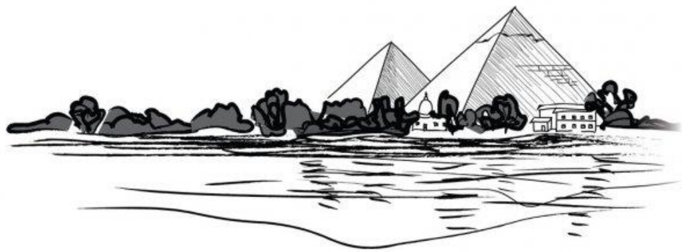
Science and Technology Facilities Council

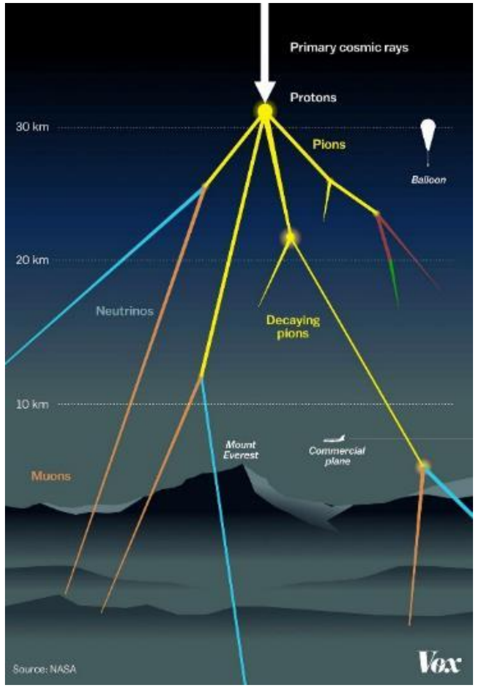
Compact neutron sources at NILE, the new Neutron Irradiation Laboratory for Electronics

Carlo Cazzaniga

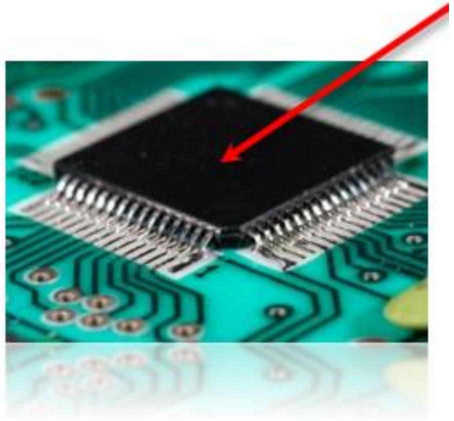
16 November 2021



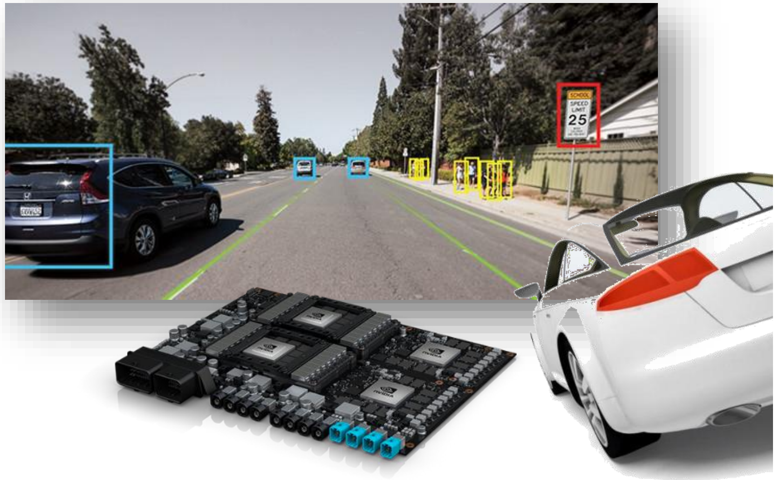
Motivation



Cosmic rays



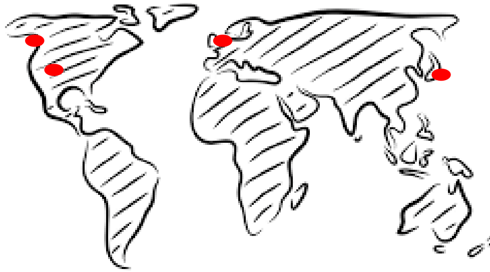
Single Event Effects



errors in electronics

… used for **safety critical applications.**

Industry wide problem!

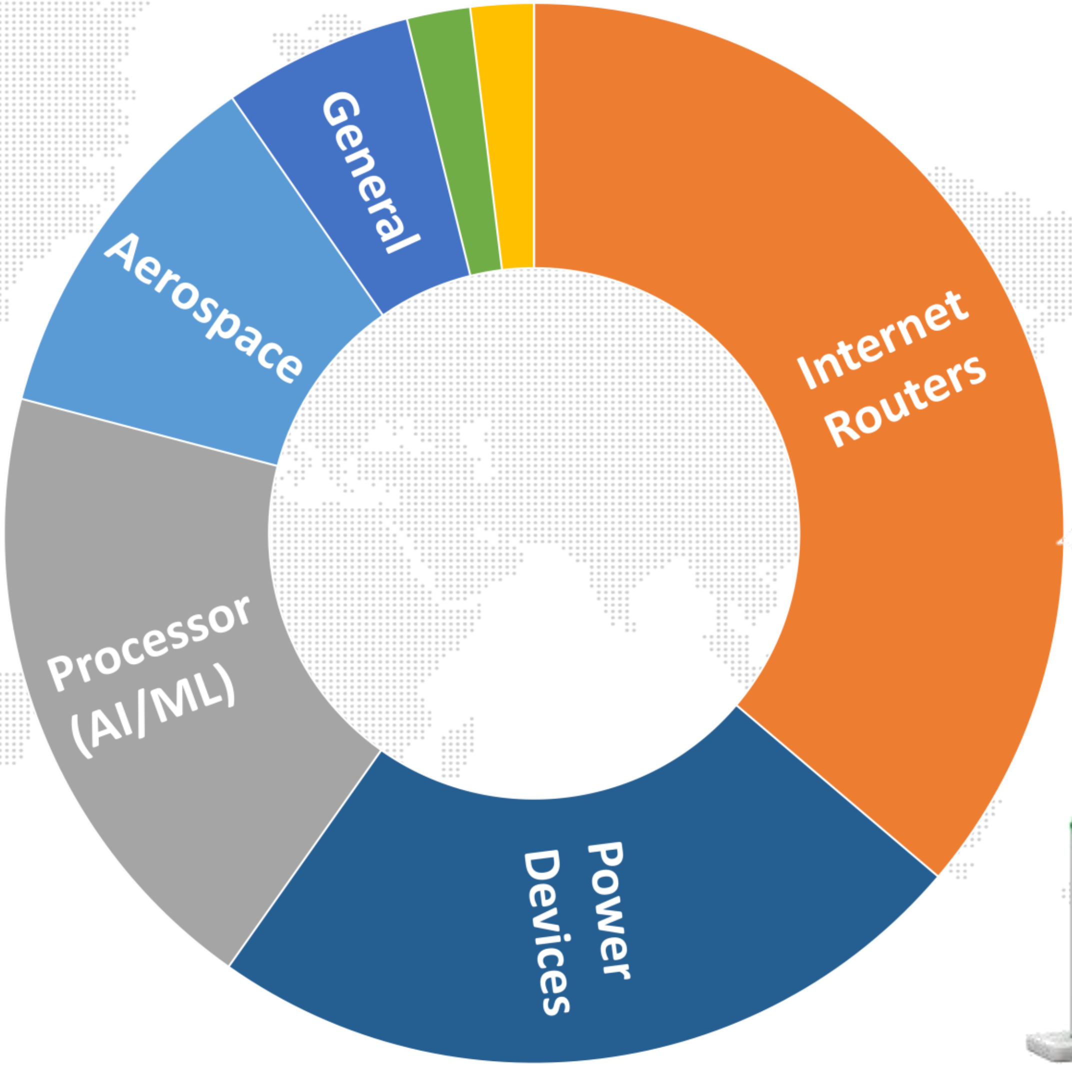


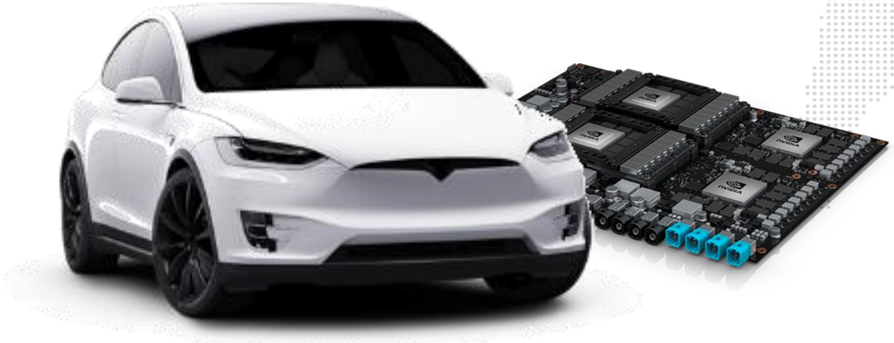
Facilities for accelerated testing.

ChipIR

Addressing Key Strategic Areas

- Driverless Cars
- Electric Vehicles
- Renewable power systems
- Artificial Intelligence
- Internet Infrastructure
- Robotics
- Avionics & Space





Neutron Irradiation Laboratory for Electronics (NILE)

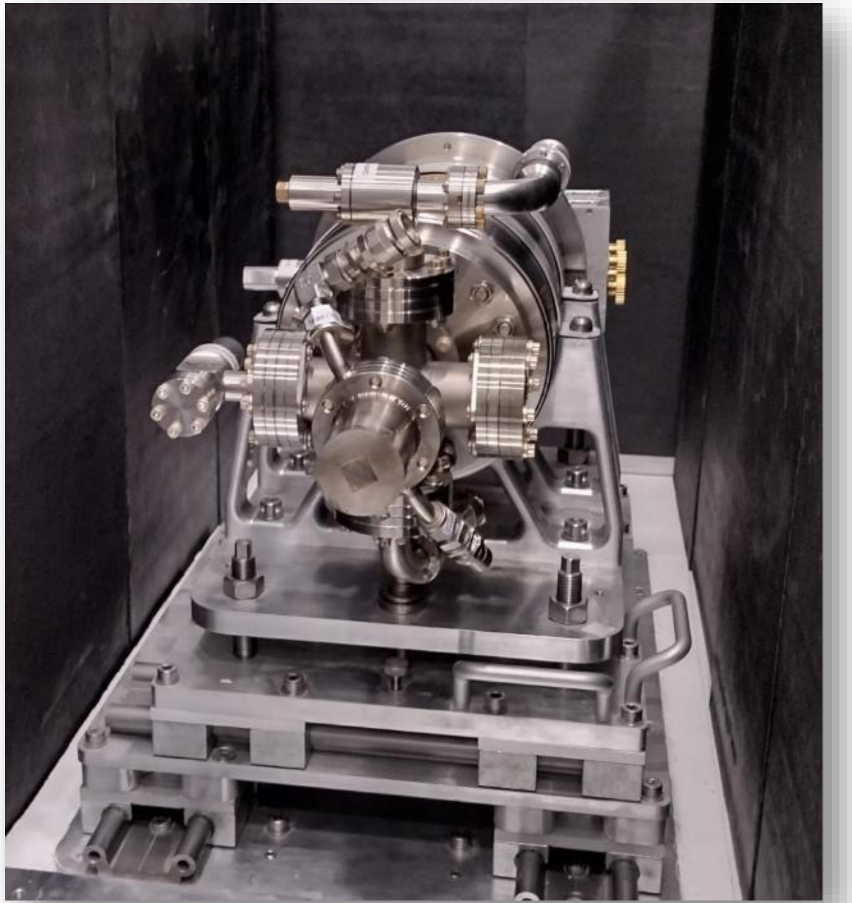
Development of a new facility

SEE testing:

- **Complementary to ChipIr** → methods and test setups.
- **Training**.
- **Reactors environment**.

