Neutronic Calculations for the Planning of the In-Vessel Neutron Calibration Campaigns

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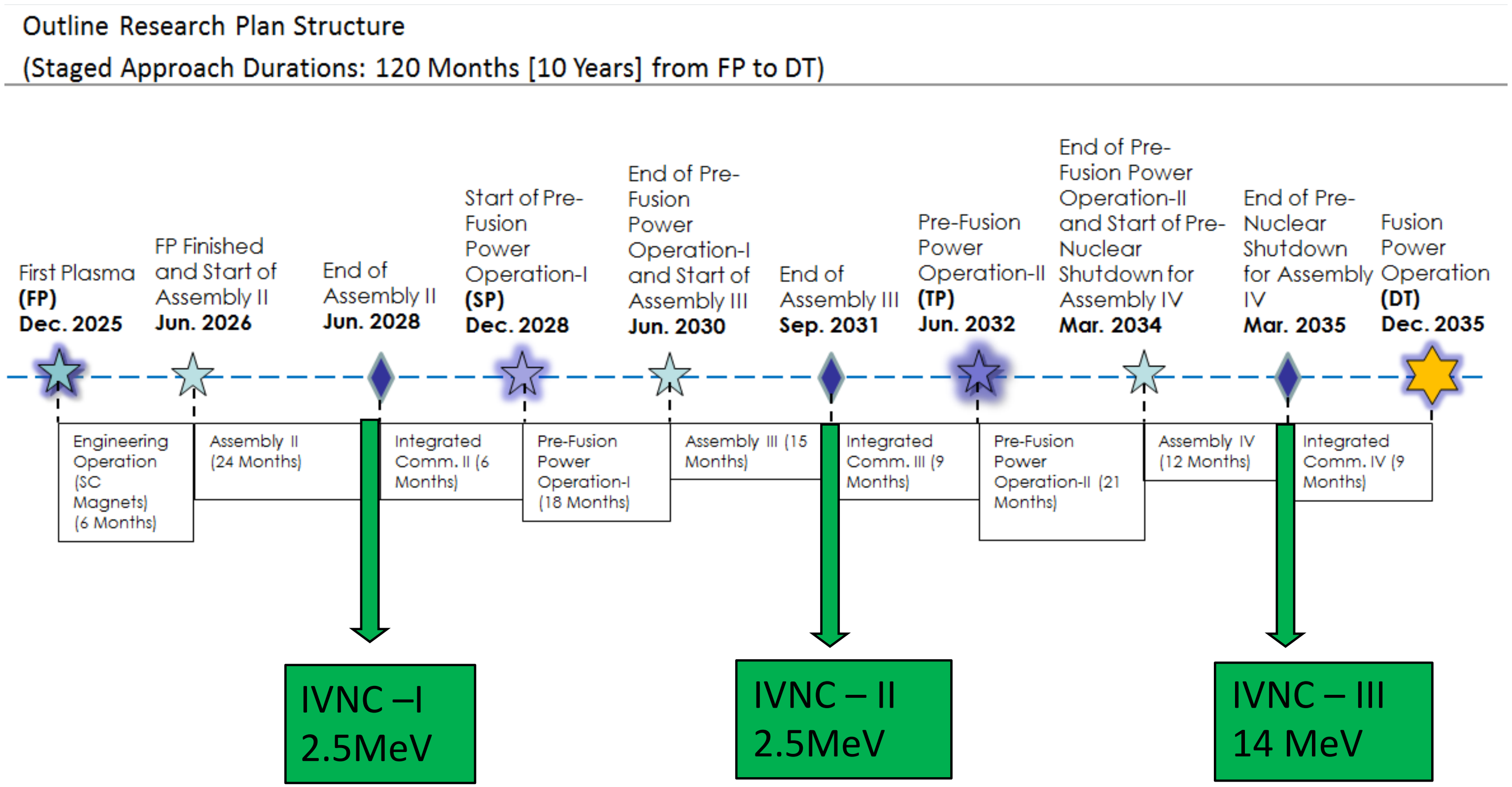
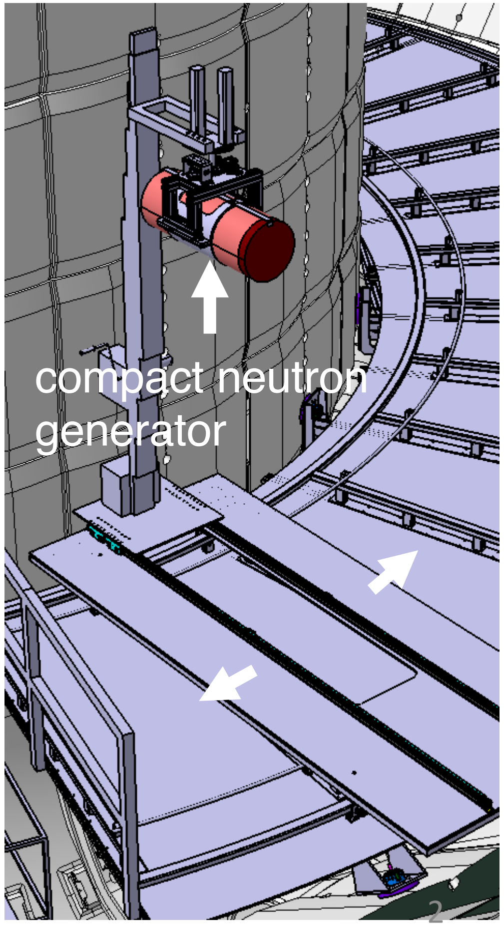
Introduction

- Neutronic simulation of the neutron calibration is important for making strategy and scheduling of the calibration.
- Neutronic simulation of the neutron calibration using D-T compact compact neutron generator has been carried out by using simplified ITER 360˚ model.

