Contributions to the development of nuclear instrumentation for the EU test blanket modules for ITER

Axel Klix, Maurizio Angelone, Bradut Ghidersa, Laurent Ottaviani, Prasoon Raj, Dora Szalkai

INSTITUTE FOR NEUTRON PHYSICS AND REACTOR TECHNOLOGY

Thanks to

M. Angelone[1], P. Batistoni[1], U. Fischer[2], D. Gehre[3], B. Ghidersa[2], G. Kleizer[4], A. Lyoussi[5], L. Ottaviani[6], M. Pillon[1], P. Raj[2,*], Th. Reimann[2], I. Rovni[4], T. Rücker[7,**], D. Szalkai[2,***], K. Tian[2]
and many others

[1] ENEA Frascati, Frascati, Italien
[2] Karlsruhe Institute of Technology, Karlsruhe, Germany
[3] Technische Universität Dresden, Dresden, Germany
[4] Budapest University of Technology and Economics, Budapest, Hungary
** Now: Khalifa University, Abu Dhabi, UAE*
[5] CEA Cadarache, Cadarache, Frankreich
[6] Aix-Marseille University, Marseille, Frankreich
[7] University of Applied Sciences Zittau-Görlitz, Zittau, Germany
*** Now: Balcke-Dürr Nuklear Service GmbH, Karlsruhe, Germany*
**** Now: Budapest University of Technology and Economics, Hungary*

Tritium breeding blanket

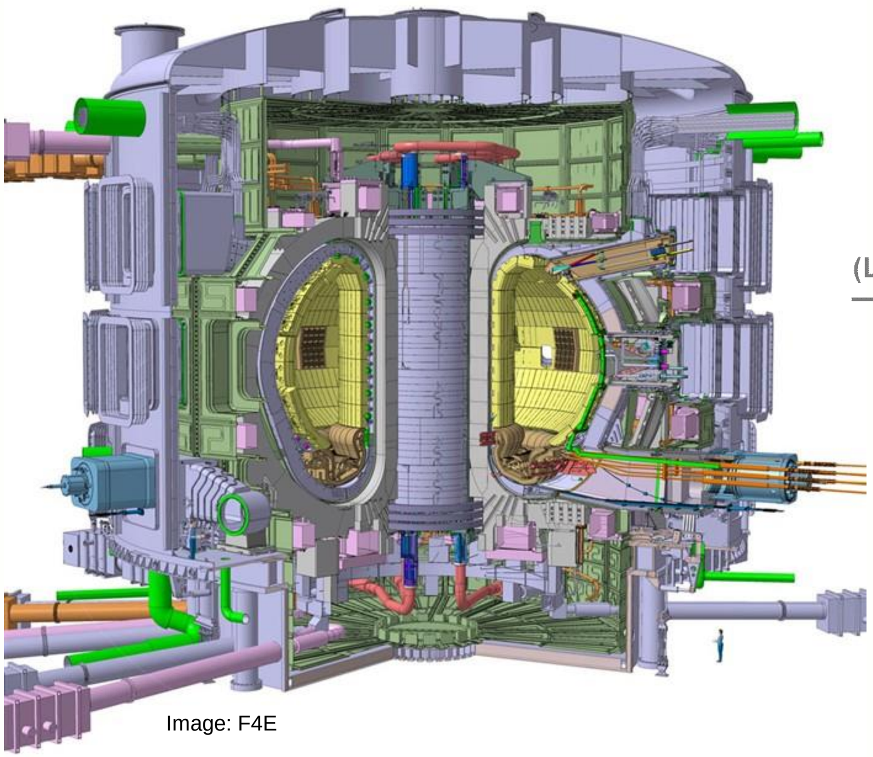
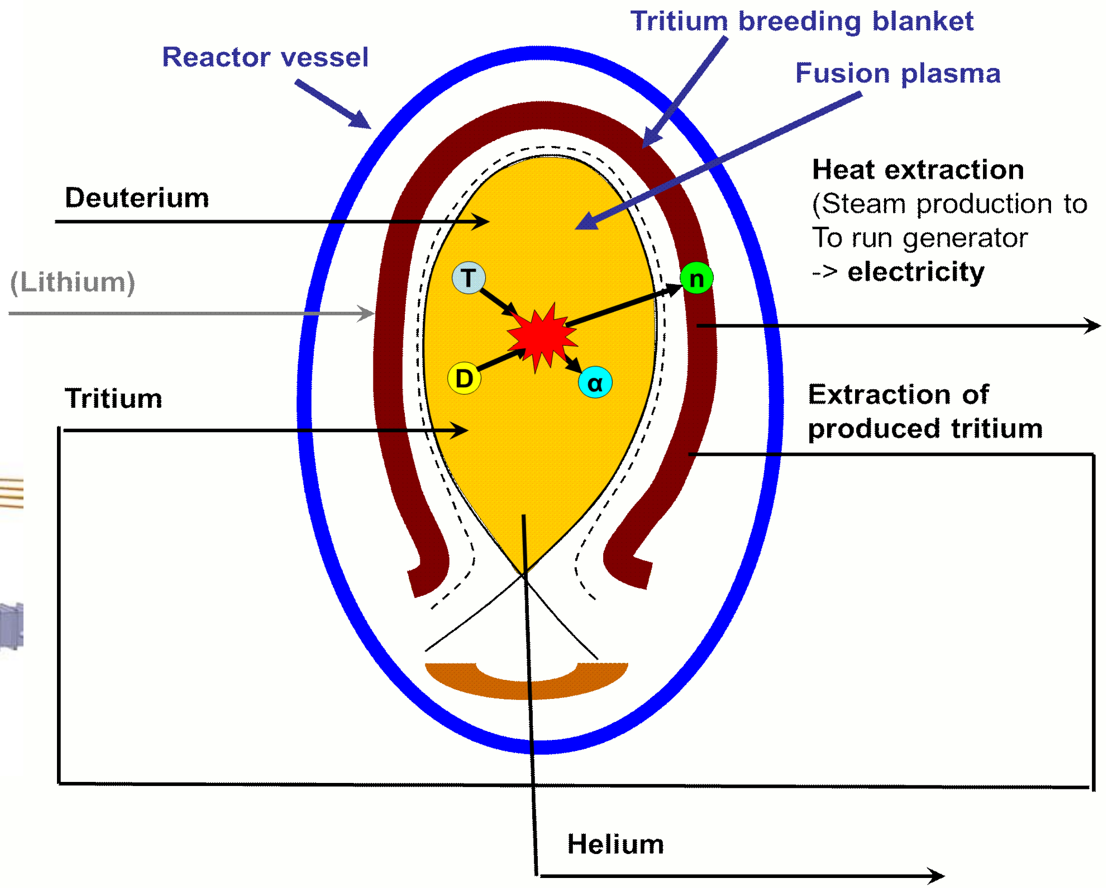


Image: F4E



- ***Energy conversion*** *(→ Heat generation)*
- ***Shielding*** *for field coils behind the blanket (heat generation)*
- ***Tritium production****, sufficient to sustain fusion reaction, compensate for losses, startup of new reactors, on the order of 600 g/day*

Nuclear instrumentation for the ITER Test Blanket Modules

ITER TBM (neutronics) experiments are an important step on the way to DEMO and power reactor breeding blankets

Local neutron flux measurements:

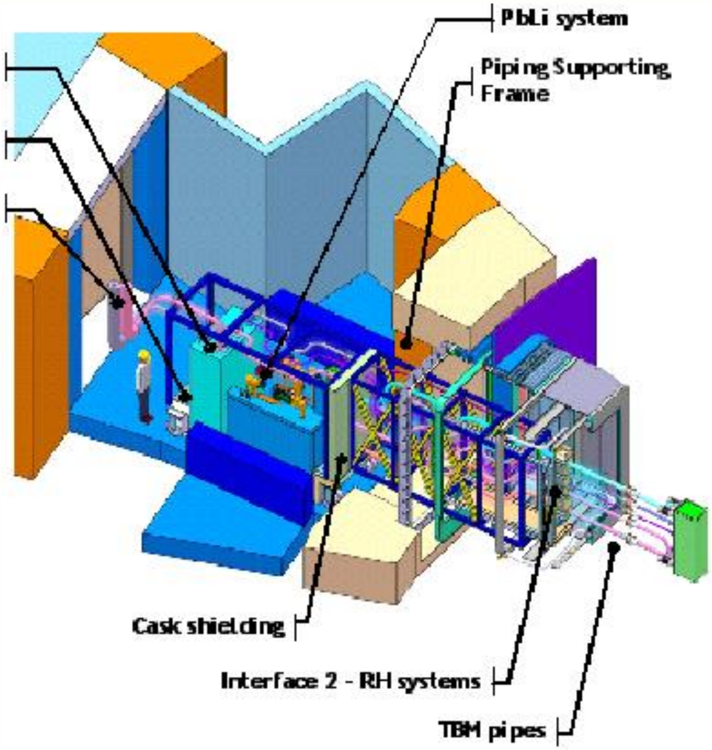
- normalization for other parameters (also „non-neutronics“) in the TBM
- better accuracy than interpolated flux values from measurements outside the TBM

Particular importance for Tritium accountancy!

ITER TBM neutronics experiments will allow to check

- **high-fidelity calculational tools**
- **Modelling of heterogeneous fusion reactor relevant complicated structures under fusion reactor relevant conditions**

Nuclear instrumentation for the ITER TBM
- Conditions in the TBM -



R&D work within F4E Tasks (F4E-2008-GRT-09, GRT-056) and others

Conditions in the TBM not good for any kind of detectors / diagnostics

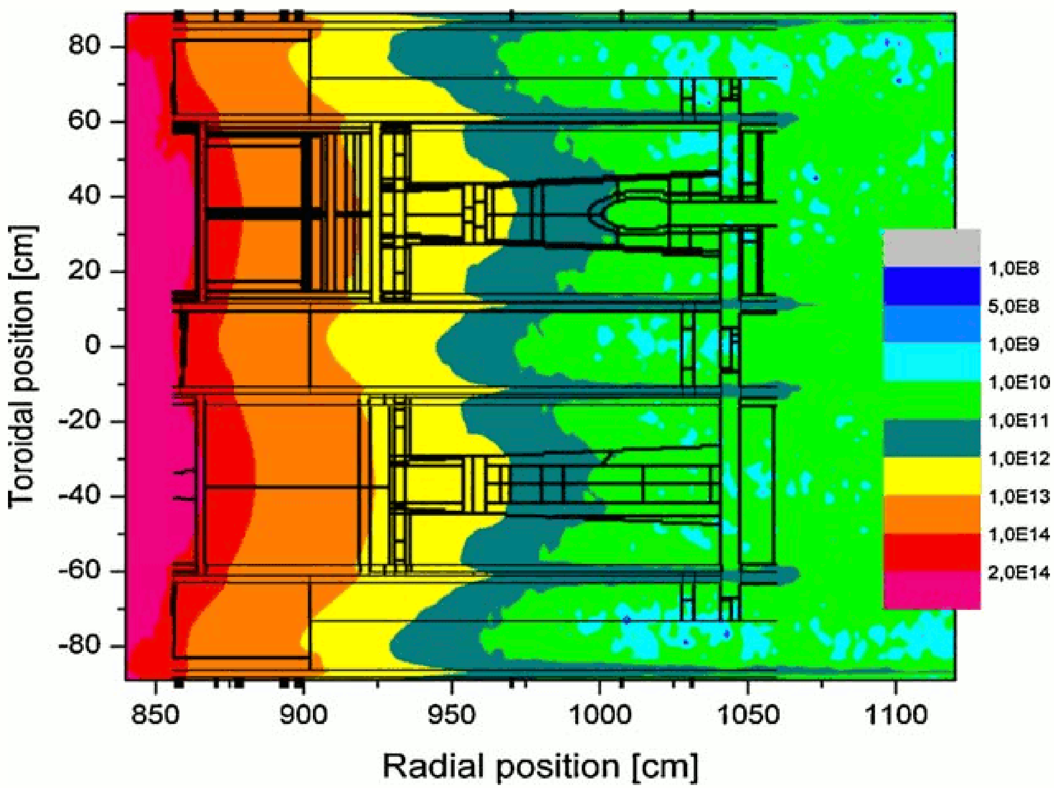
- ***10^9~10^{14} n*cm^{-2}s^{-1}***
- **300..550 ºC**
- **Magnetic fields ~4 T**
- **difficult access**
- **little space**