Other applications:

- Detector testing (eg. **Dark Matter** detector).
- Fast neutron imaging.
- Benchmark of Monte Carlo simulations



Compact fusion neutron sources, 14 MeV (DT) and 2.5 MeV (DD).

NILE

Development of a new facility

2019

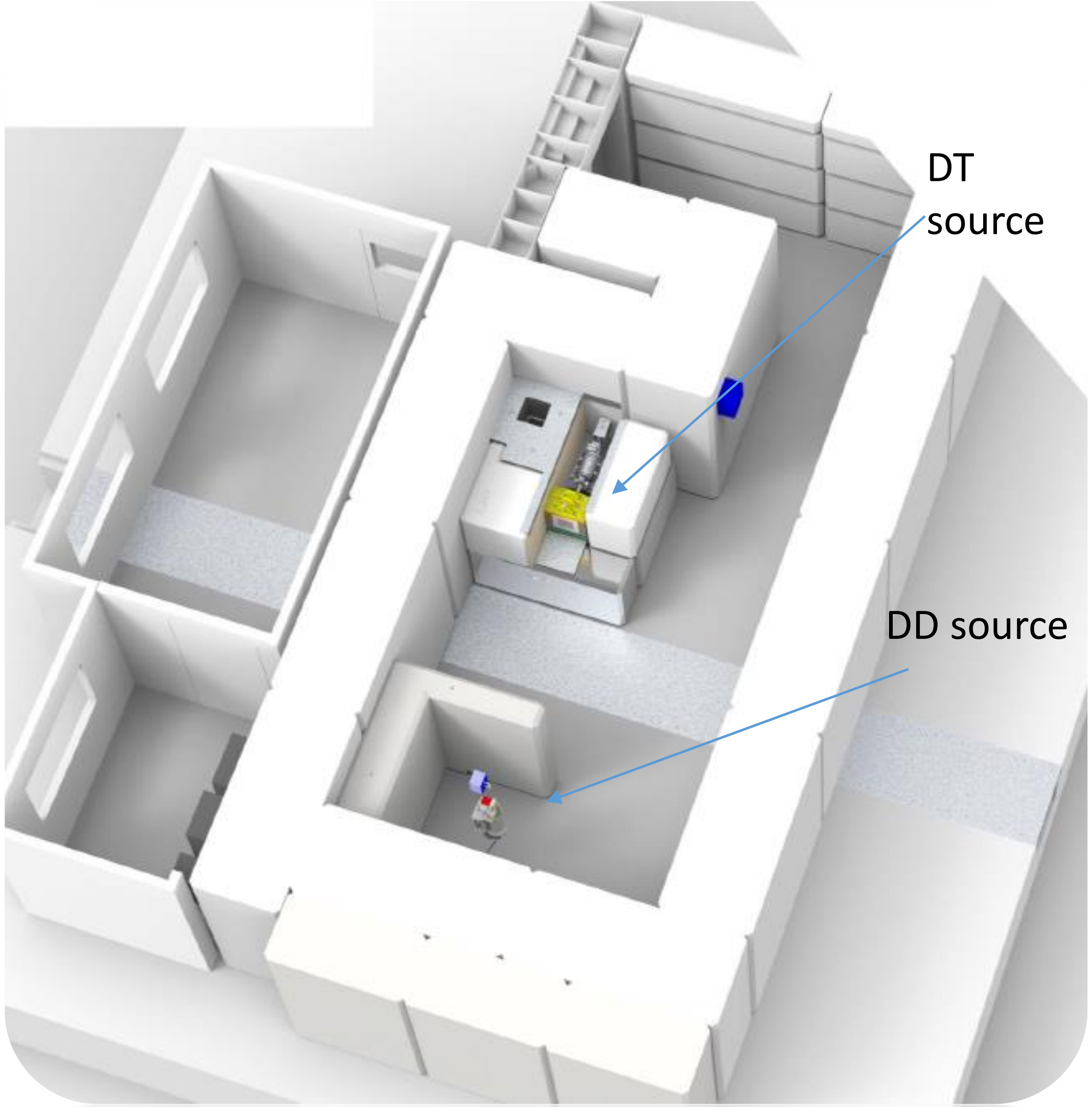
- Proposal approved
- **Project starts**

2020

- **Technical design** of the facility
- Radioprotection and safety

2021

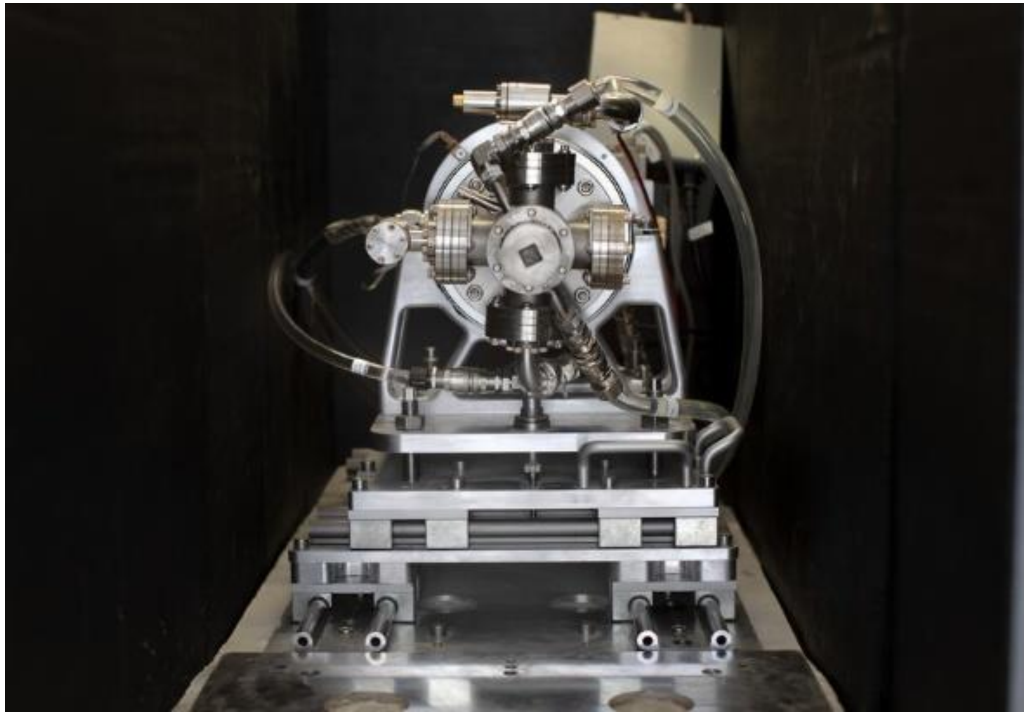
- Bunker finalized
- **First neutron** – July 2021

