Neutron cross section measurements with diamond detectors

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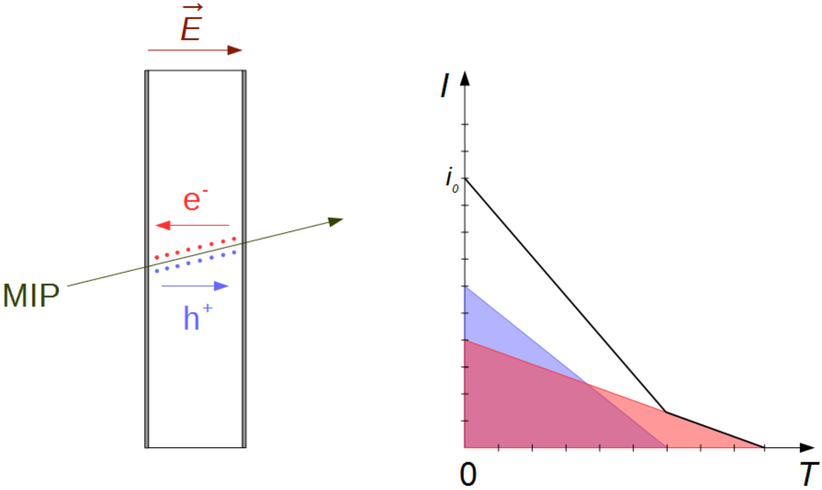
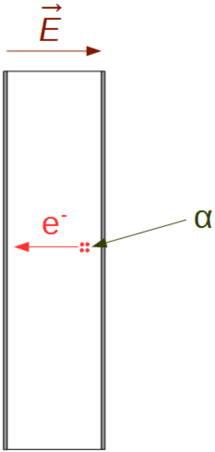
Diamond as a particle detection material

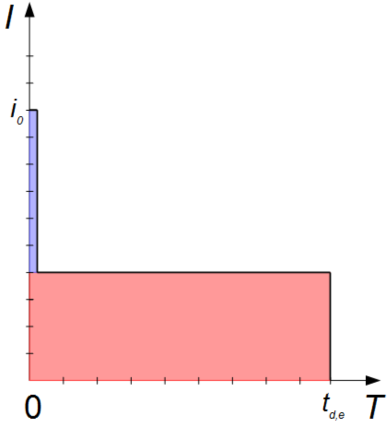
- Mechanical robustness
- High radiation resistance
- Low leakage current
- Operation without external cooling
- Subnanosecond response time
- Thermal neutron detection: With a neutron converter (^{6}Li, ^{10}B)
- Fast neutron detection: Diamond acts as a sample and a sensor
- Discrimination between different types of particle interactions based on the analysis of the detector current pulse shape

