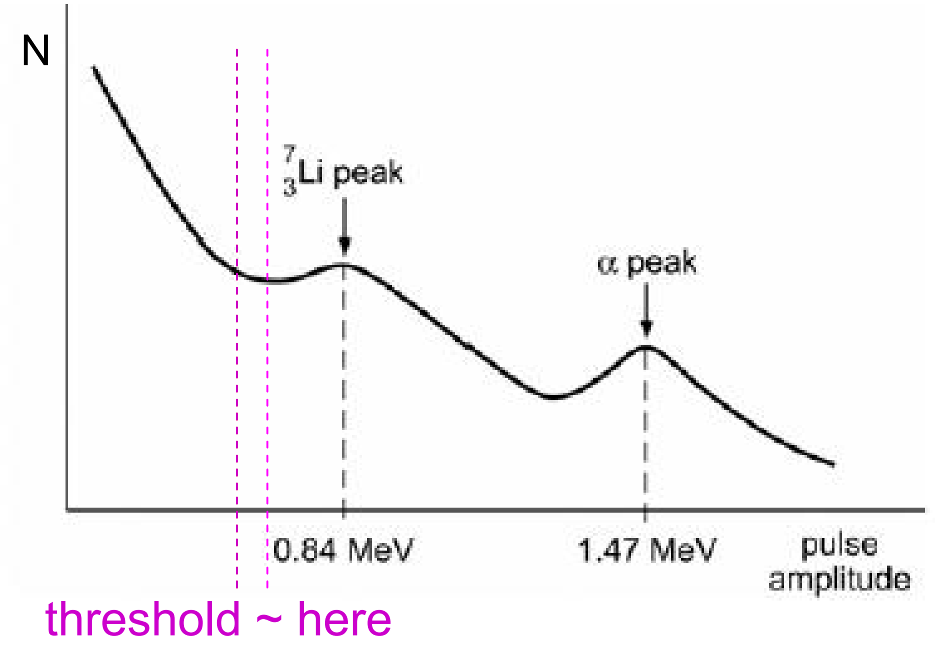
• interior walls of a conventional proportional counter coated with solid boron.

• use standard proportional gas

• Neutron interactions with ^{10}B take place in the wall of the counter→ Only one of the two emitted particles (^{7}Li or α) reaches the gas with some fraction of its initial energy

the energy of particles entering the gas and producing pulses varies:

^{7}Li: from 0 to 0.84 MeV
α: from 0 to 1.47 MeV



As there is no well-defined "valley" to set the threshold in, the count rate plateau curve is ~10%/100V

Comparing Boron-lined with BF3 proportional counters:

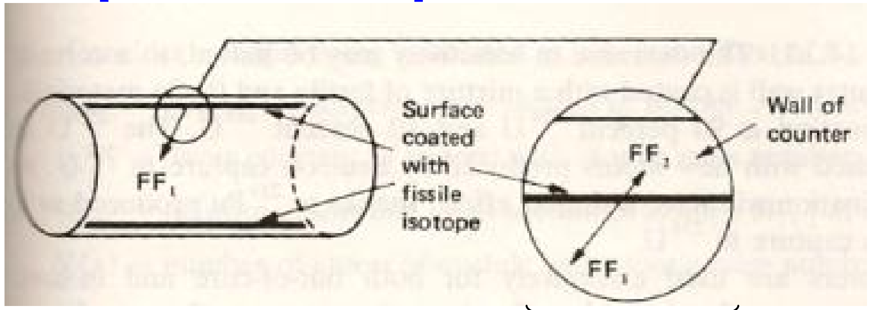
- A more suitable proportional gas can be used
- Higher gamma-ray insensitivity (due to lower fill pressure and lower operating pressure)
- Less aging effects
- Can give faster signals (by proper choice of gas)

- worse long-term counting stability
- lower efficiency (~10%)

Fission chambers: principle of operation

Neutron cause fission of the material covering one (or both electrode) of the chamber

The high energy ionising products → output pulses of the ionization chamber.



for slow neutrons, the two FF are emitted in oposite directions

Fission fragments (FF) are very energetic (for example ^{235}U : Q~200 MeV → FF share about 160 MeV);

α and γ background also present;

^{235}U is the most used material; ^{238}U and ^{232}Th are used for fast neutrons

Other fissionable isotopes are ^{239}Pu, ^{237}Np, ^{234}U and ^{233}U.

