Aalto-yliopisto

Neutrons in fusion experiments and reactors

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Outline

- Nuclear fusion as a source of neutrons
- Fusion neutrons as plasma diagnostics
- Neutrons in fusion reactors
- Modelling fusion neutrons
- Conclusion

Nuclear fusion as a source of neutrons

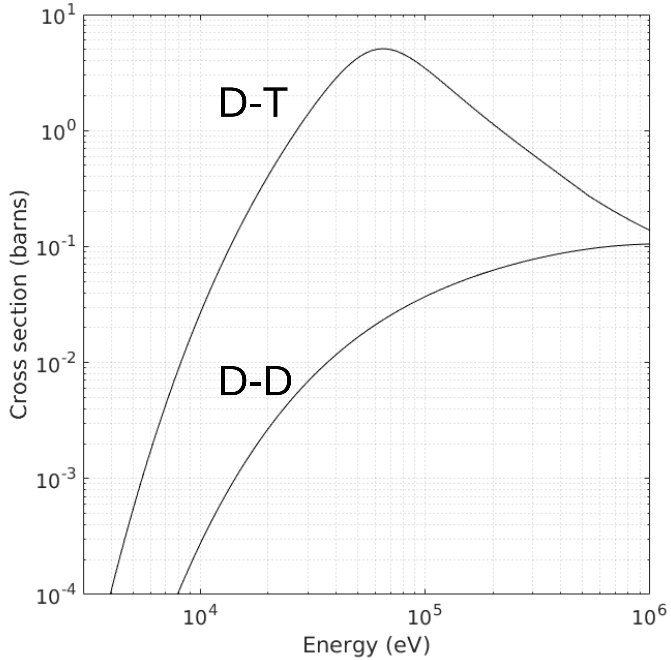
Fusion of hydrogen nuclei releases energy in charged particles and neutrons

$$^{2}D + {}^{2}D \rightarrow {}^{3}He\ (0.82\ \text{MeV}) + \boldsymbol{n}\ \mathbf{(2.45\ MeV)}$$

- Reaction used in most existing experiments
- Requires high energies

$$^{2}D + {}^{3}T \rightarrow {}^{4}He\ (3.5\ \text{MeV}) + \boldsymbol{n}\ \mathbf{(14.1\ MeV)}$$

- Higher reaction rate at lower temperatures
- Radioactive tritium, higher neutron activation



Nuclear fusion as a source of neutrons

Fusion plasmas feature multiple reactant populations at various energies

Thermal reactants

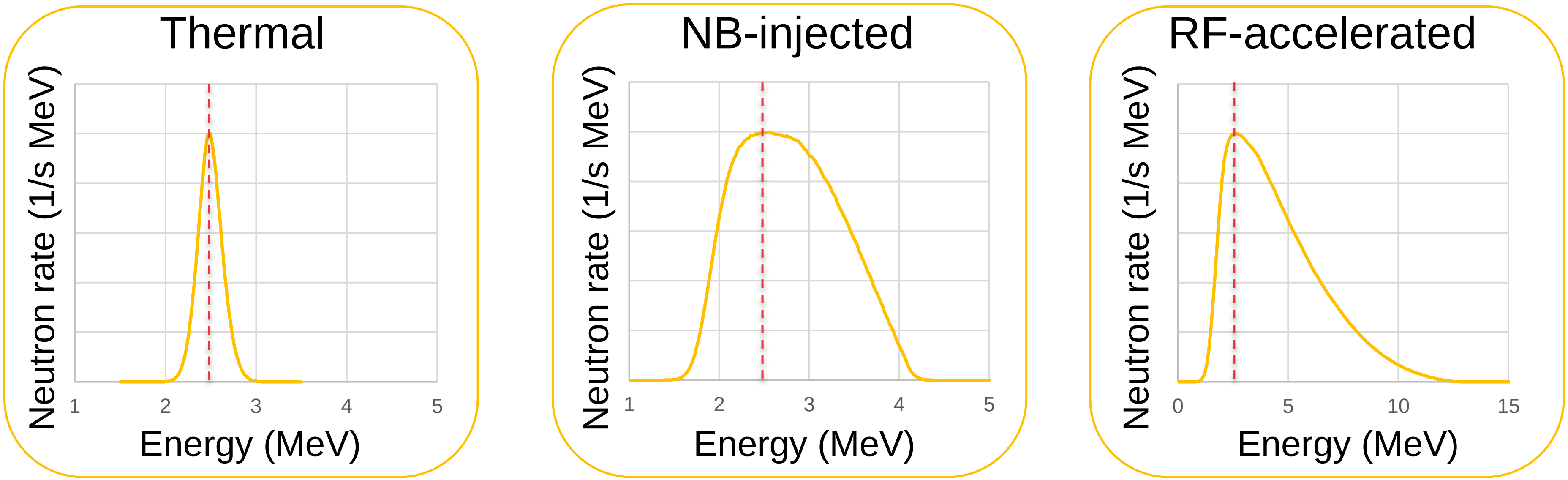
- Thermonuclear fuel plasma
  ~ 5 – 20 keV
- Dominant reactants in reactors