Uniform ionization profile

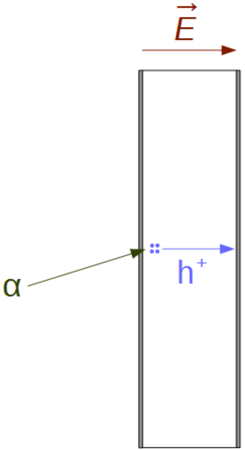


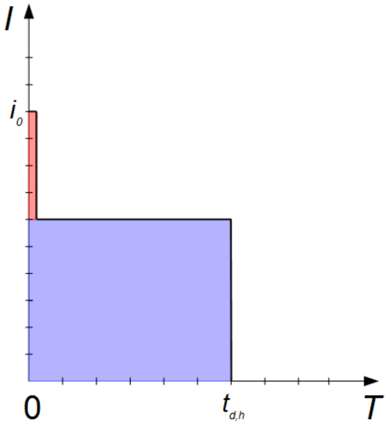
Electron drift profile



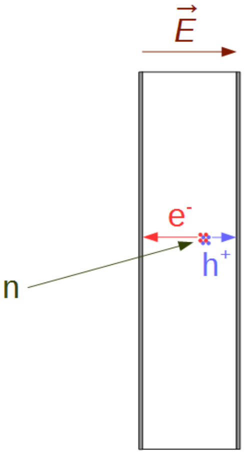


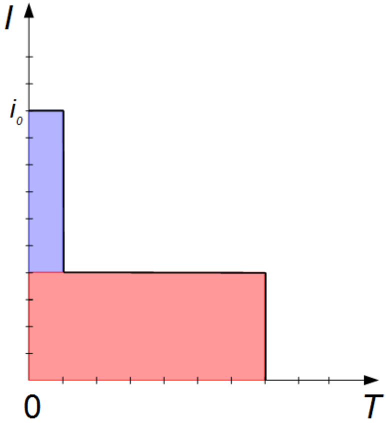
Hole drift profile



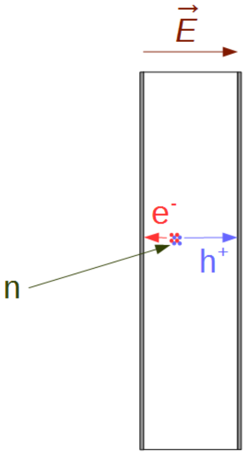


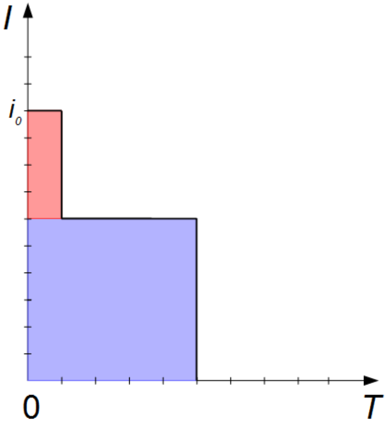
Electron-dominated profile



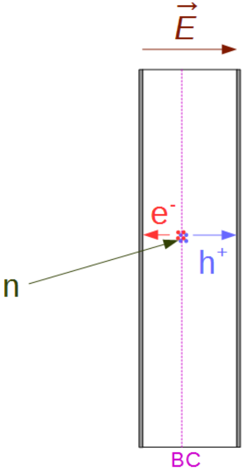


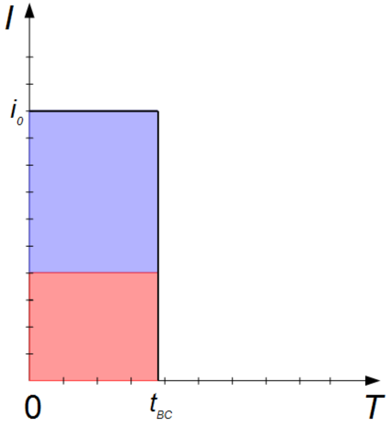
Hole-dominated profile



