# Neutron Activation System for the European ITER Test Blanket Modules

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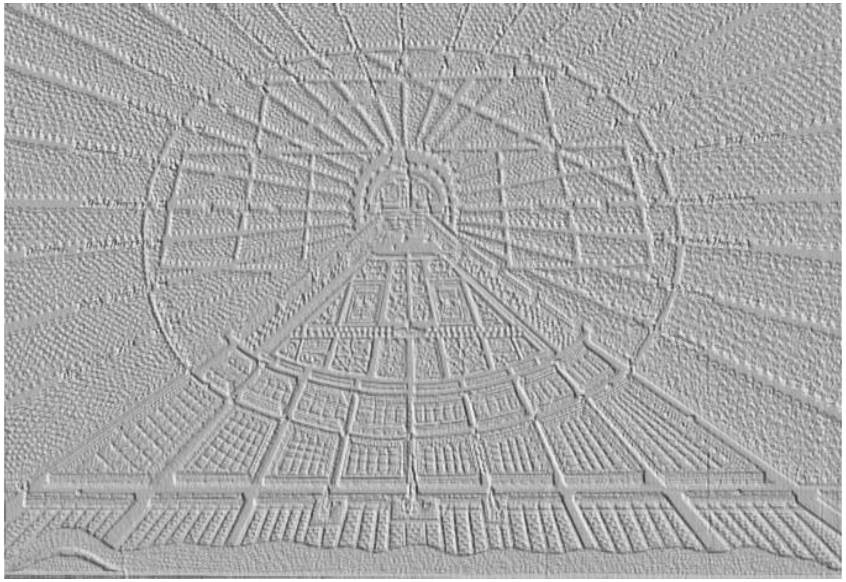
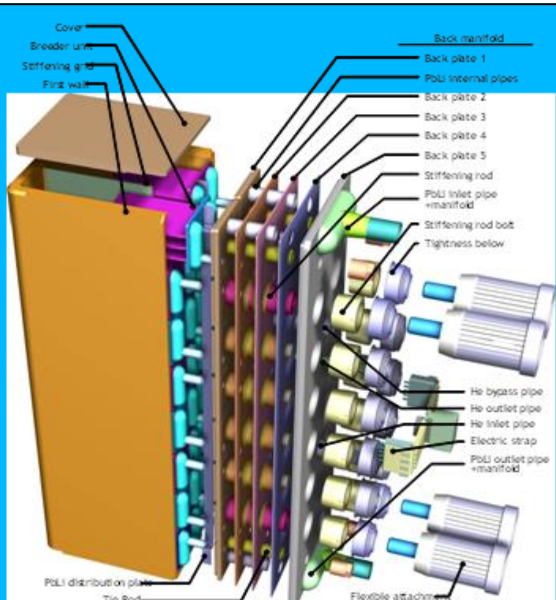


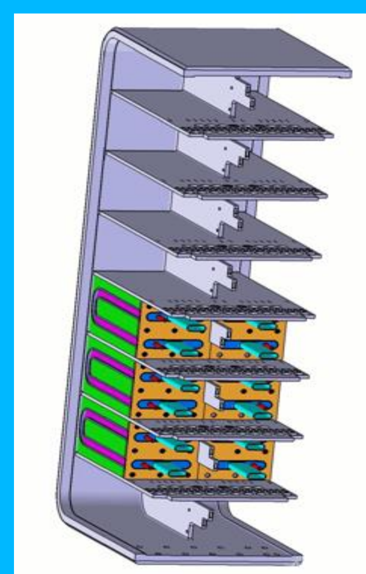
# Breeding blanket concepts (EU)
## to be tested in ITER

| | Helium-Cooled Lithium-Lead (HCLL) | Helium-Cooled Pebble Bed (HCPB) |
|---|---|---|
| Tritium breeder | Liquid lithium lead | $Li_4SiO_4$ or $Li_2TiO_3$ |
| Neutron multiplier | Liquid lithium lead | Beryllium |
| Coolant | Helium | Helium |

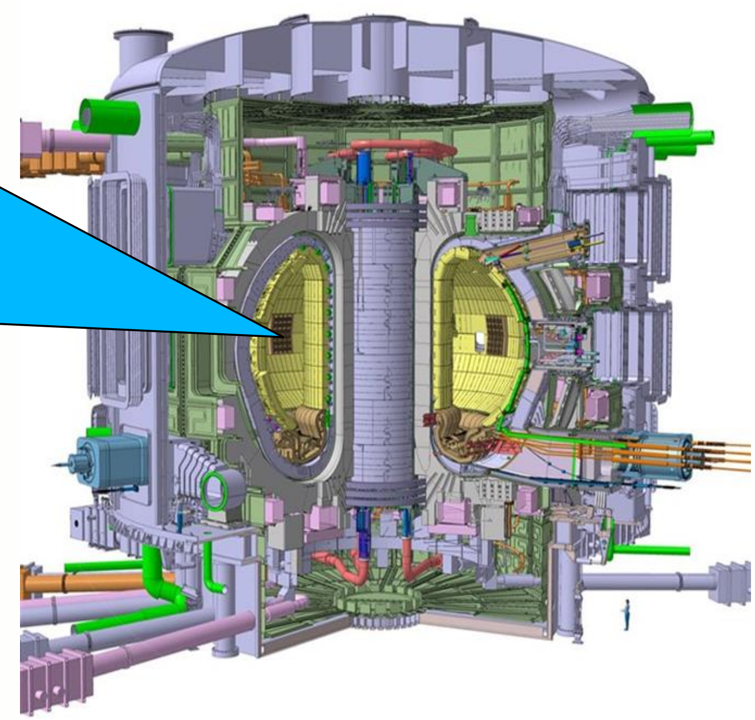
**T**est **B**lanket **M**odules will be inserted in equatorial port #16