- The most common filling gas is Argon plus 10% methane (or 2% N_2), with filling pressures typically from 1 to 5 atm (pressure depending on the application). At this pressure the range of FF is ~ a few cm.

Fission chambers

Coating thickness should be as large as possible to increase efficiency

BUT

smaller than the range of fission fragments in the coating material

(average range of FF from ^{235}U is ~7 μm ≡13mg/cm^2 coating;

➡ Typical coating thickness: 0.02 to 2 mg/cm^2

➡ Typical efficiency for thermal neutrons: 0.5 -1% (and even lower for fast neutrons)

Fission chambers can operate in pulse mode, DC or MSV mode.

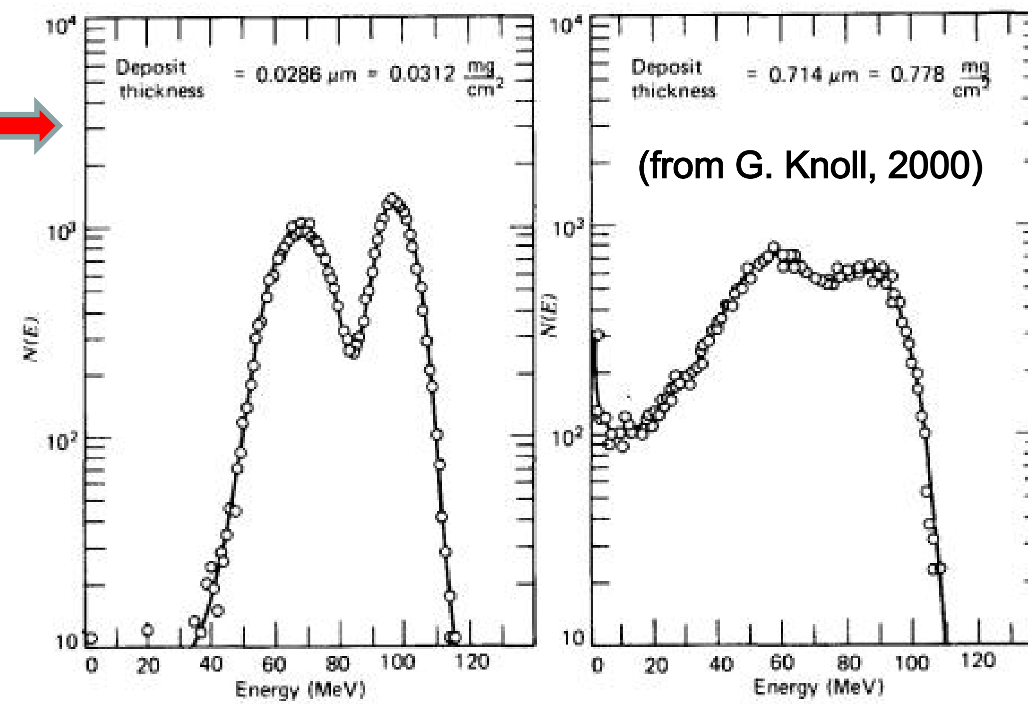
- Pulse chambers are limited to count rates typically < 10^5 cps;
- for higher count rate, DC or MSV fission chambers are used.

Fission chambers: pulse mode

- allow direct α and γ discrimination based on amplitude threshold

  - The spectrum depends on the wall coating thickness

  - the wall thickness must be thin enough so that the pulses due to any of the fission fragments are greater than the pulses due to α particles (for α **discrimination**)



FF deposited energy >> gammas

Fission chambers have **high insensitivity** to gammas

but limited to count rates < 10^5 cps

Gamma-sensitivity and **neutron efficiency** of some neutron detectors

Table 13-3. Typical values of efficiency and gamma-ray sensitivity for some common neutron detectors (T.W. Crane &M. Baker, Neutron detectors)