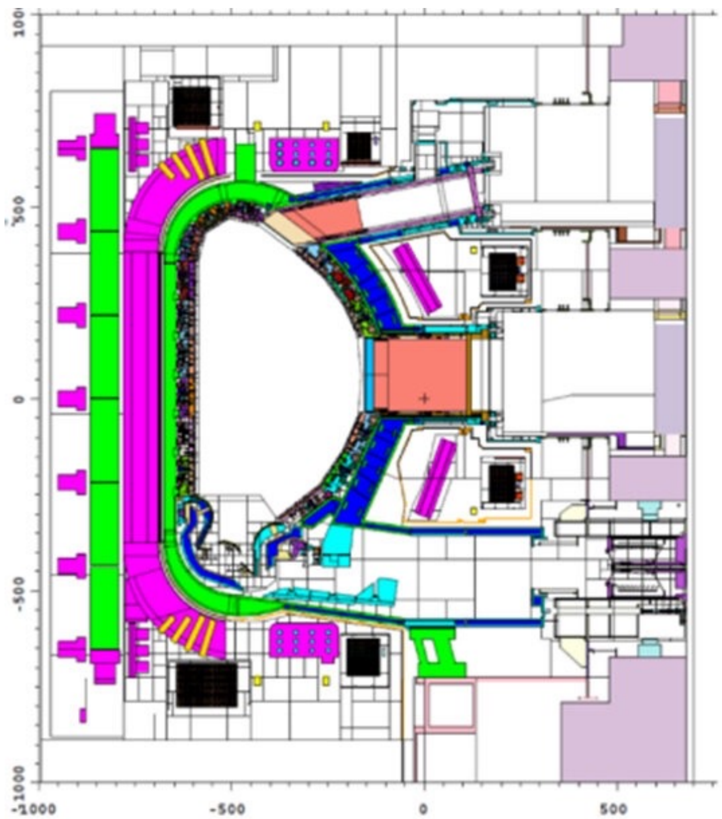




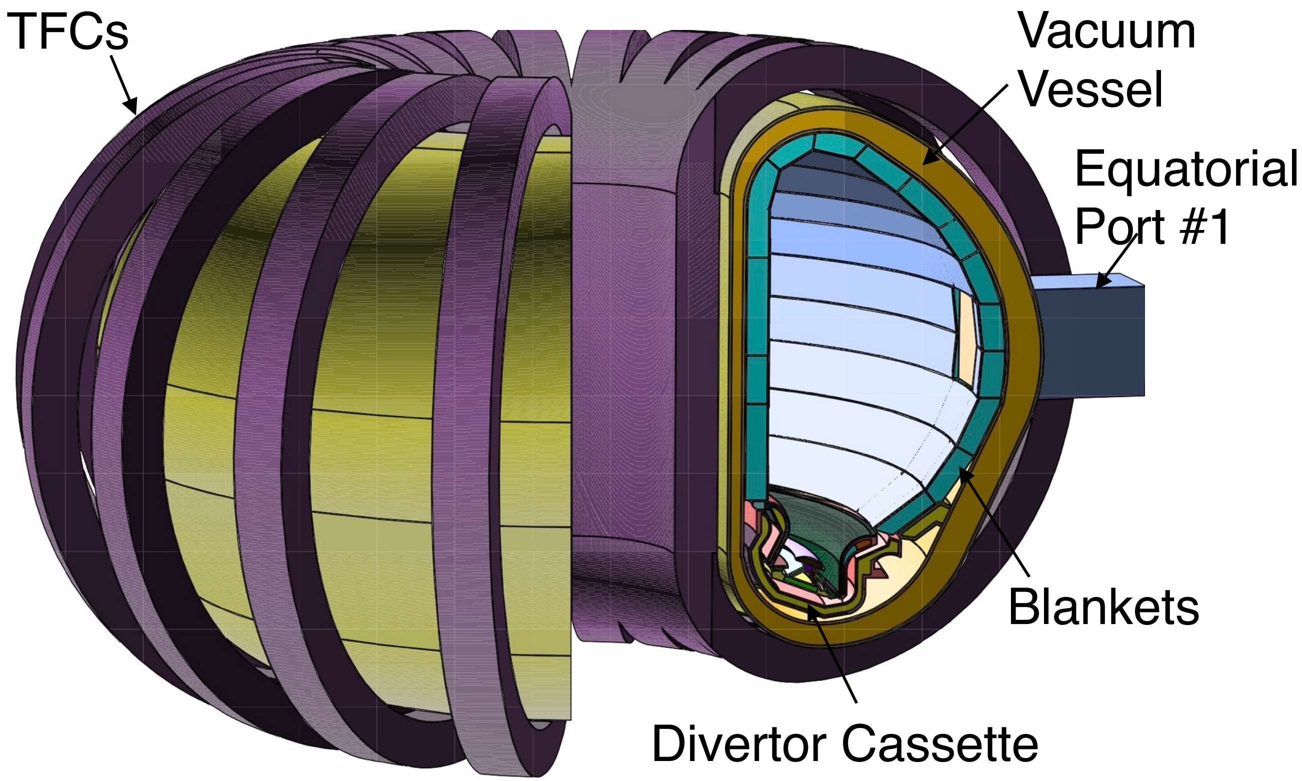
Simplified ITER model for MCNP

- ITER has a 40° standard MCNP model, C-model, which is too heavy.
- We have established simplified 360 degrees ITER models as the synthetic in-vessel neutron diagnostics to make a strategy of the neutron calibration.

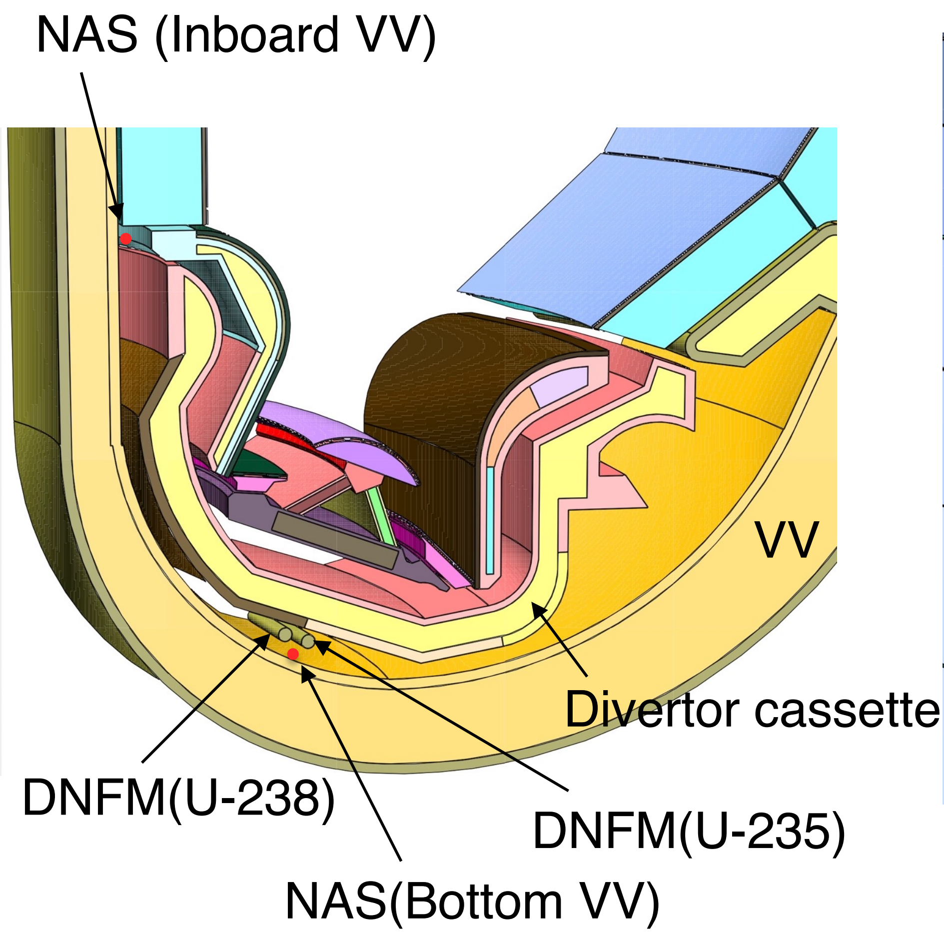
ITER C-model (40° sector)

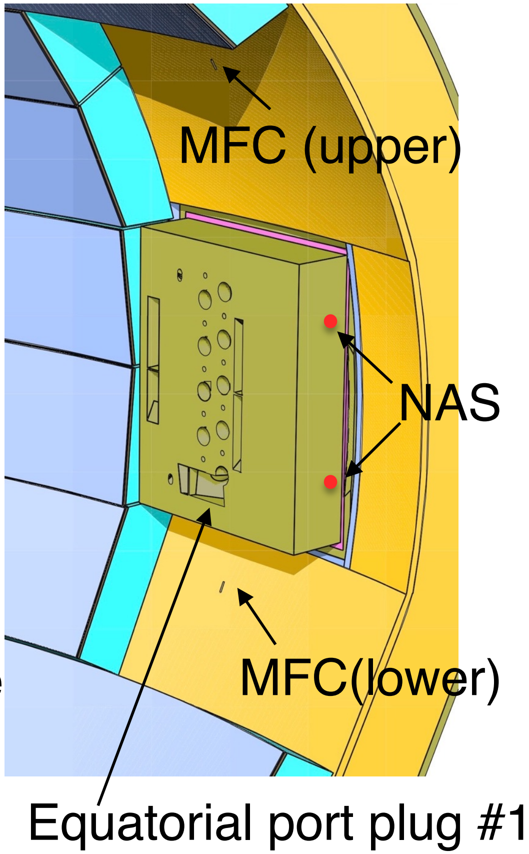


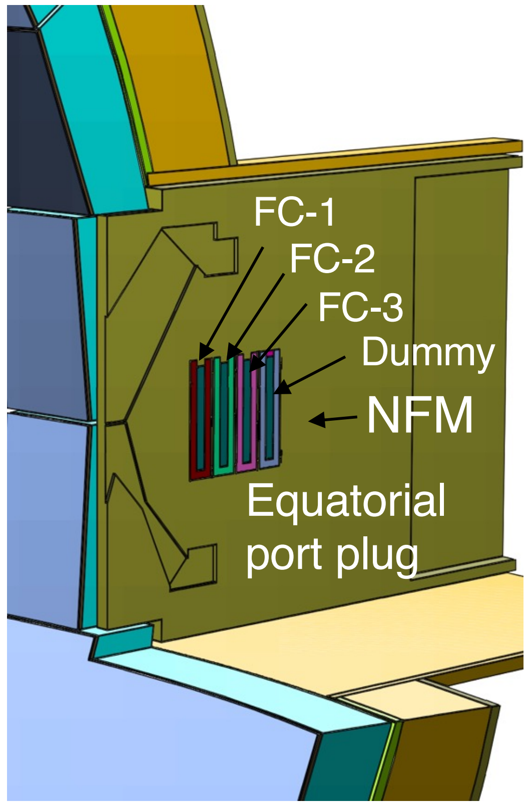
Simplified ITER model



The simplified models include neutron flux monitors (NFM) in an equatorial port, micro fission chambers (MFC), diverter neutron flux monitors (DNFM), and a neutron activation system (NAS). Those assumed to be installed on the same section. The equatorial port (EQ) plug with NFM is imported from the EQ#1 detailed structure of the C- model.