Fast reactants

- Minority particles for heating the plasma
- Neutral beam-injected ~ 100 keV
- RF-accelerated ~ 1-10 MeV
- Dominant in today’s experiments

Nuclear fusion as a source of neutrons

Increased reactant energy results in widened neutron spectrum



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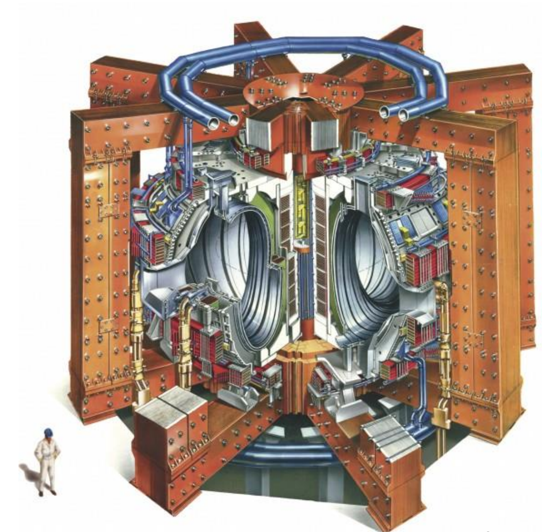
Fusion neutrons as plasma diagnostics

Neutrons act as a diagnostic method in existing fusion experiments with DD plasmas

- Neutron counters, cameras, spectrometers
- Fusion performance, plasma physics
- Fast particle reactions dominate
  $\rightarrow$ Fast ion diagnostics

JET



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Neutron counters

Total neutron rate is directly proportional to fusion rate
→ *Volume-integrated* neutron rate measures fusion performance

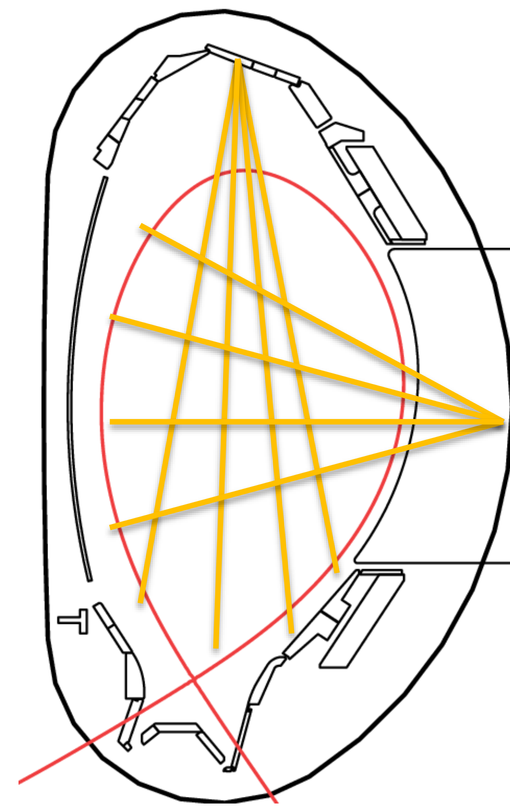
Measured using e.g.

- Uranium fission chambers
- Sample activation methods

Neutron cameras

Line-integrated neutron rate resolves the spatial distribution of fusion rate

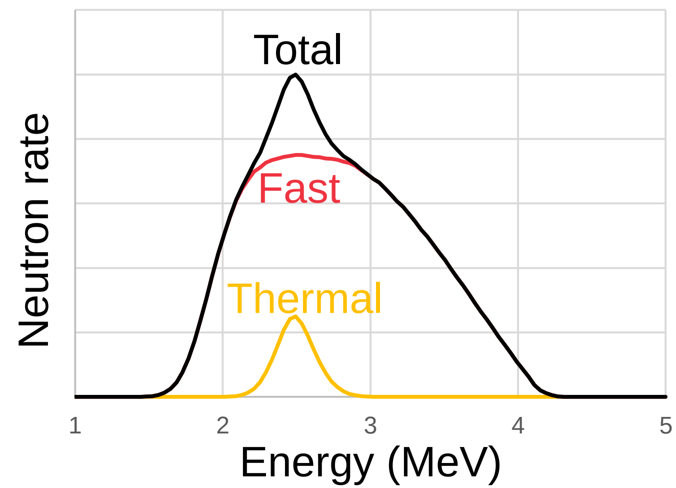
- Measured through narrow apertures viewing the plasma
- Multiple intersecting lines of sight
  → 2D tomography
- Snapshot of fast particles!