Detector Type	Size	Neutron Active Material	Incident Neutron Energy	Neutron Detection Efficiency[a] (%)	Gamma-Ray Sensitivity (R/h)[b]
Plastic scintillator	5 cm thick	^{1}H	1 MeV	78	0.01
Liquid scintillator	5 cm thick	^{1}H	1 MeV	78	0.1
Loaded scintillator	1 mm thick	^{6}Li	thermal	50	1
Hornyak button	1 mm thick	^{1}H	1 MeV	1	1
Methane (7 atm)	5 cm diam	^{1}H	1 MeV	1	1
^{4}He (18 atm)	5 cm diam	^{4}He	1 MeV	1	1
^{3}He (4 atm), Ar (2 atm)	2.5 cm diam	^{3}He	thermal	77	1
^{3}He (4 atm), CO_2 (5%)	2.5 cm diam	^{3}He	thermal	77	10
BF_3 (0.66 atm)	5 cm diam	^{10}B	thermal	29	10
BF_3 (1.18 atm)	5 cm diam	^{10}B	thermal	46	10
^{10}B-lined chamber	0.2 mg/cm^2	^{10}B	thermal	10	10^3
Fission chamber	2.0 mg/cm^2	^{235}U	thermal	0.5	$10^6 - 10^7$

[a]Interaction probability for neutrons of the specified energy striking the detector face at right angles.
[b]Approximate upper limit of gamma-ray dose that can be present with detector still providing usable neutron output signals.

Activation-based neutron detectors

A sample of a material with high cross-section for activation by neutrons is exposed to a flux of neutrons for a period of time and then removed so that the induced radioactivity (usually γ or β) may be counted.

For a thin foil irradiated with a contant flux of neutrons, the rate of activated species is:

$$R = \phi \sigma V$$

ϕ = neutron flux averaged over the foil surface
σ = activation cross section averaged over the neutron spectrum
V = foil volume

During irradiation the activity of the material:

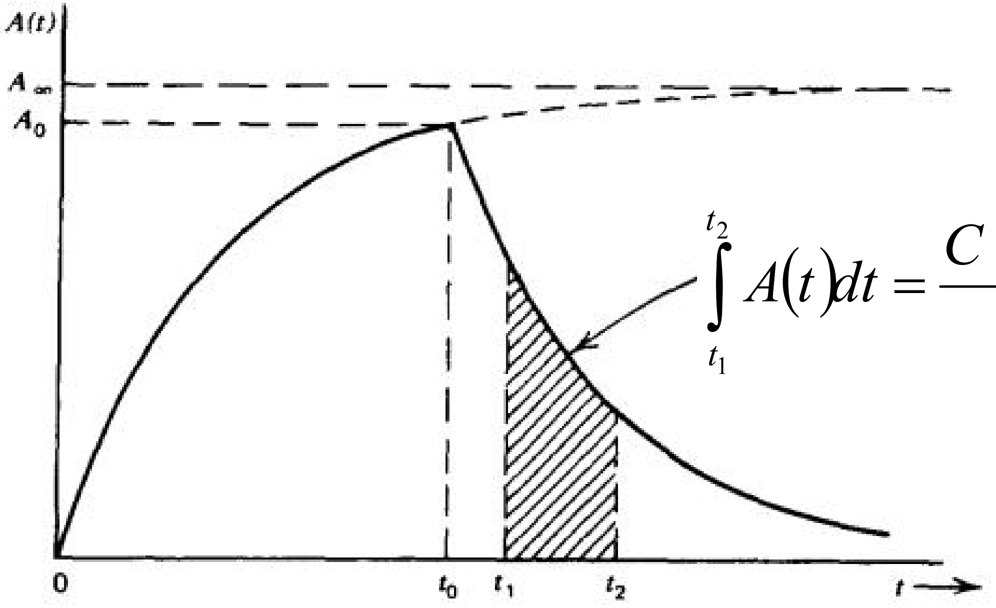
$$A(t) = R\left(1 - e^{-\lambda t}\right)$$

λ = decay constant of the radioactive species formed under irradiation

$$\lim_{t \to \infty} A(t) = A_{\infty} = R = \phi \sigma V$$

After exposure to the neutron flux during a time t_0, the foil is transferred to an appropriate radiation counter for measurement of its activity.