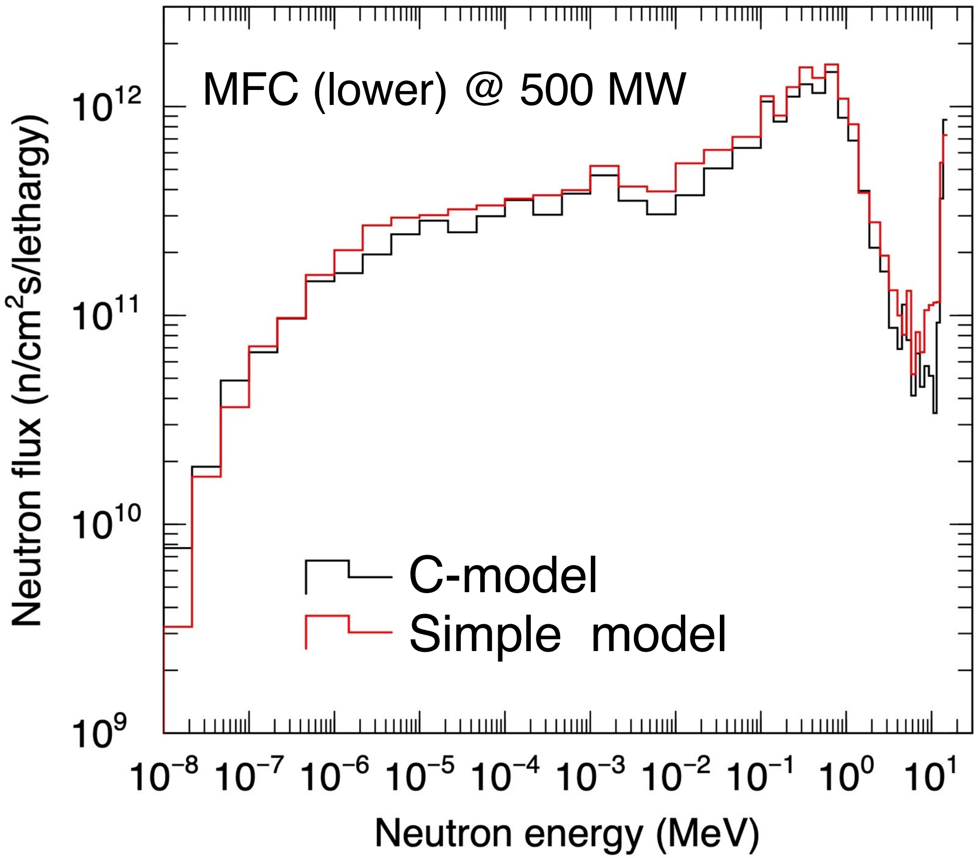


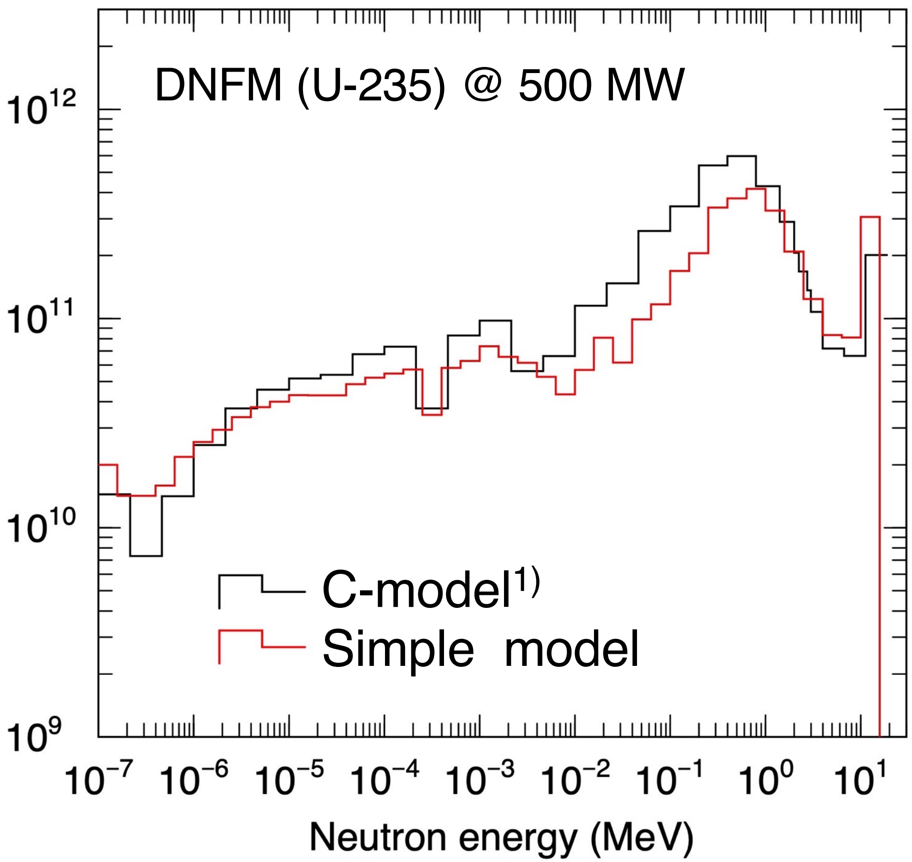




Benchmark of the MCNP model

- Neutron spectra at MFC and DNFM by the simple ITER model have been compared with those by ITER C-model.
- Neutron spectra at MFC have a good agreement. That of DNFM by the simple ITER model is a little bit lower than that by the ITER C-model.
- Consequently, we confirmed the usefulness of the simple model.

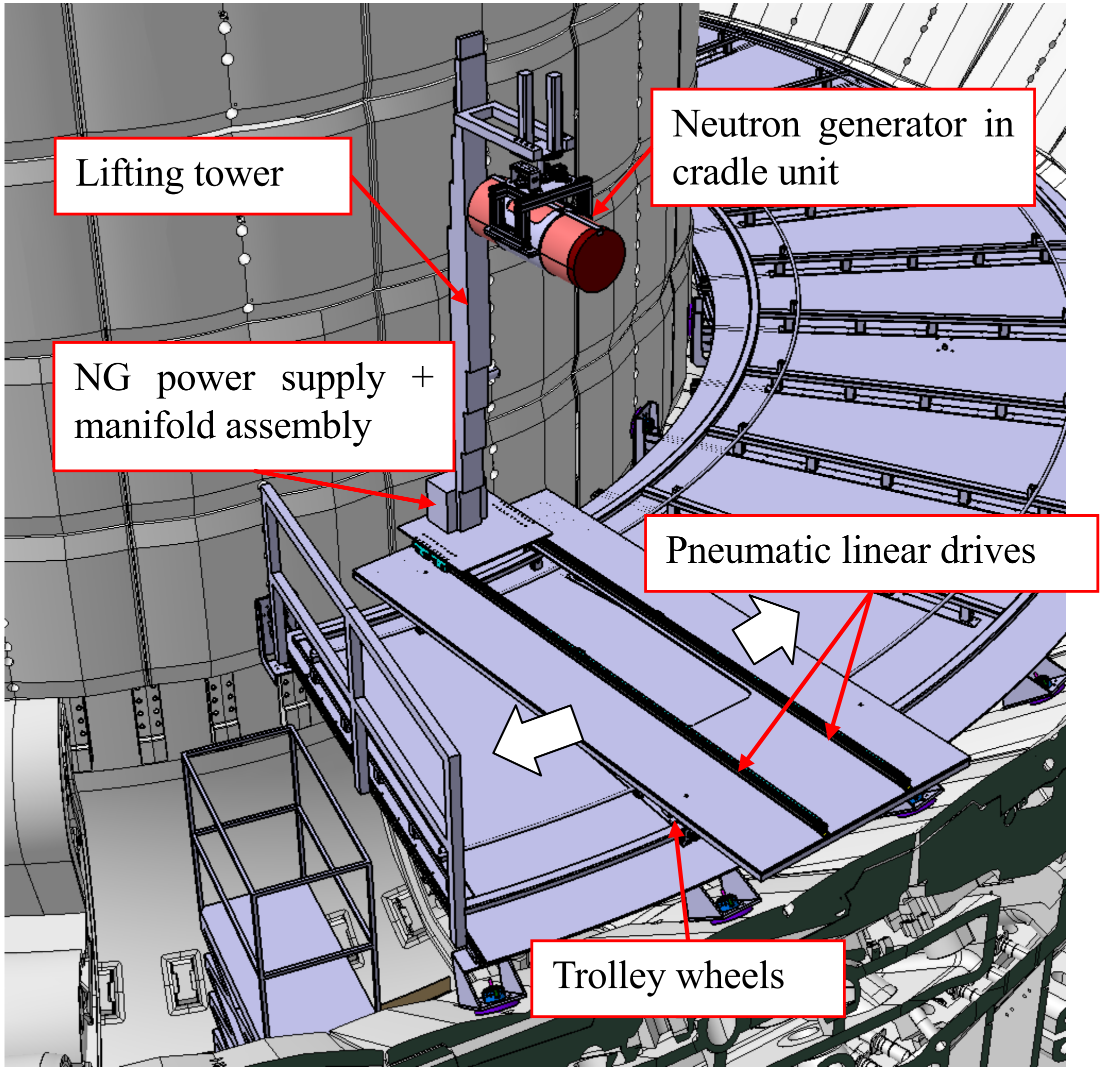


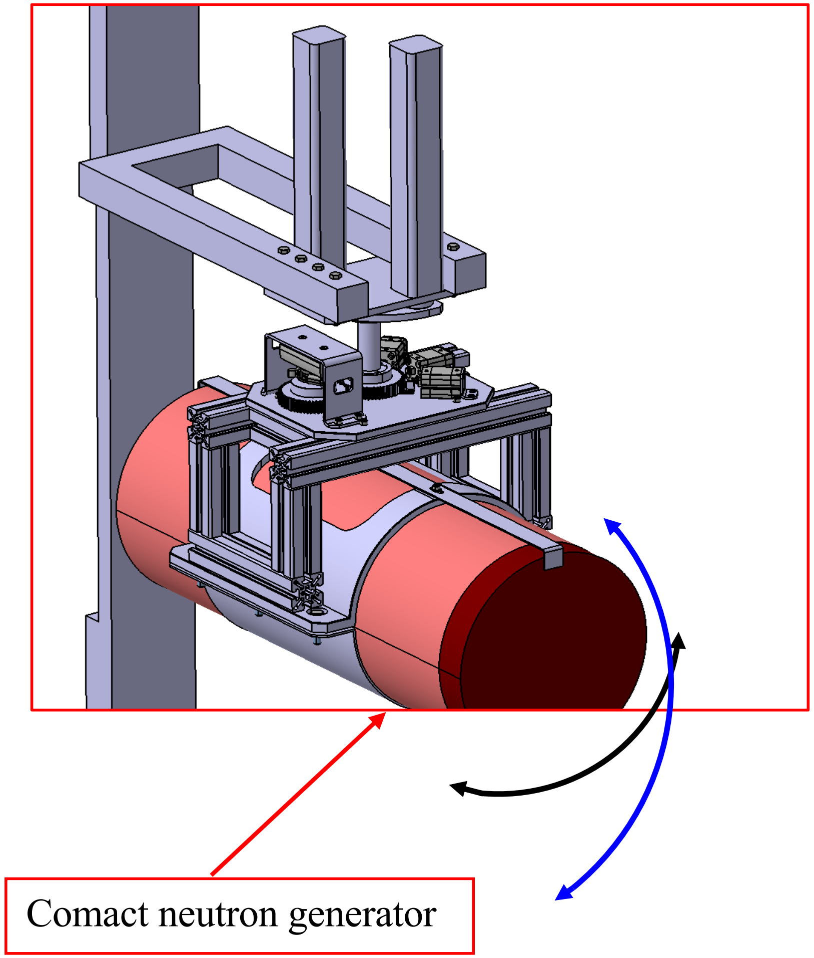


[1] D. Kumplinov et al., J. Instrum. 14 (2019) C11019.