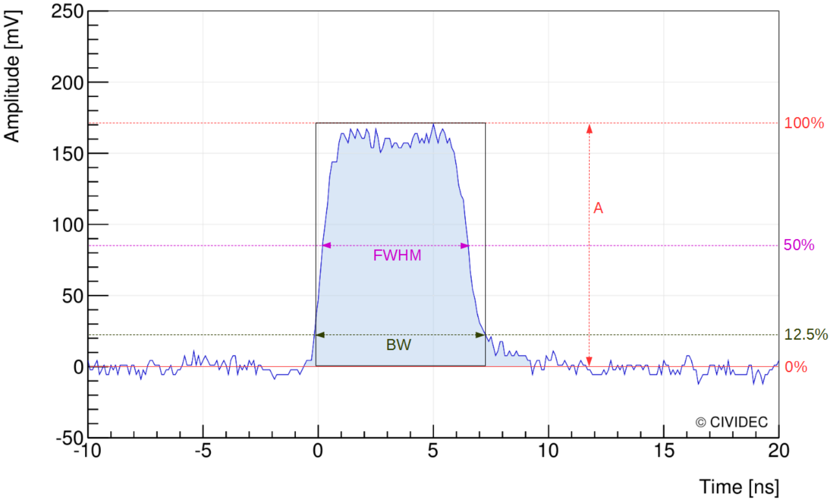


Ballistic center interaction profile

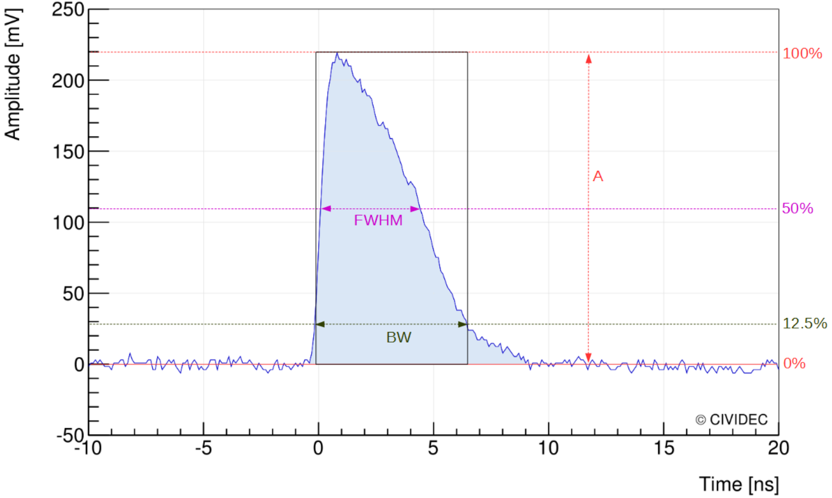




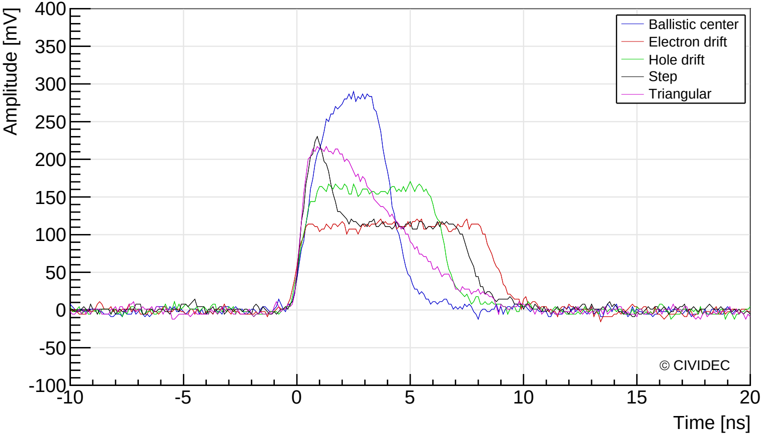
Pulse-shape analysis - Rectangle



Pulse-shape analysis - Triangle



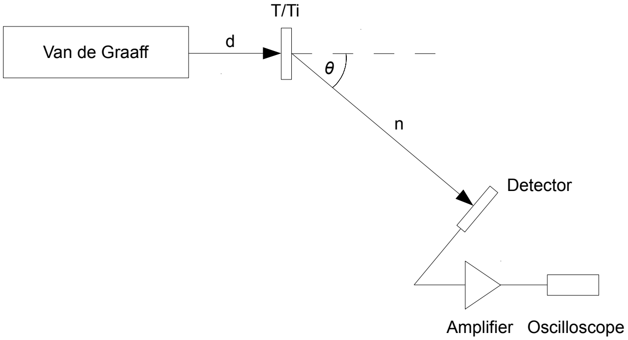
Pulse-shape analysis - Measured pulses



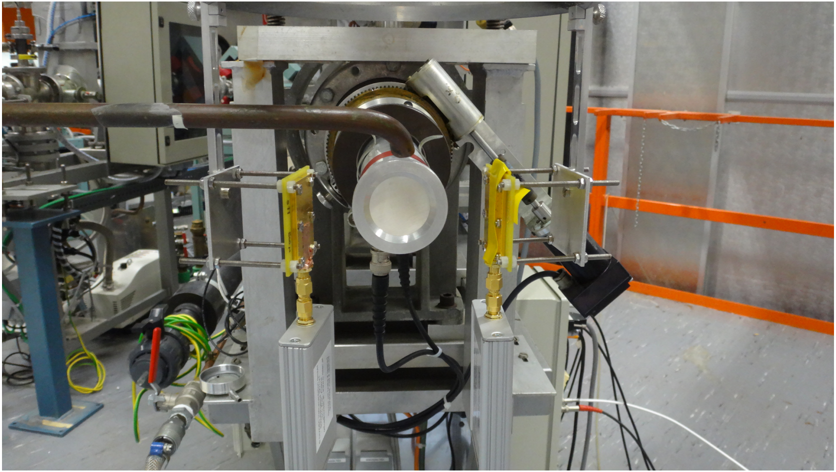
- Fast neutrons interacting in the *ballistic center* produce **rectangular** pulses with a minimum **drift time**

Measurement setup (I)