Activation-based neutron detectors



$$\int_{t_1}^{t_2} A(t)dt = \frac{C-B}{\varepsilon}$$

C = total number of counts in $t_2 - t_1$,

B = the number of background counts in $t_2 - t_1$,

ε = the overall counting efficiency (including any self-absorption effects);

• Because the activity is continuously decaying during this stage, careful account must be made of each of the times involved.

• If the counting is carried out over an interval between t_1 and t_2, **the number of counts,** C,

$$C = \epsilon \int_{t_1}^{t_2} A_0 e^{-\lambda(t - t_0)}\, dt + B$$

$$A_\infty = \frac{\lambda(C-B)}{\epsilon(1 - e^{-\lambda t_0}) e^{\lambda t_0} (e^{-\lambda t_1} - e^{-\lambda t_2})}$$

from A_∞ the neutron flux can be determined

Activation-based neutron detectors

Table 19.3 Materials Useful as Slow Neutron Activation Detectors (by (n,γ) reactions)

Element	Isotope (Abundance in Percent)	Thermal Activation Microscopic Cross Section (in 10^{-28} m^2)	Induced Activity	Half-Life
Manganese	^{55}Mn (100)	13.2 ± 0.1	^{56}Mn	2.58 h
Cobalt	^{59}Co(100)	16.9 ± 1.5	^{60m}Co	10.4 min
		20.2 ± 1.9	^{60}Co	5.28 y
Copper	^{63}Cu(69.1)	4.41 ± 0.20	^{64}Cu	12.87 h
	^{65}Cu(30.9)	1.8 ± 0.4	^{66}Cu	5.14 min
Silver	^{107}Ag(51.35)	45 ± 4	^{108}Ag	2.3 min
	^{109}Ag(48.65)	3.2 ± 0.4	^{110m}Ag	253 d
Indium	^{113}In(4.23)	56 ± 12	^{114m_1}In	49 d
		2.0 ± 0.6	^{114}In	72 s
	^{115}In(95.77)	160 ± 2	^{116m_1}In	54.12 min
		42 ± 1	^{116}In	14.1 s
Dysprosium	^{164}Dy(28.18)	2000 ± 200	^{165m}Dy	1.3 min
		800 ± 100	^{165}Dy	140 min
Gold	^{197}Au (100)	98.5 ± 0.4	^{198}Au	2.695 d

Source: K. H. Beckurts and K. Wirtz, *Neutron Physics.* Copyright 1964 by Springer-Verlag, New York. Used with permission.

Activation-based neutron detectors

Table 19.4 Materials Useful as Threshold Activation Detectors (useful for fast neutrons)

Material	Reactions of Interest	Isotopic Abundance (at %)	Half-Life	γ Energy (MeV)	γ Abundance (%)	Threshold (MeV)
F	$^{19}F(n, 2n)^{18}F$	100.0	109.7 min	0.511^{+}	194°	11.6
Mg	$^{24}Mg(n, p)^{24}Na$	78.7	15.0 h	1.368	100	6.0
Al	$^{27}Al(n, \alpha)^{24}Na$	100.0	15.0 h	1.368	100	4.9
Al	$^{27}Al(n, p)^{27}Mg$	100.0	9.46 min	0.84–1.01	100	3.8
Fe	$^{56}Fe(n, p)^{56}Mn$	91.7	2.56 h	0.84	99	4.9
Co	$^{59}Co(n, \alpha)^{56}Mn$	100.0	2.56 h	0.84	99	5.2
Ni	$^{58}Ni(n, 2n)^{57}Ni$	67.9	36.0 h	1.37	86	13.0
Ni	$^{58}Ni(n, p)^{58}Co$	67.9	71.6 d	0.81	99	1.9
Cu	$^{63}Cu(n, 2n)^{62}Cu$	69.1	9.8 min	0.511^{+}	195°	11.9
Cu	$^{65}Cu(n, 2n)^{64}Cu$	30.9	12.7 h	0.511^{+}	37.8°	11.9
Zn	$^{64}Zn(n, p)^{64}Cu$	48.8	12.7 h	0.511^{+}	37.8°	2.0
In	$^{115}In(n, n')^{115m}In$	95.7	4.50 h	0.335	48	0.5
I	$^{127}I(n, 2n)^{126}I$	100.0	13.0 d	0.667	33	9.3
Au	$^{197}Au(n, 2n)^{196}Au$	100.0	6.18 d	0.33–0.35	25–94	8.6
Li	$^{7}Li(n, \alpha n')t$	92.58	12.3 y	$0–0.019^{\times}$	$100^{\times}$	3.8

