09 - Neutron detection

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Version 2

Neutron detection

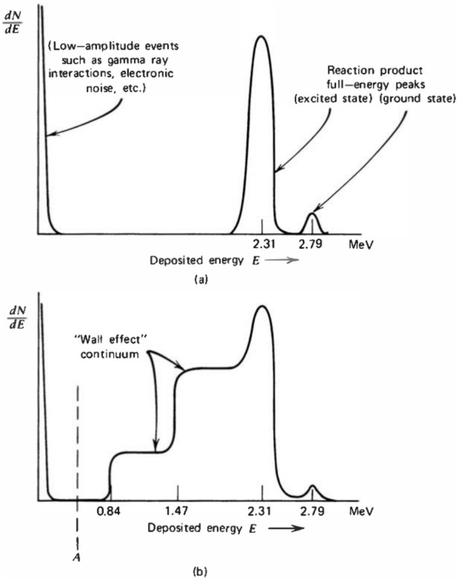
- Neutrons detected via charged particle producing charged particles
- Detector consists of target material for conversion and conventional radiation detector
- Different methods for slow neutrons (energy < 0.5 eV) and fast neutrons
- Slow neutrons important in nuclear reactors
- Products of conversion may be recoil nucleus, proton, α or fission fragments
- Suitable reactions are exothermic, kinetic energy of charged products given by Q-value of the reaction, not by small energy of slow neutrons

Reactions for slow neutron detection

- ^{10}B(n,α)
- ^{6}Li(n,α)
- ^{3}He(n,p)
- Gadolinium neutron capture
- Neutron-induced fission reactions

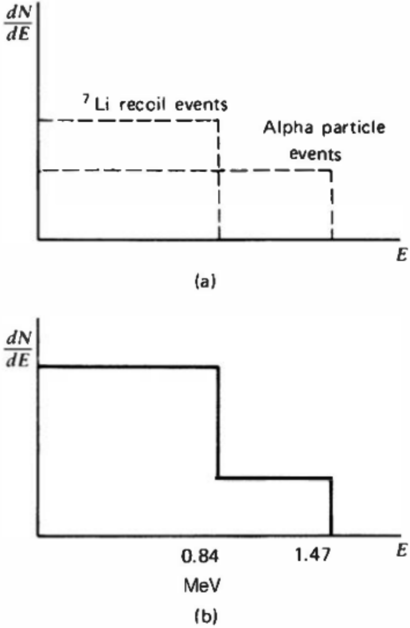
BF_3 proportional tube

- Proportional tube filled by BF_3, acts both as proportional gas and slow neutron converter
- Reaction products may be fully stopped (a) or one of them hit the outer wall (b)
- Counting of neutron-induced events above discriminator level A
- Construction as cylindrical tube with small-diameter anode wire



Boron-lined proportional counter

- Boron introduced as solid coating on inner walls of conventional proportional tube
- Allows for better proportional gas, good for timing application
- Only one reaction product detected per interaction
- Products deposits energy remaining after passage of conversion boron wall
- Spectrum starts at zero

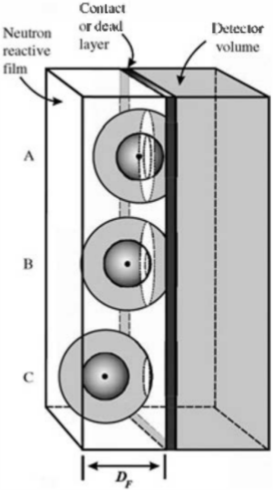


Boron-loaded scintillators

- Scintillator made by fusing B_2O_3 and ZnS, or plastic scintillator with 5 % of boron content
- Light yield would decrease with higher boron concentration (opacity of material)
- Lower discrimination against gamma background
- Application in neutron time-of-flight measurement