Neutron spectrometers

Energy spectrum of the neutrons gives information on the underlying reactant populations

- Fuel ion temperature
- Plasma composition
- Thermal / fast particle reactions



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Neutrons in fusion reactors

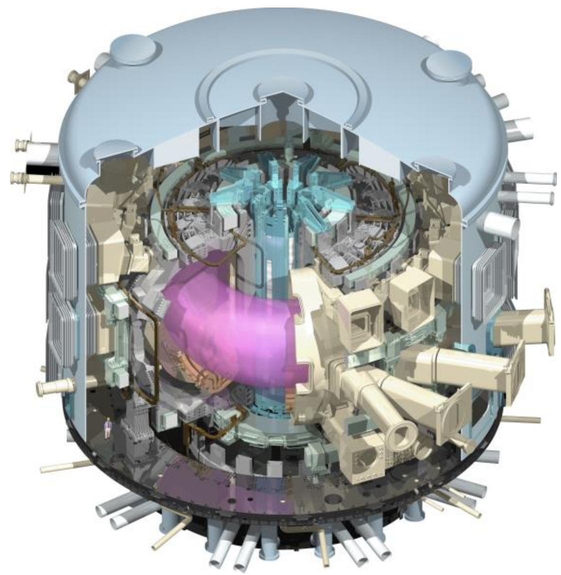
Fusion reactors with DT fuel will represent orders of magnitude increase in fusion and neutron yield

- ITER: 500 MW → DEMO: 2.5 GW
- 80% of energy released in neutrons

$$^{2}D + {}^{3}T \rightarrow {}^{4}He\,(3.5\ MeV) \quad + n\,(14.1\ MeV)$$

- Radiation damage in diagnostics, material activation, radiation safety

ITER



Neutrons in fusion reactors

Fusion power plants must further breed their fuel with fusion neutrons

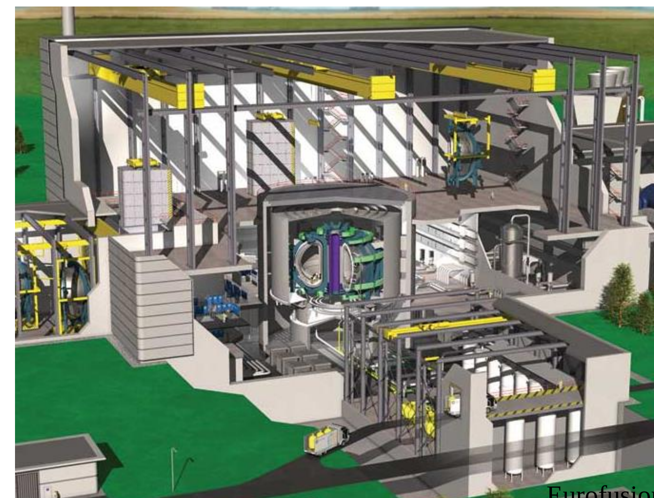
- Tritium decays with a half-life of 12.3 years
- Plasma surrounded by lithium breeding blankets

$$n + {}^{6}Li \rightarrow {}^{3}T + {}^{4}He$$

$$n + {}^{7}Li \rightarrow {}^{3}T + {}^{4}He + n$$

- High breeding efficiency required

"DEMO"



