Neutron detection techniques with digital systems

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1. Safety
2. Comments on
   neutron sources and detectors
   digital signal processing

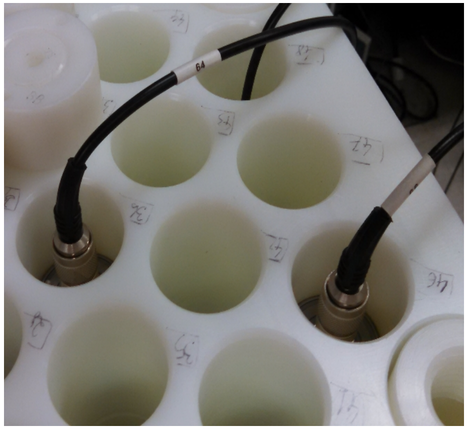
The purpose of this activity is to familiarize you with neutron detection techniques with the use of digital signal processing methods.

Passive Nondstructive Assay of Nuclear Materials
Editors : Doug Reilly, Norbert Ensslin and Hastings Smith
NuREG/cR-5550 LA-UR-90-732
http://www.lanl.gov/orgs/n/n1/panda/

Some safety remarks

Hazards:
Sealed gamma ray and neutron sources
High voltage
Compressed 3He cylinders

- The EBSS team operates the sources, cables and the HV
  Use your brain !



CAUTION
RADIOACTIVE MATERIAL
Cf-262-5444 | 105
53.8 µCi = 6/7/05
2.64 yr | FTC-CF-250
Steve Owens 241-4519
RADIATION SURVEY READINGS
EXTERNAL DOSE RATE
BETA + GAMMA 11/5
GAMMA
NEUTRON 13/0.9
TOTAL DOSE RATE 24/5.9
6/13/05

Neutron detection

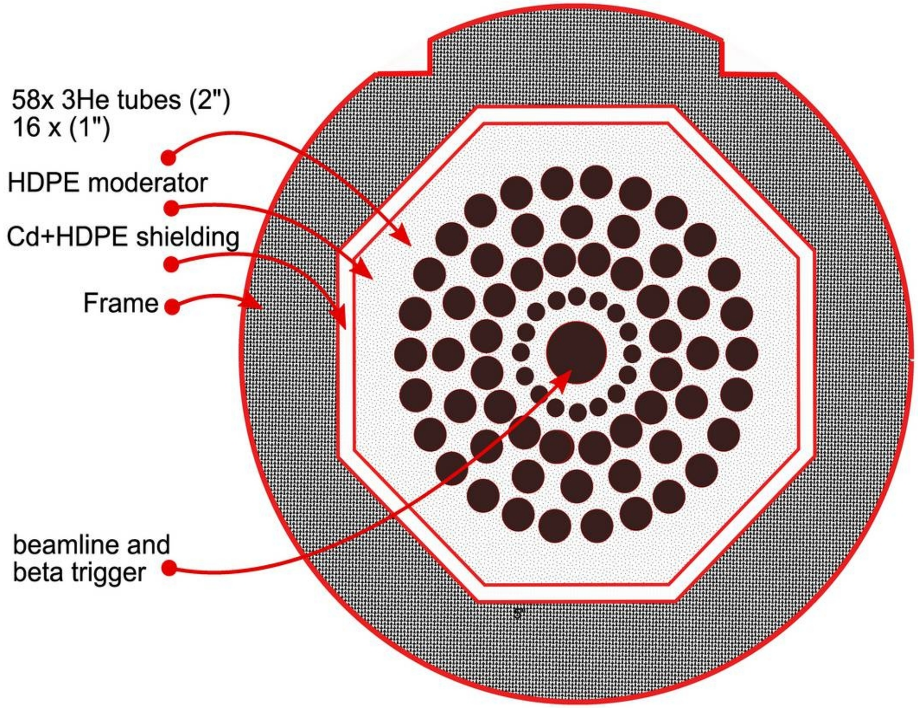
Neutrons don't carry electric charge !

The principal mode of interaction of neutron with material are:
- scattering
- reactions (radiative capture)

Scattering is a fundamental for "fast" neutron detection (~keV or larger)

Capture requires "thermalization" (slowing-down) of neutrons down to very low energies.

3Hen – efficient neutron counter



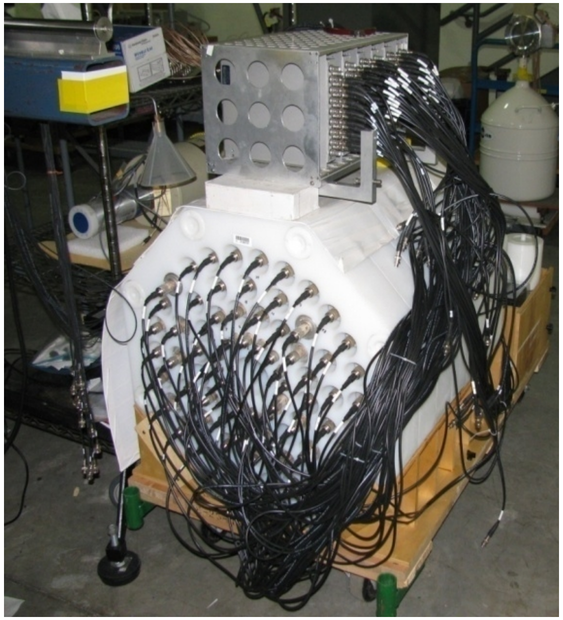
58x 3He tubes (2")
16 x (1")