Neutron converter structures

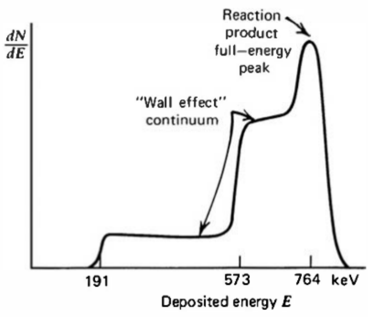
- Thin layer of boron on silicon diode or other semiconductor detector
- Maximal layer thickens given by range of the reaction products (sketched as the spheres on the drawing)



Lithium-containing slow neutron detectors

- Scintillator containing Li, crystalline ^{6}LiI(Eu), similar properties as NaI(Tl)
- Decay time of scintillation 0.3 µs
- Crystal easily larger than range of reaction products, 1 cm of thickness sufficient for 100 % efficiency for slow neutrons
- Detector very compact with use of silicon photodiode
- Other configurations may use thin layer of Li on ZnS(Ag) or ^{6}Li in liquid scintillator

^{3}He proportional counter



- ^{3}He as fill gas in proportional counter, works also as proportional gas
- Significant wall effect (range of products larger than tube dimensions) affecting pulse height spectrum (above), plateaus below full-energy peak
- Not used in Geiger mode due to need for discrimination against gamma background

Fission counters

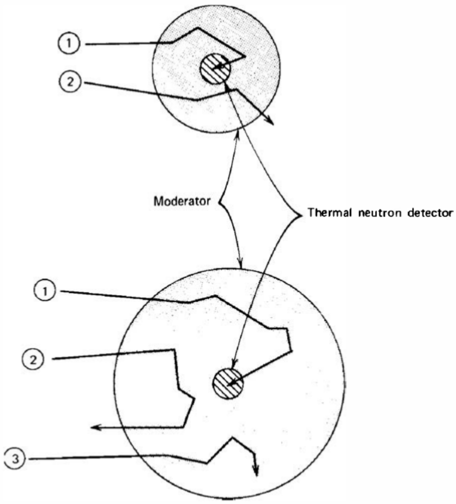
- Products of neutron-induced fission reaction detected in conventional detector
- Constructed as ionization chamber with fissile deposit on inner surface
- Applicable for fast timing with use of ionization chamber with small thickness of gas volume between electrodes

Fast neutrons detection

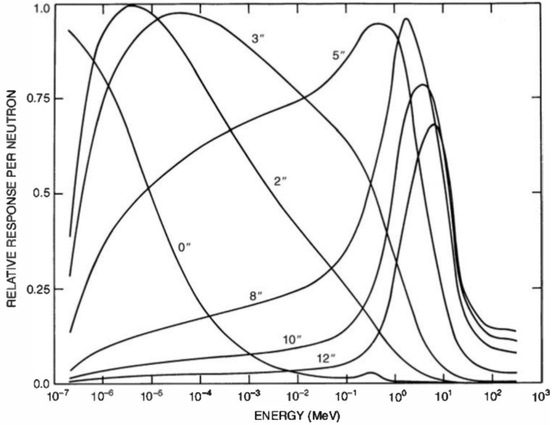
- Reactions suitable for slow neutrons usually have small cross section for fast neutrons, resulting in low detection efficiency
- Additional conversion mechanism such as elastic neutron scattering on proton
- Measurement of energy of neutrons by measuring energy of reaction products
- Counting of neutrons with neutron moderation and use of slow-neutron detector

Counters based on neutron moderation

- Detector is surrounded by hydrogenous material, polyethylene or paraffin
- Neutrons loose energy in moderator, reach detector as slow neutrons (1)
- Depending on energy and moderator thickness, neutrons may be partially moderated and escape without detection (2)
- Neutron can be parasitically captured in the moderator (3)