- 7 MV Van de Graaff accelerator, EC-JRC (Geel, Belgium)
- Quasi-monoenergetic neutron beam via T(d,n)^{4}He reaction
- Deuteron (2 MeV) on Ti/T target
- Detector positions: 98° (E_n=14.3 MeV), 45° (E_n=17.0 MeV)



Measurement setup (II)



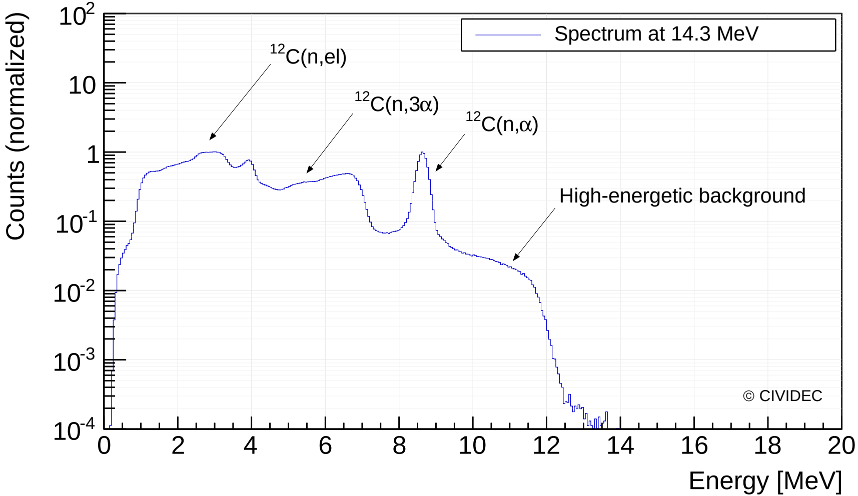
Measurement setup (III)

- Van de Graaff facility of the EC-JRC, Geel, Belgium
- Neutron energies: 14.3 MeV and 17.0 MeV
- CIVIDEC B1 Single-Crystal Diamond Detector
  - Thickness 500 μm
  - Active area 4 mm $\times$ 4 mm
  - Bias electric field 1 V/μm
  - Diamond detector was used as a sample and as a sensor
- CIVIDEC C2 Broadband Amplifier
  - Analogue bandwidth 2 GHz
  - Equivalent input current noise 0.4 μA
- LeCroy Waverunner oscilloscope
- Dedicated pulse-shape analysis for background rejection
- Cross section of ^{13}C(n,α)^{10}Be was measured relatively to ^{12}C(n,α)^{9}Be

Deposited energy spectrum at 14.3 MeV (I)

$^{12}C(n,\alpha_0)^9Be$: mean 8.6 MeV

$^{13}C(n,\alpha_0)^{10}Be$: mean 10.5 MeV



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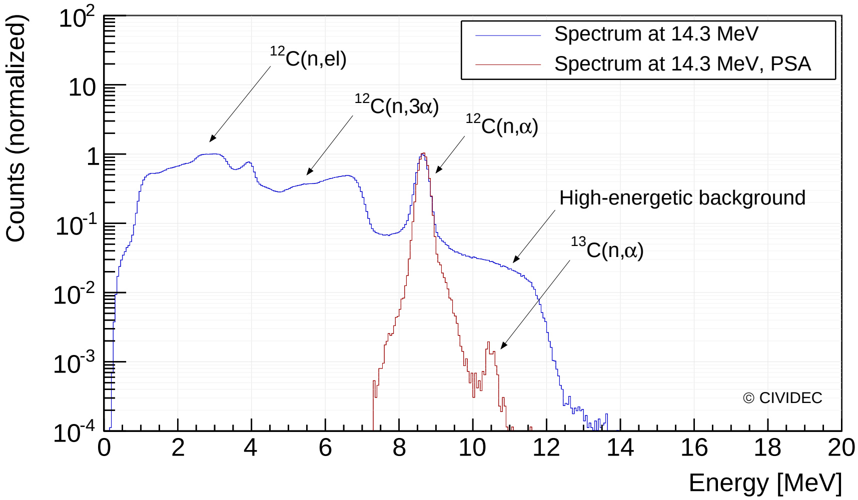