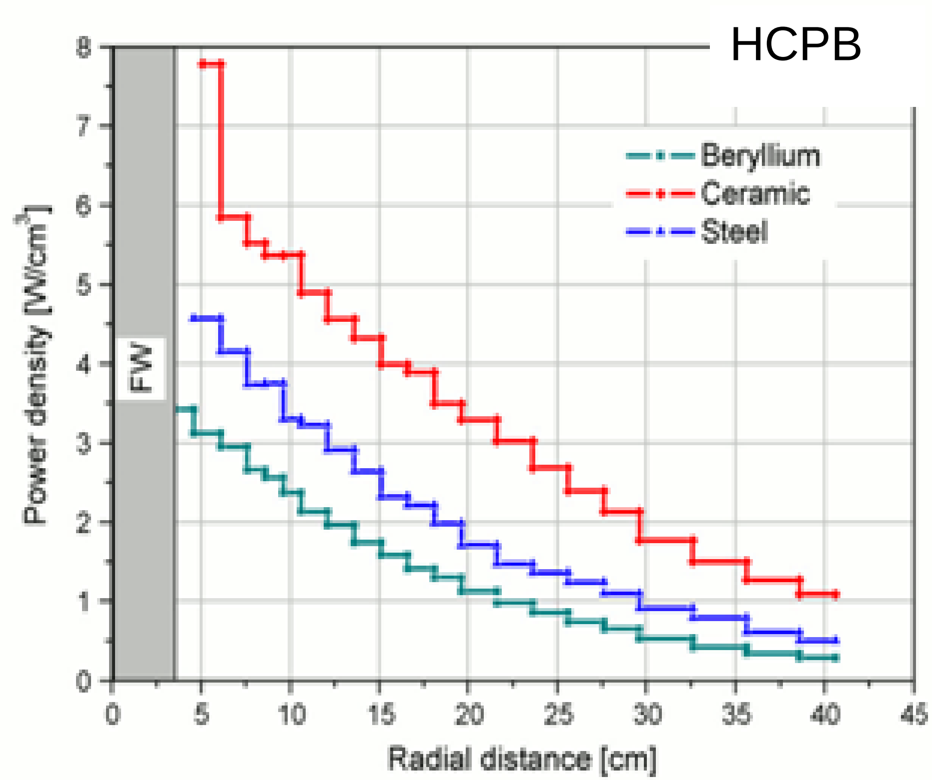
Possible candidates for neutron flux measurements:

Activation foils*, miniature fission chambers, diamond detectors,* ***silicon carbide detectors, self-powered neutron detectors***

Testing and qualification underway

Nuclear instrumentation for the ITER TBM
- Conditions in the TBM at 500 MW fusion power -





Neutron flux

First-wall side: 2×10^{14} $s^{-1}cm^{-2}$
Just behind TBM: $>10^{12}$ $s^{-1}cm^{-2}$

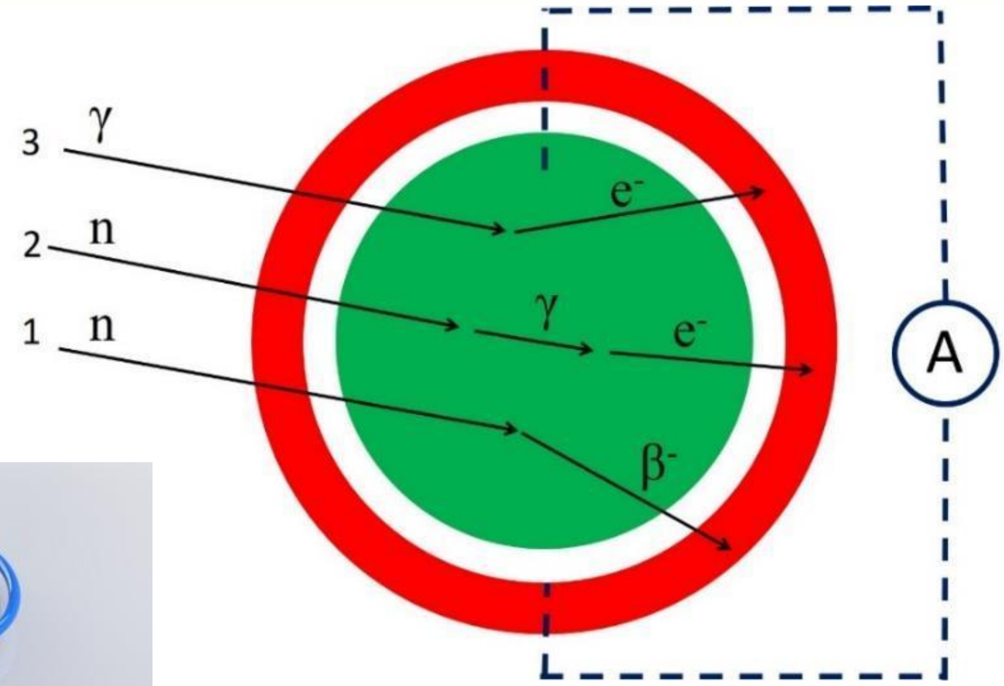
Heating

First-wall side: 3.5 - 8 Wcm^{-3}
Just behind TBM: up to 0.5 Wcm^{-3}

Self-powered neutron detectors (SPND)

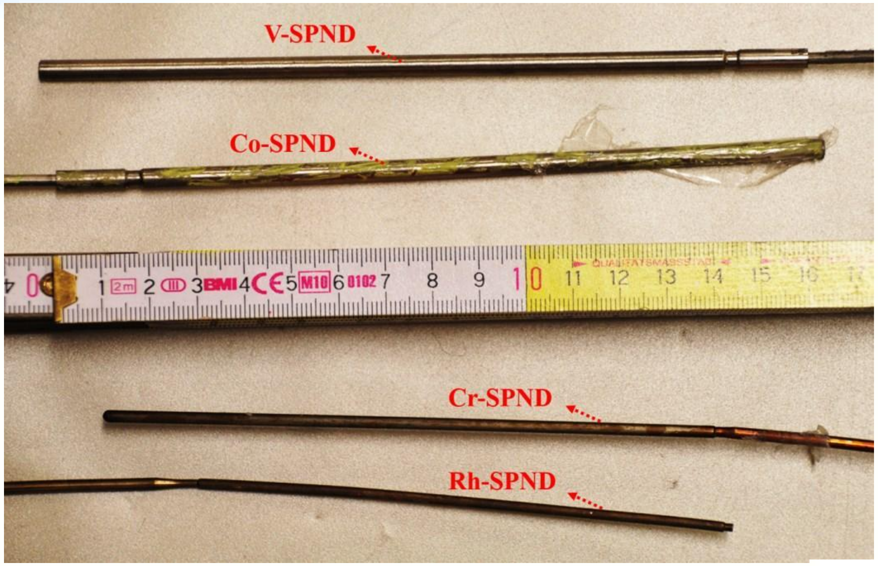
Operational principle in neutron fields:

- Neutron-induced beta activity
- Neutron-induced prompt gamma
  -> Compton electrons
- Photon-induced Compton electrons



In fast neutron field the reaction cross sections are much lower, „parasitic“ effects contribute to the signal at similar level.

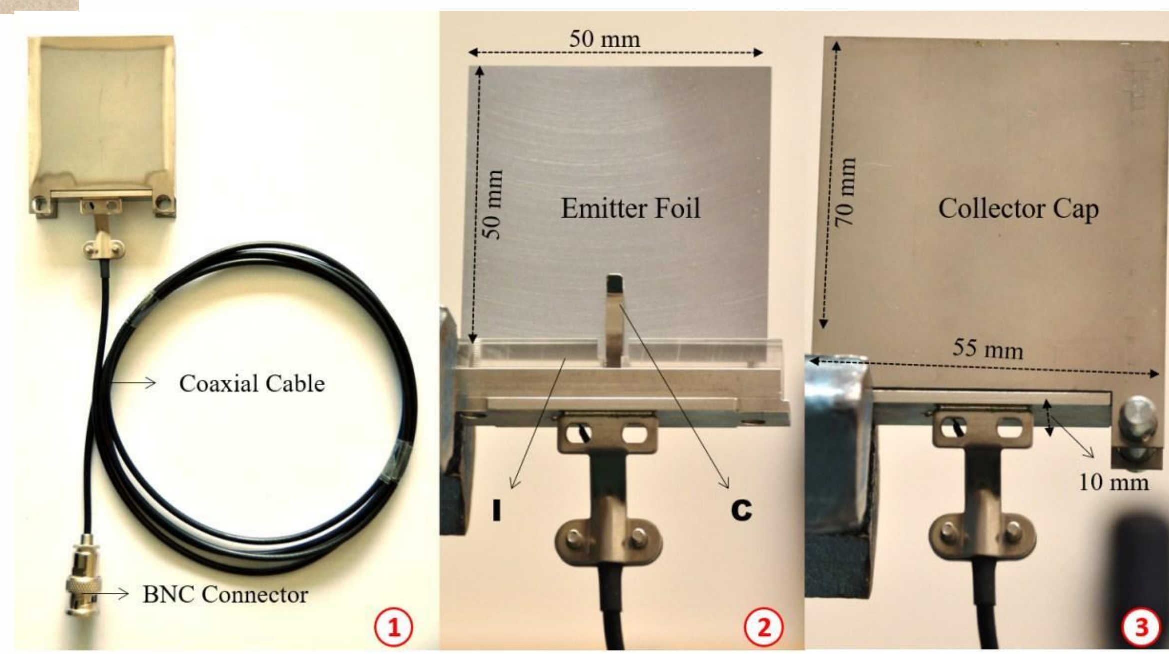
Self-powered neutron detectors (SPND)



Typical examples of commercially available SPND for fission reactors

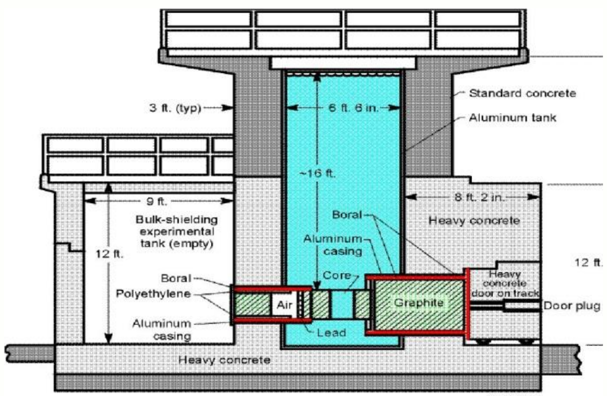
Initial tests with fast reactor neutrons (TAPIRO/ENEA) and Co-60 gamma rays (CALLIOPE/ENEA)