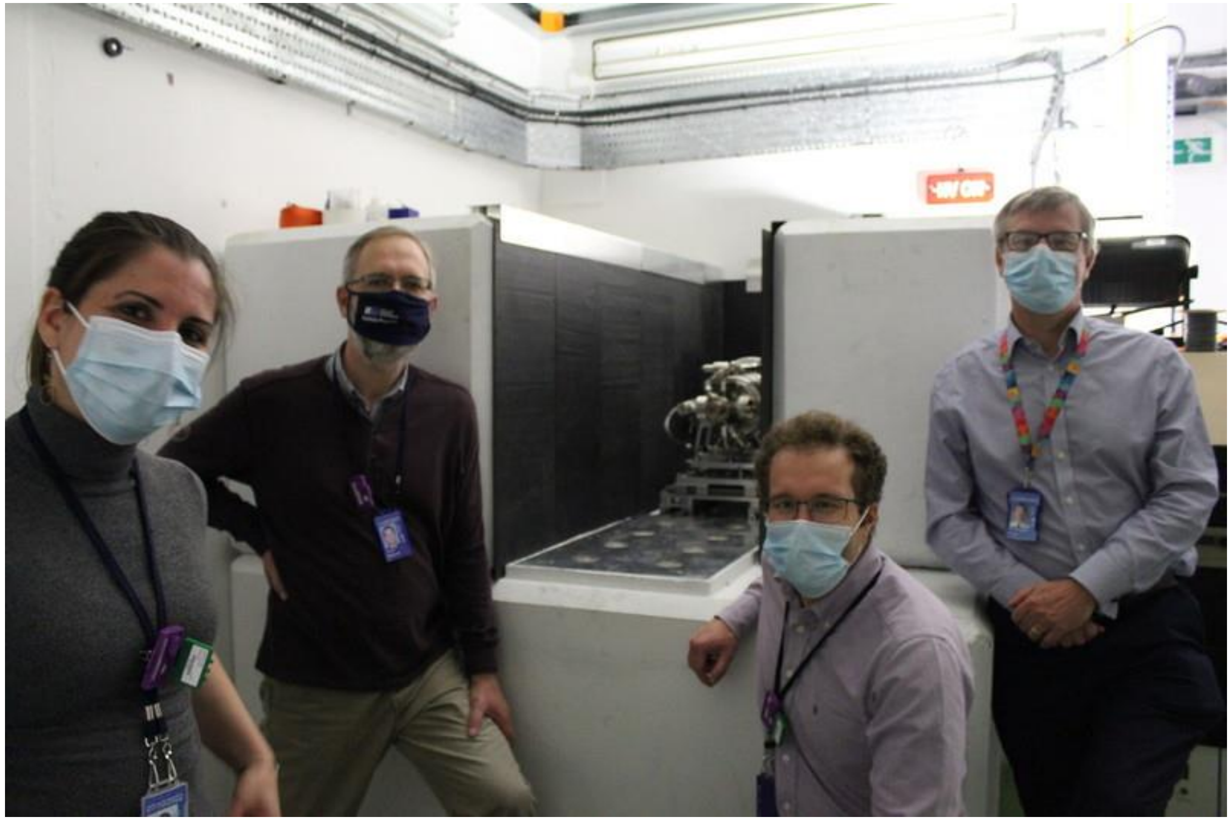


Drawing of the NILE bunker


HV ON

DT setup





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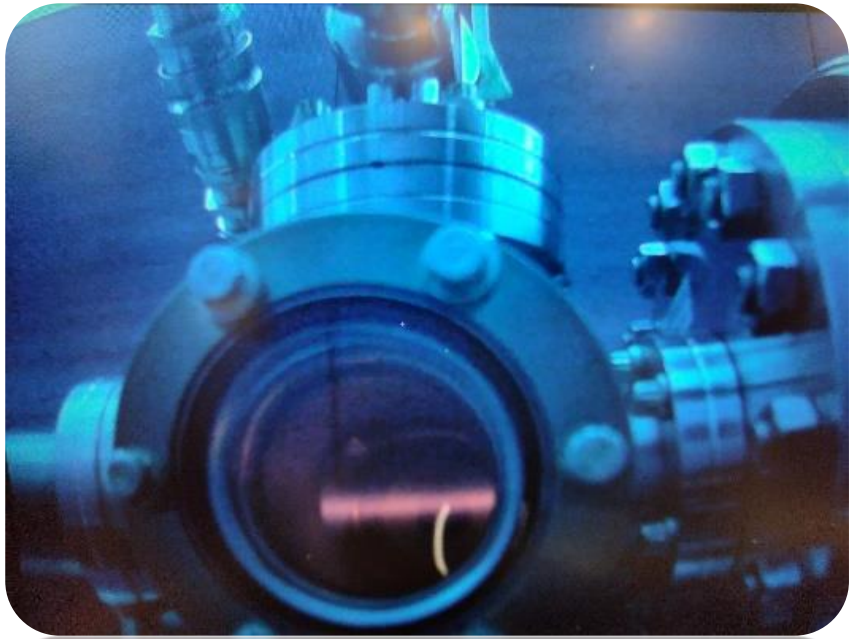
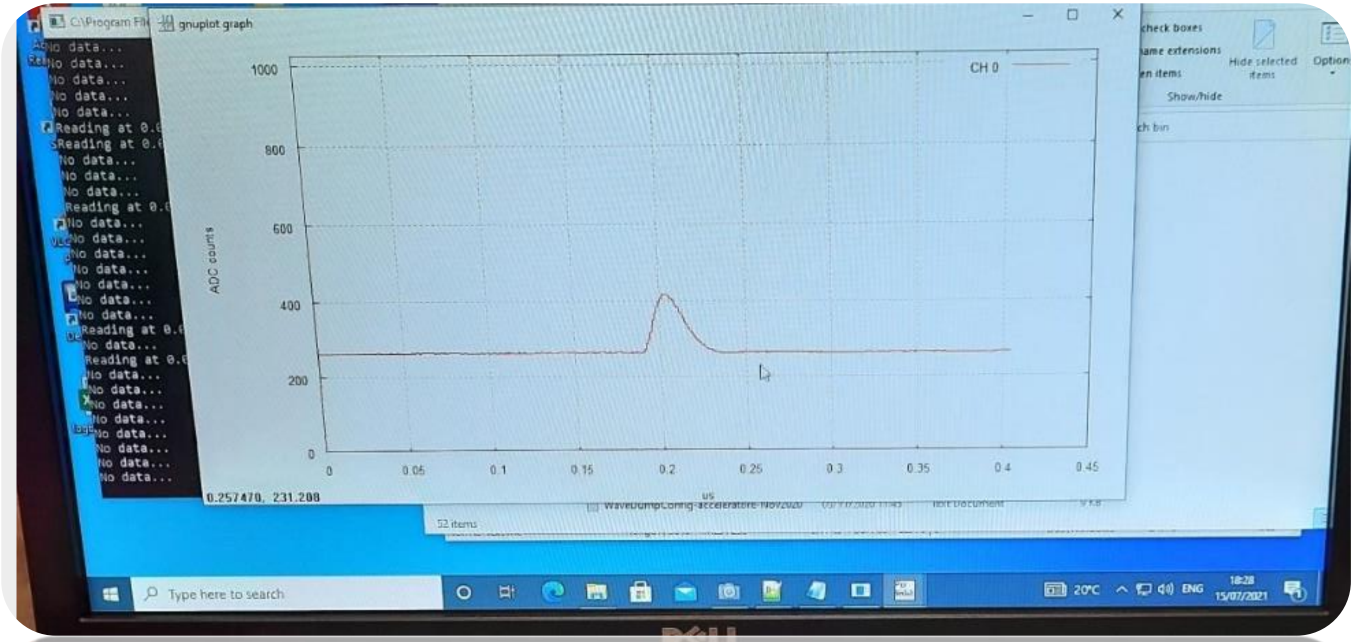
DT - First Neutrons

Plasma of DT source



July 2021: First Neutron!



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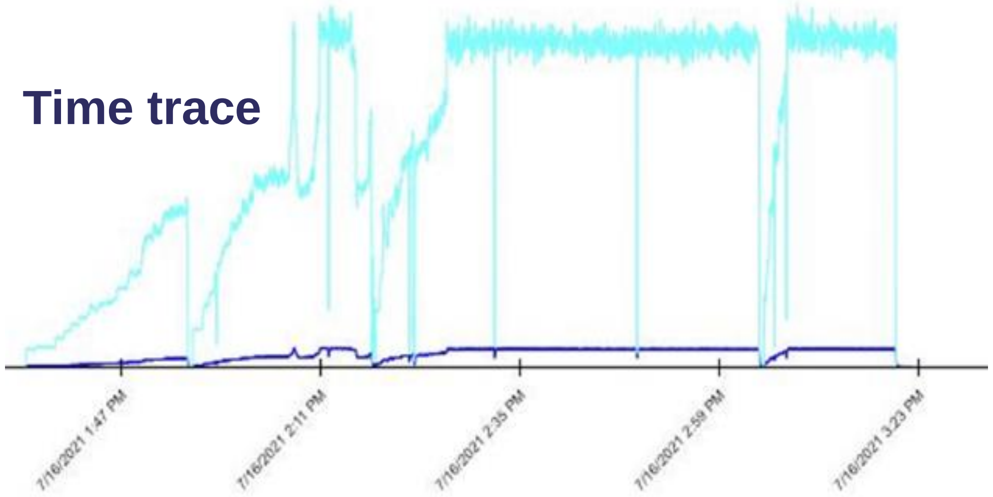
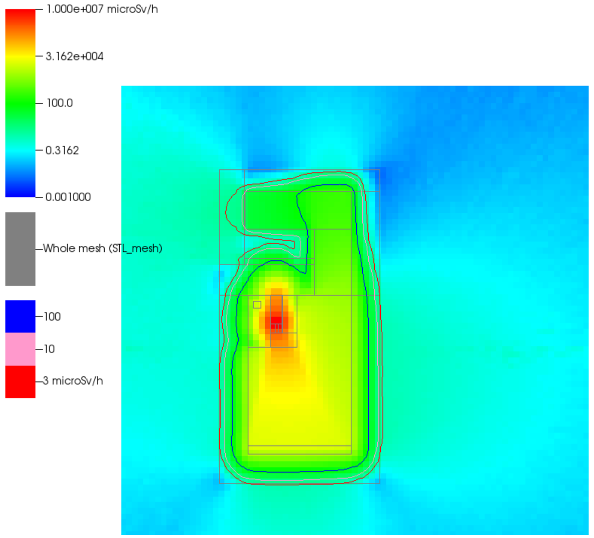
Important goals achieved

- Learning how to operate the source
  - Starting up / conditioning
  - Parameters to optimize
- Stability verified
- Radioprotection verified

Time trace



0h 1h 2h



Dose rates

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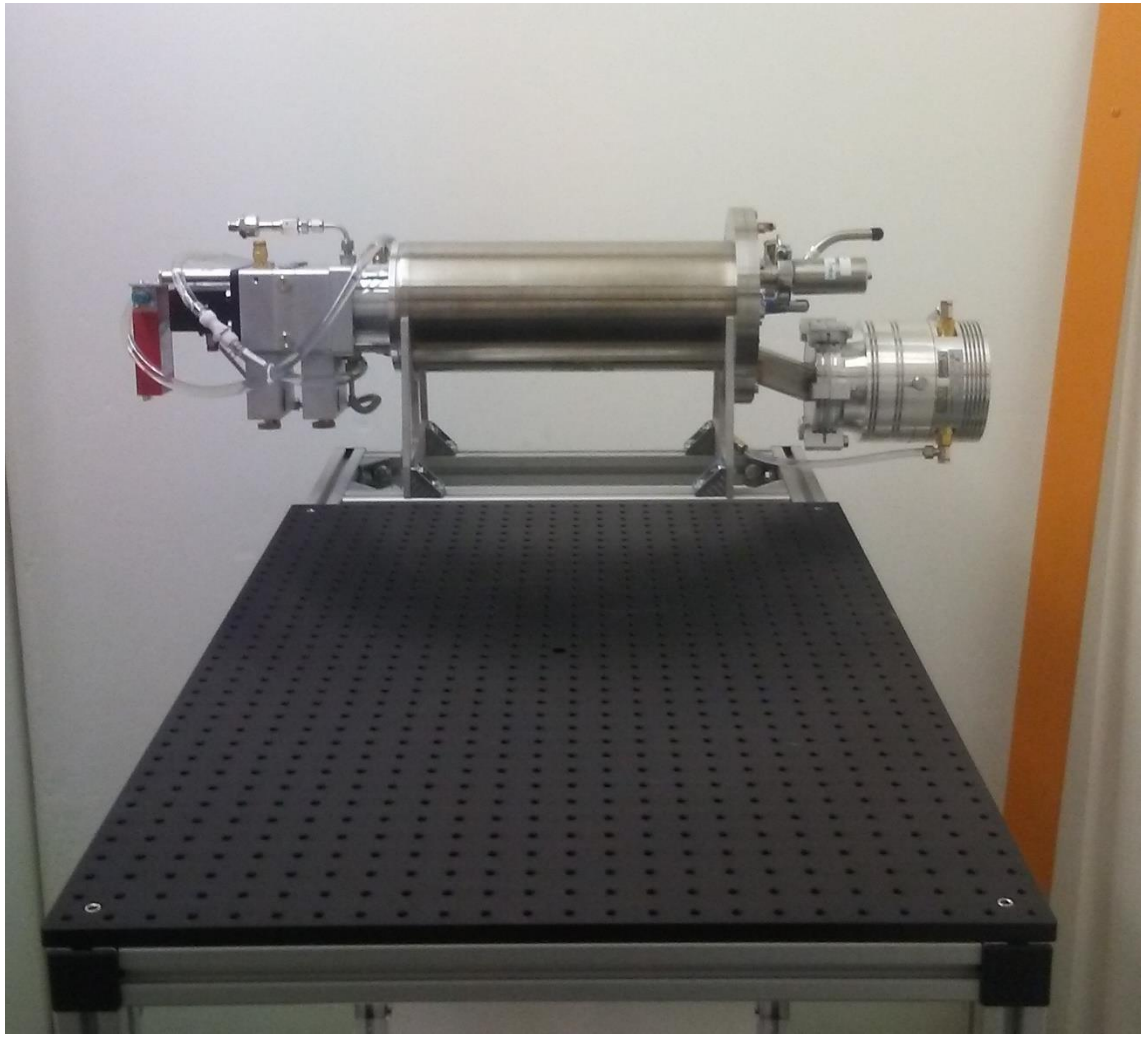
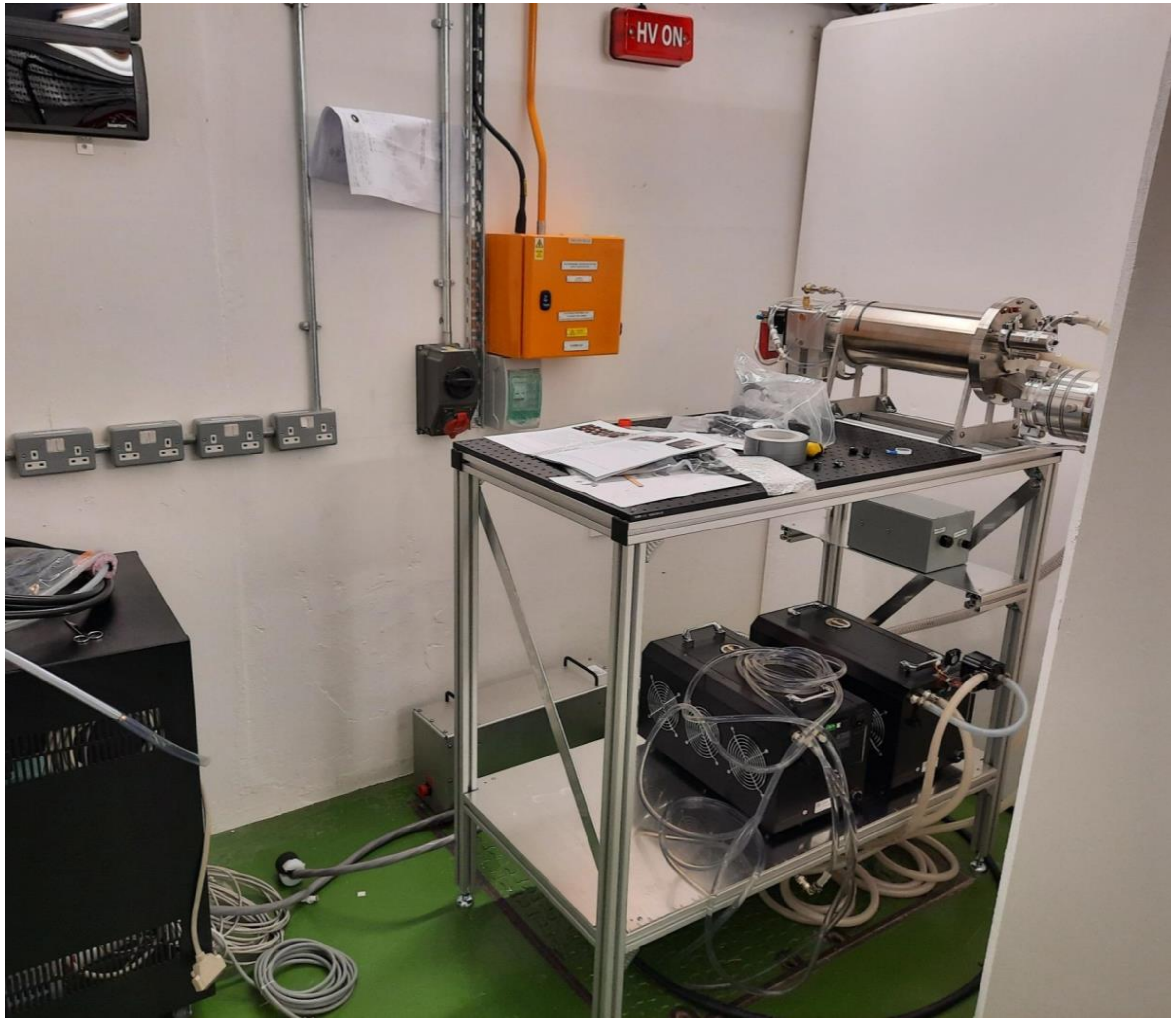
Setup of DD