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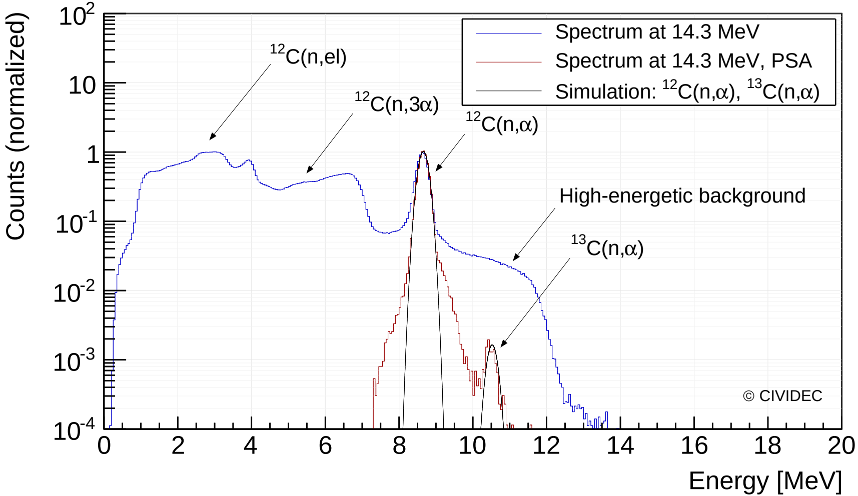
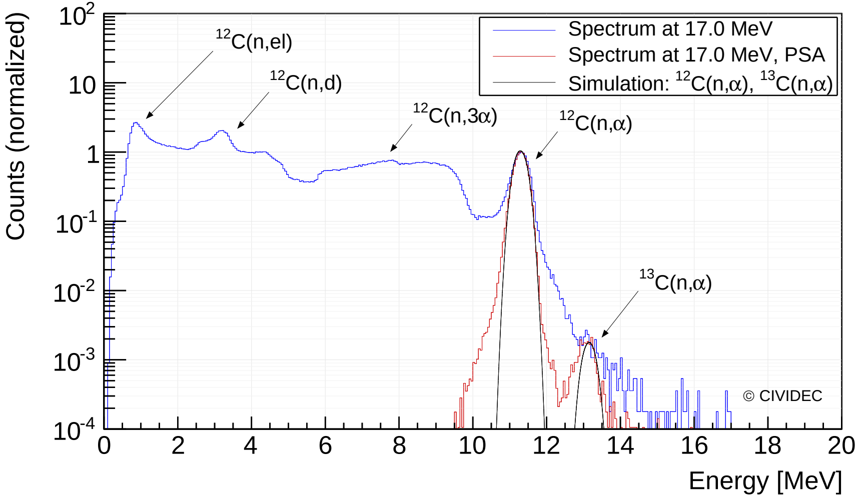


Deposited energy spectrum at 17.0 MeV (I)

$^{12}C(n,\alpha_0)^9Be$: mean 11.3 MeV
$^{13}C(n,\alpha_0)^{10}Be$: mean 13.2 MeV



Results

- The ratio of the ^{13}C(n,α_0)^{10}Be and ^{12}C(n,α_0)^{9}Be reaction was derived as:

$$\frac{\sigma_{13}}{\sigma_{12}} = \frac{I_{13}}{I_{12}} \cdot \frac{N_{12}}{N_{13}} \tag{1}$$

  where I_{12} and I_{13} are the net peak areas corresponding to the two reactions of interest, N_{12} and N_{13} are the fractions of ^{12}C and ^{13}C isotopes in diamond.

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- Cross section ratio:

$$\sigma_{13}/\sigma_{12} = (0.15 \pm 0.02) \text{ at } 14.3 \text{ MeV.}$$

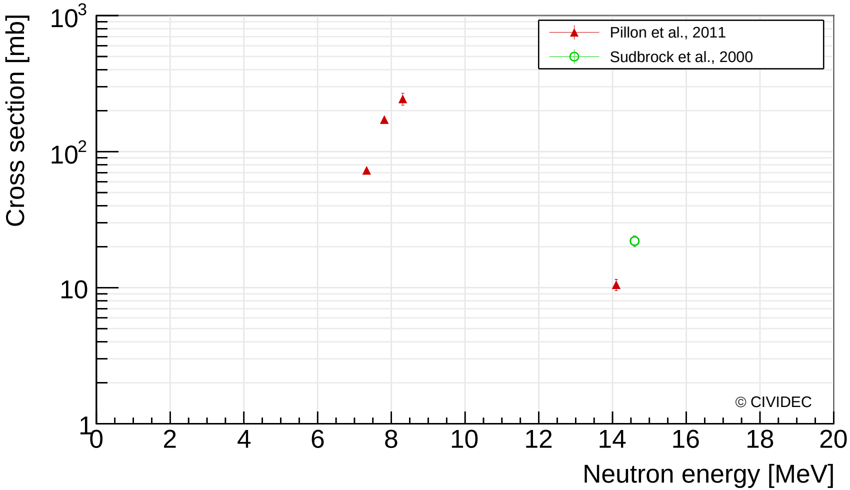
$$\sigma_{13}/\sigma_{12} = (0.17 \pm 0.02) \text{ at } 17.0 \text{ MeV.}$$