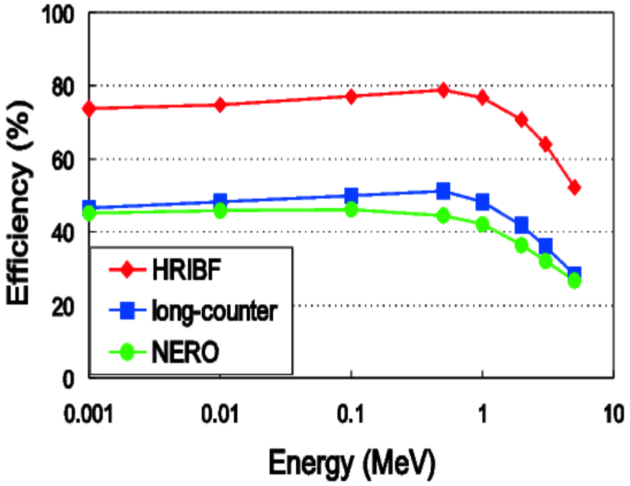
HDPE moderator

Cd+HDPE shielding

Frame

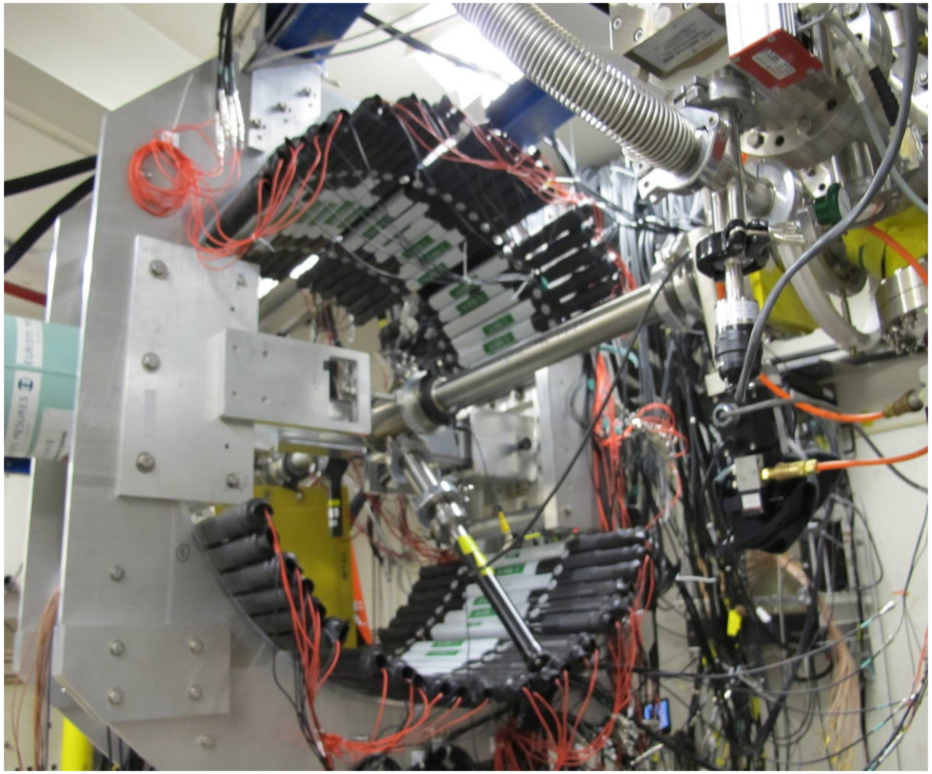
beamline and
beta trigger

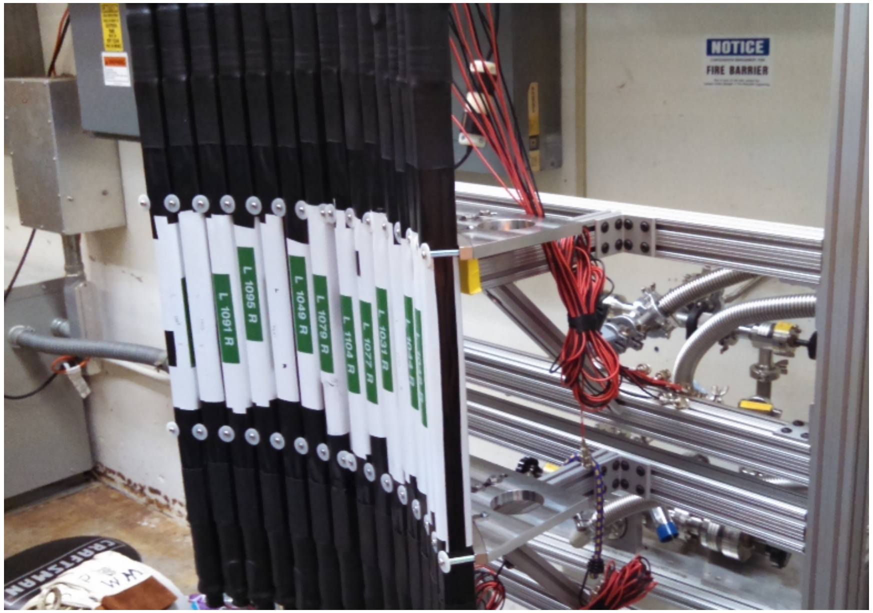




