Sensori a diamante per neutroni

INFN-E/MAFLUNE

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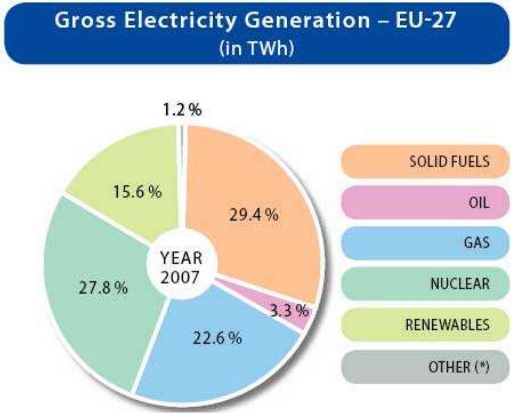
Nuclear Power Share in EU



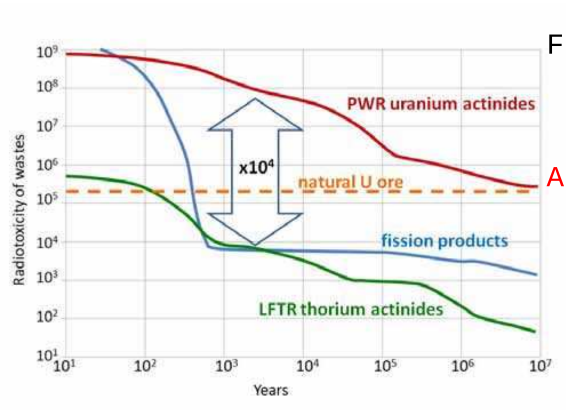
`Advantages`:

- low cost per kWh (in some countries),
- zero CO_2 emission,
- long lifetime.

`Problems`:

- risk of accidents,
- radioactive wastes. ✓

Radioactive Wastes



`Fission Products`:

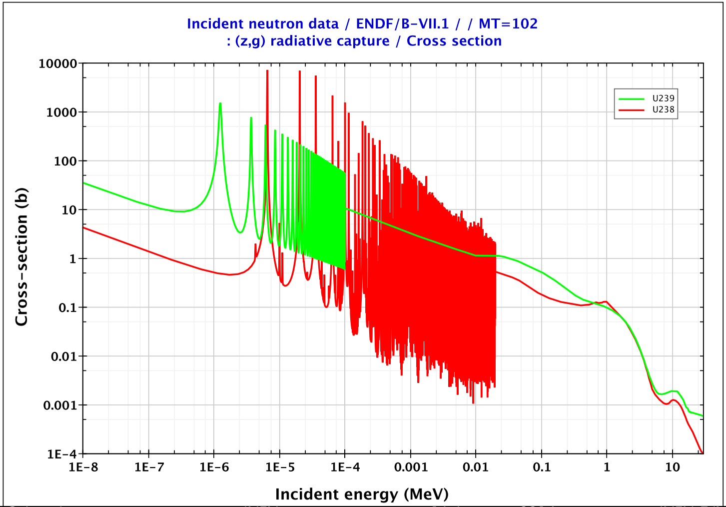
- high activity,
- mostly short-lived.

`Actinides`: ✓

- very long-lived,
- after 60-80 years become main concern.

Fast Reactors

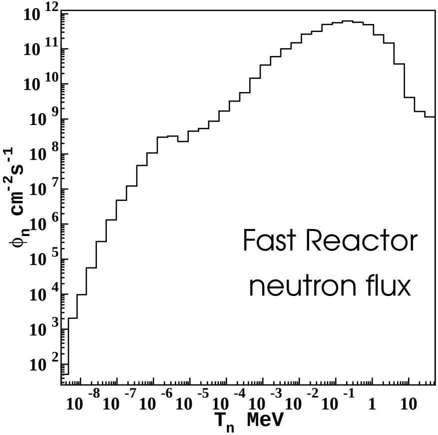
- capture of neutrons at $>$ 1 keV is unlikely,
- fast reactors produce less actinides. ✓



Neutron Spectrum Monitoring

`Goal`: to monitor neutron spectrum inside reactor core.

`Our Solution`: single crystal CVD diamond detectors. ✓



`Features`:

- radiation hard,
- insensitive to γ,
- fast response,
- compact size.

`Problems`:

- small signals.

`Aim`:

- measure neutron energy,
- range $<$ 10 MeV,
- resolution $<$ 300 keV.

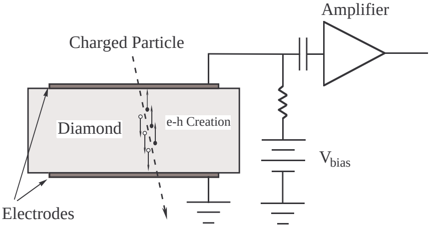
Other Active Detectors

In fluxes <10^{12} n/cm^2/s Diamond detector can substitute Fission Chamber as active monitor.