$^{+}$Annihilation radiation.

$^{\circ}$Yield of annihilation photons assuming all positrons are stopped.

$^{\times}$β particle energy and percent abundance.

Activation foils as neutron detectors

− They are **integrating** detectors $\Rightarrow$ no information on any time variation of neutron flux

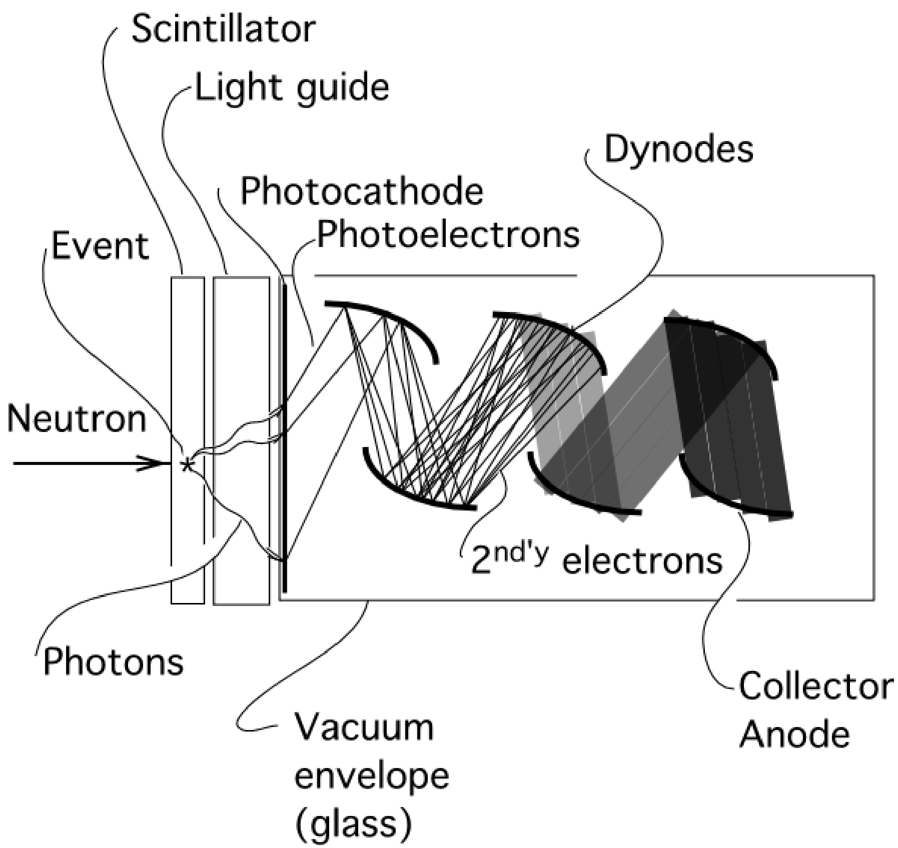
\+

- can be small in size
- insensitive to gamma-rays
- low cost
- can be installed in very harsh enviroments regarding temperature, pressure and high radiation fluxes (e.g. the core of a reactor)
- do not require any electrical connections (so they are handy)

⇓

They are widely used for mapping the spatial variation of steady-state neutron fluxes in reactor cores

Scintillation Detectors



$$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79\ \text{MeV}$$

$$\sigma = 940 \frac{\lambda}{1.8} \text{barns}$$

Some Common Scintillators for Neutron Detectors

Intrinsic scintillators contain small concentrations of ions (“wave shifters”) that shift the wavelength of the originally emitted light to the longer wavelength region easily sensed by photomultipliers.