VANDLE

The Versatile Array for Neutron Detection at Low Energies





Beta-delayed neutron emission

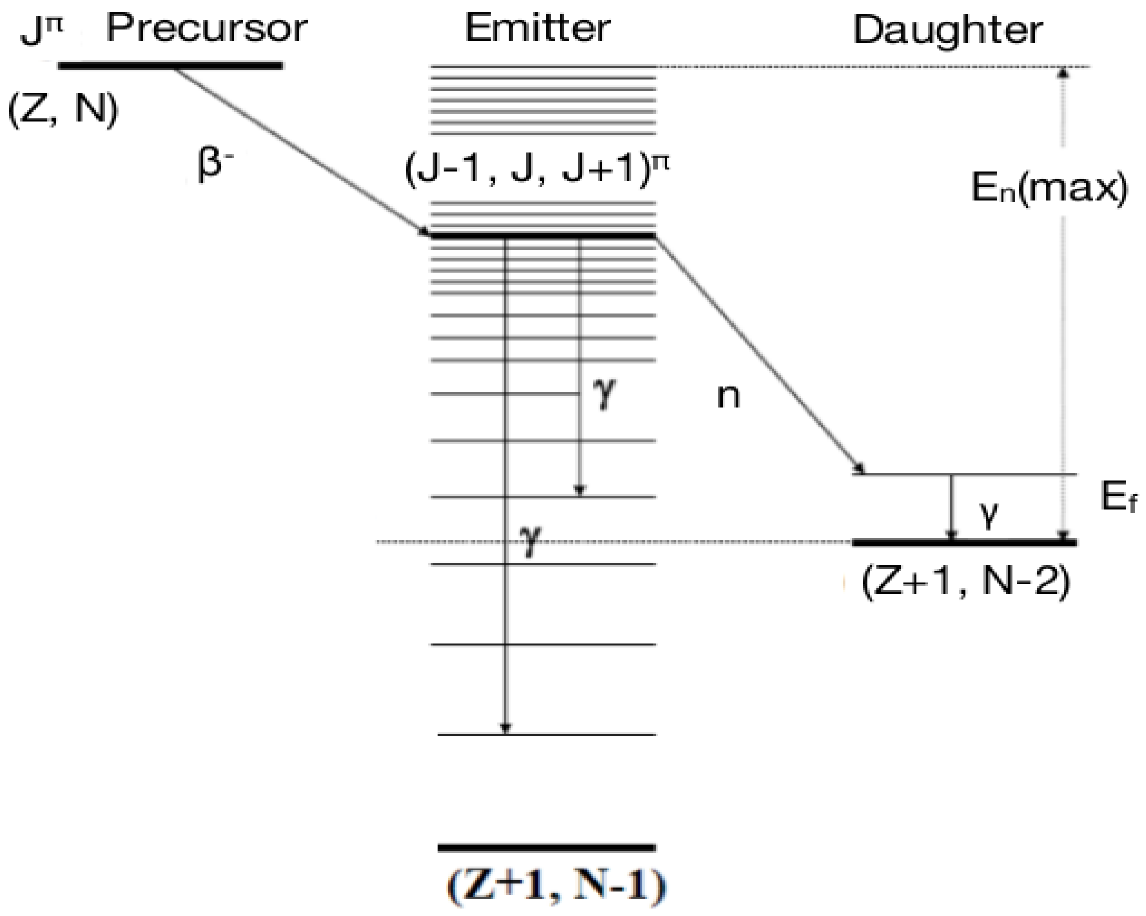
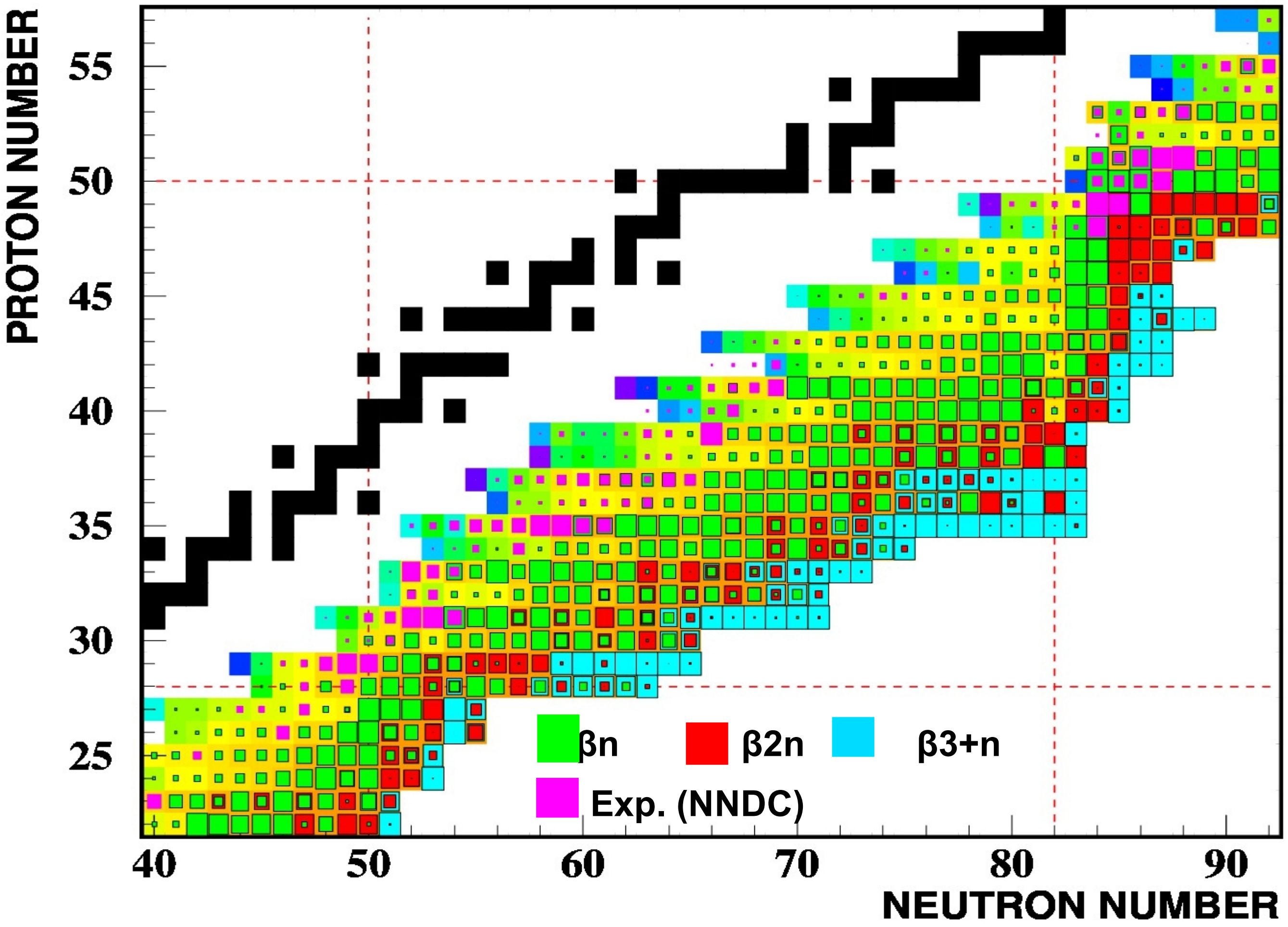