**HCLL TBM**



**HCPB TBM**




NSS-MIC 2016
29 Oct. – 5 Nov. 2016, Strasbourg, France
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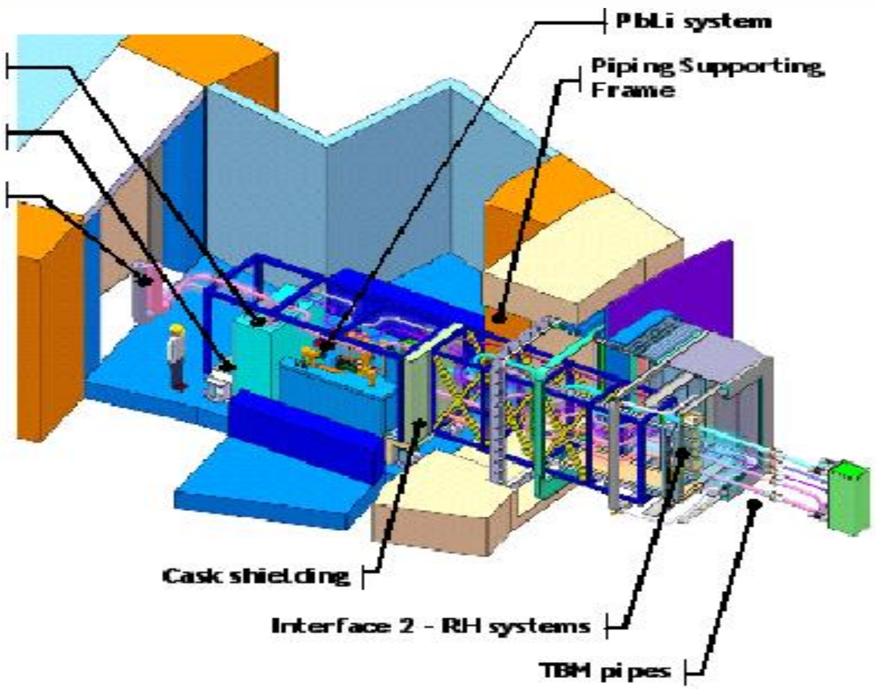
# Neutronics instrumentation for the ITER TBM
# Conditions in the TBM




Conditions in the TBM bad for any kind of detectors / diagnostics

- neutrons $10^{8}$~$10^{14}$ $cm^{-2}s^{-1}$
- from thermal to 15 MeV
- photons $10^{7}$~$10^{13}$ $cm^{-2}s^{-1}$
- 300..550 ºC
- magnetic fields ~4 T
- difficult access
- little space

Possible candidates for neutron flux measurements:

- ***neutron activation system***
- *miniature fission chambers*
- *diamond detectors*
- *silicon carbide detectors*
- *self-powered neutron detectors*
- *miniature fission chambers*

# Neutron activation system

## General considerations

- Neutron field and surface heat flux fundamental for establishing test conditions of the TBMs, will be measured by several ITER diagnostic systems
- Breeder and multiplier modify the neutron field substantially inside the TBM
- Measurement of the neutron field inside the TBM therefore essential for fulfillment of the scientific mission

**Particular importance for Tritium accountancy!**

## ITER TBM neutronics experiments will allow to check

- High-fidelity calculational tools
- Modelling of heterogeneous complicated structures under fusion reactor relevant conditions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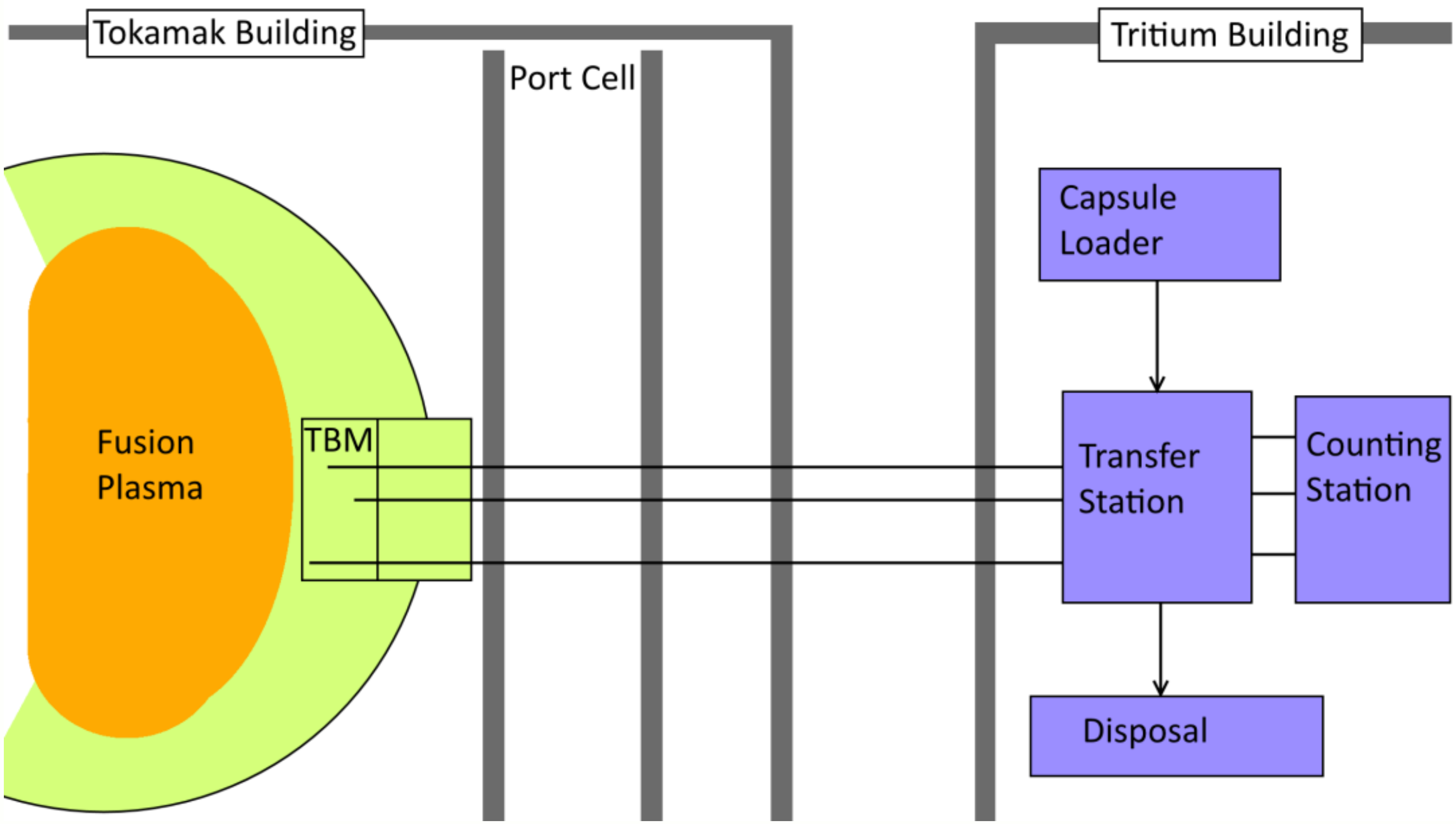
# TBM Neutron Activation System