Concept of Neutron Calibration at ITER

- Compact D-D or D-T neutron generator will be used as a neutron source for the neutron calibration, where the neutron source will move in the vacuum vessel.
- The head of the neutron generator can be rotated horizontally and tilled vertically.



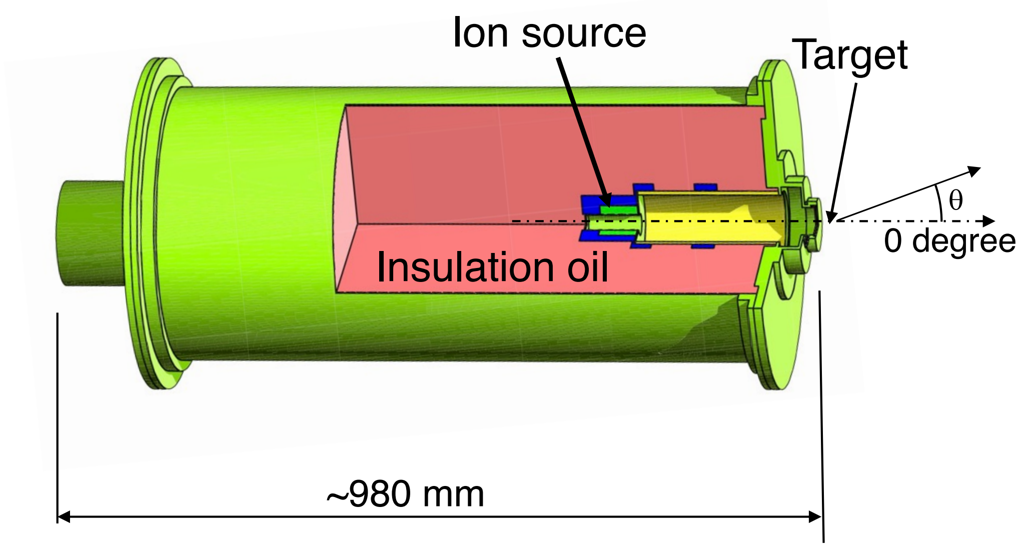


Neutronic characteristics of Compact Neutron Generator

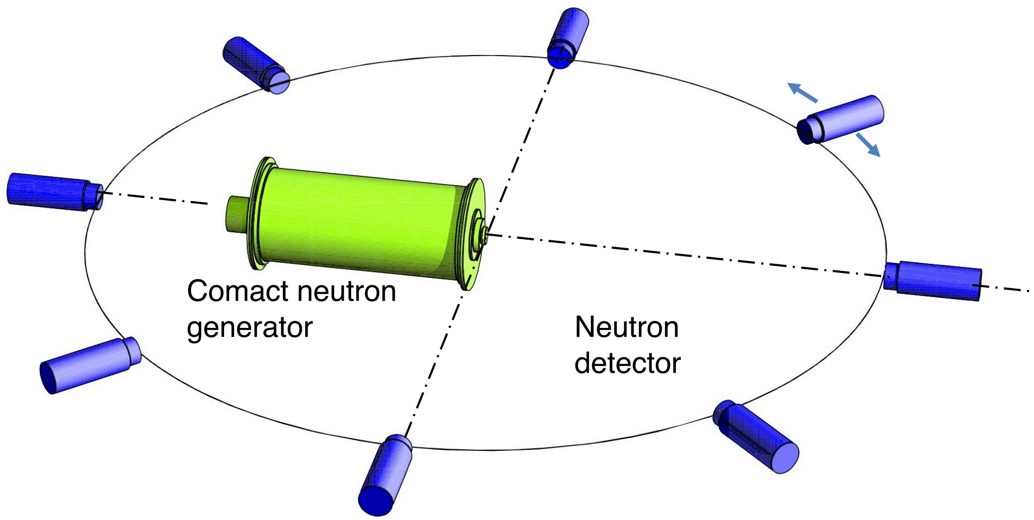
- D-T reaction is almost isotropic, however, the angular target neutron spectra has a week anisotropy and an angular dependent energy spectrum due to the kinematics.
- Angular neutron fluxes are calculated by PHITS code with D-T "Frag-data" which is a DDX table for the source term of neutron calibration simulation.

Structure of the compact neutron generator, NG24m (Voltage:180 kV)

- The generator has a large insulation oil tank.



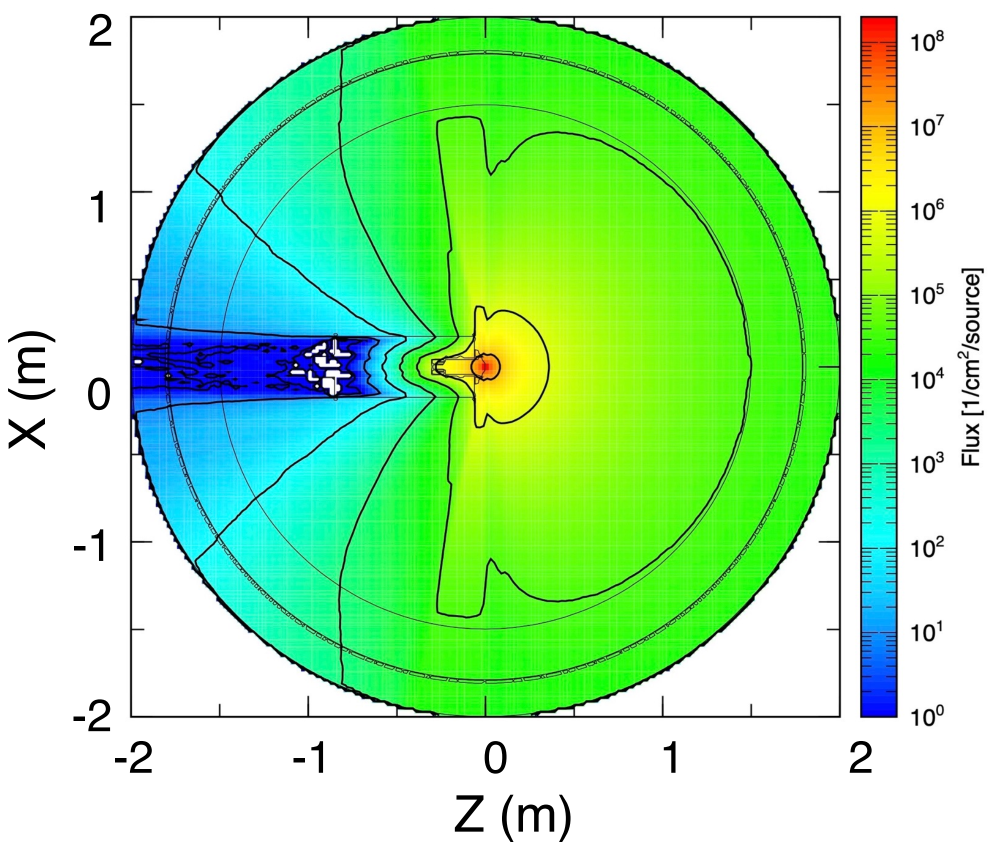
Simulation of the angular neutron flux measurement for the compact D-T neutron generator.