Figure: T. Kawano

Beta-xn channels in very n-rich nuclei

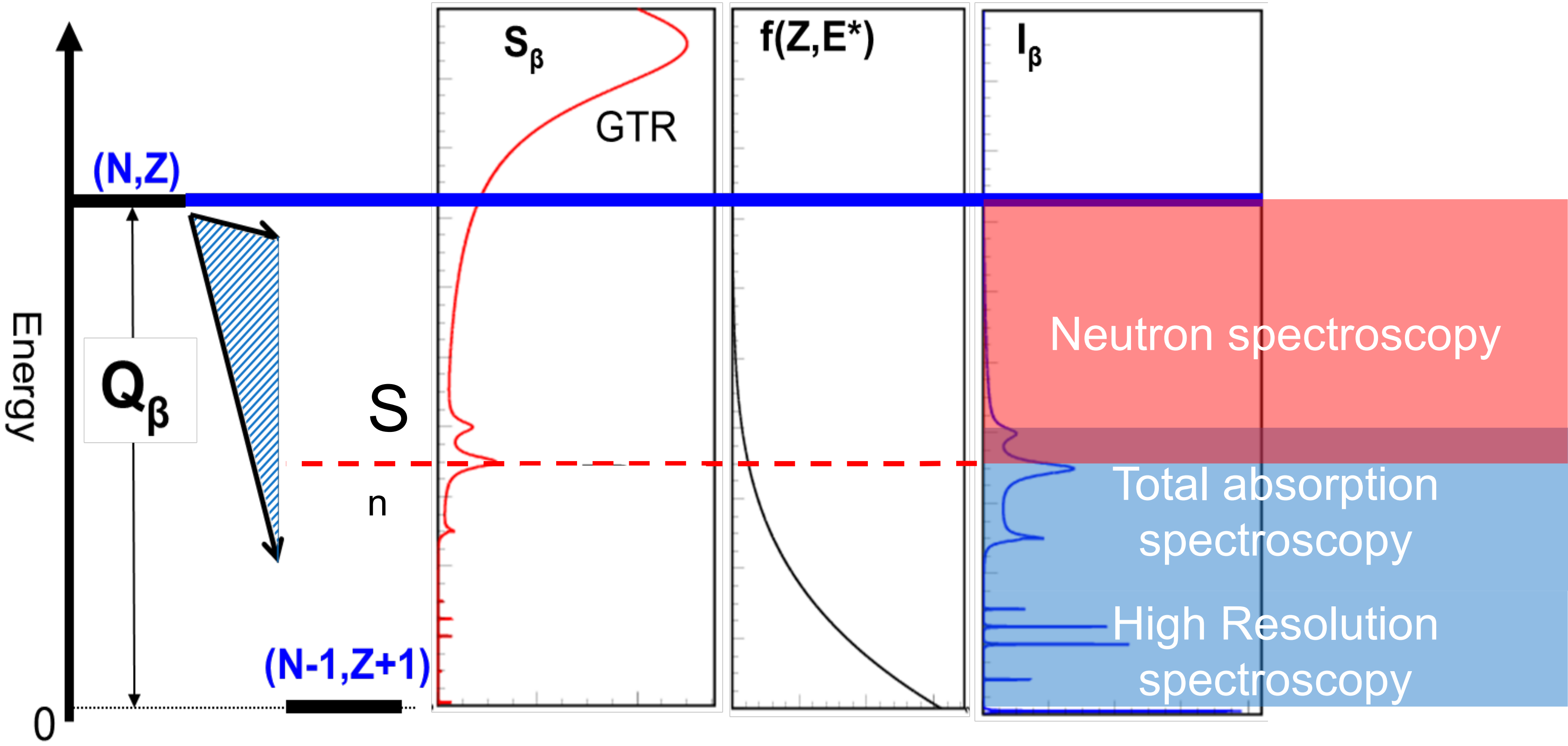


Möller, P.; Nix, J. R.; Kratz, K.-L.
and Nuclear Data Tables, Vol. 66, p.131

Decay strength distribution and lifetimes/branching ratios

$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

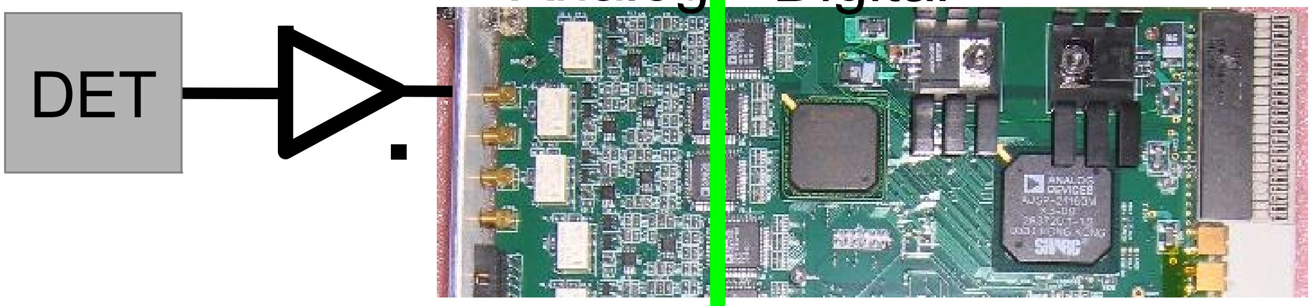
$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$



The essential components of the real-time DSP system

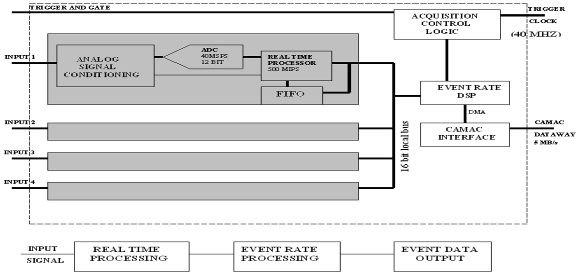
60 MB/s/channel total system load 5.8 GB/s

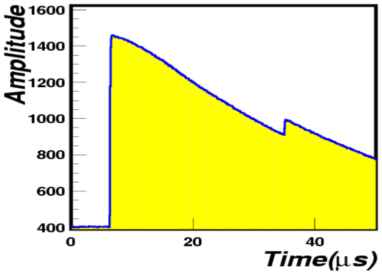
Analog Digital



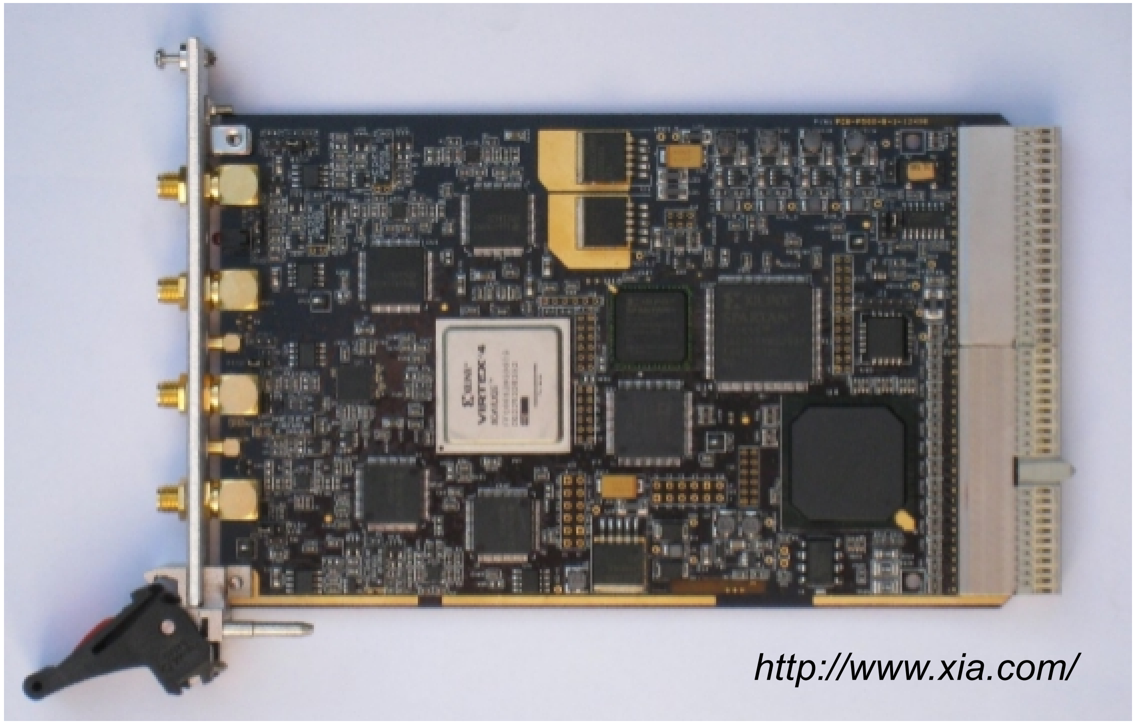
sampling ADC
(40 MHz-1 GHz)