Layout of a TBM neutron activation system

# TBM Neutron Activation System

## Mechanical part

Mechanical test system under construction at INR

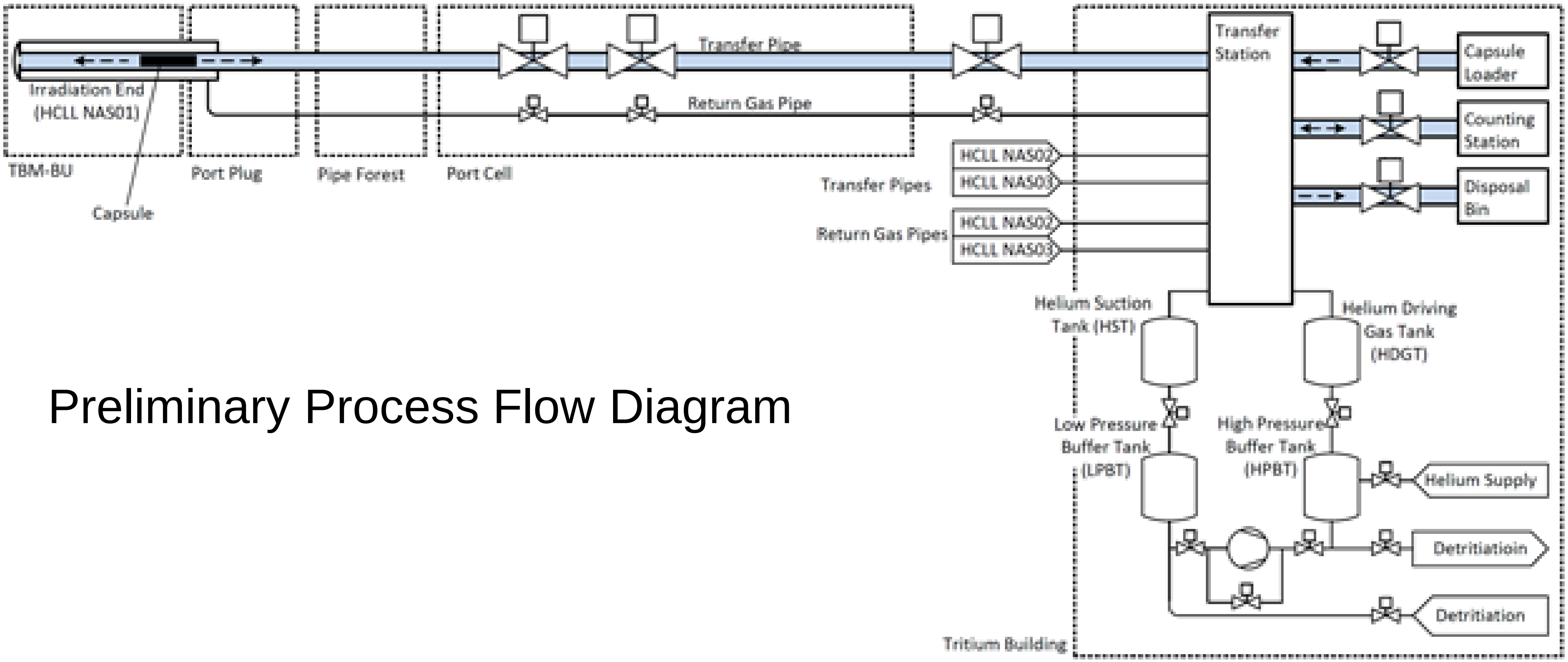
Preliminary engineering assessment completed

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

## Neutronics part

- Selection of suitable activation materials
- Test measurements with neutron generator and pneumatic transport system
- Optimization of mass ratios and rabbit design
- Investigation of measurement uncertainties