HV ON

Energy angular dependency

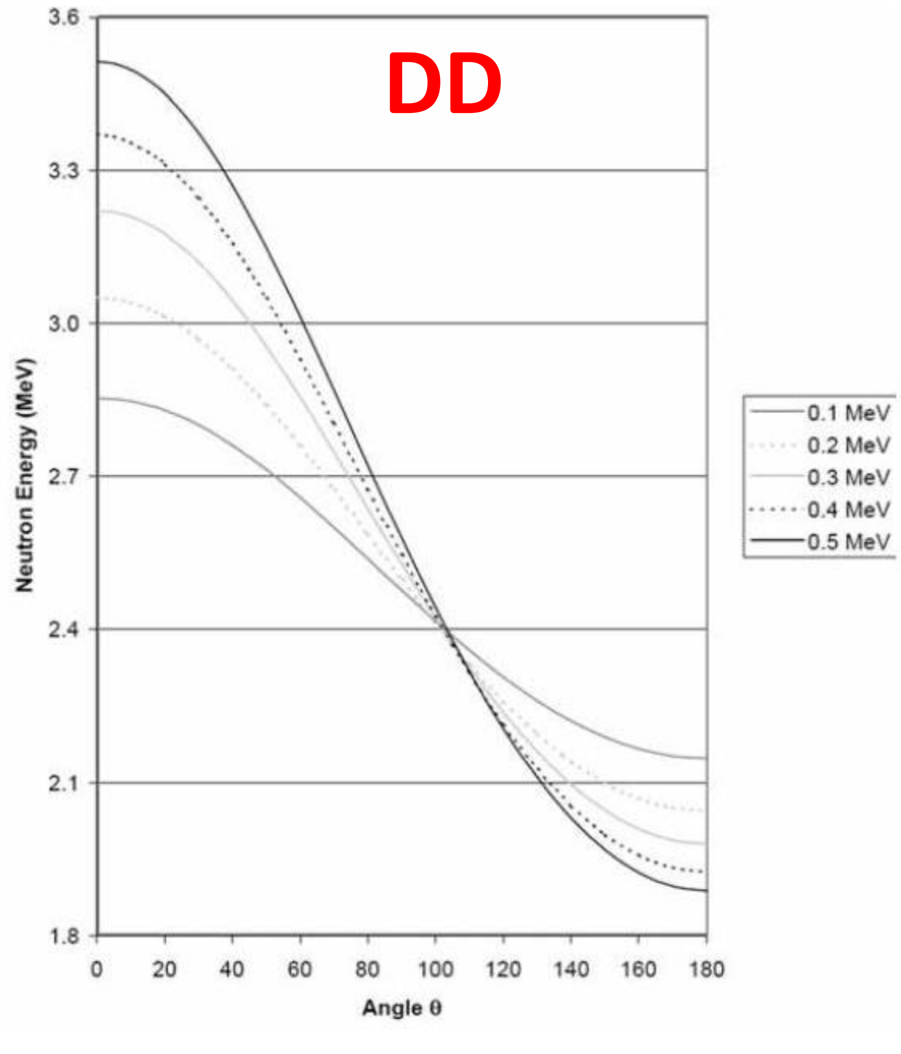


FIG. 5. DD neutron energy angular distribution as a function of deuteron energy.

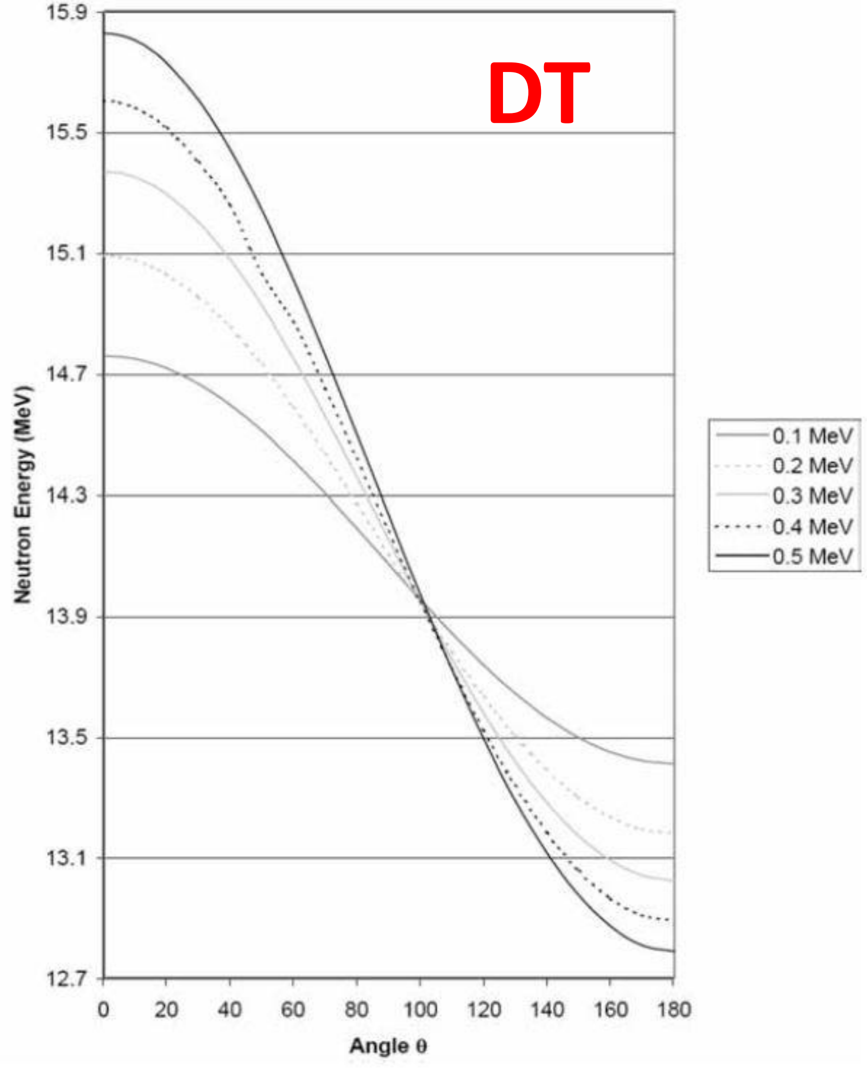


FIG. 6. DT neutron energy angular distribution as a function of deuteron energy.