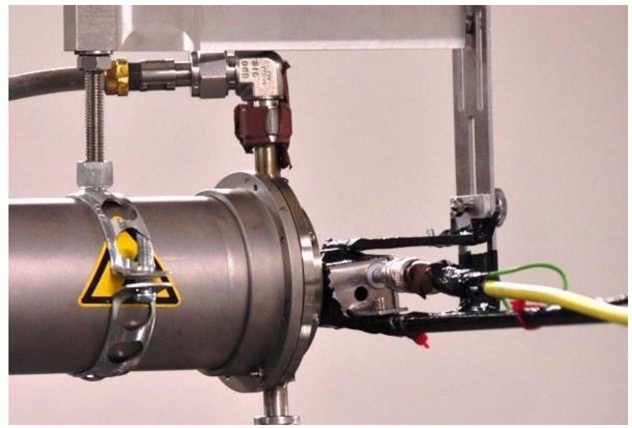
Flat sandwich geometry with intention to optimize for neutron generator testing

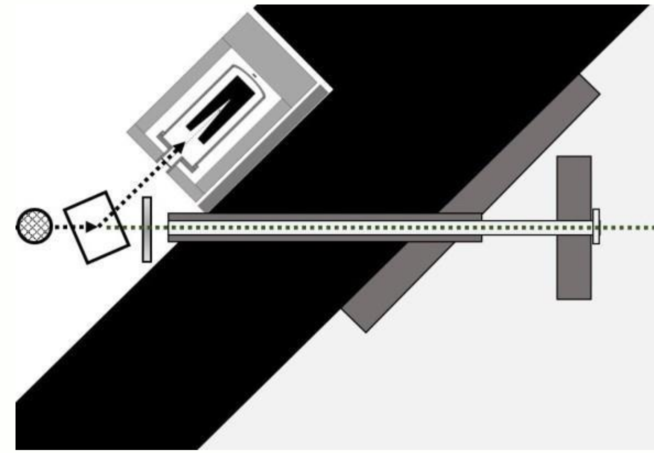


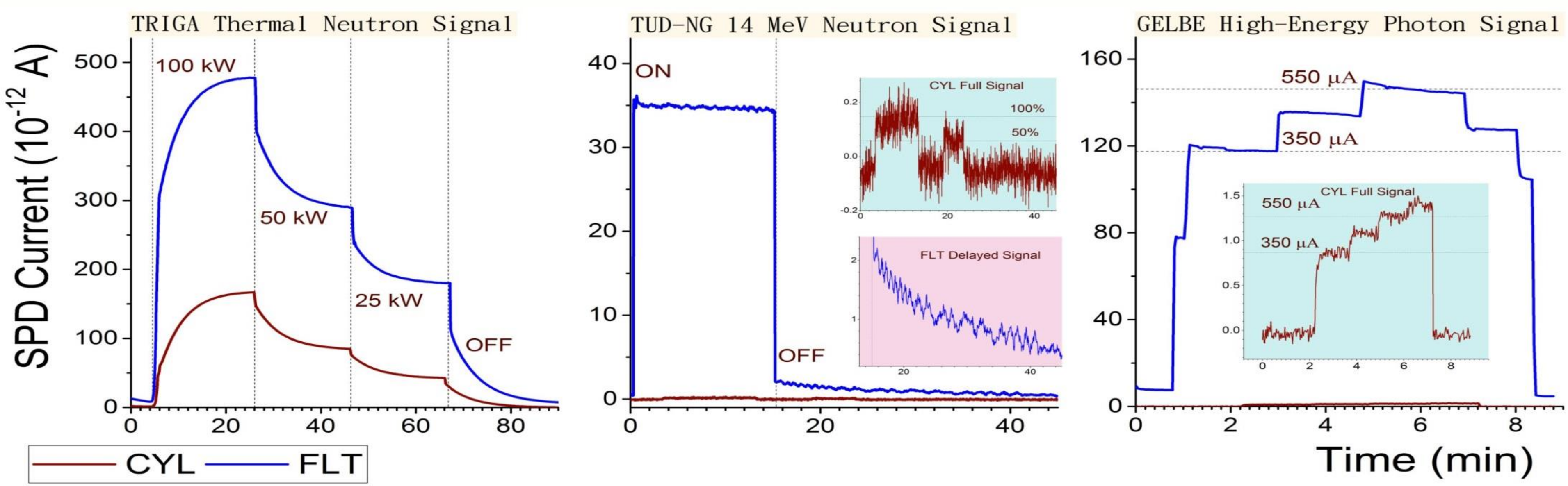
Self-powered neutron detectors (SPND)

Detector responses were experimentally investigated with thermal neutrons from TRIGA reactor (Uni Mainz), DT neutron generator (TU Dresden) and Bremsstrahlungs source (ELBE, Helmholtz-Zentrum Dresden-Rossendorf)









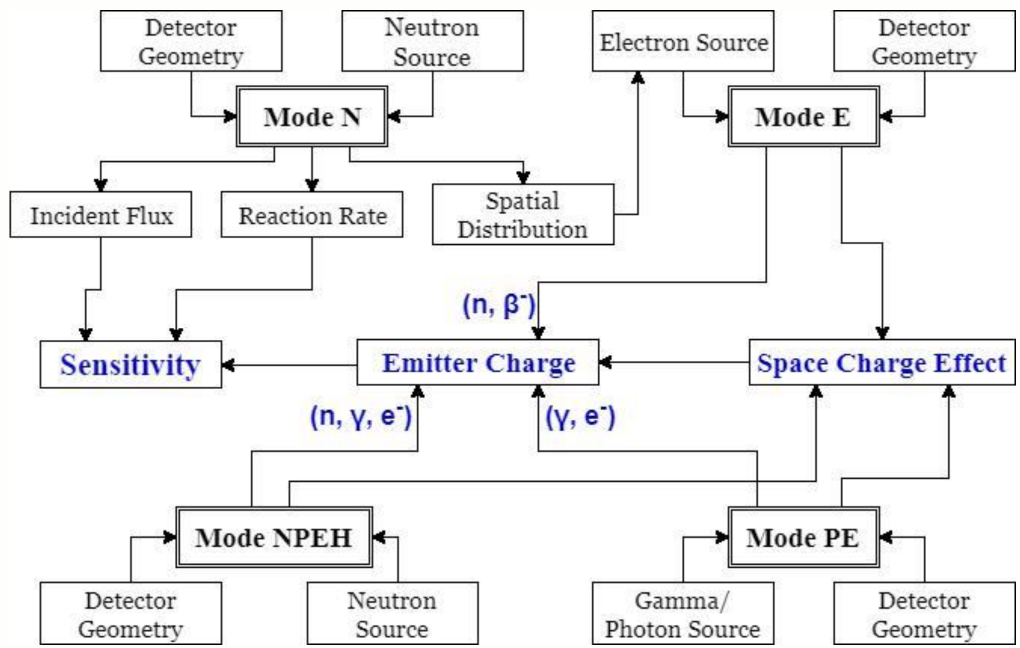
Self-powered neutron detectors (SPND)

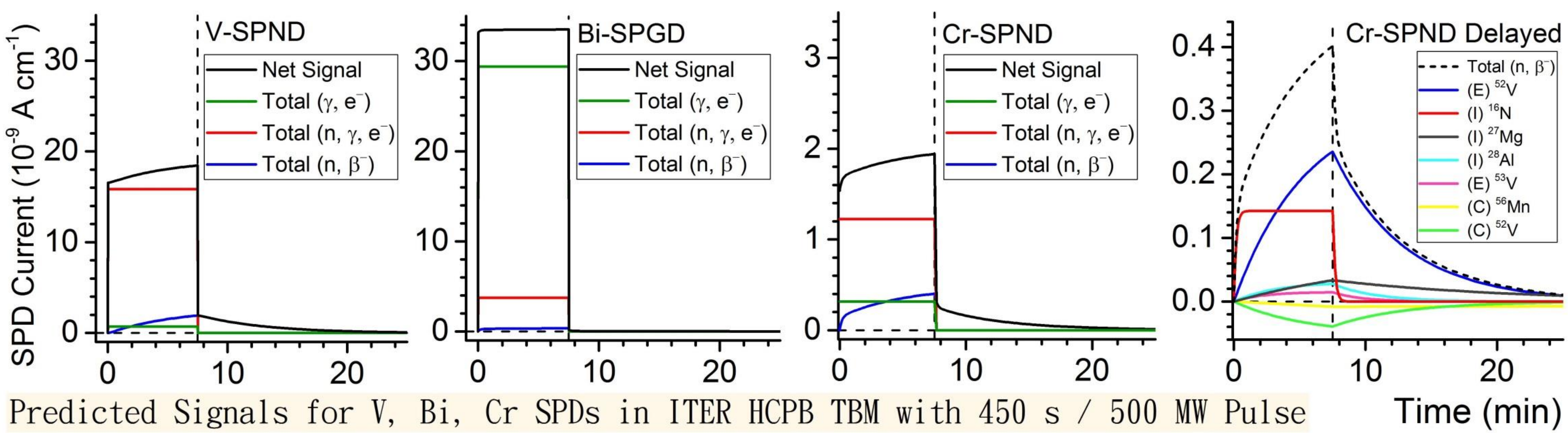
Modeling of detector response:

$$Sensitivity\ (S) = \frac{SPD\ Current\ (I)}{Incident\ Flux\ (\varphi)}$$

A cm² s or A cm⁻¹

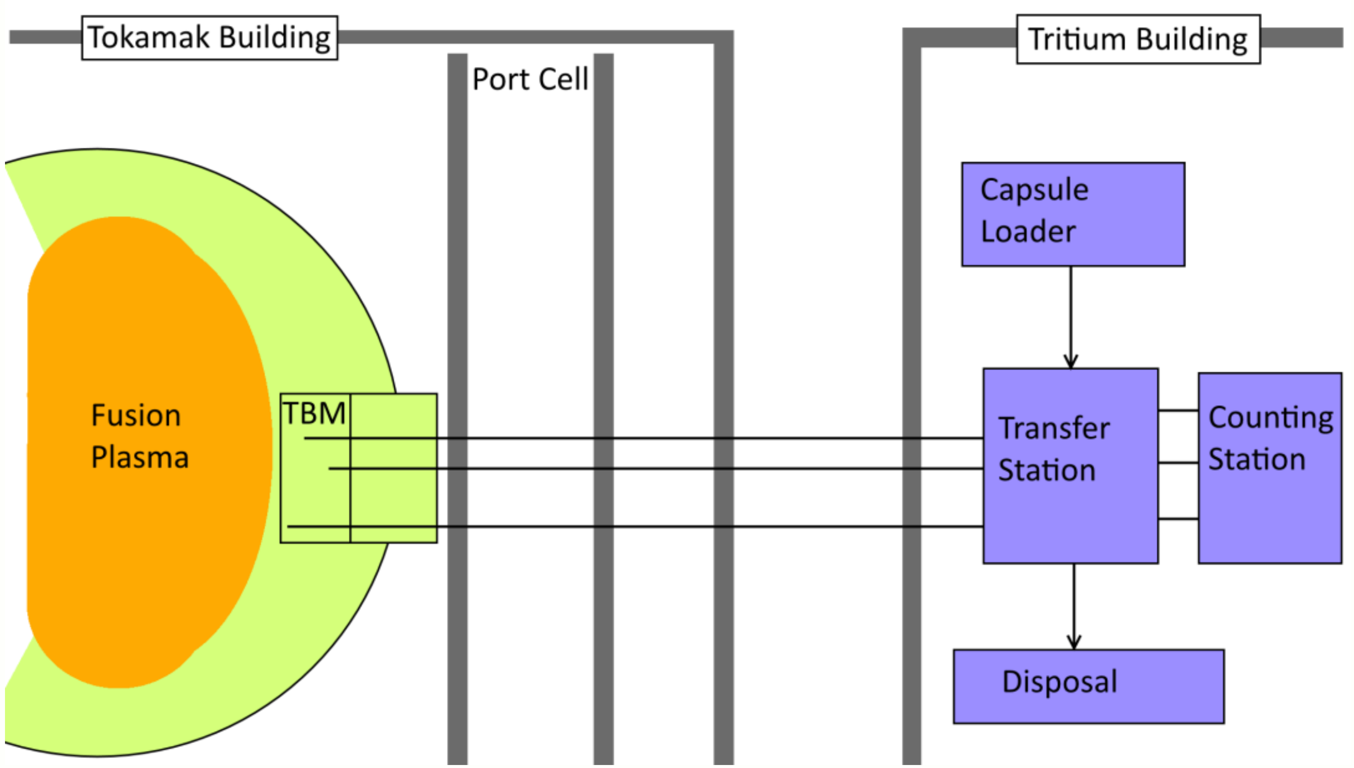
- Neutron-induced beta activity
- Neutron-induced prompt gamma -> Compton electrons
- Photon-induced Compton electrons