	Fission Chamber	Diamond Detector
Charge Mobility	0.3-0.4 cm^2/V/s	2000 cm^2/V/s
Charge Collection time	5-7 μs	2-10 ns
Counting Rate	20 kHz	10 MHz
Size	4×10 mm^2	2×2 mm^2
Converter	U,Th,Pu	H, Li, B
Efficiency at 0.5 MeV	1.1 barn	0.4 barn (^{6}Li)
Signal Size	200 fC	60 fC (^{6}Li)
Spectroscopy	unfolding	direct (^{6}Li)
Energy Range	entire	<7 MeV (^{6}Li)

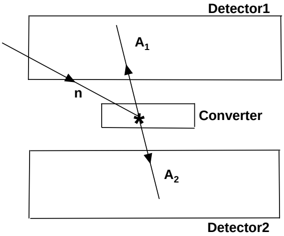
Principle of Detection

- Charged particle crossing diamond creates e - h pairs,
- To collect pairs the bias voltage has to be applied across the diamond,
- Current pulses are generated on electrodes,
- To become measurable the signals have to be amplified.

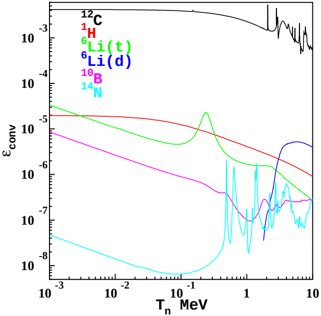


Energy Conversion

Use exothermic reactions with complete neutron energy conversion:



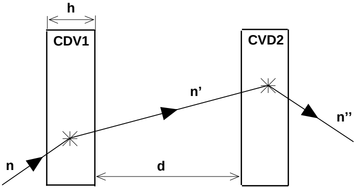
- $n + ^3He \rightarrow t(0.191MeV) + p(0.573MeV)$
- $n + ^6Li \rightarrow t(2.73MeV) + \alpha(2.06MeV)$
- $n + ^{10}B \rightarrow \alpha(1.47MeV) + ^6Li(0.84MeV)$
- $n + ^{14}N \rightarrow p(0.6MeV) + ^{14}C(0.025MeV)$



Time of Flight Technique

Measure the coincidence between two subsequent neutron interactions:

$$T_n = \Delta T_n + \frac{M_n}{2}\left(\frac{d}{c\Delta t}\right)^2$$



ΔT_n - energy lost in first interaction, Δt - time interval between two interactions.

Threshold deposited energy is critical:

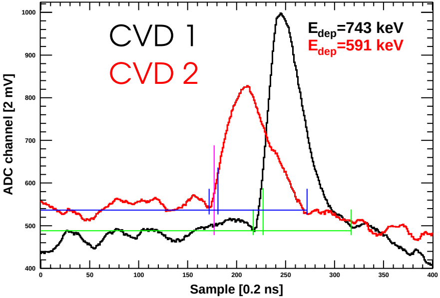
- minimal accessible neutron energy $T_n^{min} \sim 5E_{thr}$,
- efficiency loss $\epsilon(E_{thr})/\epsilon(E_{thr}=0) \sim (T_n/7E_{thr}-1)^2$.

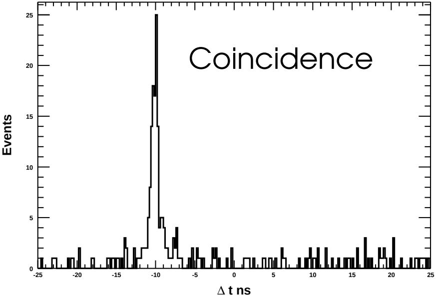
ToF Test at FNG

Two DDL diamonds attached

Experimental Results

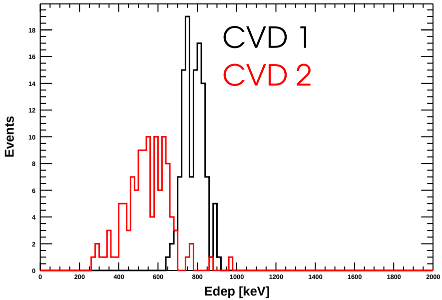
- 120 coincidence events/540 s - expected 0.25 Hz, ✓
- 5% accidentals ($\Delta t = 2$ ns) - as expected, ✓
- ToF is 0.6 ns, with timing resolutions of 0.36 ns ($\delta_{\Delta t} = 250$ ps of two amplifiers at 1 MeV) and 0.1 ns (distance),
- observed peak RMS is 0.4 ns, in agreement with estimates (100% T_n resolution).

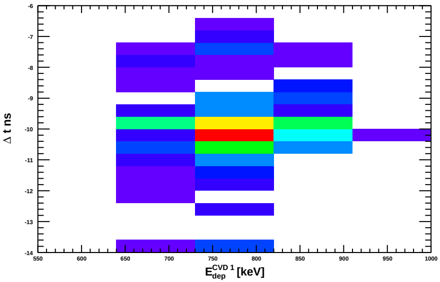




Experimental Results cont.

- energy thresholds were set ~ 0.25 MeV,
- deposited energy resolution ~ 50 keV,
- only backscattered n were detected in CVD 1 (threshold for forward n $7 \div 27$ keV),
- in CVD 2 flat angular distribution, $\theta_n^{CM} > 70^\circ$,
- within covered energy range ToF variation < 10 ps.





Summary

- scCVD diamonds were proposed for neutron spectrometers using neutron conversion and ToF techniques ($10^5 < \phi_n < 10^{10}$ n/cm^2/s),
- test measurements at FNG demonstrated feasibility of both techniques, ✓
- improved sandwich detector will be ready shortly,
- ToF detector demands a better amplifier, currently under development.