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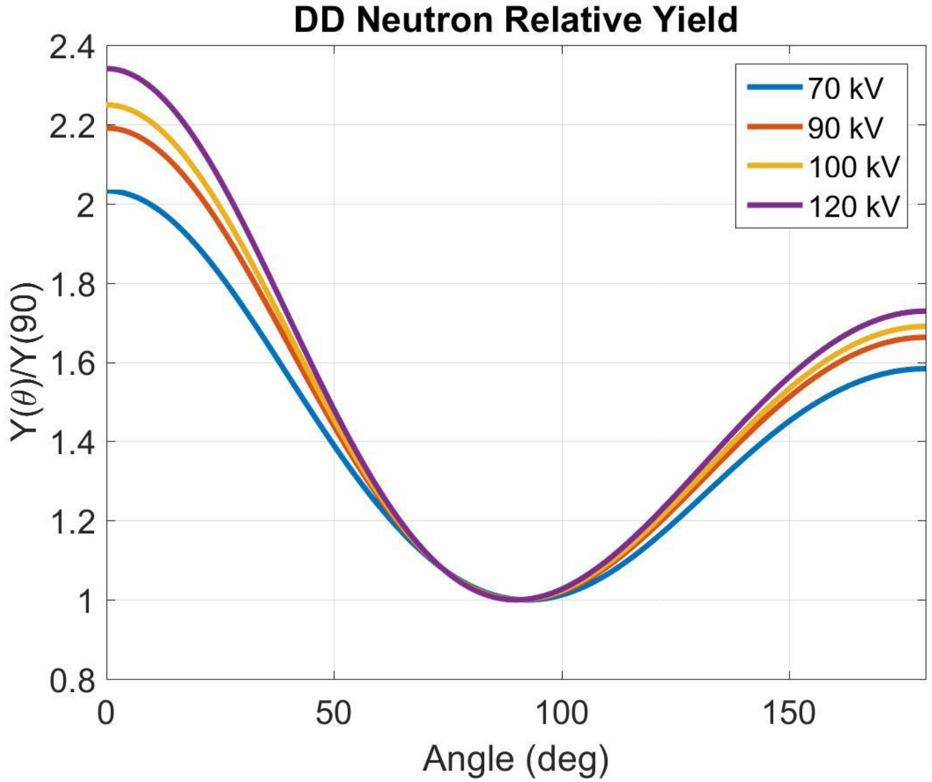
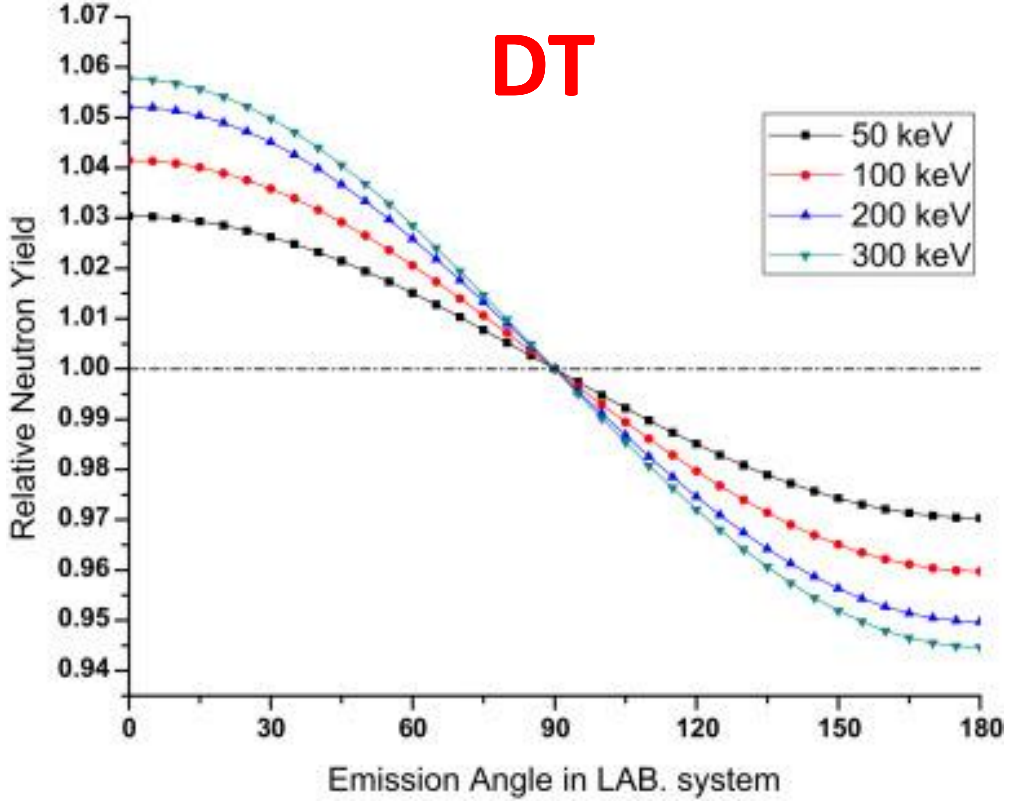
Radia, I. A. E. A., and Y. Rep. "Neutron Generators for Analytical Purposes." *IAEA radiation technology reports series, ISSN* (2012): 2225-8833.

Flux angular dependency

DD



DT

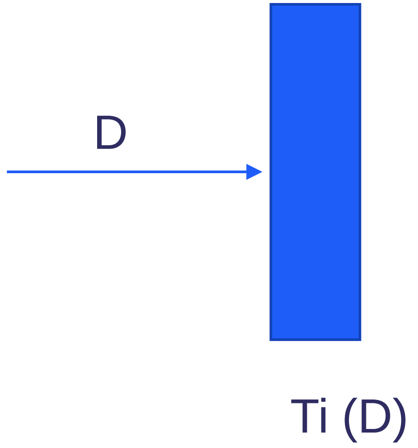


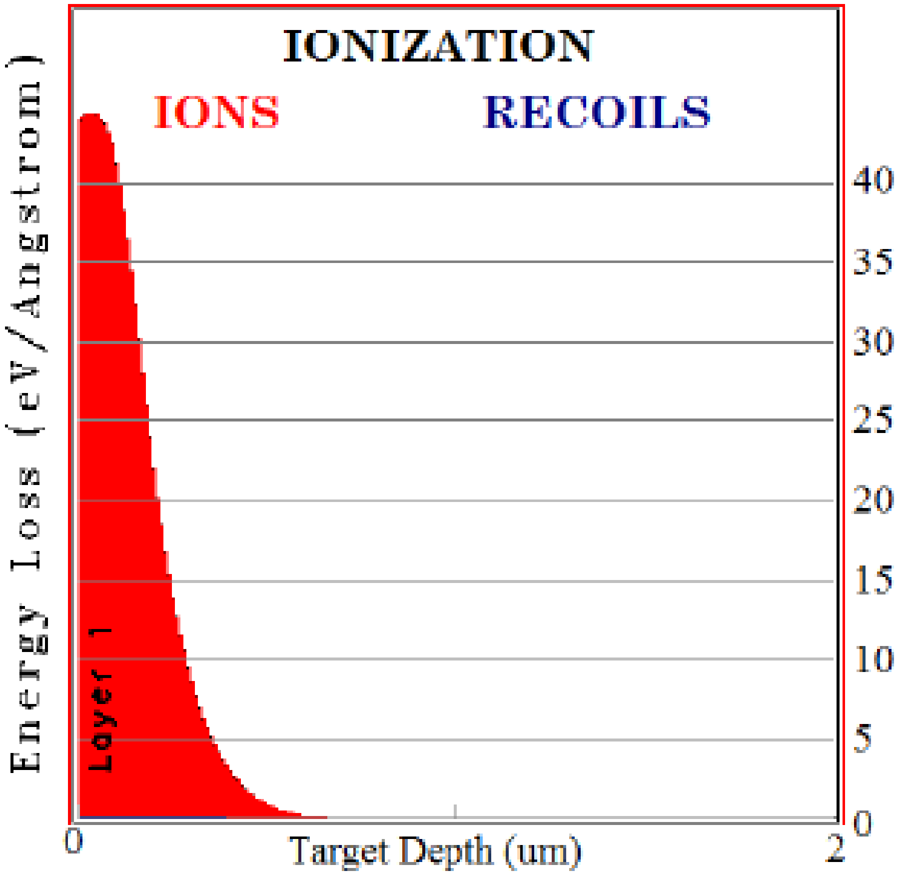
Ardon, Mauricio, et al. NIMA 903 (2018): 193-203.

Kasesaz, Yaser, and Marjan Karimi. *Applied Radiation and Isotopes* 118 (2016): 317-325.

Spectral broadening

reasons:
1. Δθ
2. Thickness and composition of the target
3. Quality of the D beam





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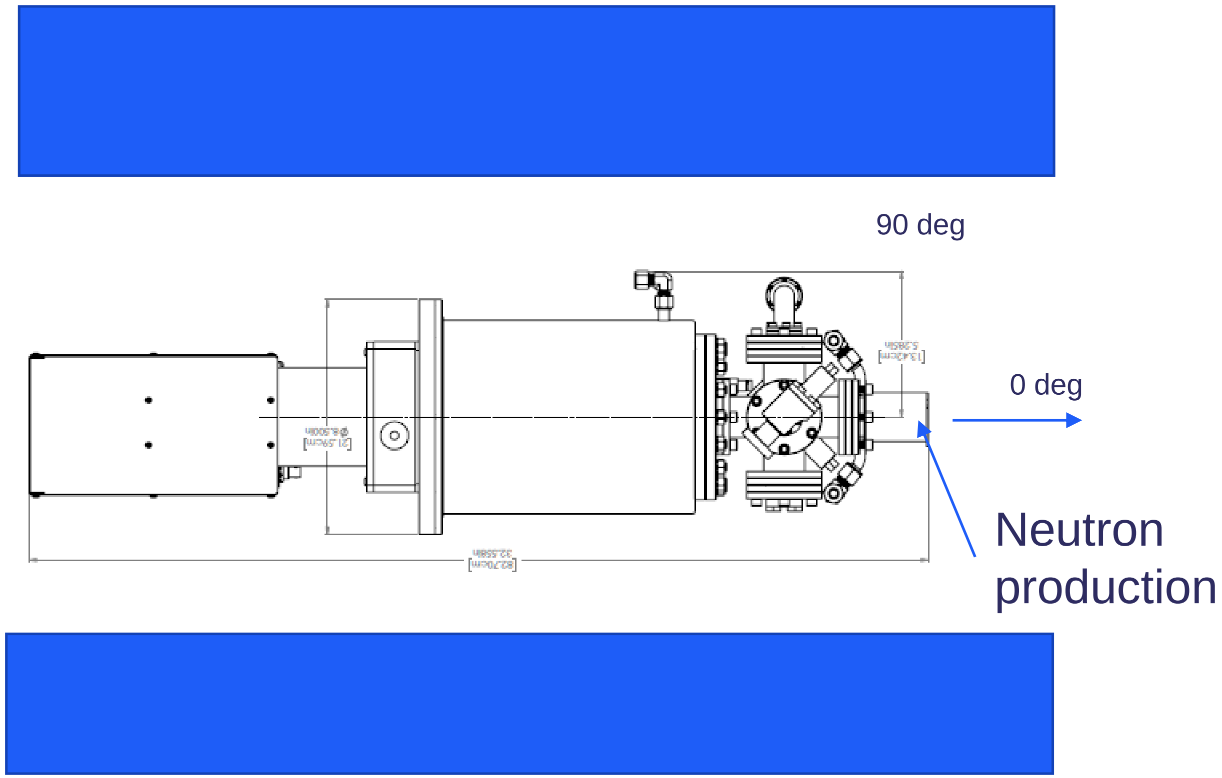
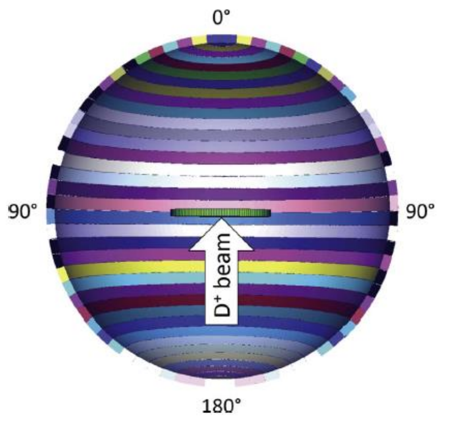
DT generator