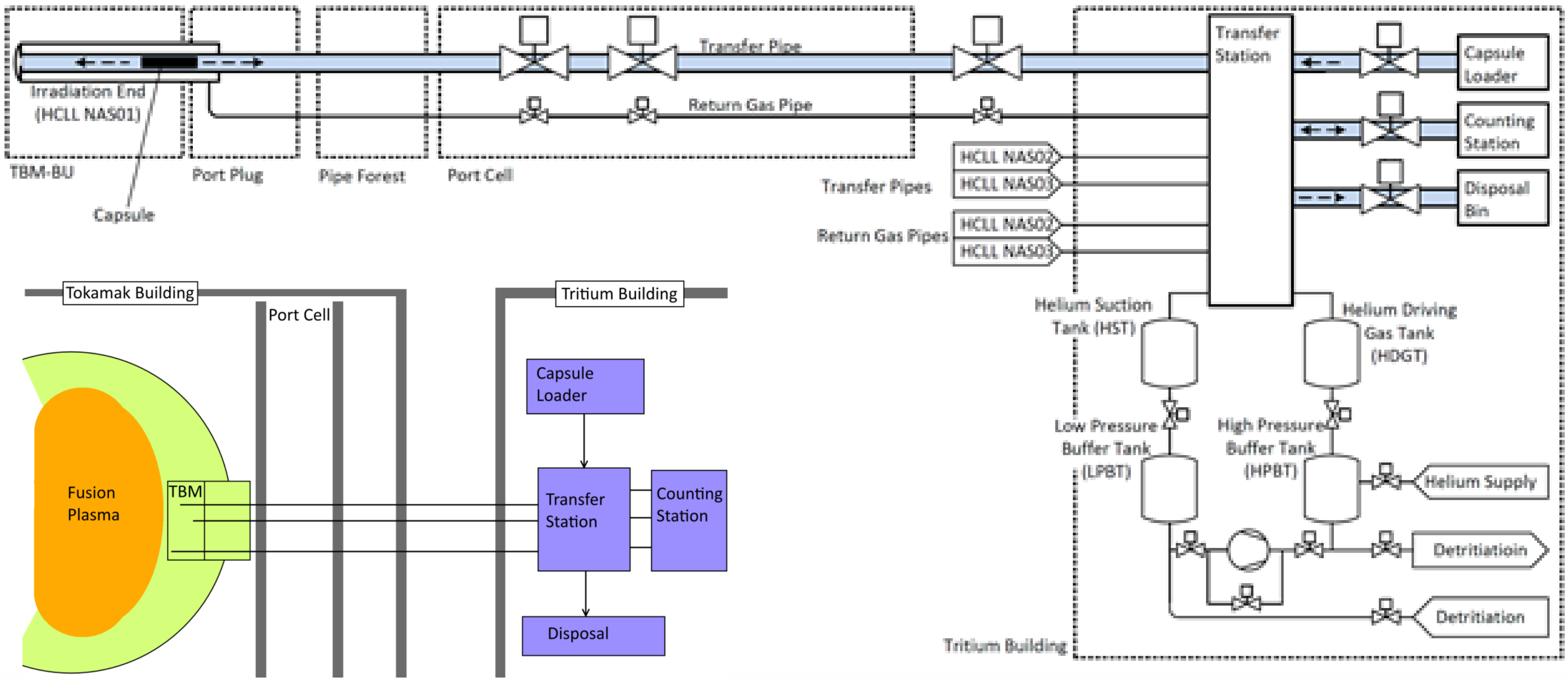
Predicted Signals for V, Bi, Cr SPDs in ITER HCPB TBM with 450 s / 500 MW Pulse

TBM Neutron Activation System



- Robust measurement system, no radiation damage concerns, absolute flux measurement
- Small activation probes are send to irradiation
- Induced gamma activity analyzed after extraction
- Neutron flux computed from activity measurement and known dosimetry cross section data

TBM Neutron Activation System



Preliminary engineering assessment within F4E Task Order OMF-331-02-01-02

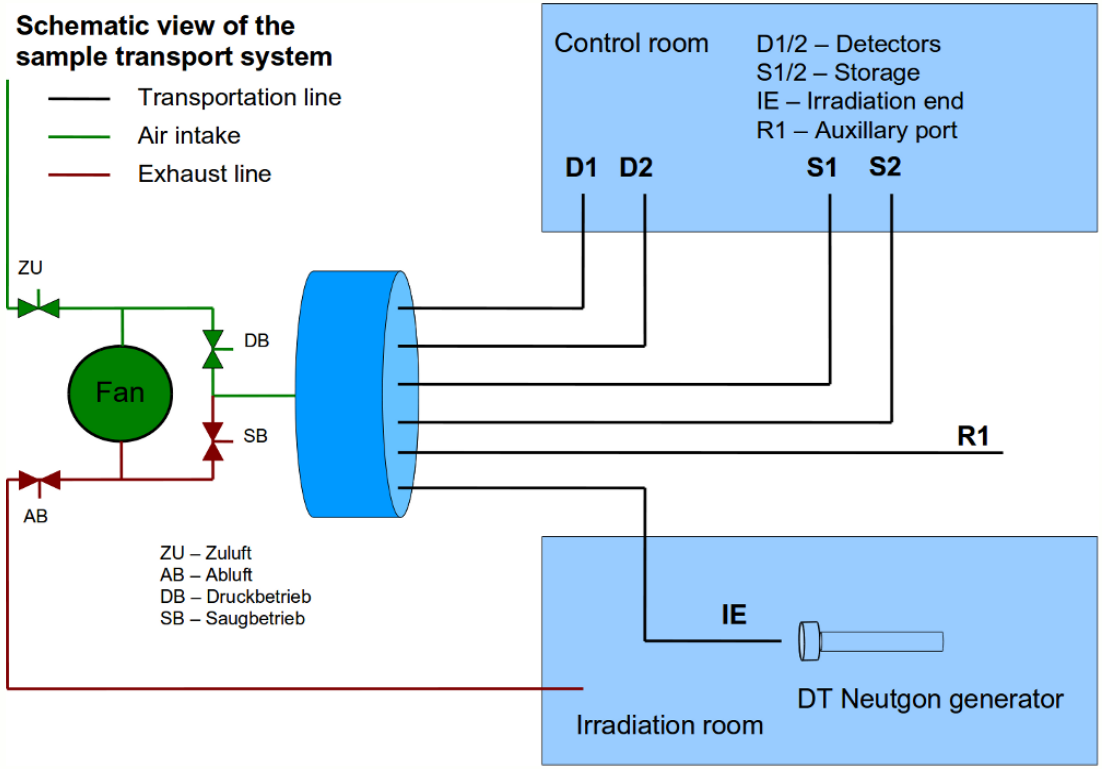
- TBM-NAS similar to ITER-NAS
- Must be driven by He; N_2 etc. would be no option
- Expect three or four measurement positions in each TBM (HCLL and HCPB)

Neutron Activation System test system at TUD-NG

Pneumatic transport system (Rabbit system) for testing at TUD-NG designed in collaboration with Technical University of Dresden

Investigate:

- Suitable dosimetry reactions and mass ratios
- Suitable measurement regimes with DT neutrons
- Measurement uncertainties
- Suitable gamma ray detectors (HPGe, CZT,...)
- Demonstration of an automated system

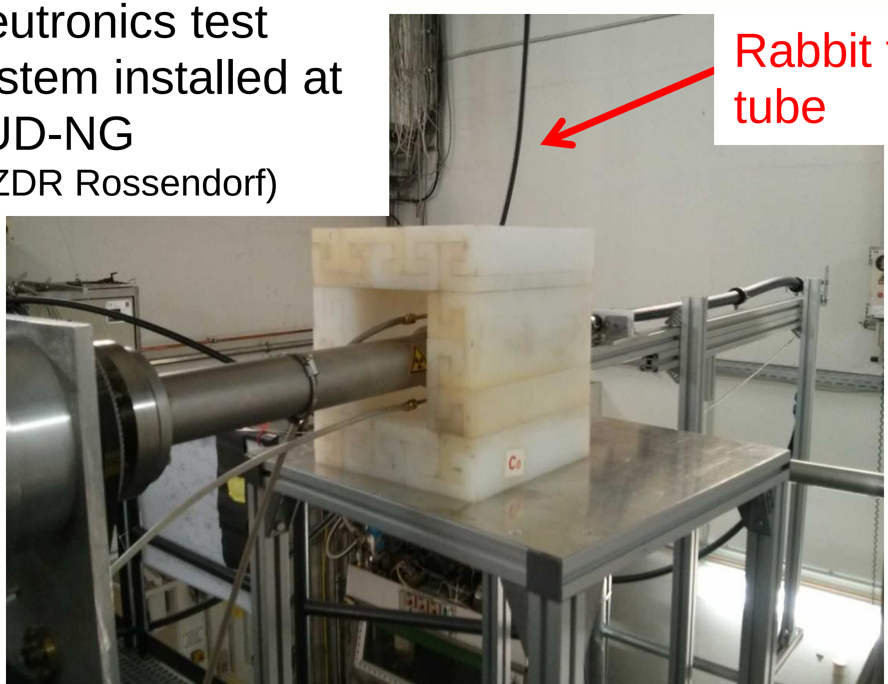


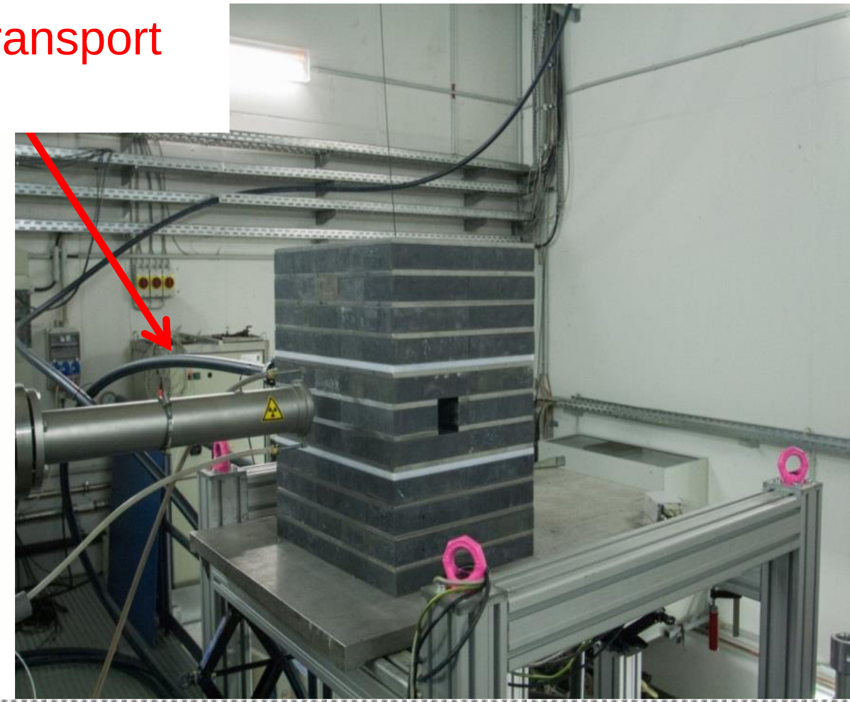
- Simultaneous gamma ray measurement of all materials in activation probe:
  - → Design (sintered, alloyed)
  - → Perhaps contaminated (tritium)