Selective
triggering
0.3Mb/s





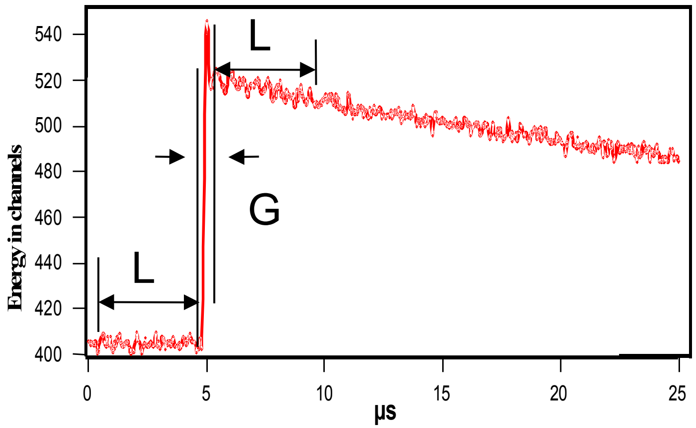
The PIXIE 500 board


http://www.xia.com/

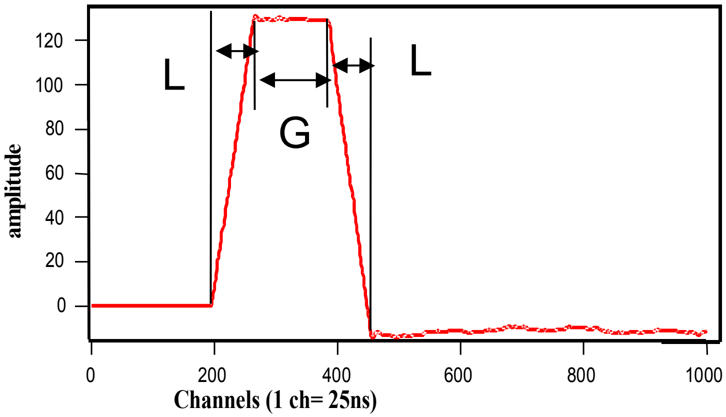
500MSPS
16 us traces
MCA
PCI interface 70 Mbytes/s
16bit DSP
Offsets -2.5 V / +2.5 V

Fast Digital Filters

Averaging filter (Trapezoidal filter)



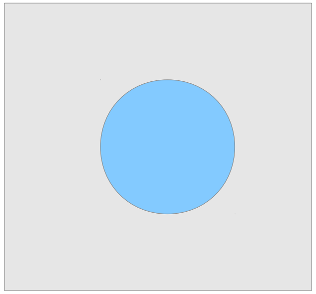
Detector pulse



Transformed pulse

Simple to implement in “real-time” system
Energy and “time-over-threshold” operations

The Neutron Counter



Proportional gas (3He,BF3) counter Inside moderator (HDPE)

Neutron slowing down may take 100μs

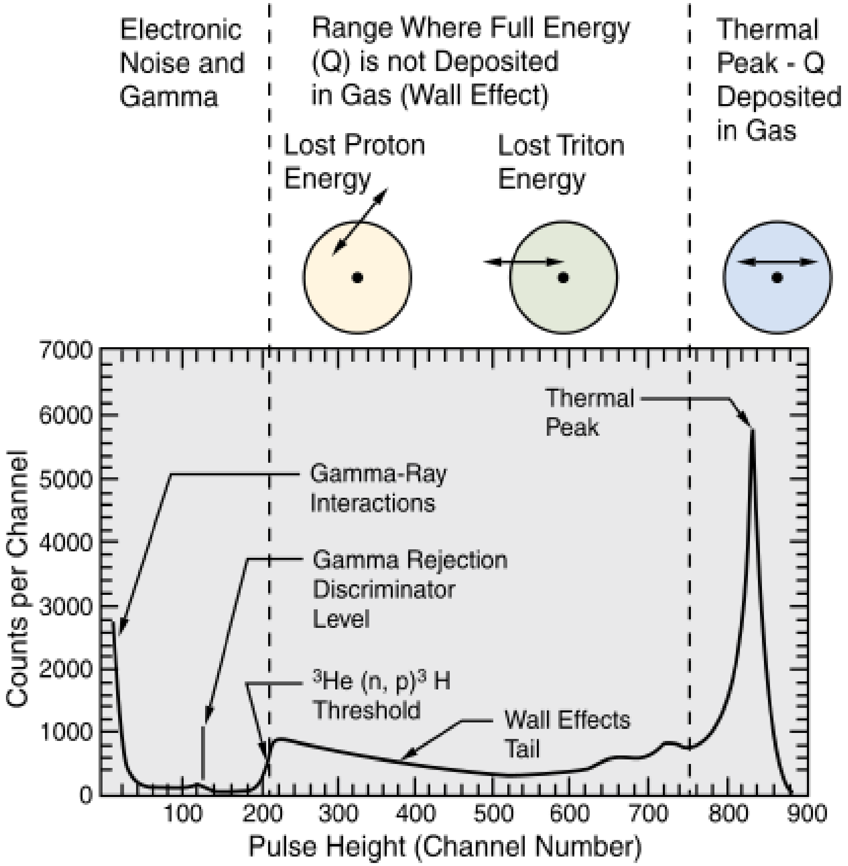


Figure 1.49 Thermal Neutron Induced Pulse Height Spectrum from a Moderated ^{3}He Detector

Canberra

Reactions generating charged particle used for Neutron Detectors

$$^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha \quad Q = 2.310\,MeV \quad 94\%$$

$$^{10}B + n \rightarrow {}^{7}Li + \alpha \quad Q = 2.792\,MeV \quad 6\%$$

$$^{6}Li + n \rightarrow {}^{3}H + \alpha \quad Q = 4.78\,MeV$$

$$^{3}He + n \rightarrow {}^{3}H + p \quad Q = 0.764\,MeV$$

The importance
of thermalization of neutrons:

Gas:
Boron Trifluoride (BF_3) and ^{3}He

Solids:
B,Li

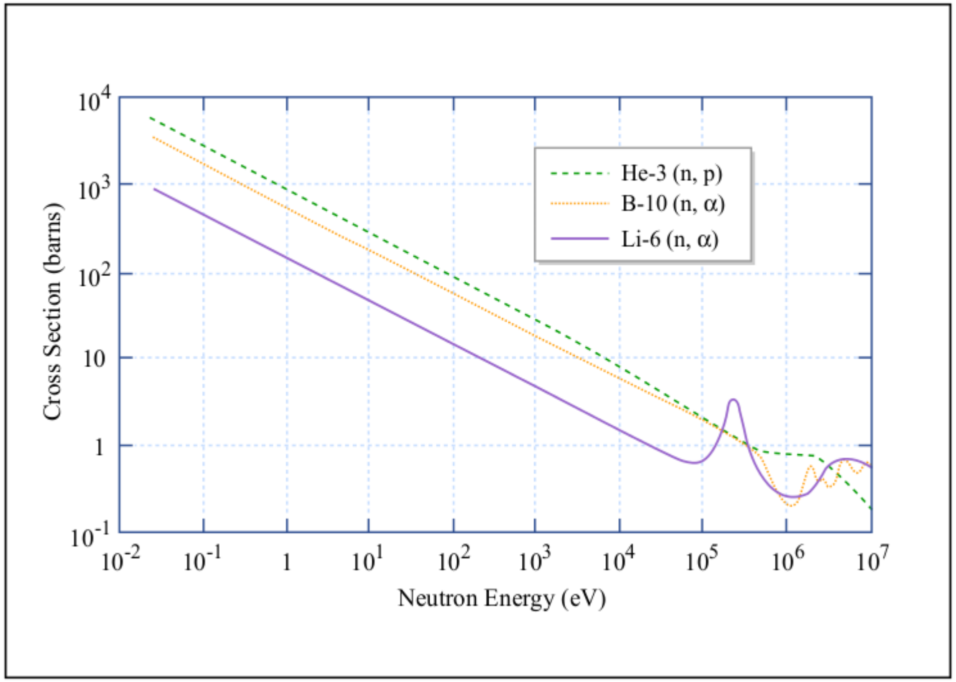


Image by MIT OpenCourseWare.

Neutron detection in scintillator

Neutron scatters of hydrogen and transfer parts of its kinetic energy onto charge particle (proton). The ionization induced in the material is detected.

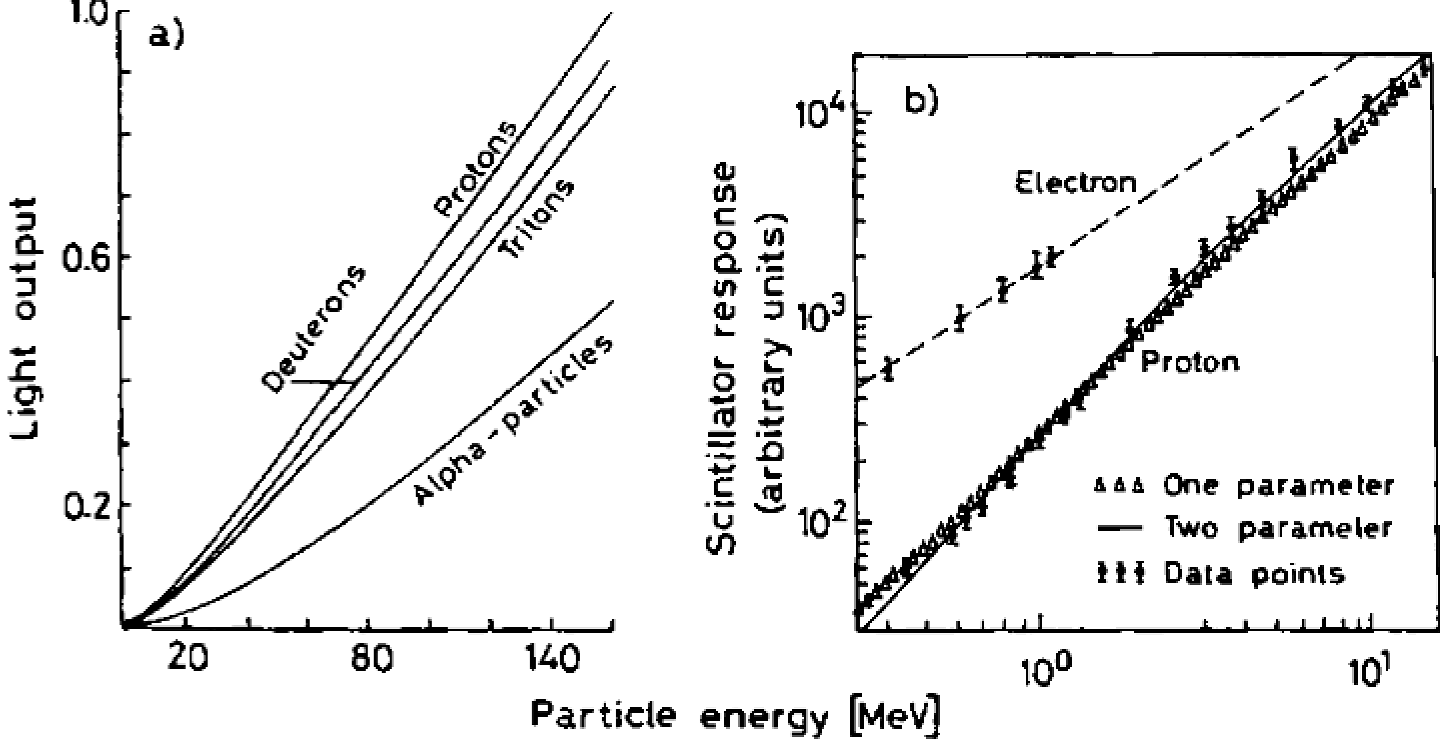


Fig. 7.8a, b. Response of NE 102 plastic scintillator to different particles ((a) from *Gooding* and *Pugh* [7.6]; (b) from *Craun* and *Smith* [7.7])

Neutron time-of-flight detection principle

Photons always win the race !