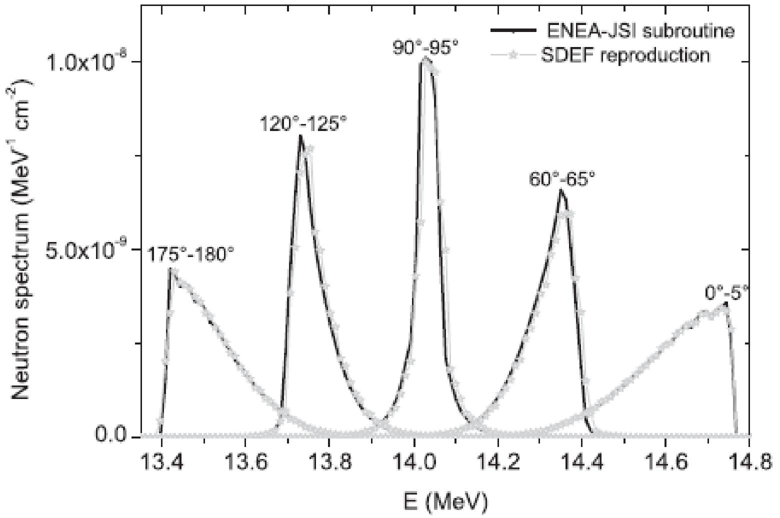
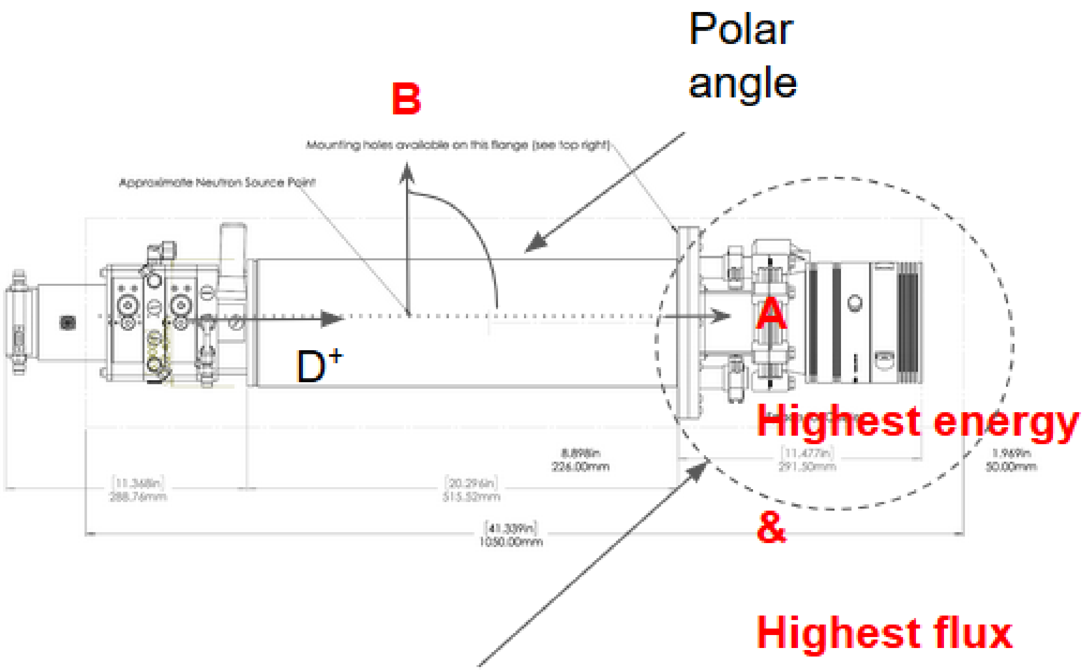


Fig. 8. Neutron spectra in five directions for the simple model using the ENEA-JSI source subroutine and source definition card recording of the same source. The reproduction of the spectra with the source definition card is relatively accurate and could further be improved by increasing the number of angles where the spectrum is calculated for reproduction.

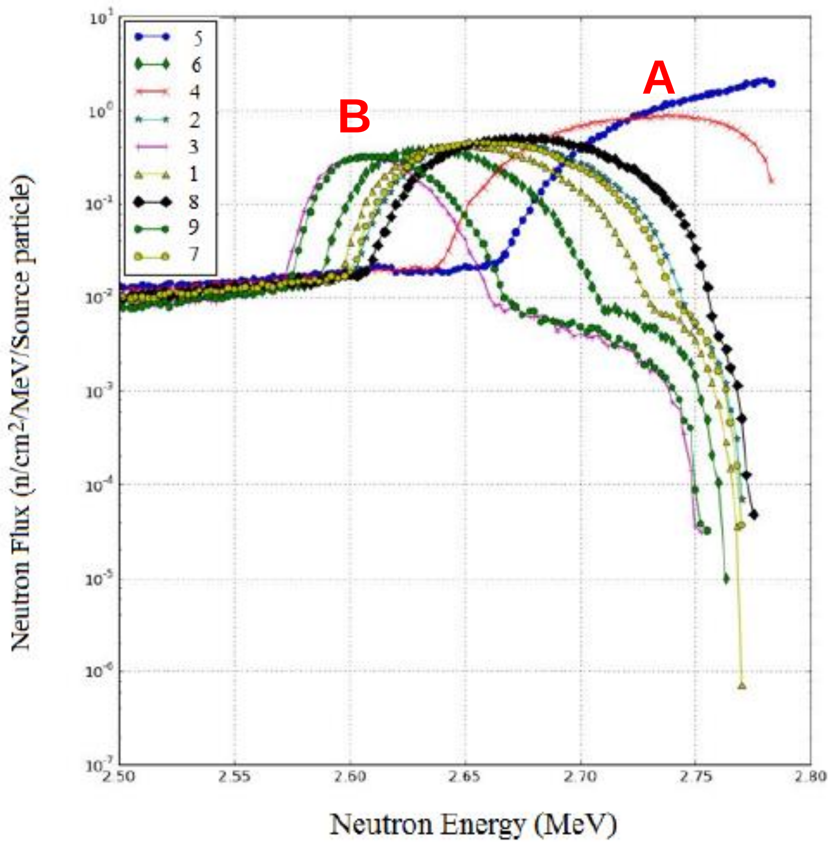
Čufar, Aljaž, et al. "Calculations to support JET neutron yield calibration: Modelling of neutron emission from a compact DT neutron generator." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 847 (2017): 199-204.

DD generator



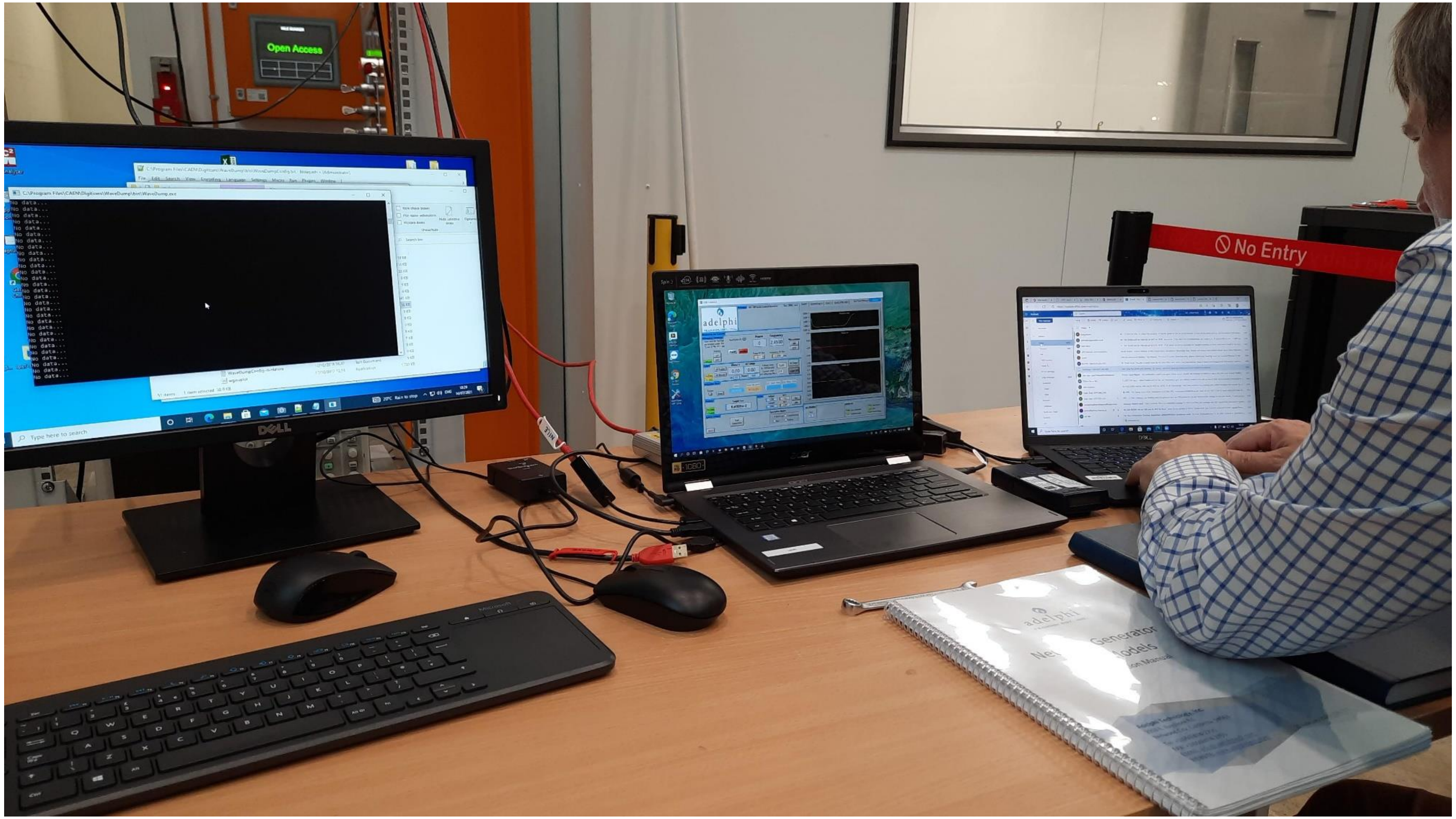
At 0 deg - A- a lot of material for neutrons to scatter off

At 90 deg - B - much cleaner situation but lower flux



Waltz, C. S. (2016). *Characterization of deuteron-deuteron neutron generators* (Doctoral dissertation, UC Berkeley).