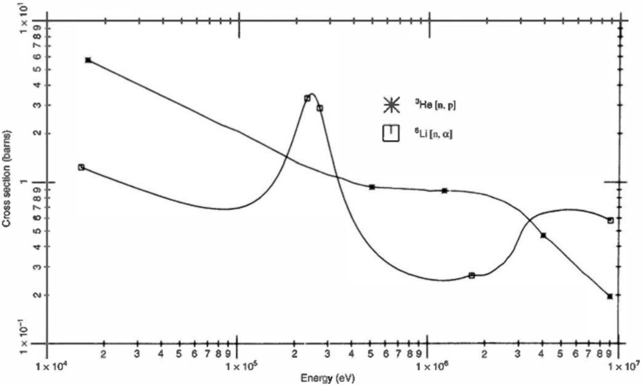
Bonner spheres



- Neutron spectrometer consisting of set of polyethylene moderating spheres with small lithium iodide scintillator at the center
- Detection efficiency vs. neutron energy (plot above) depends on sphere diameter (in inches in the plot)
- Count rate from spheres of different diameter provides energy spectrum of incident neutrons

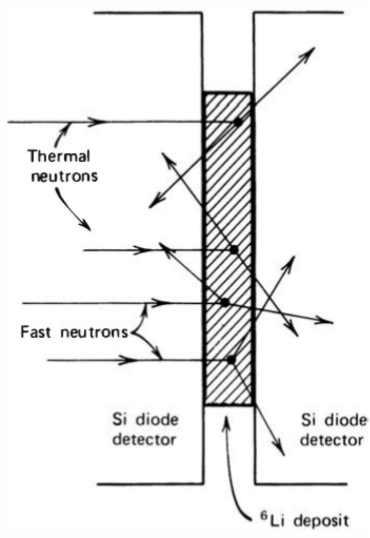
Detection based on fast neutron induced reactions

- Nuclear reaction is induced directly by fast neutron without the need for moderating
- Kinetic energy of reaction product given by energy of incident neutron and Q-value of the reaction
- Fast output signal but lower cross section compared to slow neutrons
- Suitable reactions are ^{6}Li(n,α) and ^{3}He(n,p)

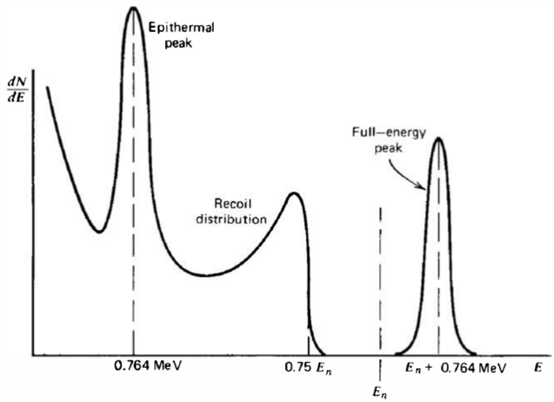


Lithium sandwich spectrometer

- Thin layer of lithium-containing material between two semiconductor diode detectors
- Sum of deposited energy in both detectors given by energy of incident neutron and Q-value of the reaction



Detection based on ^{3}He(n,p) reaction



- Spectrum of detected products of the reaction include several contributing phenomena
- Full energy peak is sum of neutron energy and Q-value of the reaction
- Continuum is present due to elastic scattering of neutron on He
- Epithermal peak is a result of moderation of some neutrons in the surrounding material
- Reaction products may be detected in ^{3}He proportional counter / ionization chamber, ^{3}He scintillator or ^{3}He semiconductor sandwich spectrometer

Detection using fast neutron scattering

- Elastic scattering of neutron on light nuclei, mainly hydrogen, or deuterium or helium
- Recoil proton is detected, carries portion of neutron energy from zero to full energy of neutron
- Proton recoil scintillator
  - Hydrogen-containing scintillator material
  - Organic crystal (anthracene, stilbene)
  - Plastic scintillator
- Gas recoil proportional counter
  - Fill gas is hydrogen or methane or helium
- External converter layer
  - Polymer containing hydrogen, polyethylene or polypropylene
  - Recoil proton escapes the layer, is detected in silicon diode or gaseous detector