ZnS(Ag) is the brightest scintillator known, an intrinsic scintillator that is mixed heterogeneously with converter material, usually Li^6F in the “Stedman” recipe, to form scintillating composites. These are only semitransparent. But it is somewhat slow, decaying with ~ 10 μsec halftime.

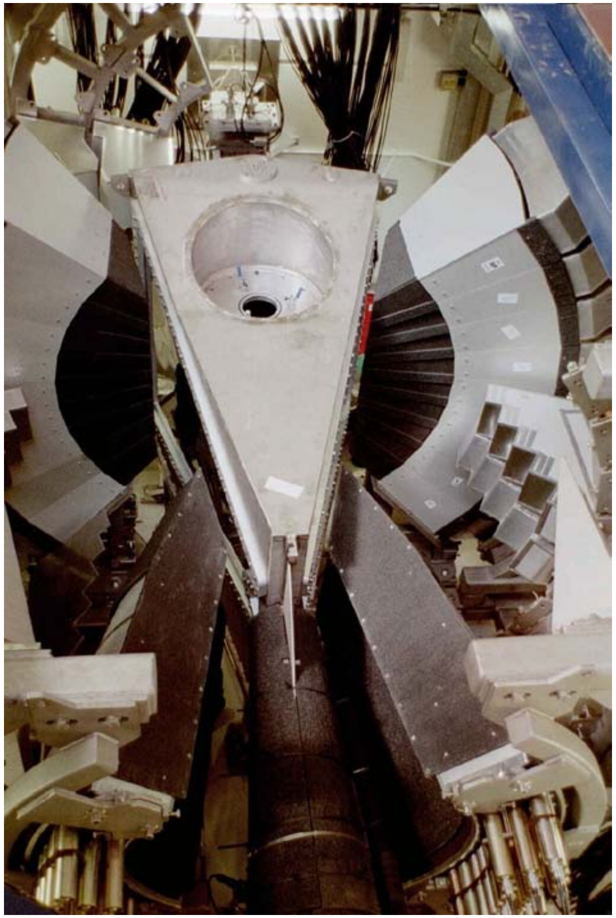
GS-20 (glass,Ce^{3+}) is mixed with a high concentration of Li_2O in the melt to form a material transparent to light.

$Li_6Gd(BO_3)_3$ (Ce^{3+}) (including ^{158}Gd and ^{160}Gd, ^6Li ,and ^{11}B), and $^6LiF(Eu)$ are intrinsic scintillators that contain high proportions of converter material and are typically transparent.