- Using the evaluated cross section σ_{12} at 14.3 MeV and 17.0 MeV (CENDL-3.1), the derived $^{13}C(n,\alpha_0)^{10}Be$ cross section is:

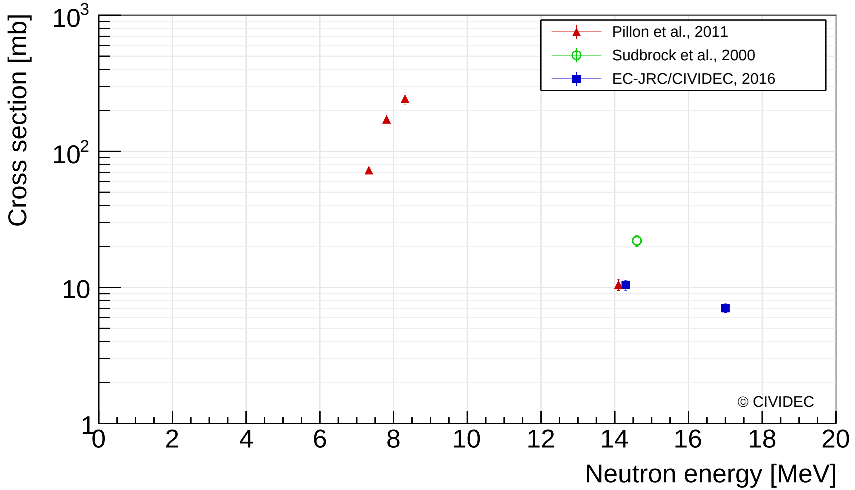
$$\sigma_{13} = (10.4 \pm 1.4) \text{ mb at } 14.3 \text{ MeV.}$$

$$\sigma_{13} = (7.1 \pm 0.8) \text{ mb at } 17.0 \text{ MeV.}$$

$^{13}C(n,\alpha_0)^{10}Be$ cross section



$^{13}C(n,\alpha_0)^{10}Be$ cross section



Conclusions

- Deposited energy spectra of fast neutrons in diamond were measured with an sCVD diamond detector using a dedicated pulse-shape analysis technique.
- The analysis method allowed to reject the proton recoil background, and extract the ^{13}C(n,α_0)^{10}Be spectrum.
- The ^{13}C(n,α_0)^{10}Be cross section was measured relatively to the ^{12}C(n,α_0)^{9}Be cross section at 14.3 MeV and 17.0 MeV neutron energies.

References

- P. Kavrigin, E. Griesmayer, F. Belloni, A.J.M. Plompen, P. Schillebeeckx, C. Weiss, *$^{13}C(n,\alpha_0)^{10}Be$ cross section measurement with sCVD diamond detector*, Eur. Phys. J. A **52**, 179 (2016)

- C. Weiss, H. Frais-Kölbl, E. Griesmayer, P. Kavrigin, *Ionization signals of diamond detectors in fast neutron fields*, Eur. Phys. J. A **52**, 269 (2016).

Thank you for your attention!

Addendum I - Neutron interactions in diamond

Reaction	Q [MeV]	E_{th} [MeV]
$^{12}C(n,el)^{12}C$	0	0
$^{13}C(n,\alpha)^{10}Be$	- 3.836	4.134
$^{12}C(n,\alpha)^{9}Be$	- 5.702	6.182
$^{12}C(n,n+2\alpha)^{4}He$	- 7.275	7.886
$^{12}C(n,p)^{12}B$	- 12.587	13.645
$^{12}C(n,d)^{11}B$	- 13.732	14.887