# TBM Neutron Activation System




Preliminary Process Flow Diagram

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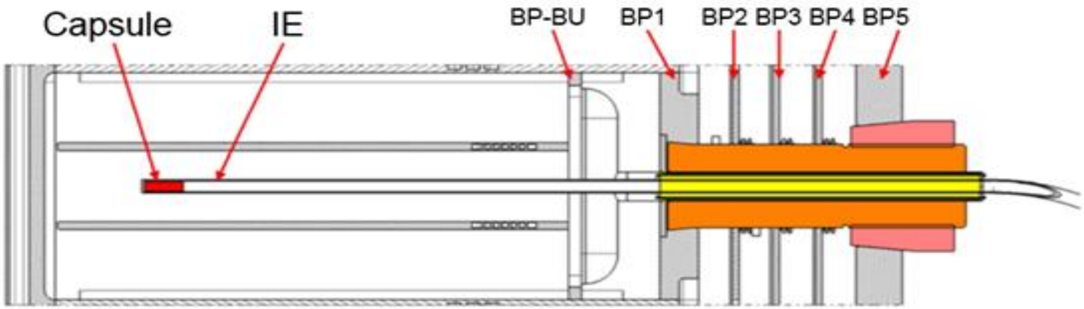
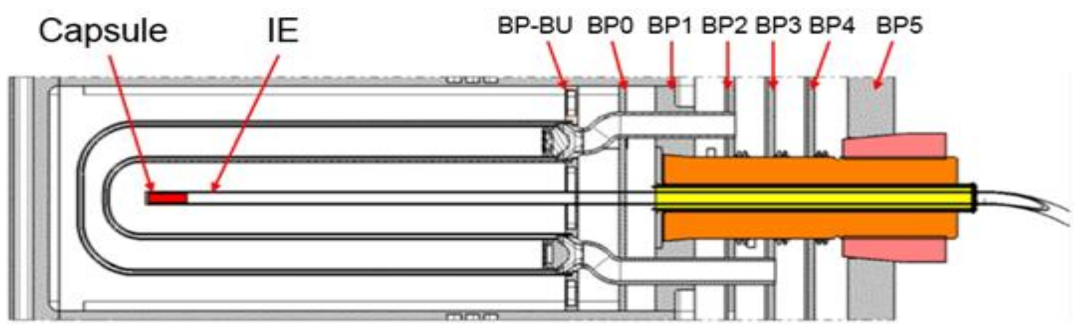
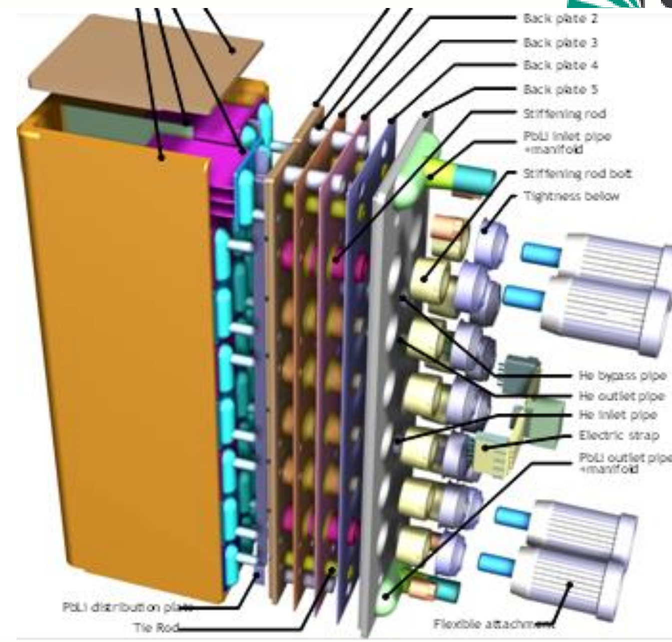
# TBM Neutron Activation System