Neutron Measurements



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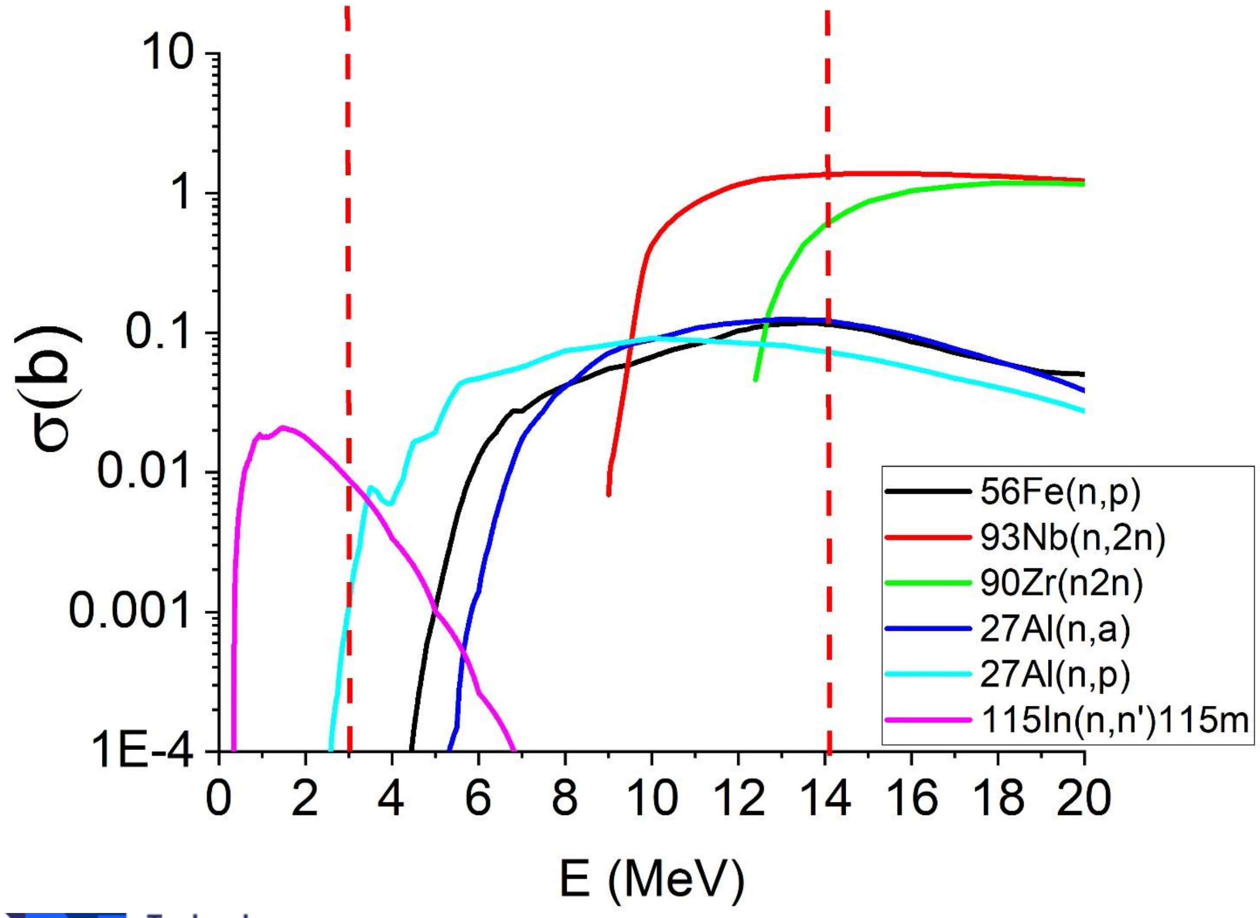
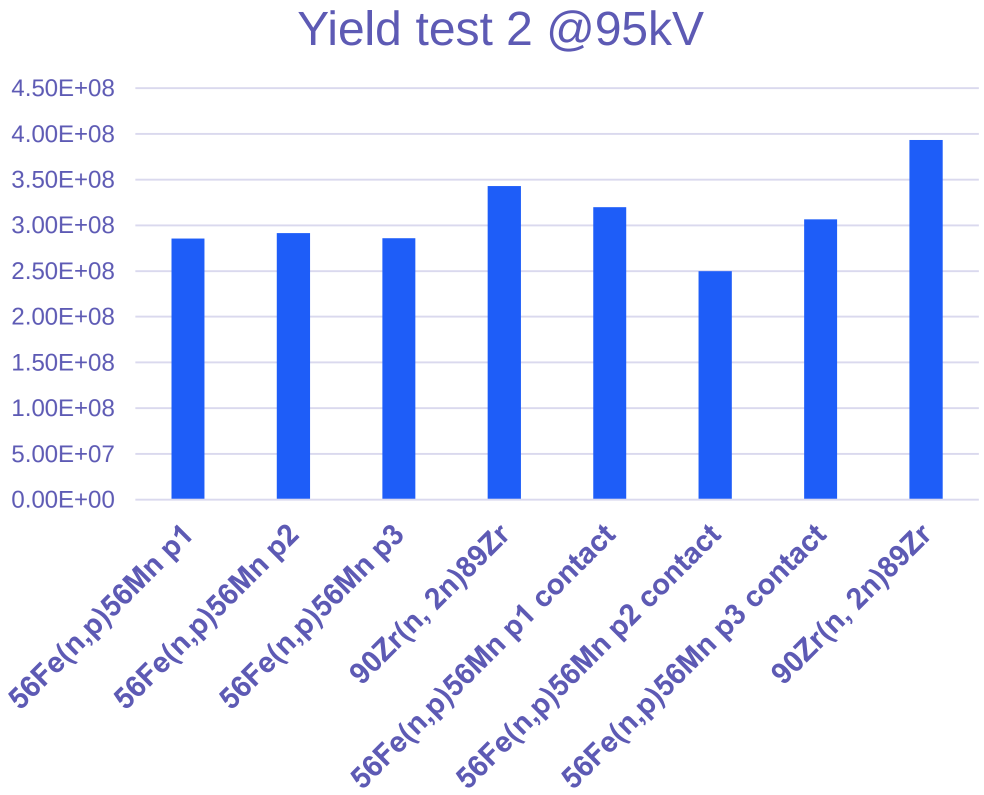
Neutron Activation analysis

Threshold reactions for fast





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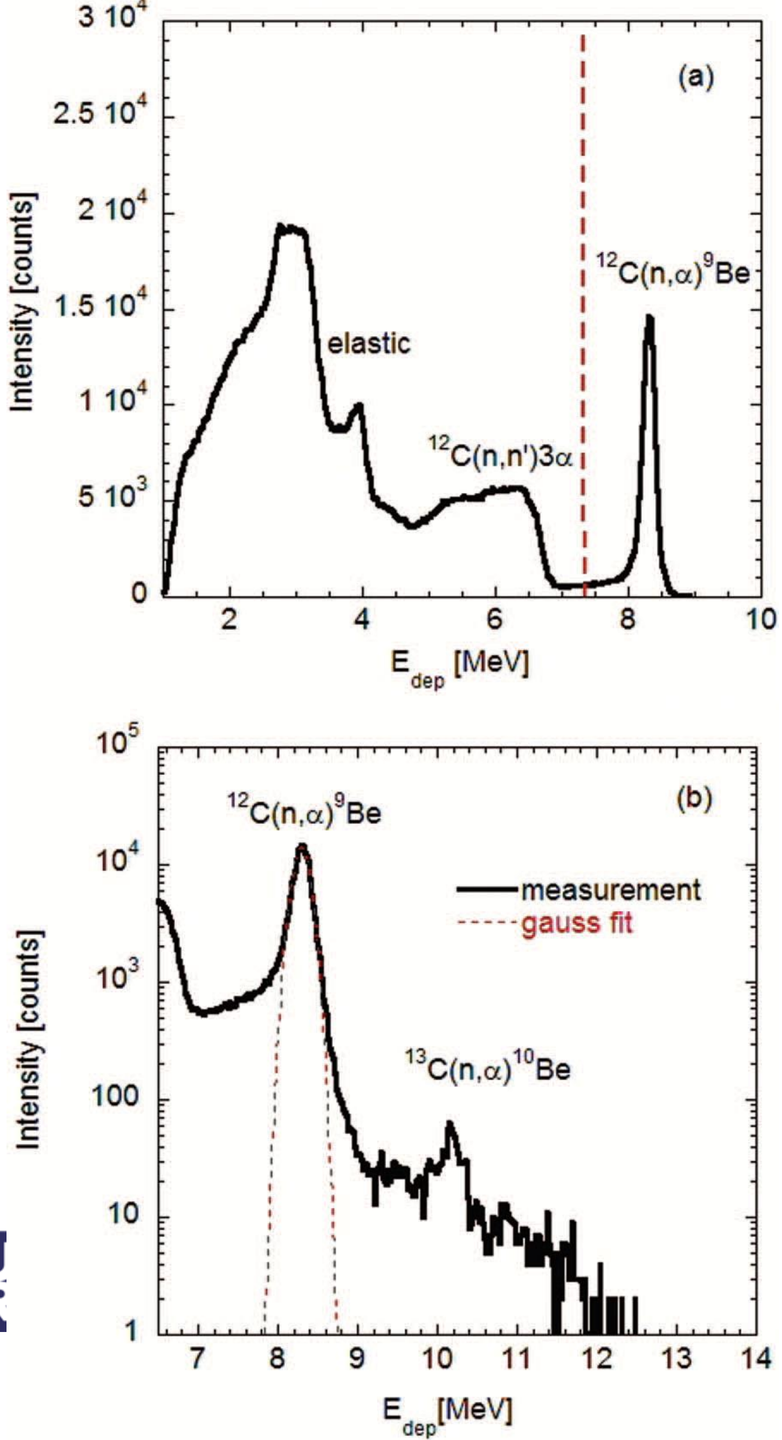
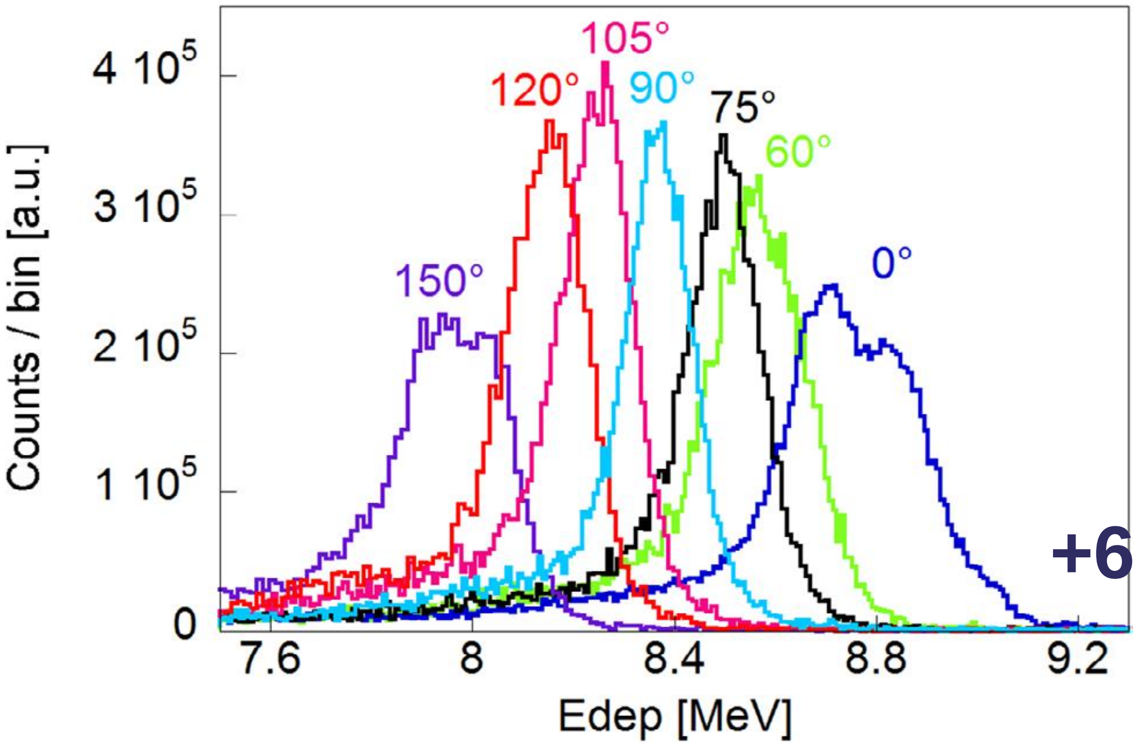
Neutron spectroscopy Single crystal Diamond Detectors