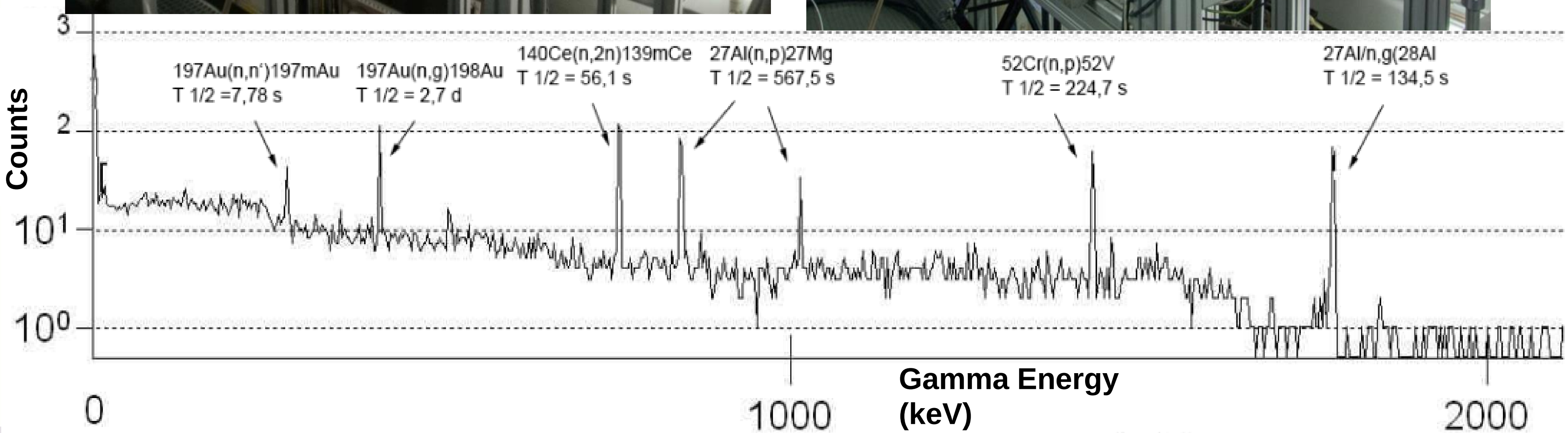
Neutron Activation System test system at TUD-NG

Neutronics test system installed at TUD-NG
(HZDR Rossendorf)

Rabbit transport tube

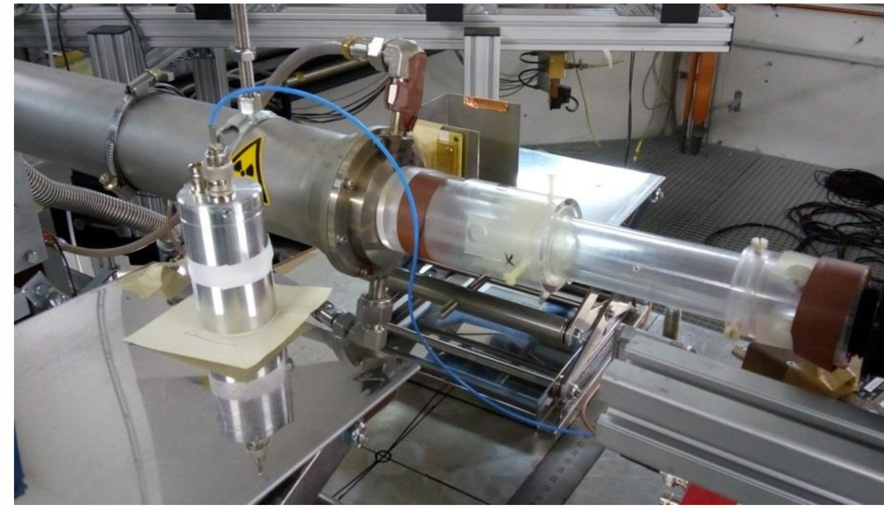




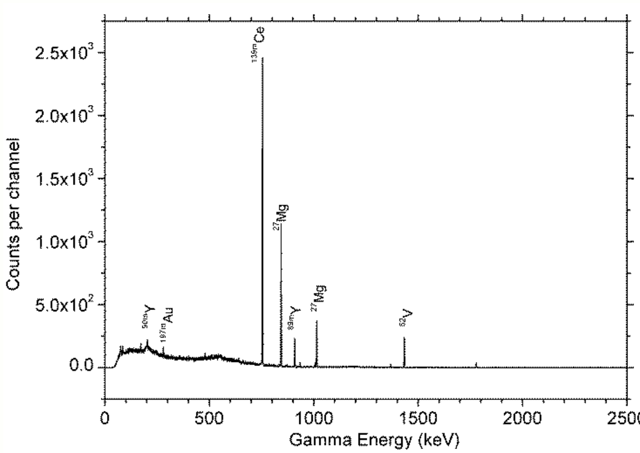


Neutron Activation System test system at TUD-NG

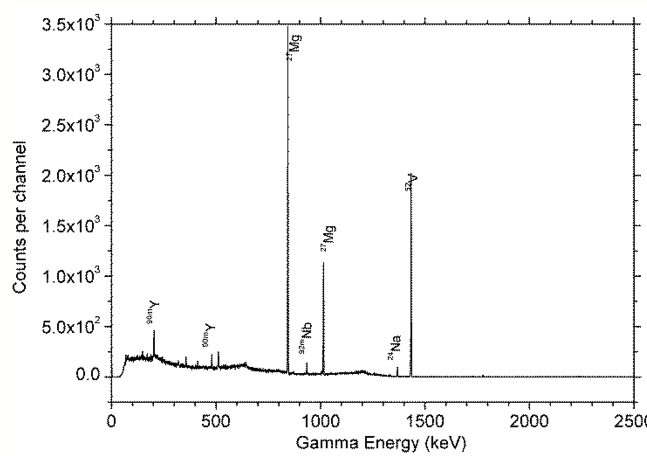
Test rabbit: Nb cylinder closed with Al plugs, Au/Cr/CeO_2 powder filling, PE carrier



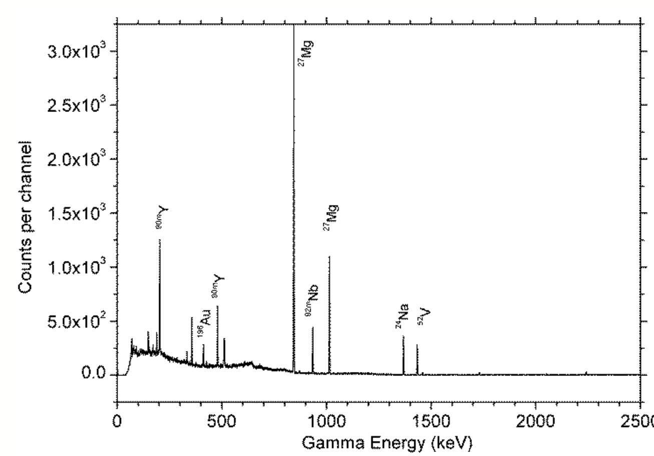
Setup at TUD-NG. Irradiation end and T target of neutron generator.



13 s to 82 s after extraction
(69 s measurement time)



380 s to 680 s after extraction
(5 min measurement time)



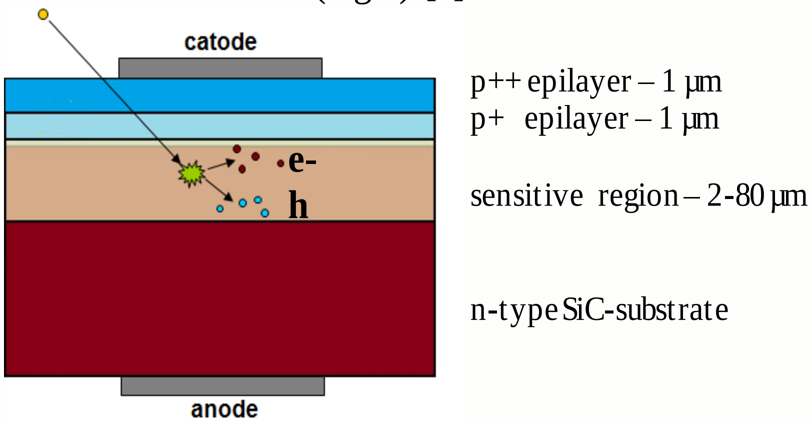
1160 s to 2360 s after extraction
(20 min measurement time)

ANIMMA 2021, Workshop N°1
Prague, 21.-25. June 2021
Institute of Neutron Physics
and Reactor Technology

Silicon carbide detector

- Large band gap semiconductor detectors
- better radiation hardness than Si
- SiC electronics proven to operate at temperatures of several hundred °C
- R&D on SiC detectors has been done since many years

nuclear interactions (Fig.1) [9].



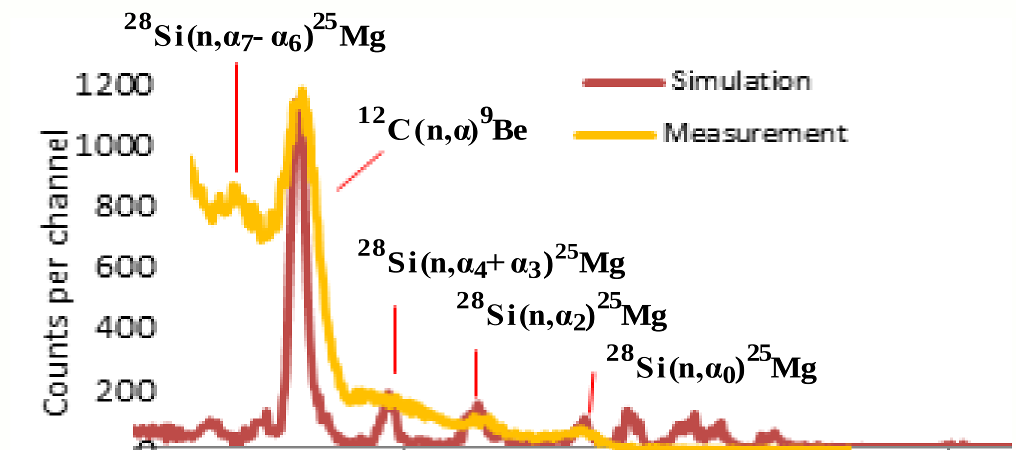
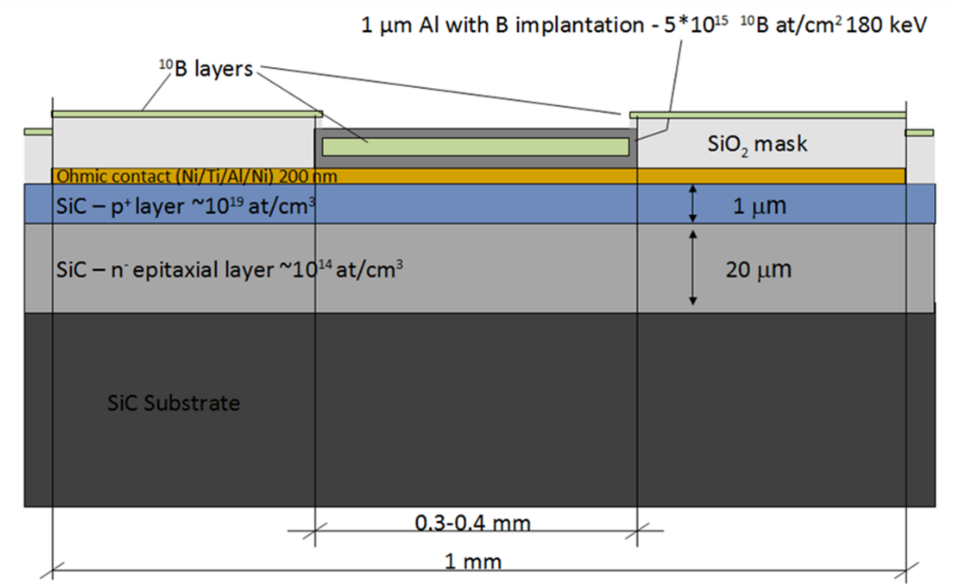