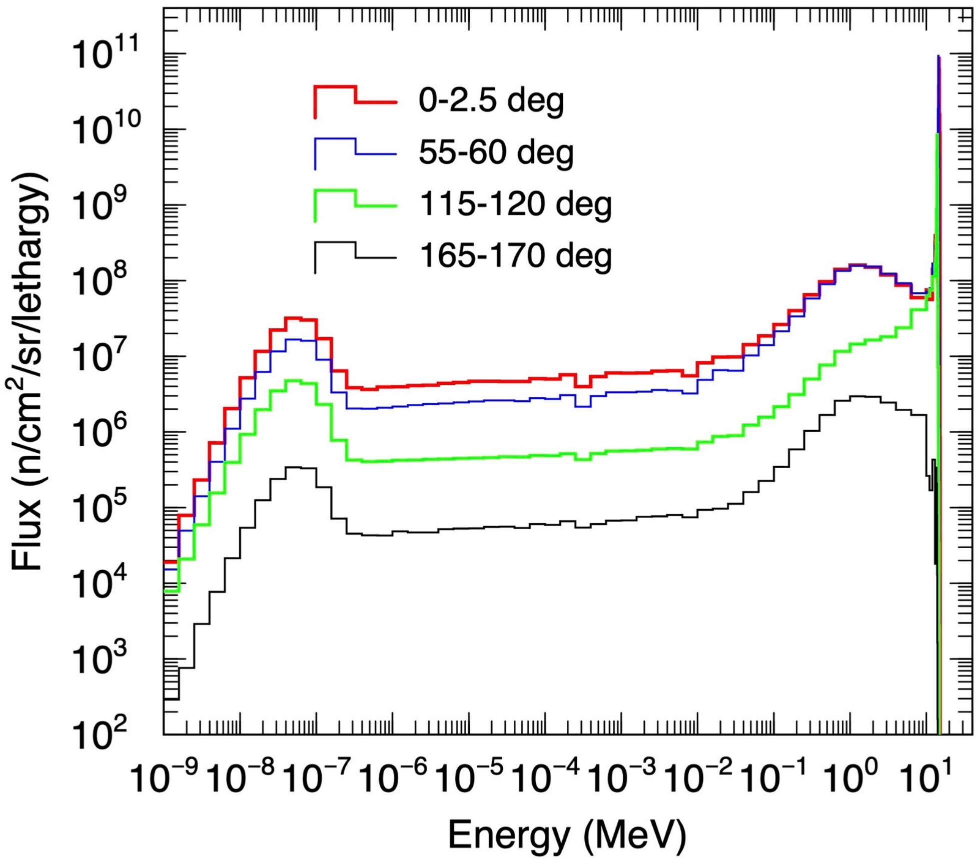


Neutron flux distributions and typical angular neutron spectra

- Neutron flux distributions around the compact D-T neutron generator were calculated with PHITS with angular dependent d-T source spectra.
- Absorption effect of the oil tank is clearly identified.