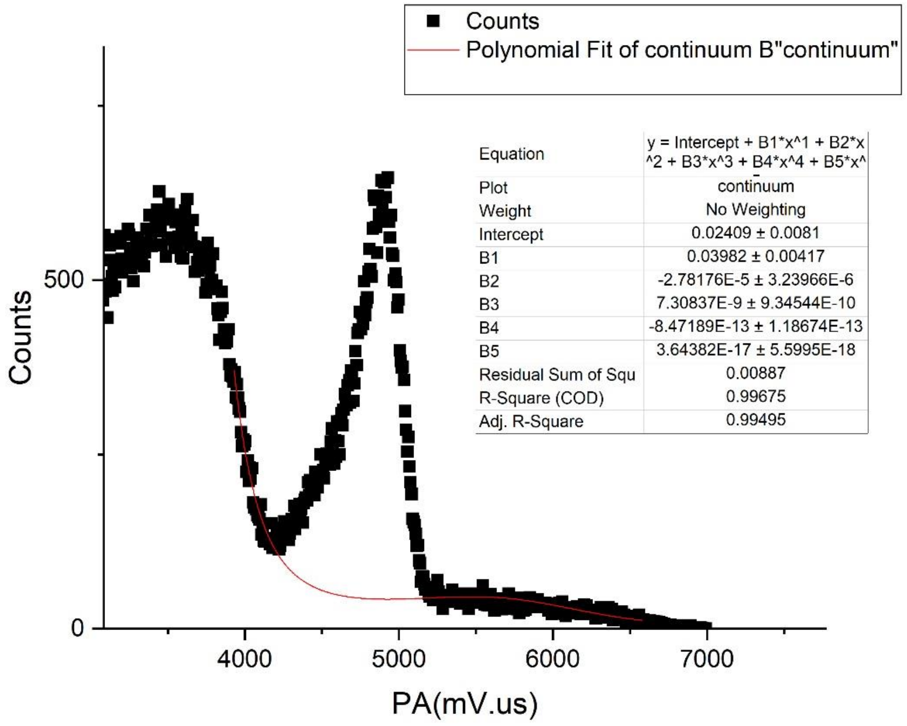




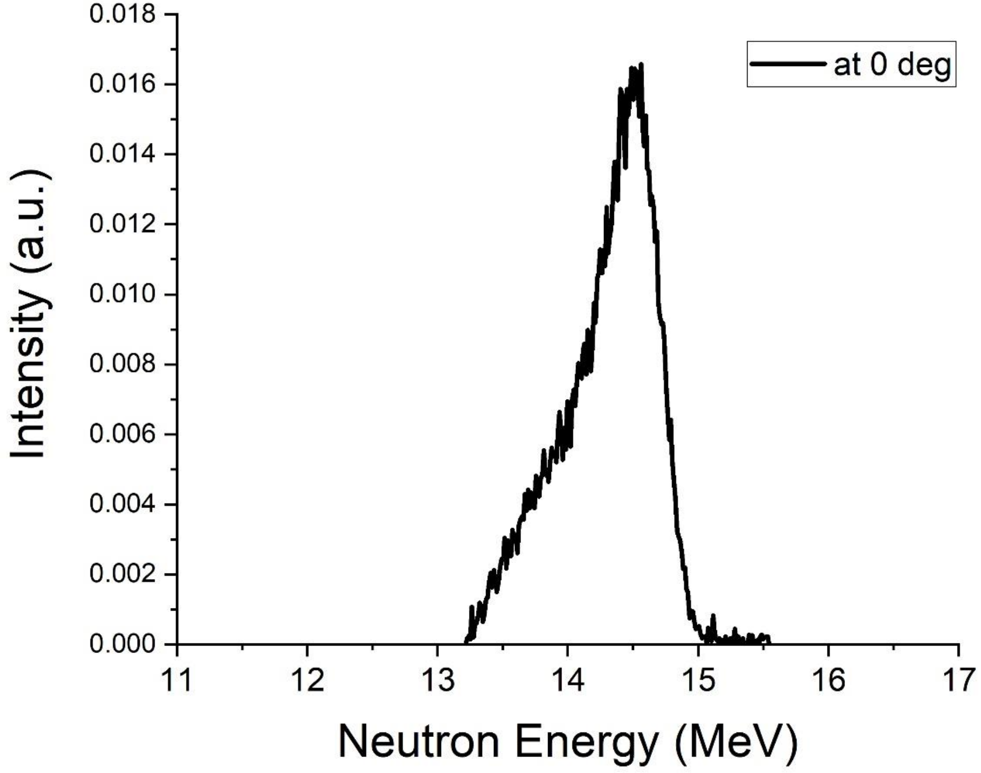
+6 MeV

D Rigamonti *et al* 2018 *Meas. Sci. Technol.* **29** 045502

Diamond - Preliminary measurements on NILE



Equation	y = Intercept + B1*x^1 + B2*x ^2 + B3*x^3 + B4*x^4 + B5*x^
Plot	continuum
Weight	No Weighting
Intercept	0.02409 ± 0.0081
B1	0.03982 ± 0.00417
B2	-2.78176E-5 ± 3.23966E-6
B3	7.30837E-9 ± 9.34544E-10
B4	-8.47189E-13 ± 1.18674E-13
B5	3.64382E-17 ± 5.5995E-18
Residual Sum of Squ	0.00887
R-Square (COD)	0.99675
Adj. R-Square	0.99495



Diamond Data → Neutron Spectrum

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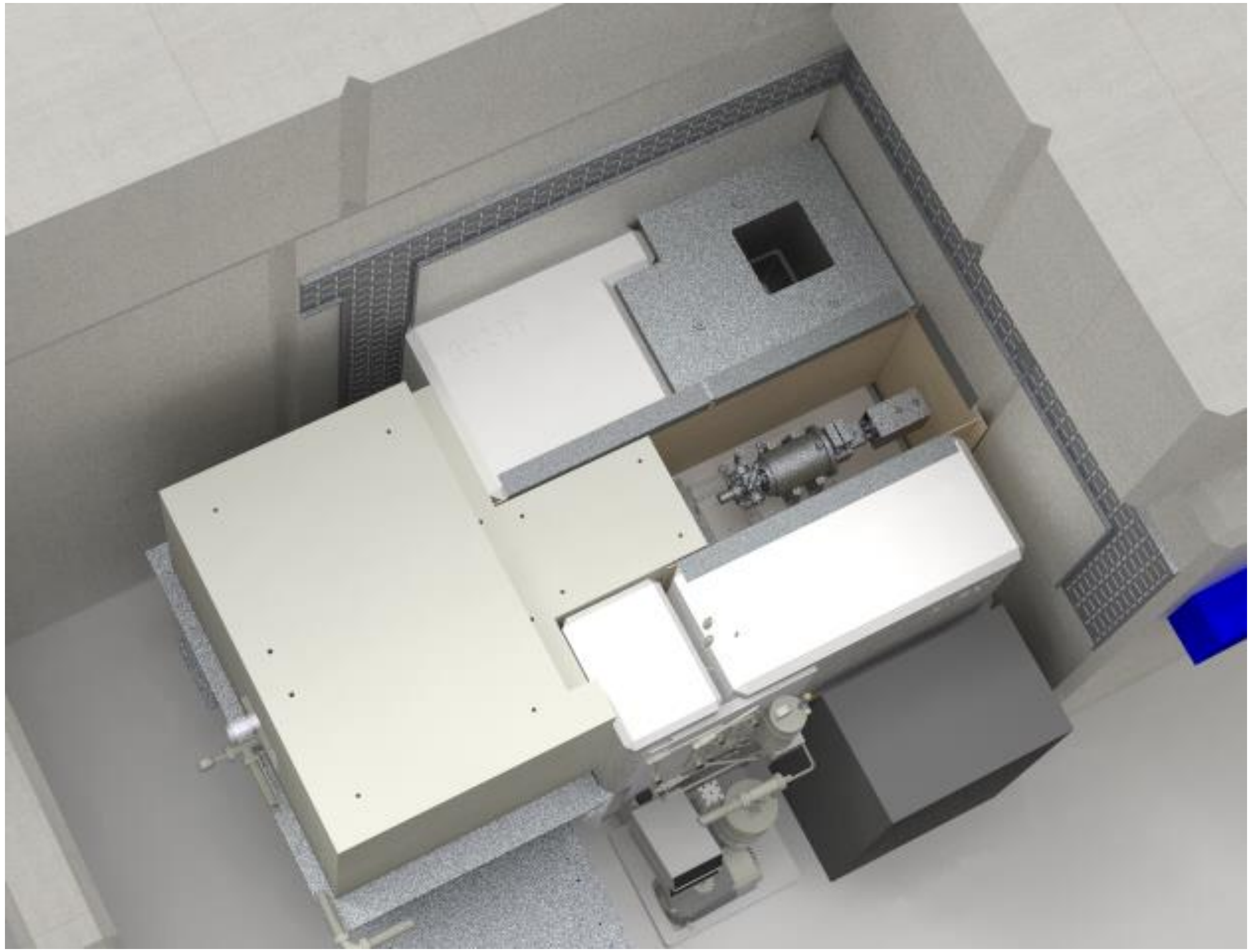
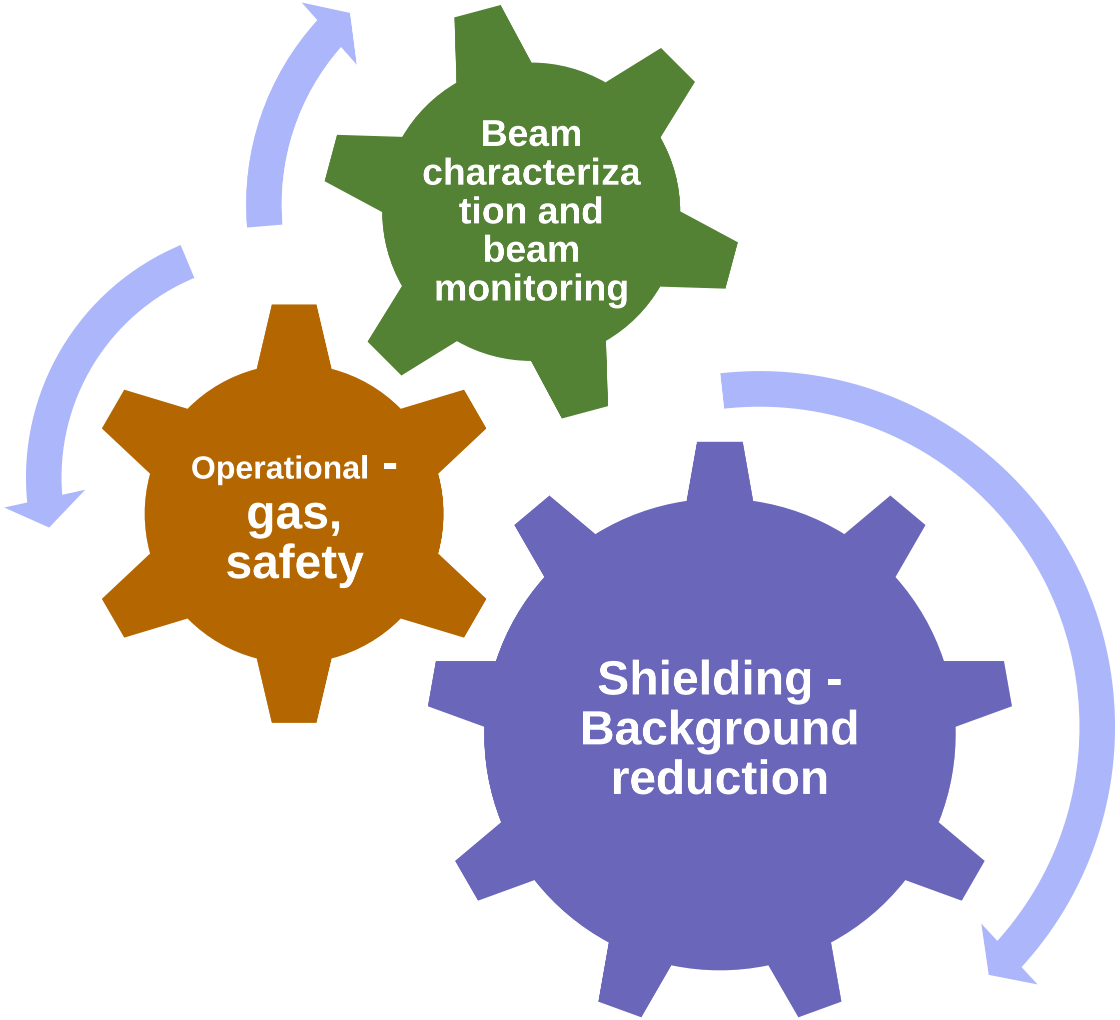
Integration of MIGDAL





Thanks for your attention!

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