Fig.1. Diode construction and the operation scheme

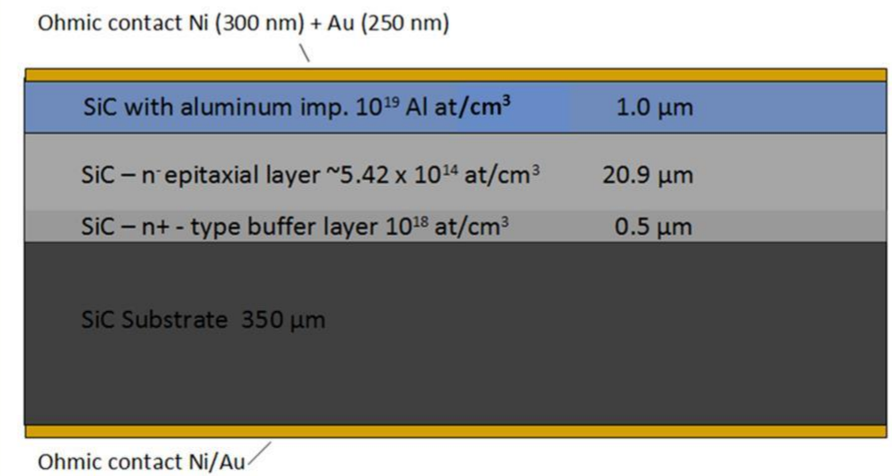
Silicon carbide detector

I_SMART (KIC-InnoEnergy)

Collaboration between
CEA, KIT, SCK*CEN, AMU, Univ. of Oslo, KTH, AGH
funded by KIC InnoEnergy with the aim to develope a SiC detector system

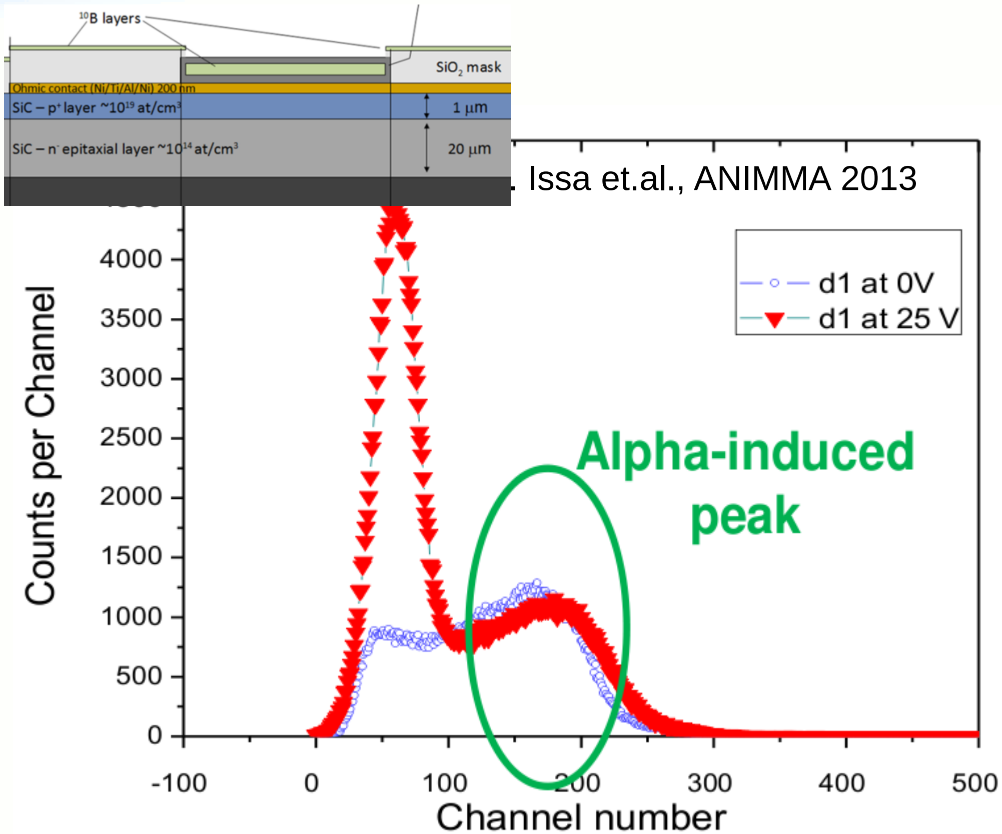


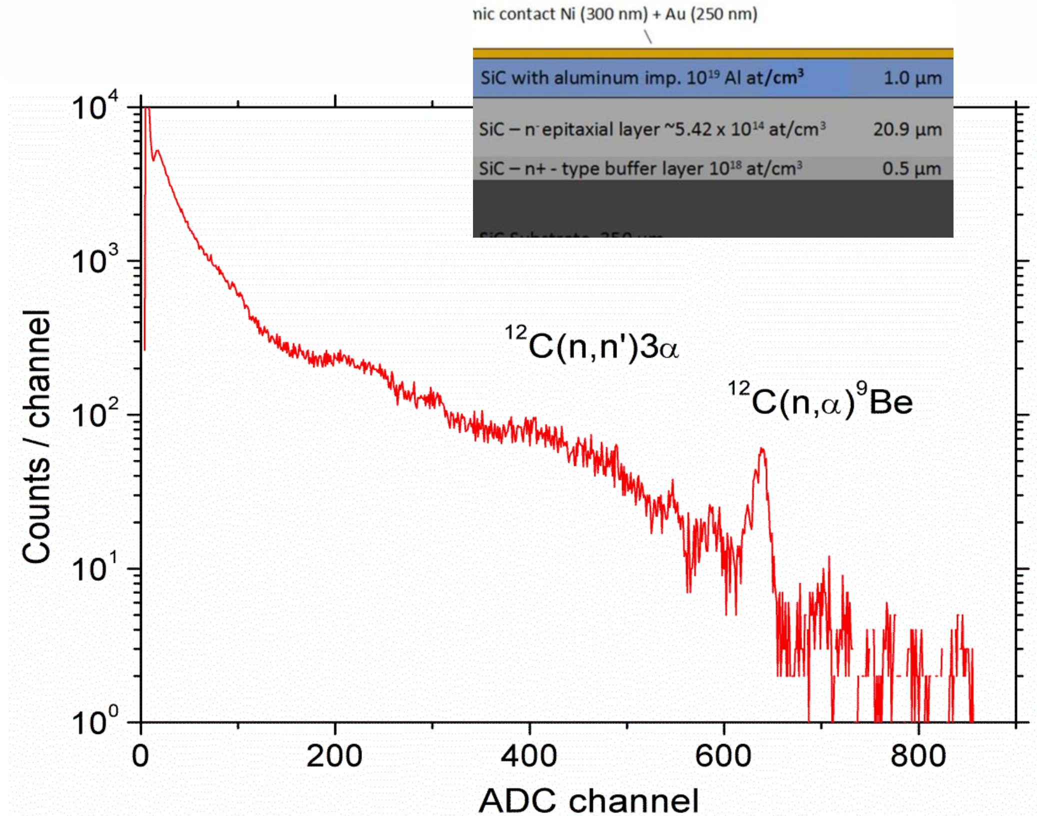
SiC diode with boron conversion layer for thermal neutrons.



Plain SiC diode

Silicon carbide detector

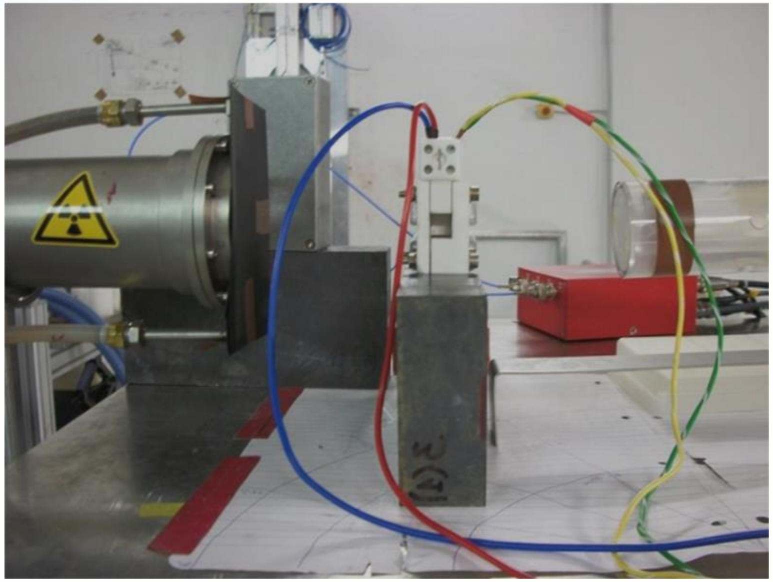


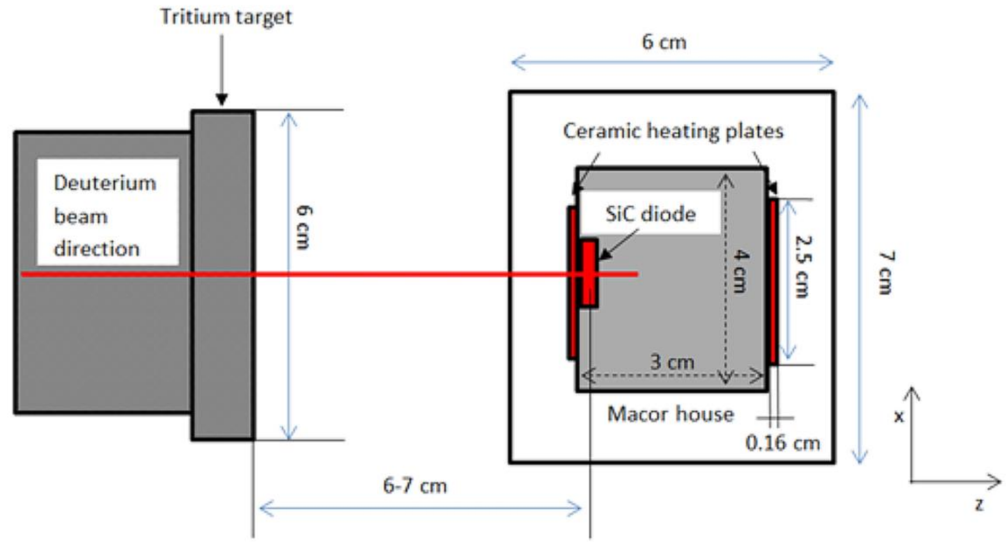


With boron implantation in thermal neutron field (BR1, room temperature)