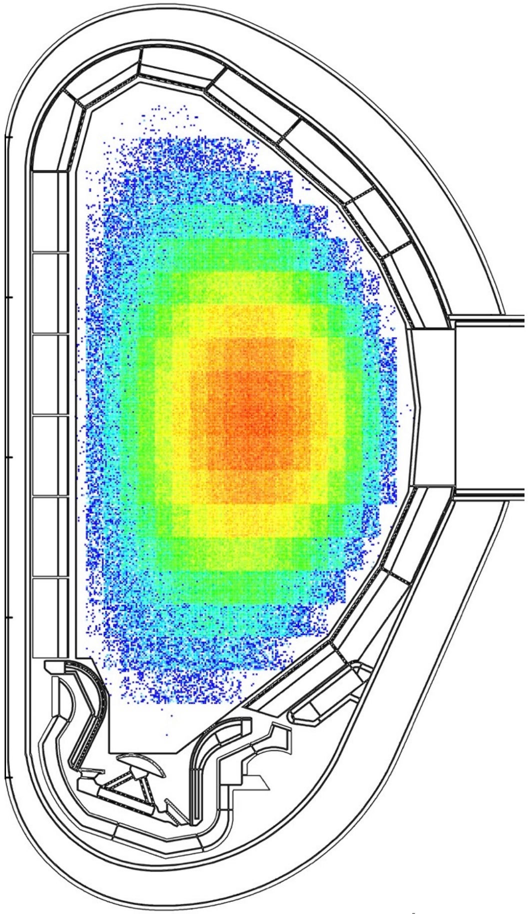
13-16 MeV neutron flux map



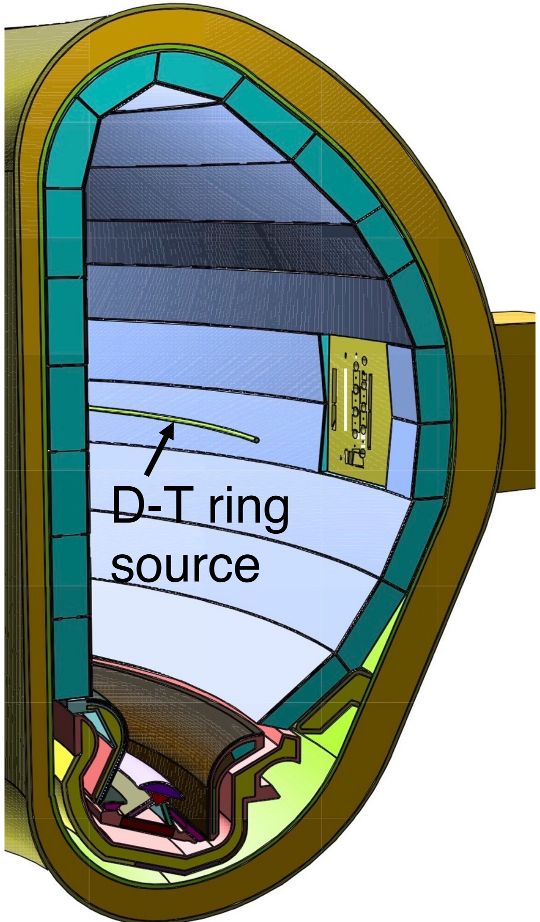


Detection efficiencies of NFM, DNFM, and MFC for different neutron source

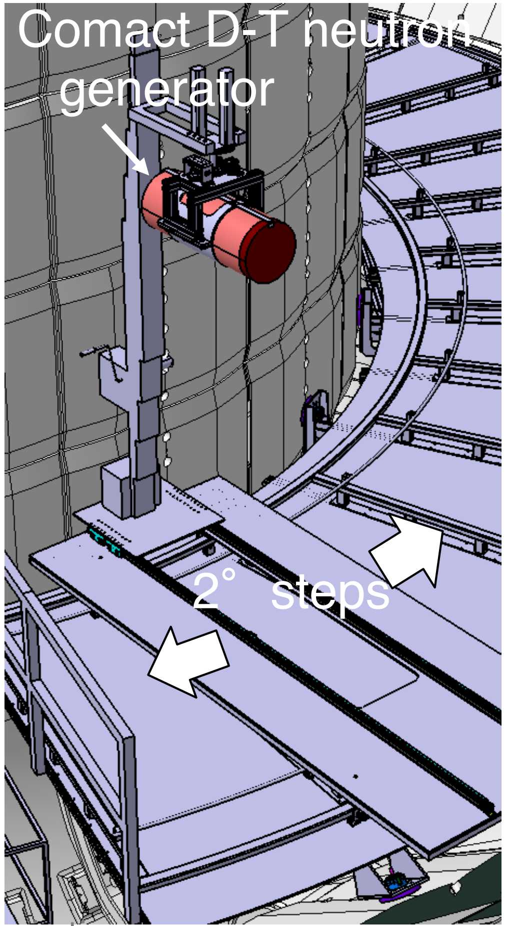
(a) Standard plasma Neutron source



(b) Idealistic D-T ring source

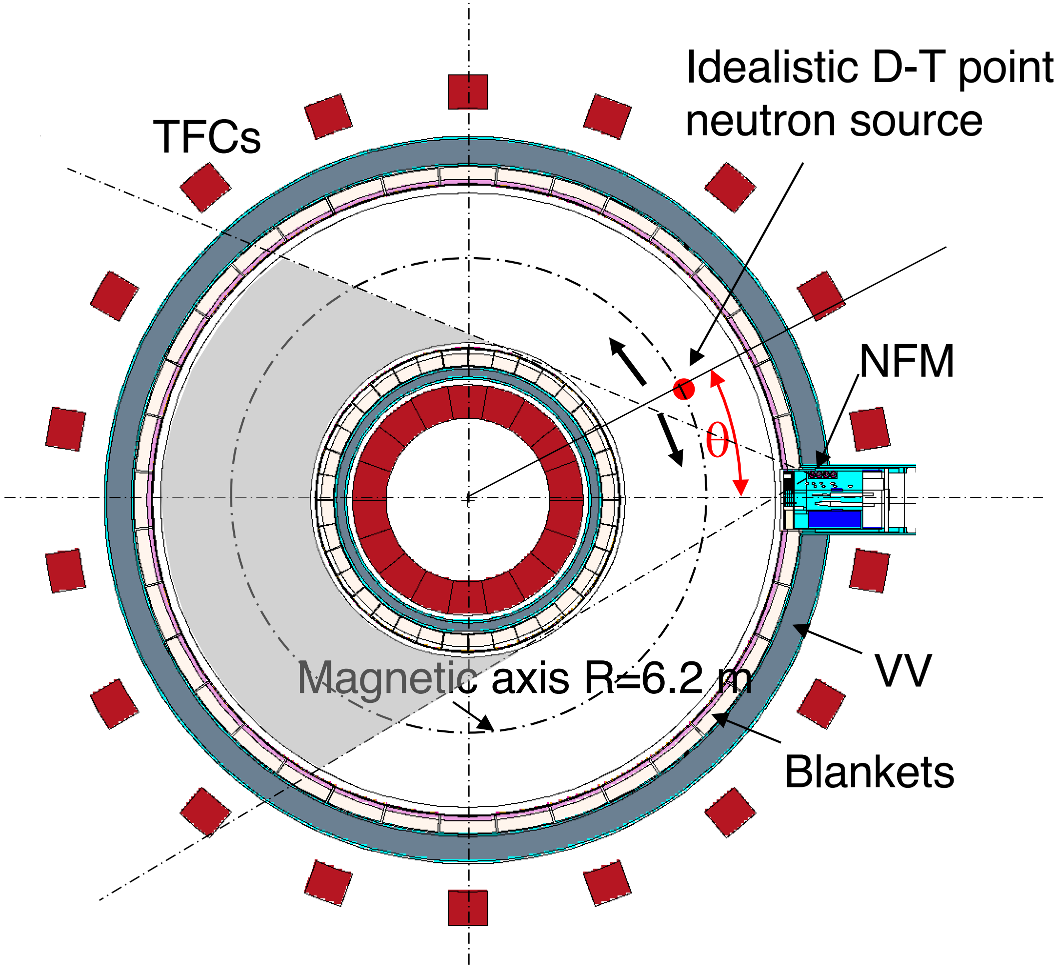


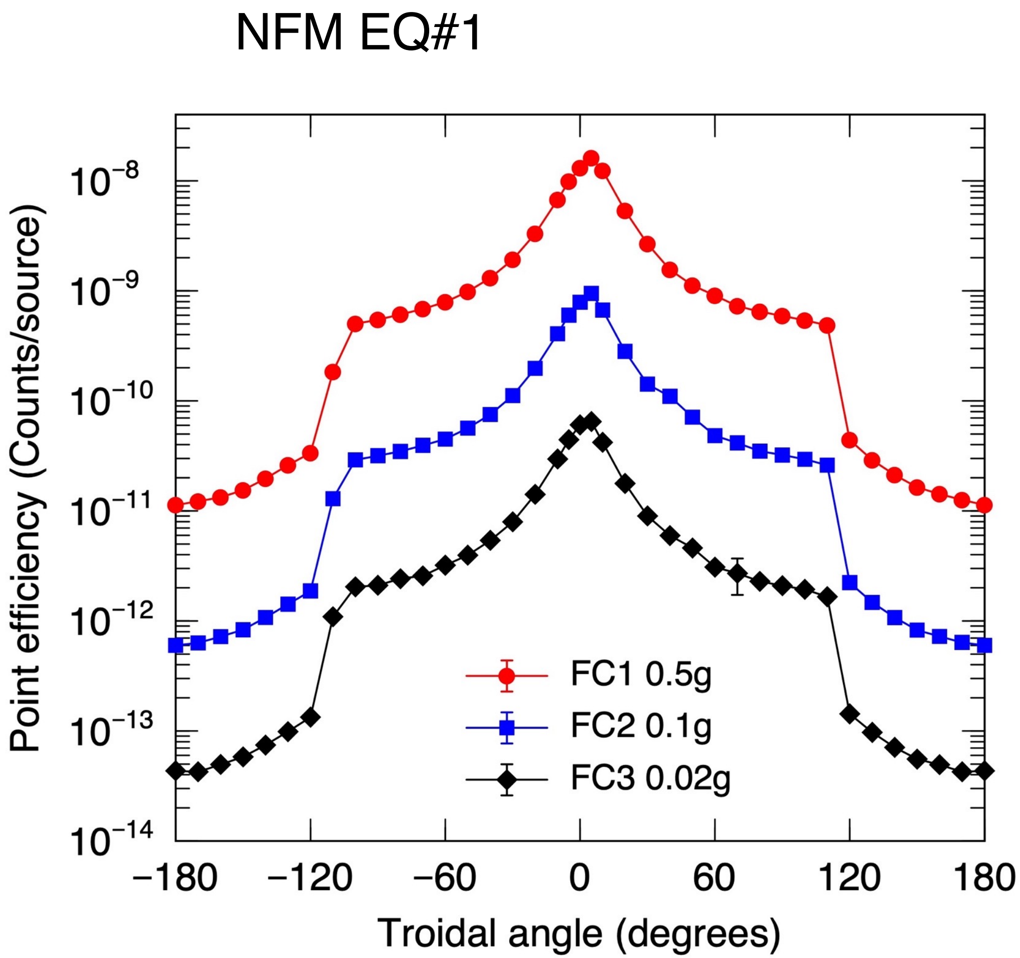
(c) Comact D-T neutron generator moving on the magnetic axis with 2° steps



Point efficiencies for an idealistic D-T point neutron source on the magnetic axis — NFM —

- Point efficiency curves of FC-1, FC-2, and FC-3 are almost similar.
- Point efficiency decreases significantly for the toroidal angle far from ± 120° due to the shielding by blankets, VV and TFCs.





Detection efficiencies of NFM, DNFM, and MFC

- Detection efficiencies except DNFM (U-238) for the D-T ring source and the compact D-T neutron generator are larger by 0-10% and ~20% against those for the standard plasma source , respectively.

Diagnostics	Detection efficiency (count/ source)		
	Standard plasma source	D-T ring source	D-T neutron generator
NFM EQ#1 FC-1 U-235 0.5g	1.48×10^{-9}	1.66×10^{-9}	2.13×10^{-9}
NFM EQ#1 FC-2 U-235 0.1g	8.45×10^{-11}	9.51×10^{-11}	1.22×10^{-10}
NFM EQ#1 FC-3 U-235 0.02g	5.77×10^{-12}	6.58×10^{-12}	8.46×10^{-12}
DNFM U-238 0.5g	1.82×10^{-12}	1.65×10^{-12}	1.74×10^{-12}
DNFM U-235 0.5g	2.42×10^{-11}	2.43×10^{-11}	2.52×10^{-11}
MFC upper U-235 0.01g	1.84×10^{-11}	1.90×10^{-11}	2.20×10^{-11}
MFC lower U-235 0.01g	2.19×10^{-11}	2.42×10^{-11}	3.12×10^{-11}

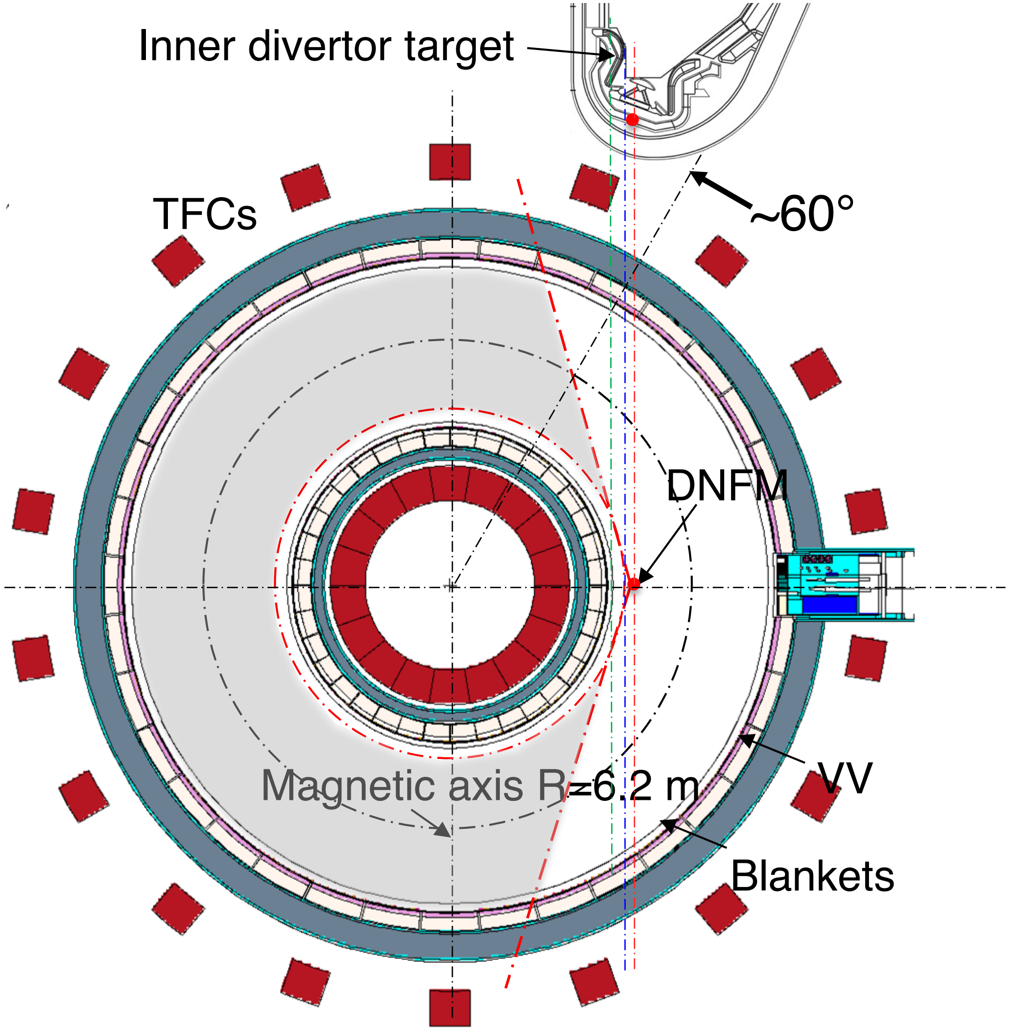
Reaction rate of NAS — $^{63}Cu(n,2n)^{62}Cu$ —