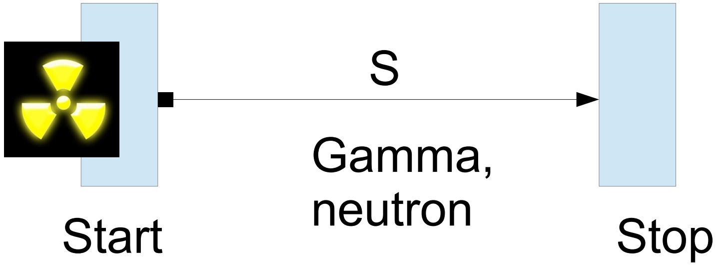
Neutrons :

$$E=\frac{mv^2}{2} \qquad v=\frac{s}{TOF}$$

$$v=\sqrt{\frac{2E}{m}} \qquad TOF=s\sqrt{\frac{m}{2E}}$$

Photons:

$V=c=const$
$TOF=const$

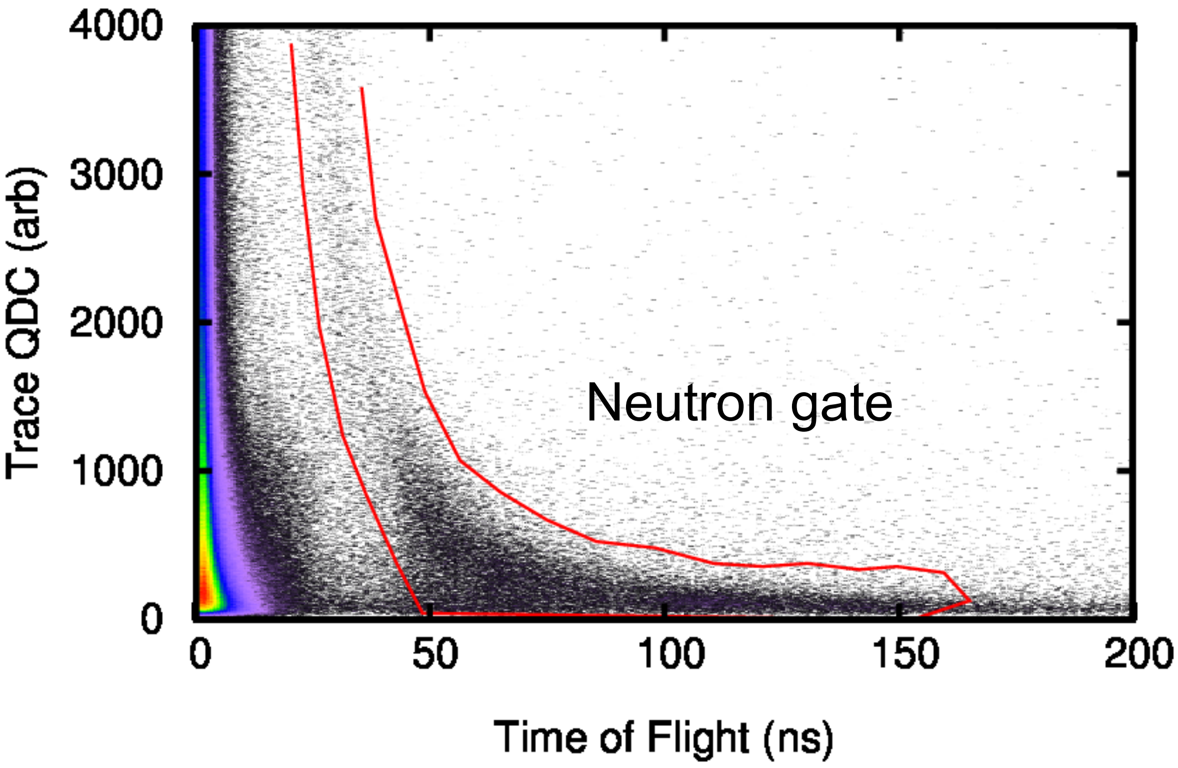


S

Gamma,
neutron

Start

Stop



Neutron pulse-shape discrimination in organic and inorganic scintillators

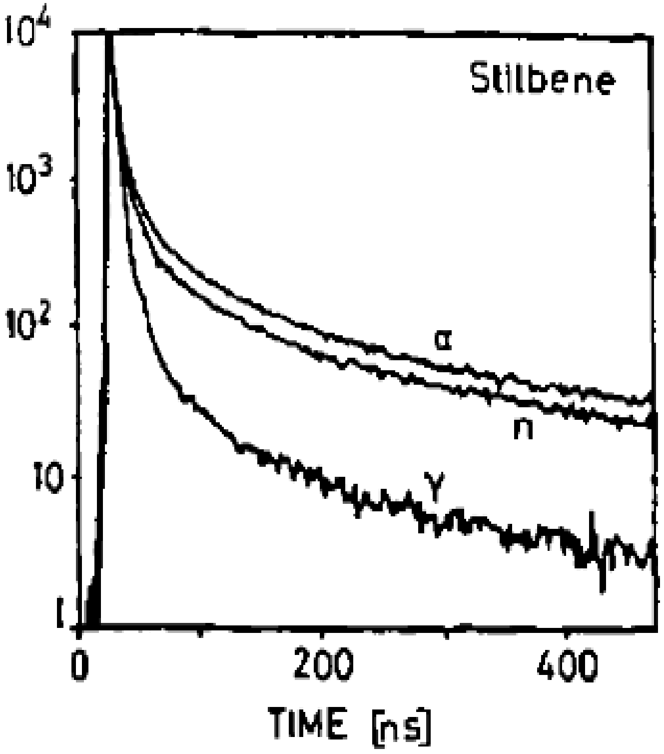
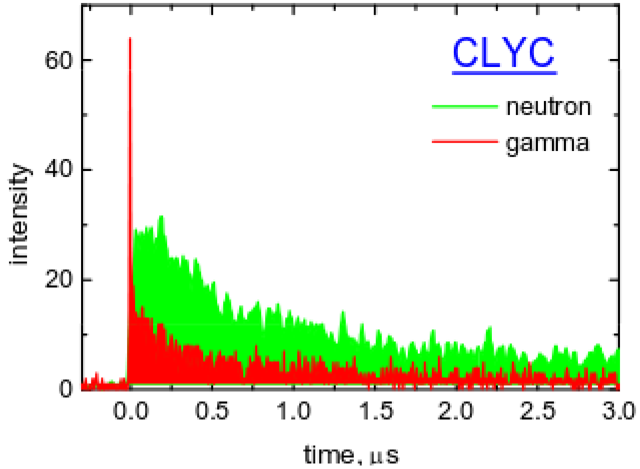


Fig. 7.11. Pulse shape of stilbene light for alpha particles, neutrons and gamma rays (from *Lynch* [7.71]; picture © 1975 IEEE)