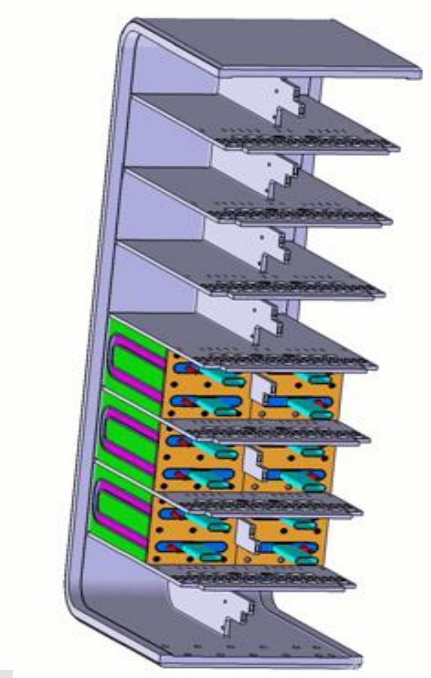



Position of one IE in HCLL TBM




Position of one IE in HCPB TBM

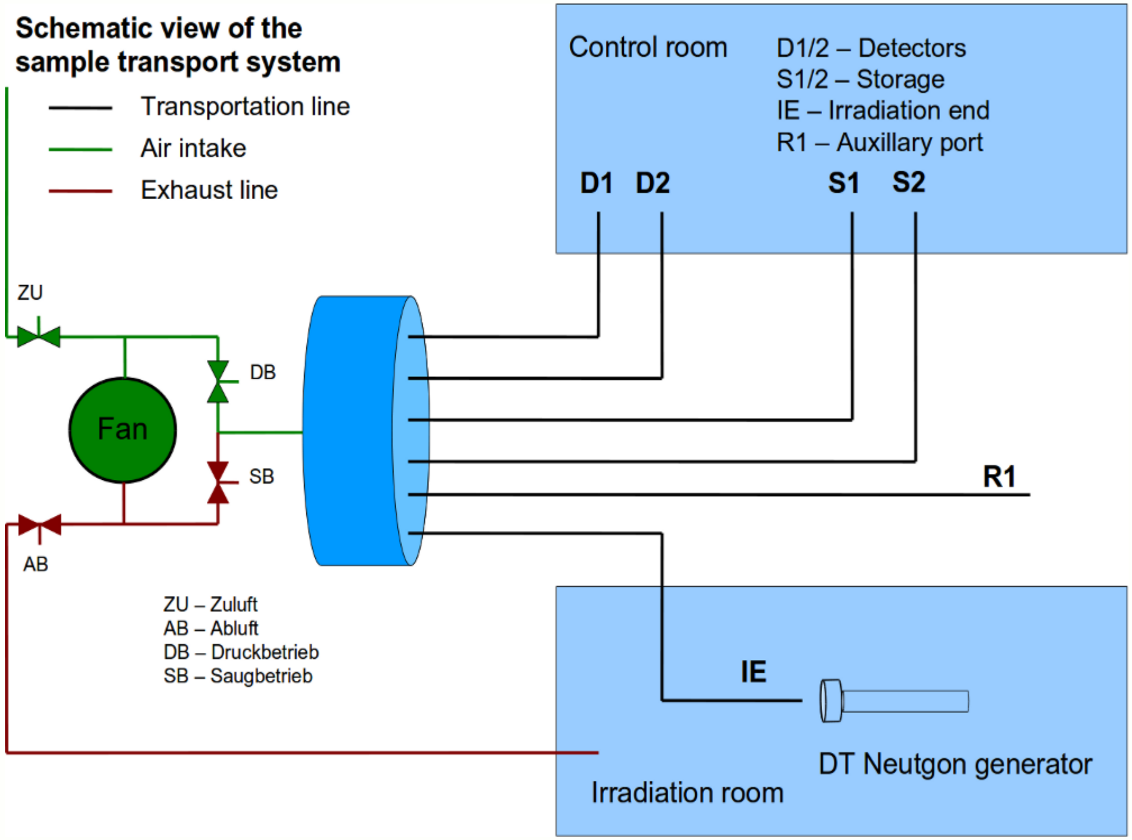


# Neutron activation test system at TUD-NG

designed in collaboration with Technical University of Dresden

Utilizing intensive DT neutron generator

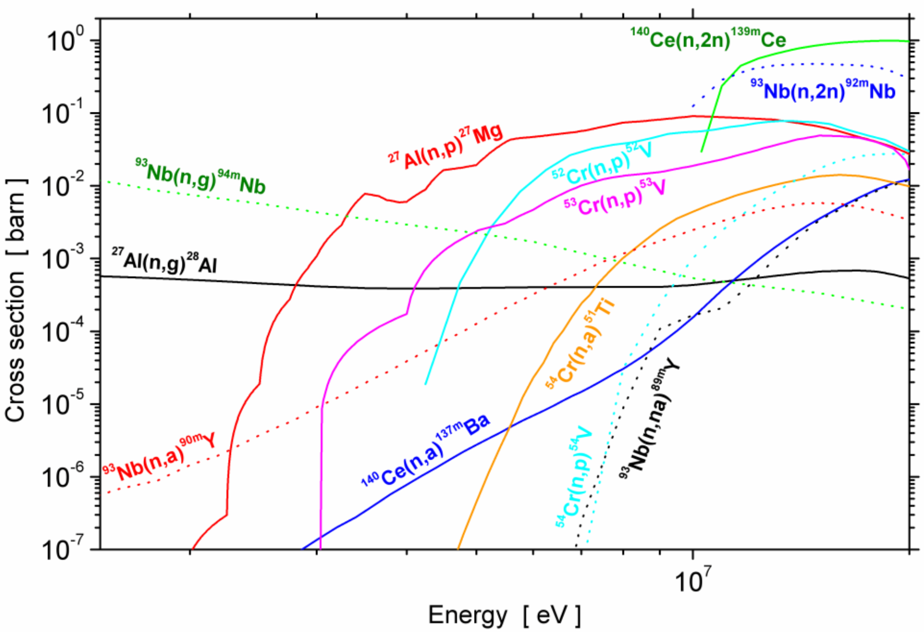


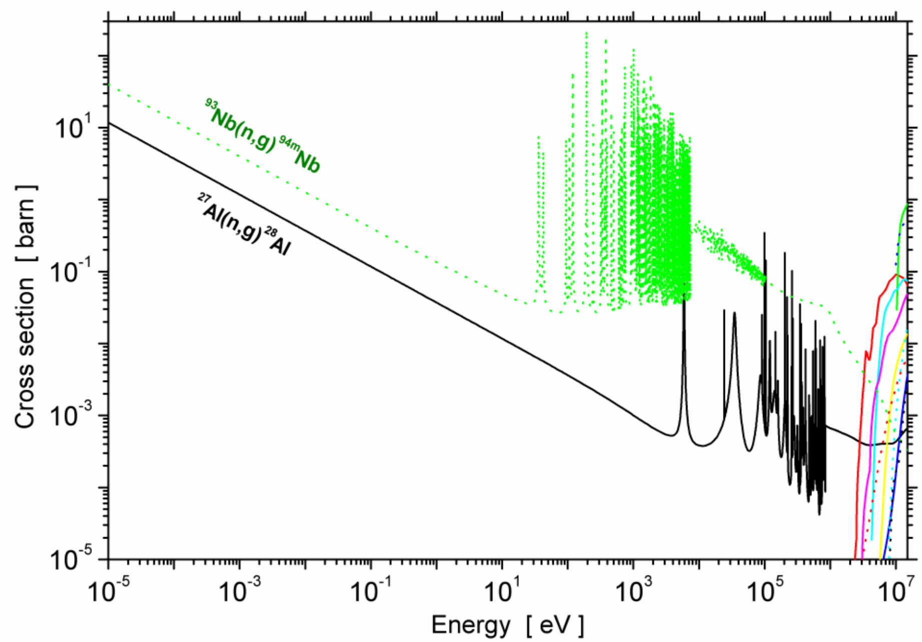

- Testing of suitable measurement regimes
- Testing of suitable gamma ray detectors (HPGe, CZT,...)
- Optimization of mass ratios and rabbit design
- Investigation of measurement uncertainties
- Simultaneous gamma ray measurement of all materials in activation probe
  In TBM NAS: no manual processing of activation probe possible