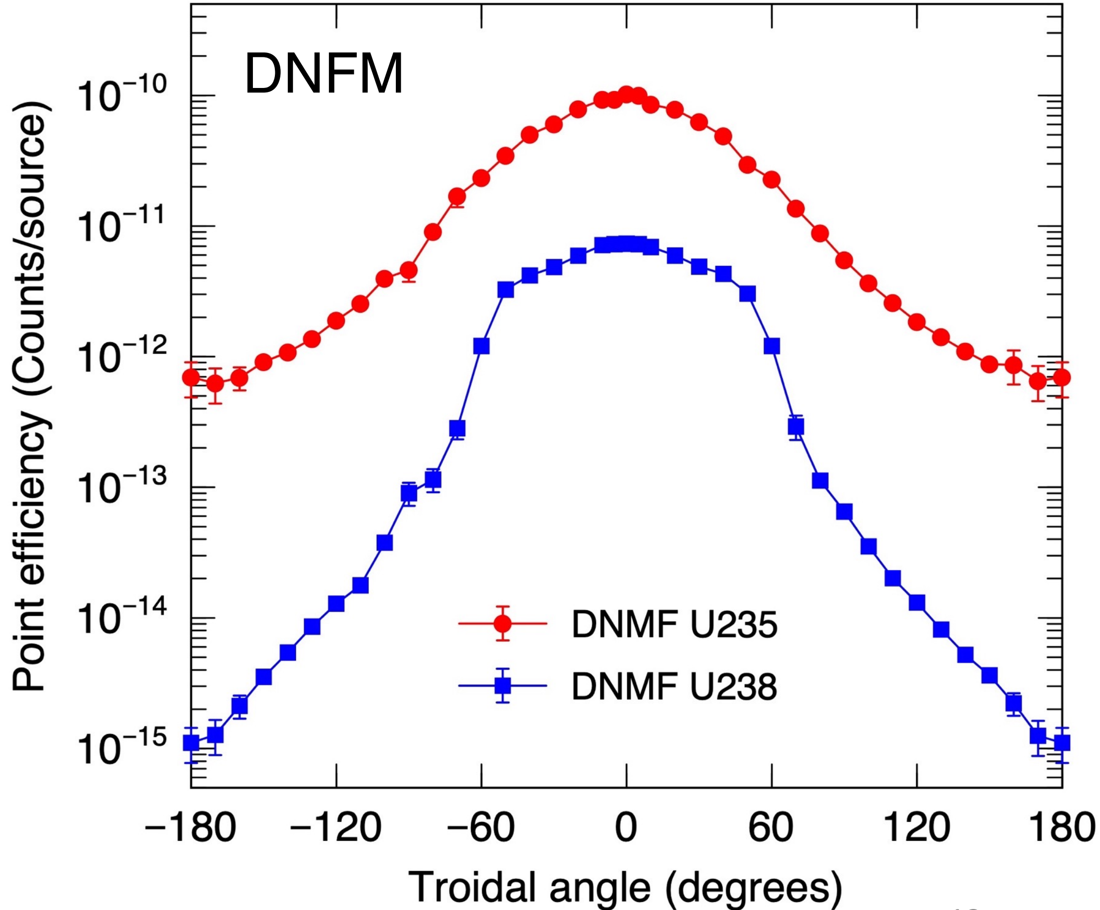
- Reaction rates at EQ for the D-T ring source and the compact D-T neutron generator are ~20% and ~70% grater that those for the standard plasma source , respectively.
- Reaction rates at inboard VV and the bottom VV for the the compact D-T neutron generator are significantly lower.

Irradiation point of NAS	Reaction rate of $^{63}Cu(n,2n)^{62}Cu$ in 1g natural copper		
	Standard plasma source	D-T ring source	D-T neutron generator
Inboard of VV	3.5×10^{-12}	2.4×10^{-12}	1.3×10^{-13}
Bottom of VV	1.4×10^{-12}	1.1×10^{-12}	3.9×10^{-13}
In vertical gap of EQ (upper)	3.2×10^{-10}	3.8×10^{-10}	5.5×10^{-10}
In vertical gap of EQ (lower)	3.4×10^{-10}	4.0×10^{-10}	5.6×10^{-10}

Point efficiencies for an idealistic D-T point neutron source on the magnetic axis —DNFM—

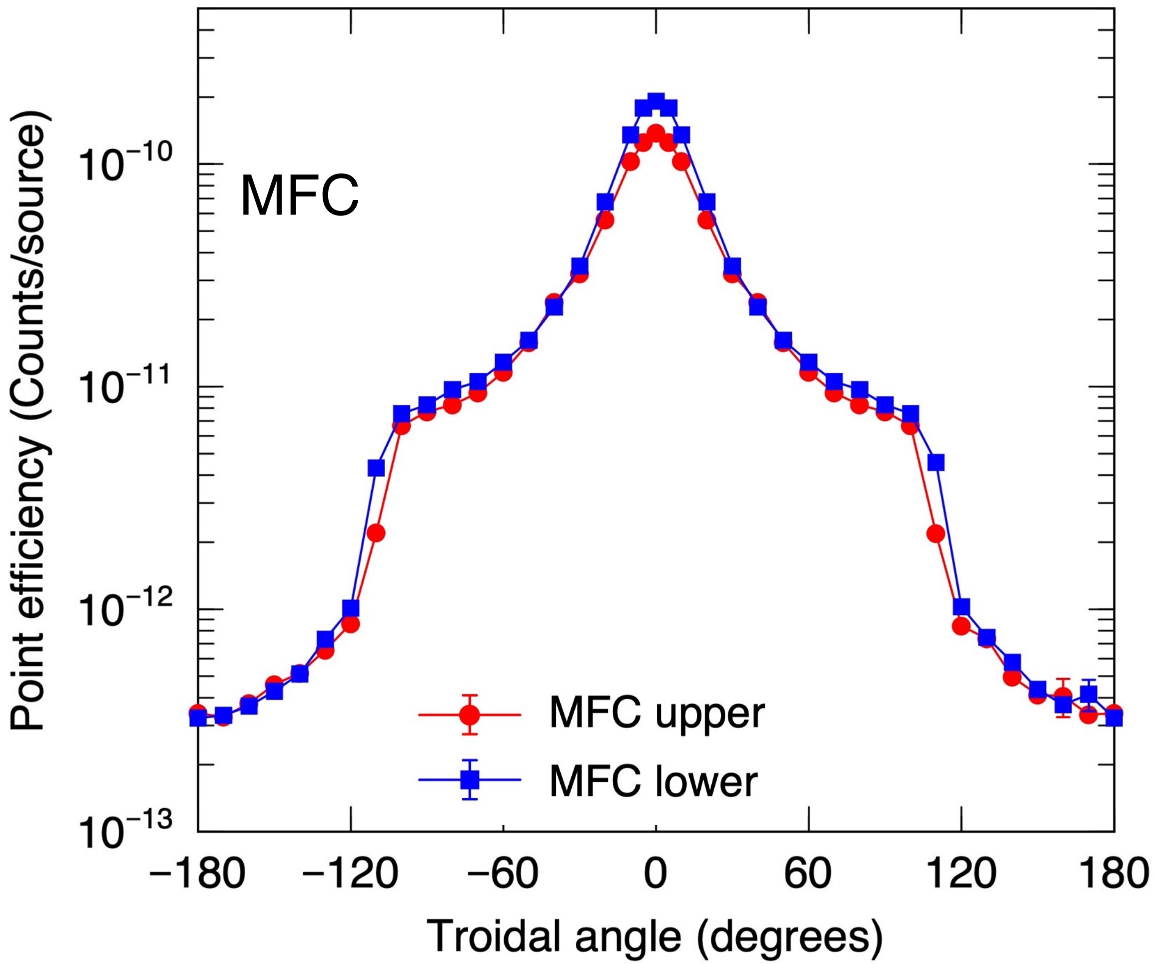
- DNFM (U-238) has a high sensitivity to neutrons for neutrons within ±60° which might be caused by the scattering with inner divertor targets and inboard blankets.
- Point efficiency curve of DNFM (U-235) is smoother than that of DNFM(U-235).