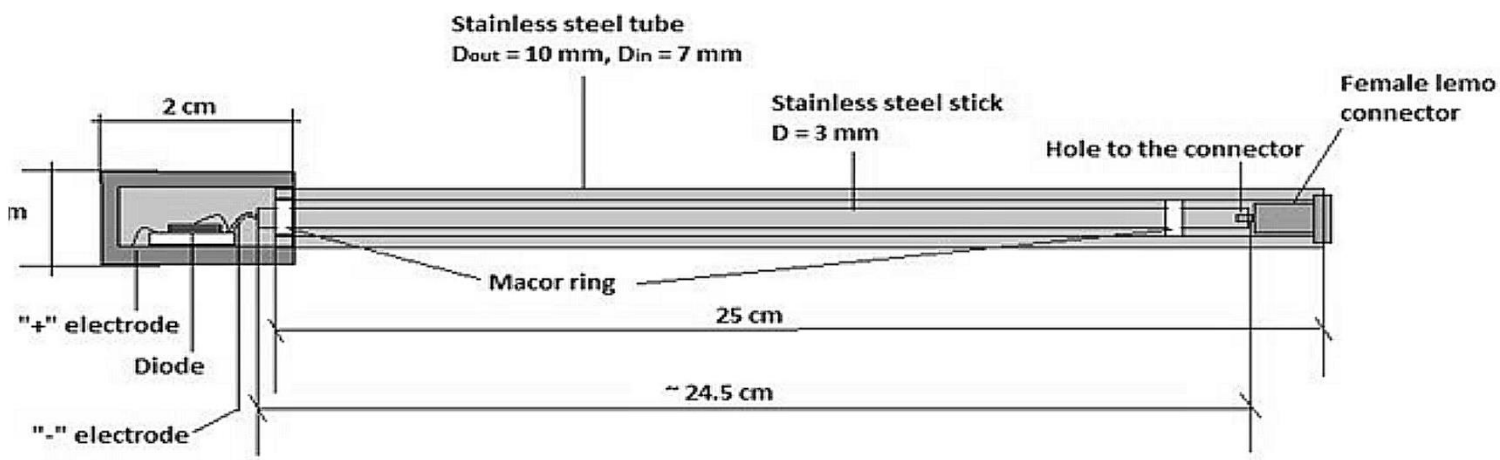
In DT neutron field (TUD-NG, room temperature)

Setup for high temperature tests at TUD-NG



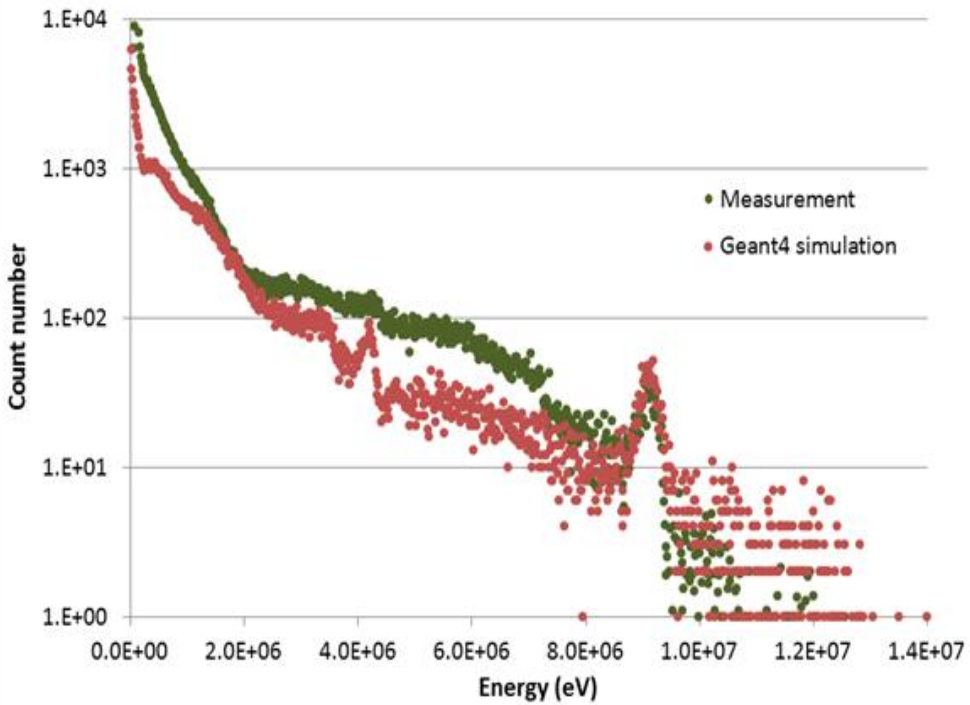


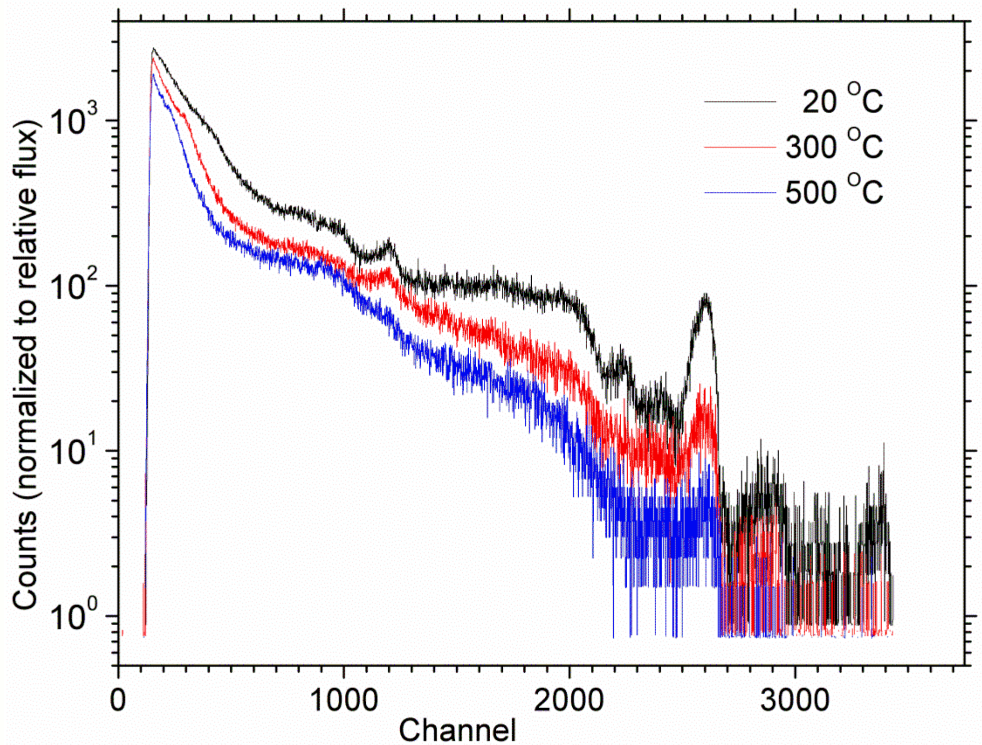
Experimental setup for high temperature tests under DT neutron irradiation



Diode encapsulation with stainless steel coaxial „cable“

Silicon carbide detector

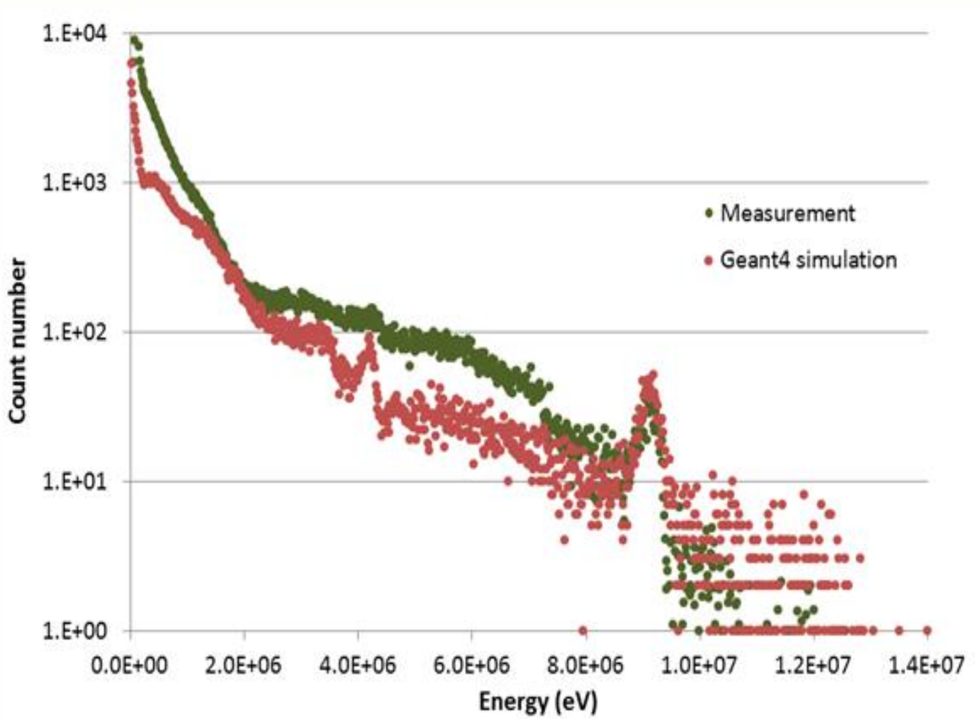


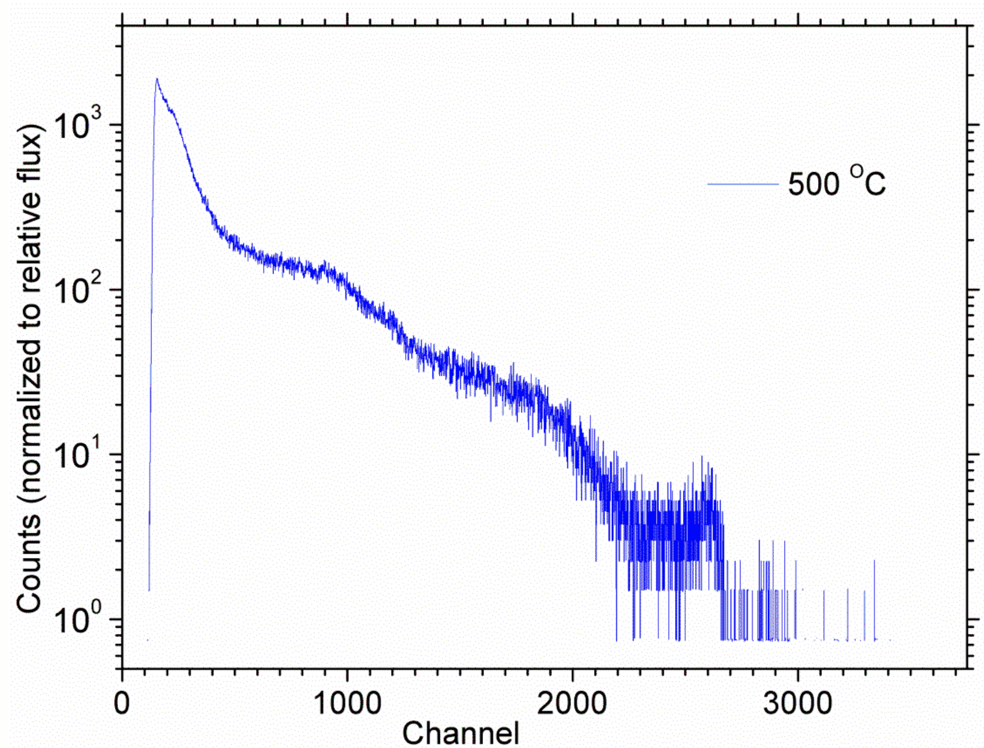


Measured and modeled (GEANT-4) pulse height spectrum under irradiation with 14 MeV neutrons

Measured pulse height spectra under irradiation with 14 MeV neutrons and at temperatures relevant for the ITER TBM

Silicon carbide detector





Even at 500 °C spectroscopic behaviour is retained to some extend.