# Selected activation materials: Ce, Al, Cr, Nb, (Au)

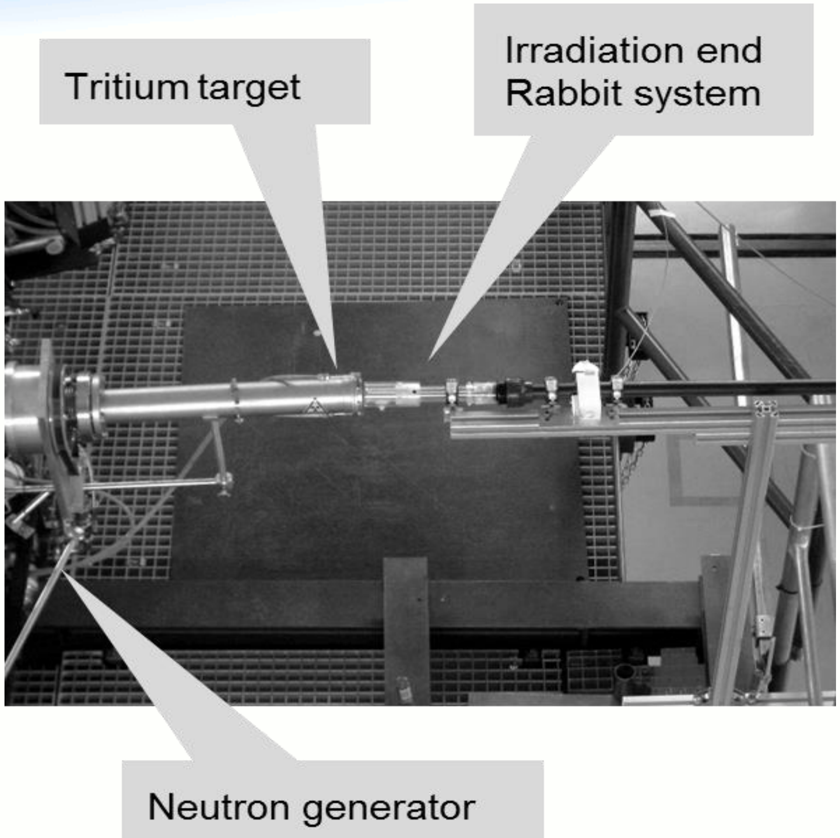
| Dosimetry reaction | Half-life (sec) | Approx. threshold energy (MeV) | Gamma-ray energy / Intensity of gamma line |
|---|---|---|---|
| $^{140}$Ce (n,2n) $^{139m}$Ce | 56.1 | 10 | 754.2 / 0.9242 |
| $^{140}$Ce (n, α) $^{137m}$Ba | 153.12 | 12 | 661.7 / 0.9007 |
| $^{27}$Al (n,g) $^{28}$Al | 134.46 | -- | 1778.7 / 1.00 |
| $^{27}$Al (n,p) $^{27}$Mg | 567.48 | 4.5 | 843.7 / 0.718   1014.4 / 0.282 |
| $^{52}$Cr (n,p) $^{52}$V | 224.7 | 5.5 | 1434.1 / 1.000 |
| $^{53}$Cr (n,p) $^{53}$V | 97.2 | 6 | 1006.3 / 0.896   1289.5 / 0.1004 |
| $^{54}$Cr (n,p) $^{54}$V | 49.8 | 11 | 834.8 / 0.971   989.1 / 0.801   2259.3 / 0.456 |
| $^{54}$Cr (n,p) $^{51}$Ti | 348.0 | 8.2 | 320.1 / 0.942 |
| $^{93}$Nb (n,g) $^{94m}$Nb | 375.6 | -- | 41.0 / 7.3e-4   871.1 / 4.95e-3 |
| $^{93}$Nb (n,a) $^{90m}$Y | 11484 | 6.9 | 202.5 / 0.9725   479.5 / 0.9074 |
| $^{93}$Nb (n,nα) $^{89m}$Y | 15.663 | 12.5 | 909.0 / 0.9916 |
| $^{93}$Nb (n,2n) $^{92m}$Nb | 876960 | 9.5 | 934.5 / 0.9904 |

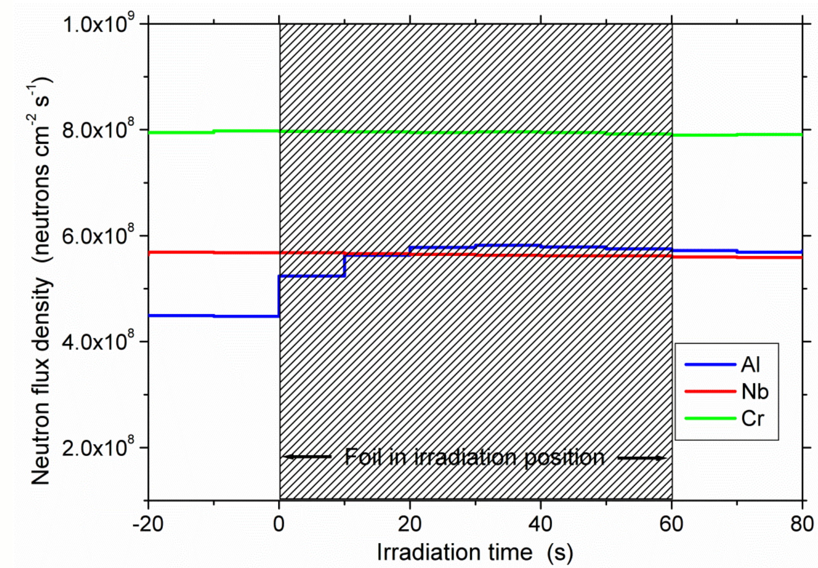
| Isotope | | Abundance (%) | Melting temp. (°C) | Contributions to radio isotope | |
|---|---|---|---|---|---|
| Ce | 136 | 0.19 | 795 | | |
| | 138 | 0.25 | | | |
| | 140 | 88.48 | | n,2n → $^{139m}$Ce; 99.99% | n,α → $^{137m}$Ba; 100% |
| | 142 | 11.08 | | | |
| Al | 27 | 100.0 | 660 | n,γ → $^{28}$Al; 100% | n,p → $^{27}$Mg; 100% |
| Cr | 50 | 4.35 | 1907 | | |
| | 52 | 83.79 | | n,p → $^{52}$V; 99.637% | |
| | 53 | 9.50 | | n,p → $^{53}$V; 99.863% | |
| | 54 | 2.36 | | n,p → $^{54}$V; 100% | n,α → $^{51}$Ti; 100% |
| Nb | 93 | 100.0 | 2468 | n,γ → $^{94m}$Nb; 100%<br>n,nα → $^{89m}$Y; 100% | n,α → $^{90m}$Y; 100%<br>n,2n → $^{92m}$Nb; 100% |