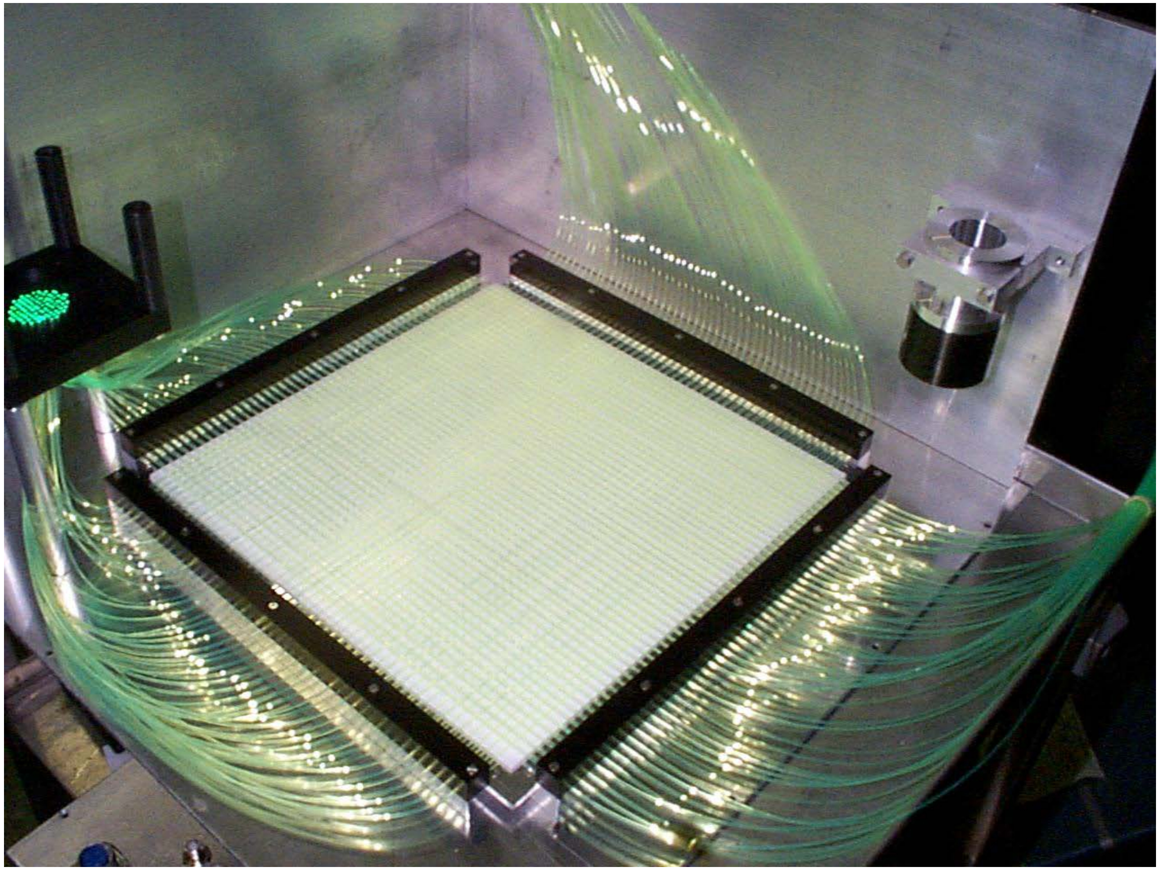
Some Common Scintillators for Neutron Detectors-cont'd

Material	Density of ^{6}Li atoms (cm^{-3})	Scintillation efficiency	Photon wavelength (nm)	Photons per neutron
Li glass (Ce)	1.75×10^{22}	0.45 %	395 nm	~7,000
LiI (Eu)	1.83×10^{22}	2.8 %	470	~51,000
ZnS (Ag) - LiF	1.18×10^{22}	9.2 %	450	~160,000
$Li_6Gd(BO_3)_3$ (Ce),	3.3×10^{22}		~ 400	~40,000
YAP	NA		350	~18,000 per MeV γαμμα

GEM Detector Module

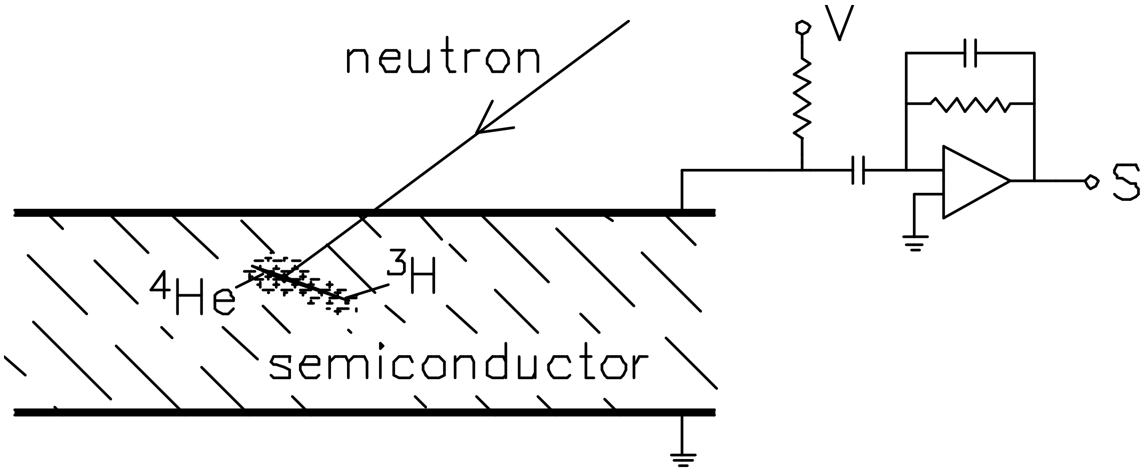


SNS 2-D Scintillation Detector Module



Shows scintillator plate with all fibers installed and connected to multi-anode photomultiplier mount.