Eurofusion

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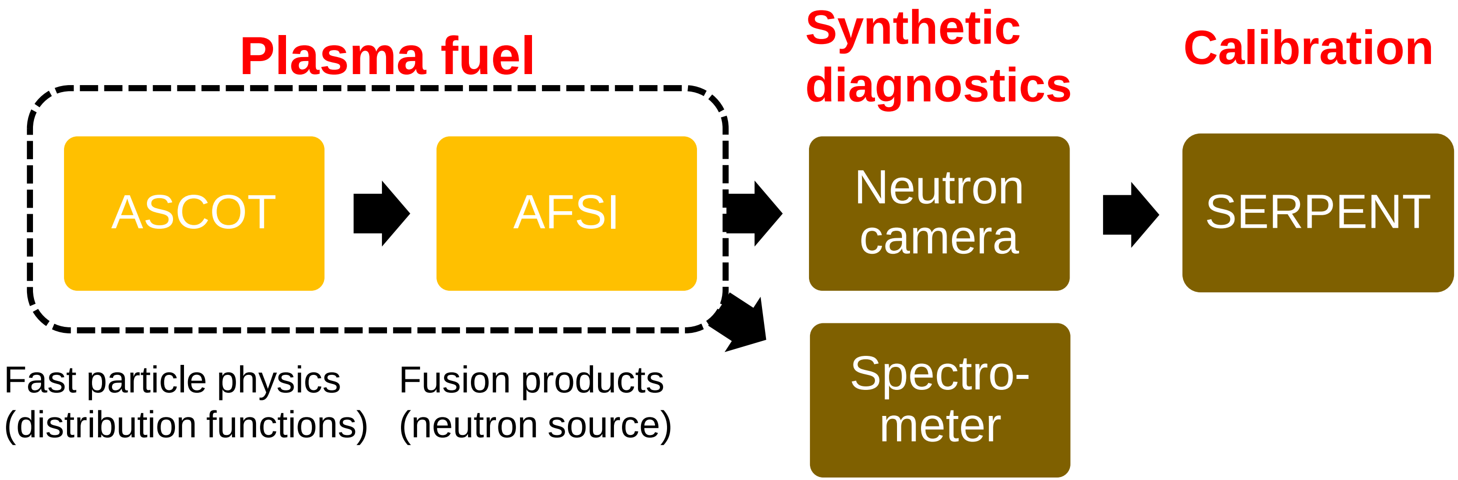
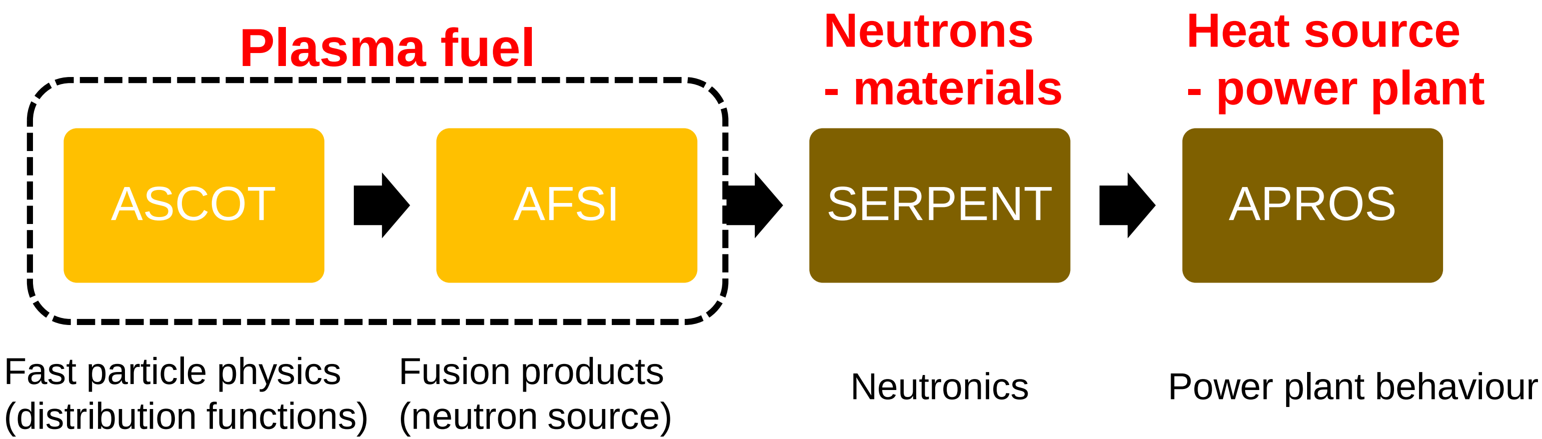
Modelling fusion neutrons

Interpretive modelling for today's experiments
– plasma physics, diagnostic calibration



Modelling fusion neutrons

Predictive modelling for future power plants
– performance, efficiency, safety



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Conclusion

- Neutrons are key players in fusion experiments and reactors
- Today neutron rates and neutron spectra are used as diagnostic methods in fusion experiments
- Fusion reactors will rely on neutrons for power output and tritium fuel breeding
- Modelling yields insight into physics and power plant operation – marriage of plasma physics and neutronics