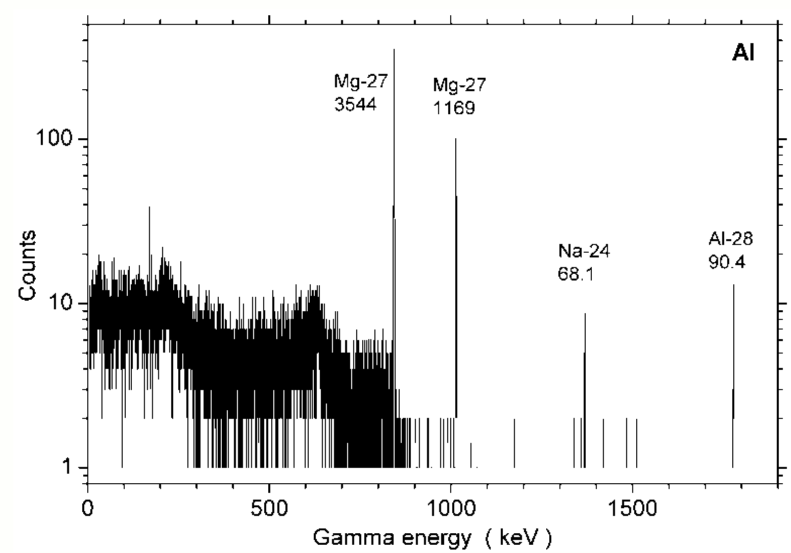


# Neutron Activation System test system at TUD-NG



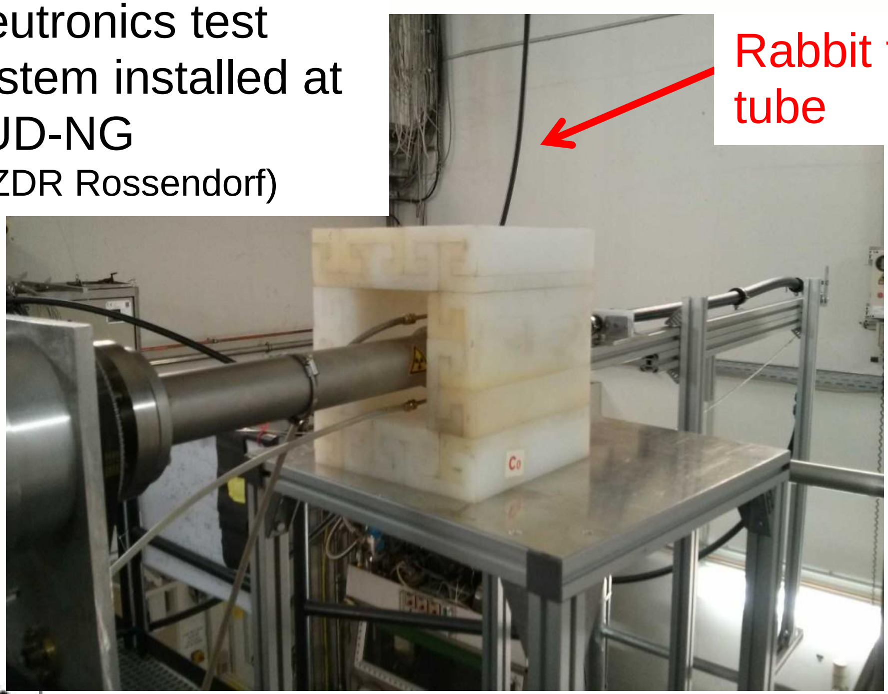



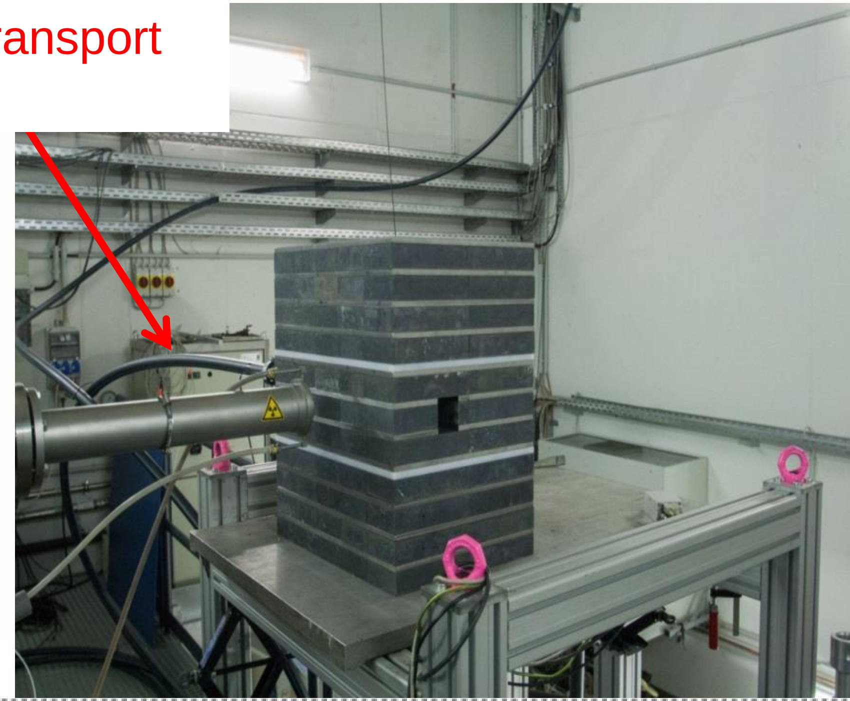

- Test foils 10 mm diameter, ~0.6 g, material purity >99.9%
- Irradiation time 60 s, fluence at sample position $3.39 - 4.77 \times 10^{10}$ n/cm$^2$
- Transport time 16..23 s
- Gamma measurement HPGe, 30%, ca. 5 cm distance 60 to 600 sec
- Measurement uncertainty here: between 5 and 30%

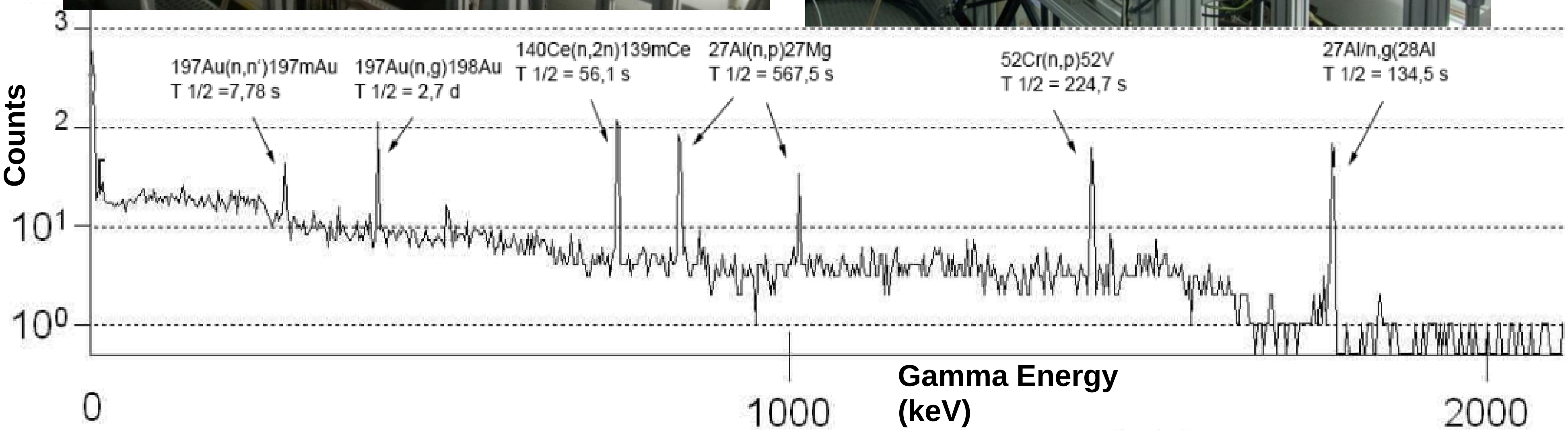
# Neutron Activation System test system at TUD-NG

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

Rabbit transport tube







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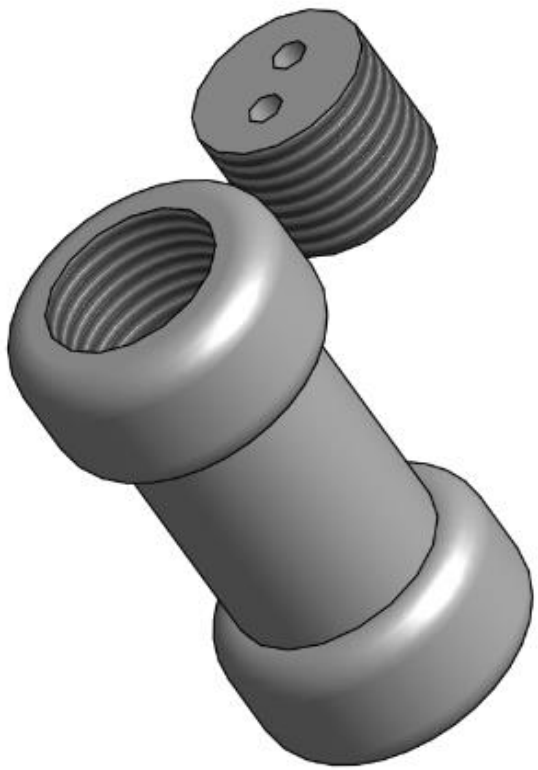
# Preliminary rabbit design



- Dimensions: 8mm diameter, 15 mm length
- Bore for accommodation of activation materials 5 mm diameter
- Material: CFC or niobium
- Niobium of interest since it can serve as activation material as well

# Summary

Neutron flux measurement inside the ITER TBM necessary for establishing test conditions of the TBM and the tritium breeding systems

Neutron activation system :
- robust, can withstand harsh TBM conditions
- no calibration needed (except for gamma counting station)
- absolute values for local neutron field
- could be used in all ITER operation phases (DD+DT, low and high duty cycles)
- *invasive and difficult to install*

Preliminary engineering assessment done for the pneumatic transport system

Neutronics tests with activation probes done, further tests underway

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.