Semiconductor Detectors



^{6}Li-loaded semiconductor

$$n + {}^6\text{Li} \rightarrow {}^4\text{He} + {}^3\text{H} + 4.79\ \text{MeV}$$

$$\sigma = 940 \frac{\lambda}{1.8}\ \text{barns}$$

Semiconductor Detectors-cont'd

- ~1,500,000 holes and electrons produced per neutron (~2.4×10^{-13} coulomb).
  - The detector acts as a capacitor. The ionization partially discharges the capacitor and can be detected directly without further amplification.
  - However, standard device semiconductors do not contain enough neutron-absorbing nuclei to give reasonable neutron detection efficiency.
    - Put neutron absorber on surface of semiconductor? These exist and are called *surface barrier detectors.*
    - Develop, for example, boron phosphide semiconductor devices? This is a challenge for future development.

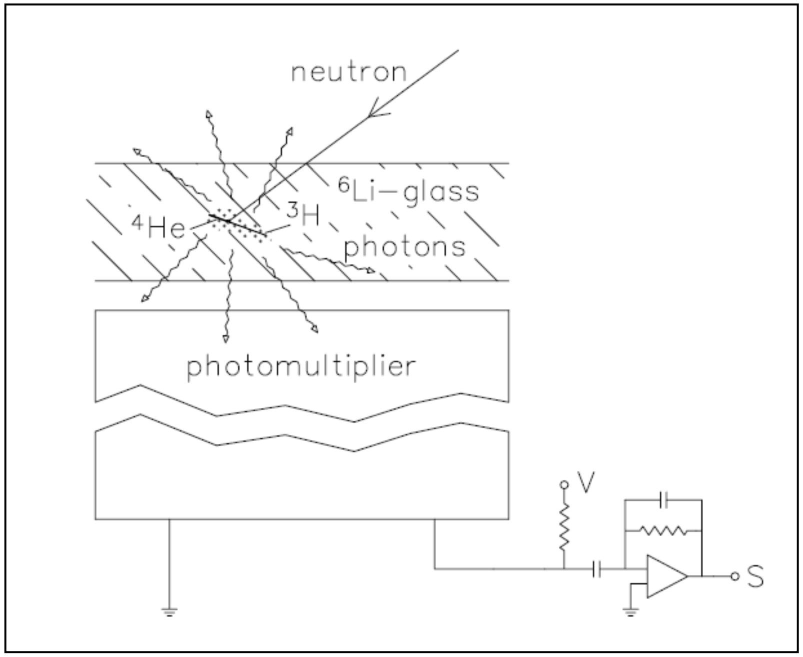
Li-based scintillators

$n + {}^6Li \rightarrow ({}^7Li)^* \rightarrow {}^4He + {}^3H$, Q = 4.78 MeV

K.E. 2.05 MeV + 2.74 MeV

- ^{6}Li loaded materials:
  - No stable lithium containing gas available

⇨ Li-loaded scintillators:
  - Solid LiI(Eu) [similar to NaI(Tl)]
    - 470nm, 51k photons/ MeV
    - No wall effects
    - Small detectors with ~ 100% efficiency (E_n < 0.5eV)
    - Single peak at Q-value with continuous γ-background (E_e=4.1MeV ~ E_{CP}=4.8)
  - Liquids: n-γ pulse-shape discrimination possible!



^{6}Li-glass: slow and fast neutron detection…
Glass-based scintillation detectors can be implemented as bulk and as long fibers (~ meters)!

Concluding remarks

Detectors must be chosen/DESIGNED for the specific application.
Typical application is “counting above threshold”

Requirements to be considered when designing detectors:

- Gamma-ray sensitivity
- Count rate
- Environment (B field, temperature etc)
- Digitize!