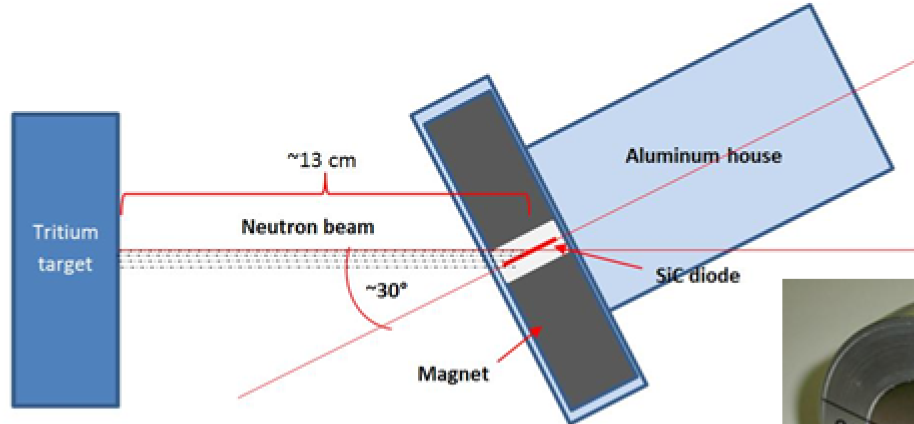
- Stable operation up to 300°C with 4H-SiC detector at high bias voltages
- Beyond 300°C up to 500°C operation at reduced bias voltages
- Stable count rate over several hours at several steps from room temperature up to 500 °C.

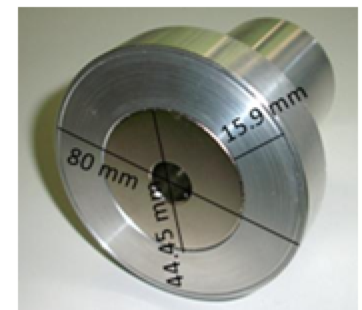
Silicon carbide detector

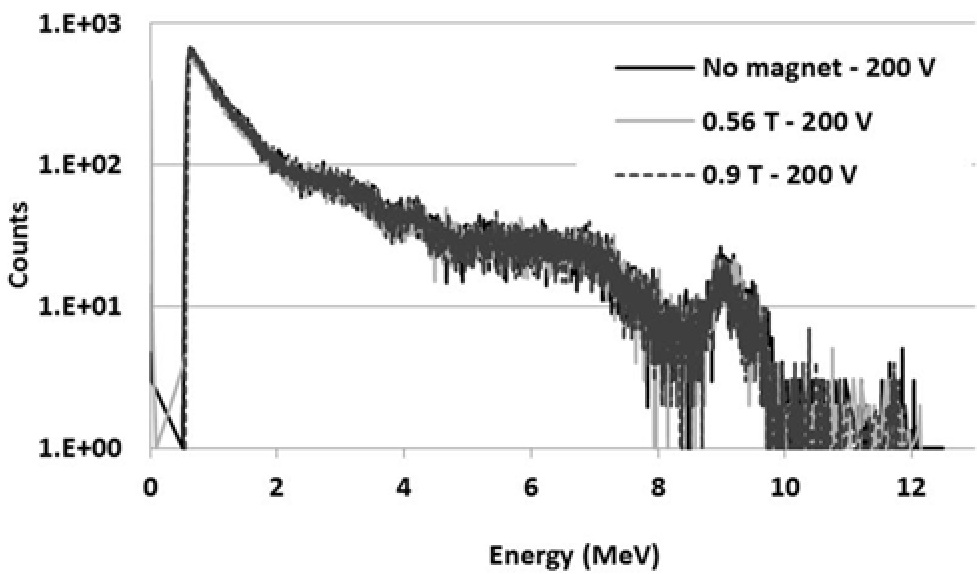
Response to fast neutrons in high magnetic fields

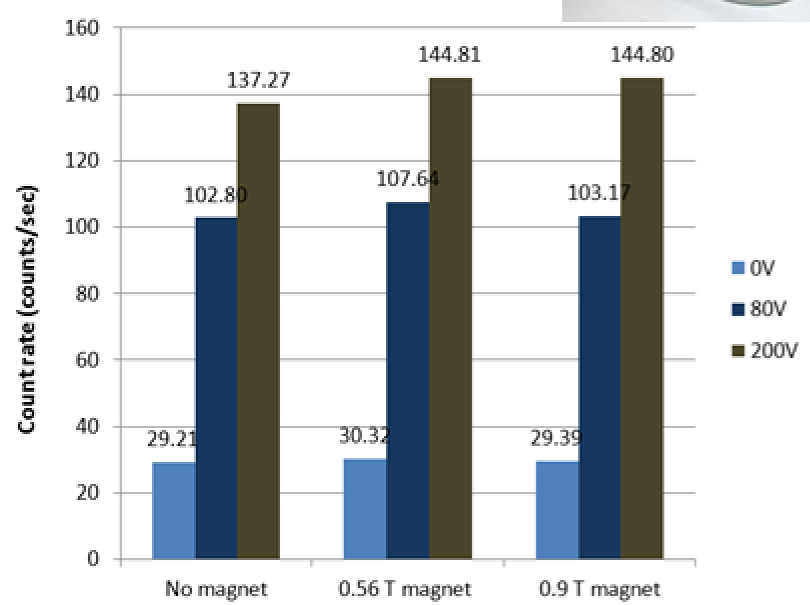
- DT neutrons from TUD-NG
- Room temperature
- Permanent magnets

No significant changes in pulse height spectrum







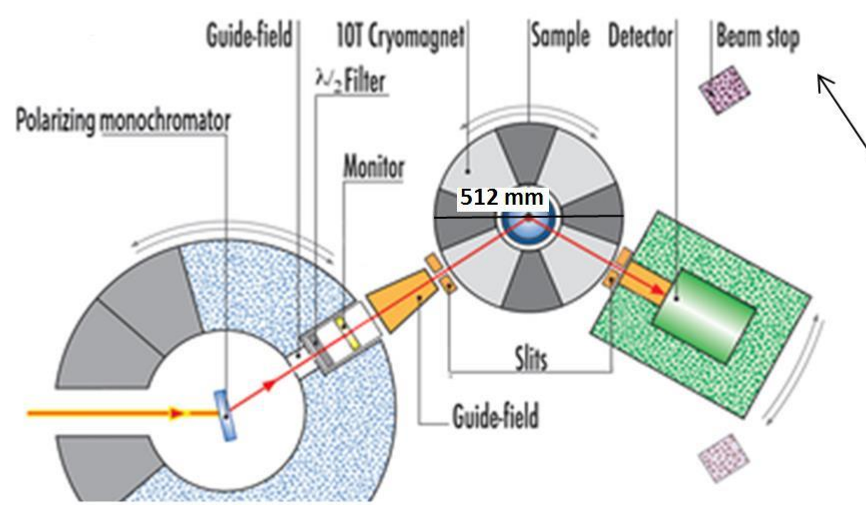


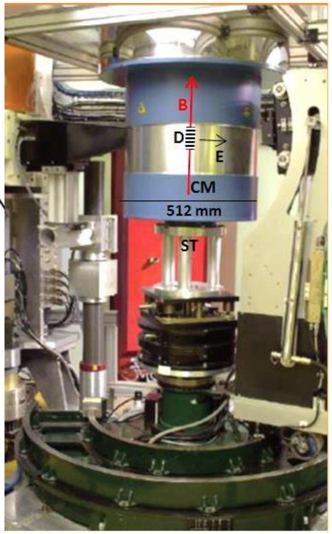
Silicon carbide detector

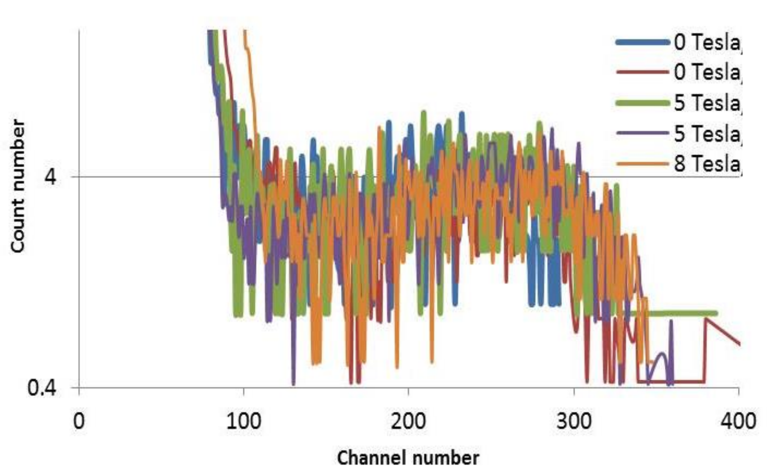
Response to thermal neutrons in high magnetic fields

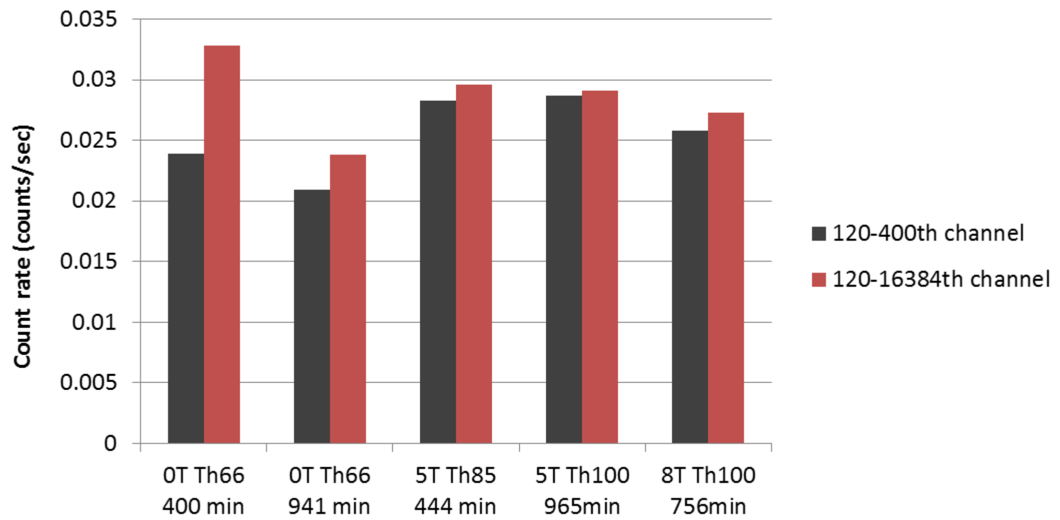
- Epithermal neutrons from D3 facility at ILL Grenoble
- Room temperature
- Magnetic field up to 8 T

No significant changes in pulse height spectrum









Continuation

Near term: TBM and DEMO

- Tests with SPND with 14 MeV fast neutrons and at elevated temperature.
- Optimization of target assembly of neutron generator (TUD-NG) for high fluence testing of specimen and possibly at elevated temperatures.

Of interest, may be…

- Concepts for integrating measurement and rapid simulation to provide instantaneous state of reactor, Virtual Reality for interface with human operator?

Summary

- Currently: neutron generators (14 MeV neutrons), nuclear reactors (high flux densities, E<14 MeV) and other neutron sources, blanket mock-up experiments

- **ITER provides an experimental environment which would allow a more reliable extrapolation to a DEMO reactor**

- Neutron flux in the TBM is a basic parameter to which many other measurements in TBM experiments will be related (neutronics and non-neutronics) (→ Tritium accountancy)

- Development of measurement methodology and nuclear instrumentation which can sustain the harsh environment in a TBM underway

Legal matters

Parts of this work have been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Acknowledgement for parts of the work presented herein:
This work, supported by the European Communities under the contracts of Association with EURATOM, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Disclaimer for parts of the work presented herein:
This work, supported by the European Communities under the Contract of Association between EURATOM and Forschungszentrum Karlsruhe, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.