CLYC

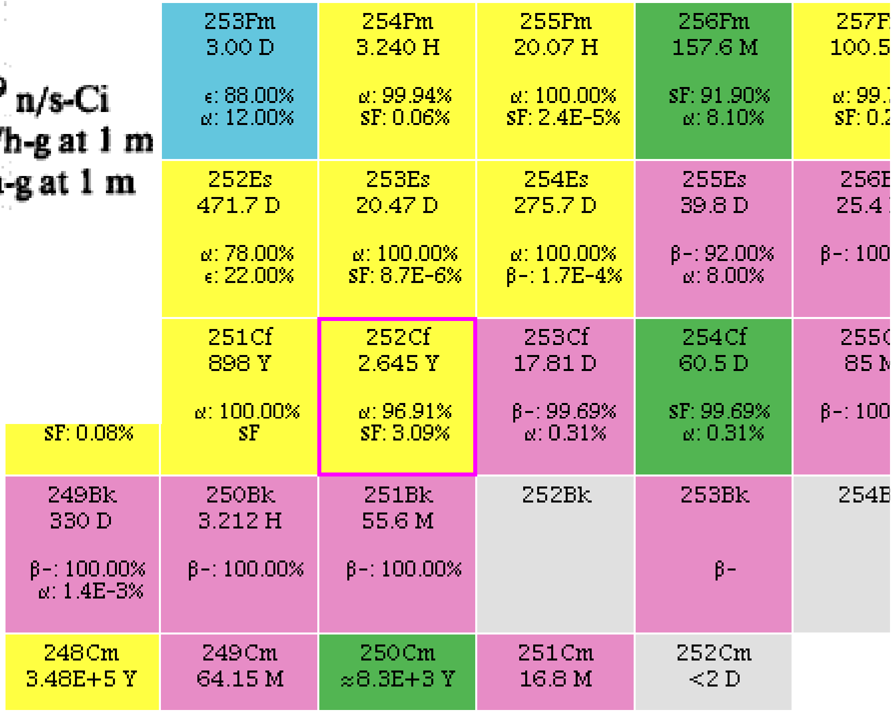


http://science.energy.gov/~/media/np/pdf/sbir %20sttr/presentations/shah_np_gamma_neutron_scintillators_1.pdf

The ^{252}Cf source

Table 11-7. Characteristics of ^{252}Cf

Total half-life	2.646 yr
Alpha half-life	2.731 yr
Spontaneous fission half-life	85.5 yr
Neutron yield	2.34×10^{12} n/s-g
Gamma-ray yield	1.3×10^{13} γ/s-g
Alpha-particle yield	1.9×10^{13} α/s-g
Average neutron energy	2.14 MeV
Average gamma-ray energy	1 MeV
Average alpha-particle energy	6.11 MeV
Neutron activity	4.4×10^{9} n/s-Ci
Neutron dose rate	2300 rem/h-g at 1 m
Gamma dose rate	140 rem/h-g at 1 m
Conversion	558 Ci/g
Decay heat	38.5 W/g
Avg. spontaneous fission neutron multiplicity	3.757
Avg. spontaneous fission gamma multiplicity	8



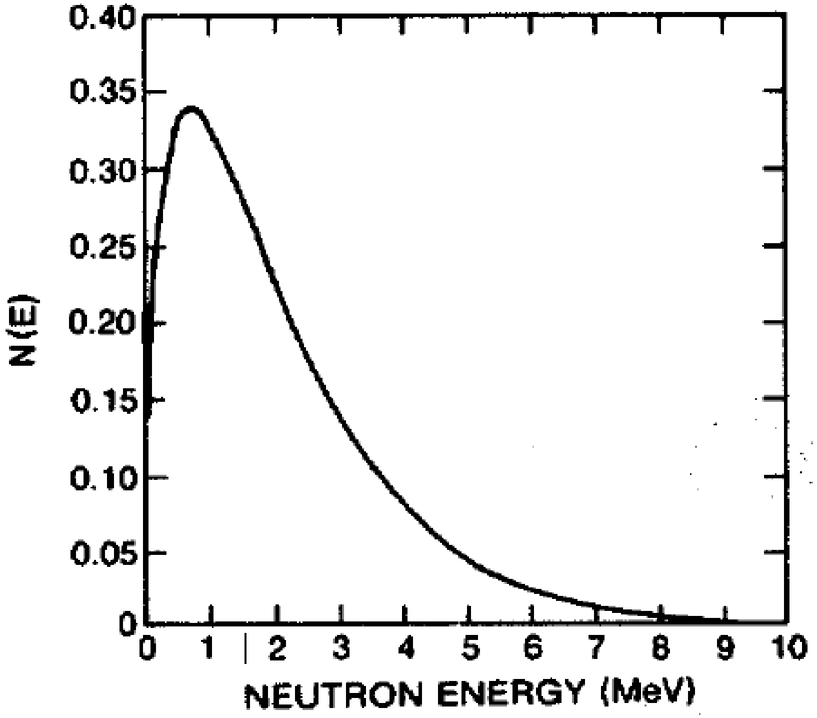
	253Fm 3.00 D ε: 88.00% α: 12.00%	254Fm 3.240 H α: 99.94% SF: 0.06%	255Fm 20.07 H α: 100.00% SF: 2.4E-5%	256Fm 157.6 M SF: 91.90% α: 8.10%	257F 100.5 α: 99. SF: 0.2
	252Es 471.7 D α: 78.00% ε: 22.00%	253Es 20.47 D α: 100.00% SF: 8.7E-6%	254Es 275.7 D α: 100.00% β-: 1.7E-4%	255Es 39.8 D β-: 92.00% α: 8.00%	256E 25.4 β-: 100
SF: 0.08%	251Cf 898 Y α: 100.00% SF	252Cf 2.645 Y α: 96.91% SF: 3.09%	253Cf 17.81 D β-: 99.69% α: 0.31%	254Cf 60.5 D SF: 99.69% α: 0.31%	255C 85 M β-: 100
249Bk 330 D β-: 100.00% α: 1.4E-3%	250Bk 3.212 H β-: 100.00%	251Bk 55.6 M β-: 100.00%	252Bk	253Bk β-	254B
248Cm 3.48E+5 Y	249Cm 64.15 M	250Cm ≈8.3E+3 Y	251Cm 16.8 M	252Cm <2 D	

^{252}Cf source has to be handled with extreme care !

The ^{252}Cf source

Neutron energy spectrum (Maxwellian distribution)

$$N(E)= E^{1/2} \exp(-E/1.43\ \text{MeV})$$



Gamma-ray spectrum