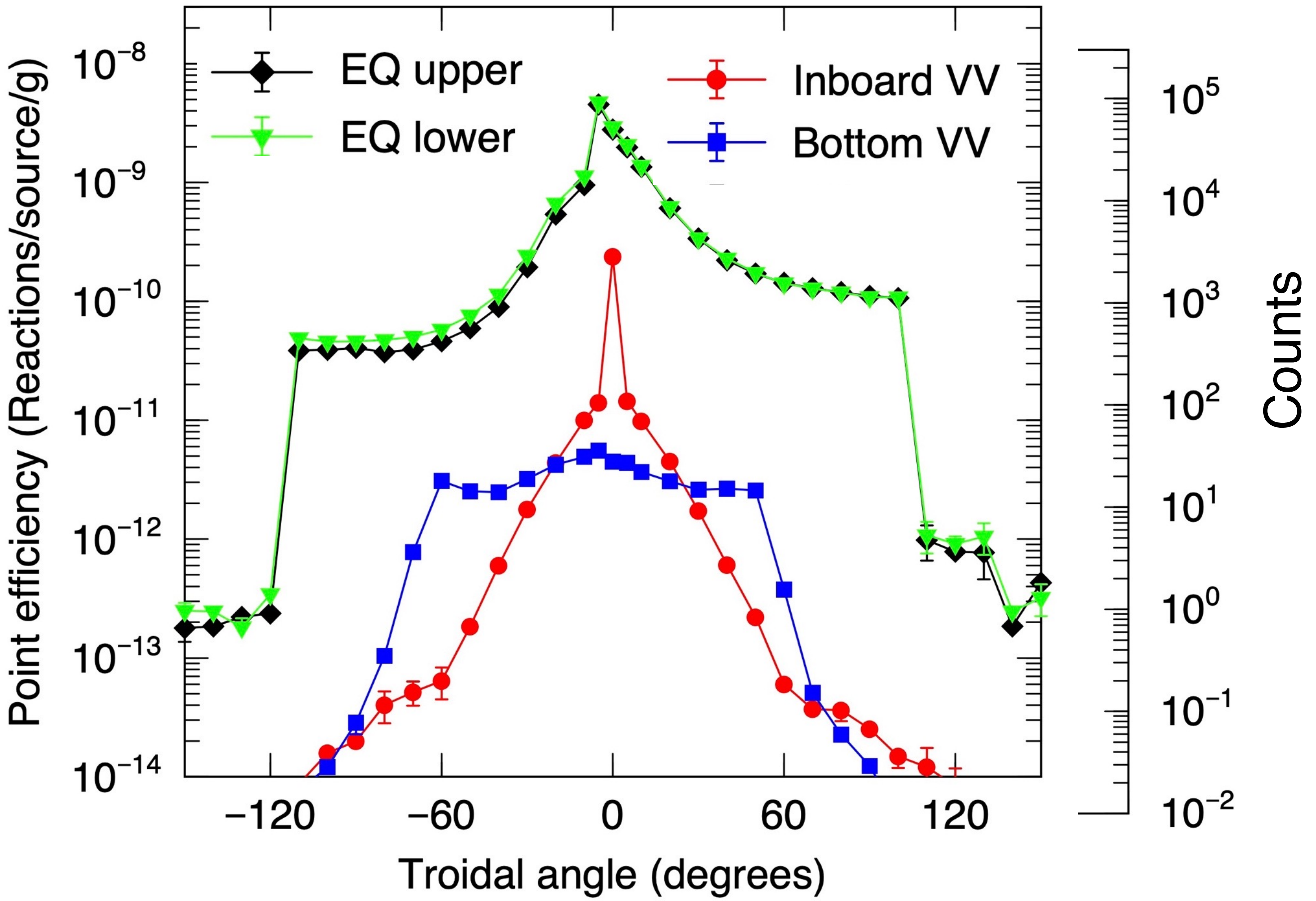
Point efficiencies for an idealistic D-T point neutron source on the magnetic axis —MFC —

- Point efficiency curves of MFCs similar to those of NFM.
- Point efficiency curves of NASs in EQ have weak asymmetry due to the EQ port structure.



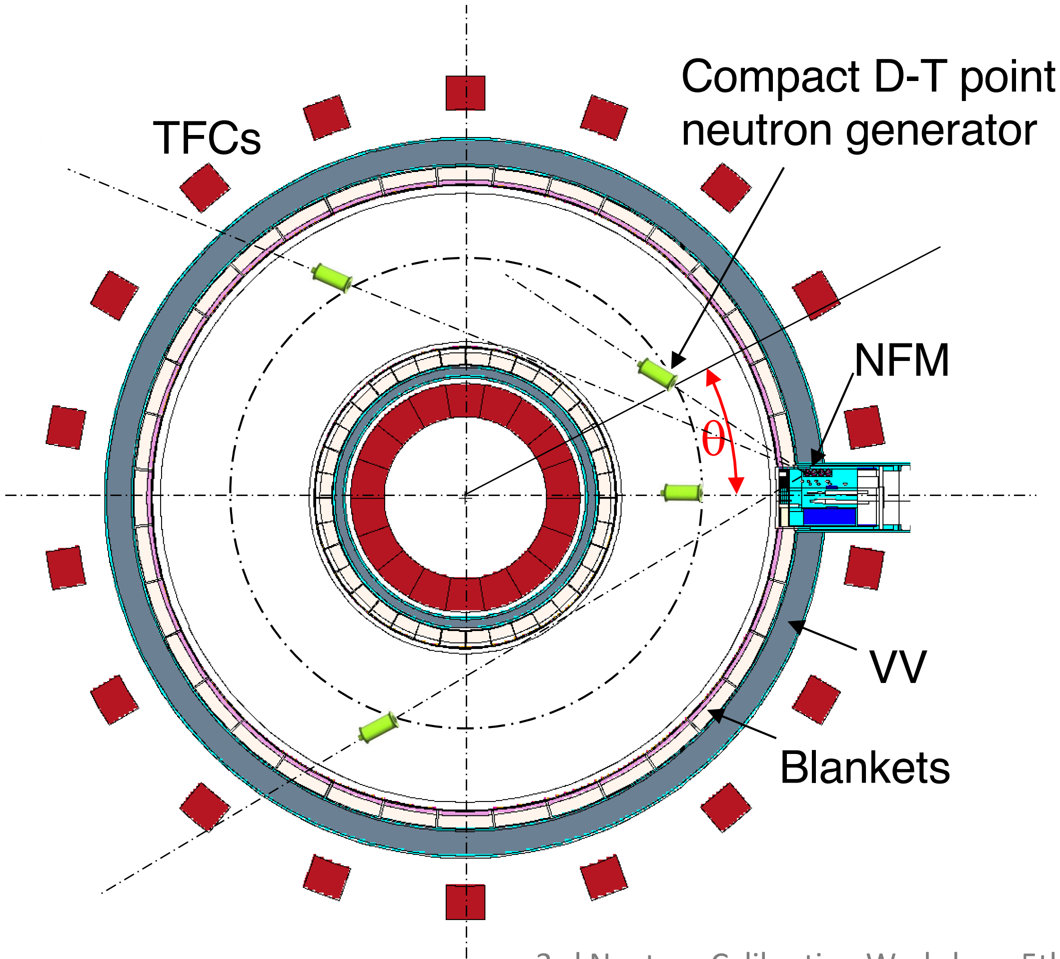
Point efficiencies for an idealistic D-T point neutron source on the magnetic axis —NAS —

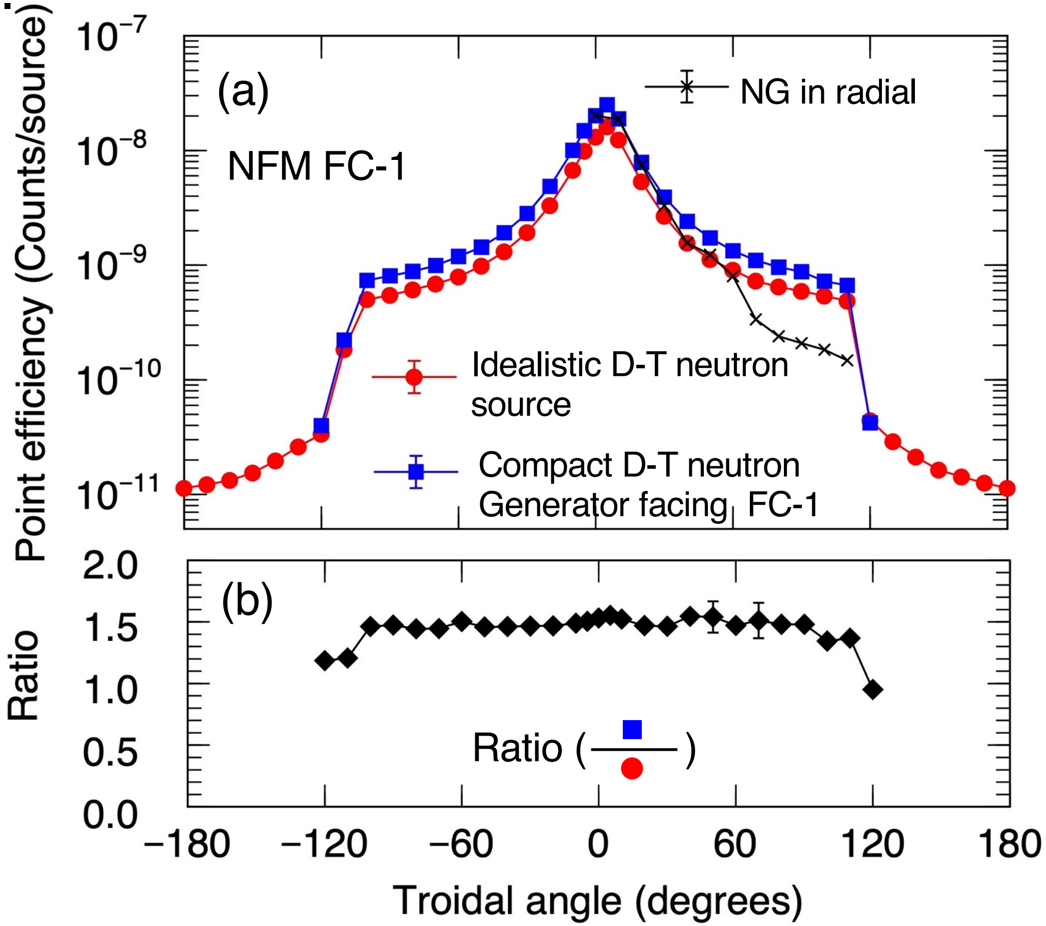
- NAS in the bottom VV has a sensitivity for neutrons within ±60° similar to DNFM(U-238) .
- Neutron streaming via vertical gap of inboard blankets is observed in NAS at inboard VV.
- If we irradiate 10g sample for 20 min and measure gamma-ray 20 min just after the irradiation, 1100 counts of 0.511 gamma-rays for the point efficiency of 1×10^{-10}.



Point efficiencies for the compact D-T neutron generator on the magnetic axis facing to NFM

- Point efficiency curves for the compact D-T neutron generator are ~1.5 time grater than those for the idealistic D-T neutron source within ± 110°.
- Point efficiencies for idealistic D-T neutron source can be derived from those for the compact D-T neutron generator.





Summary

- Neutron calibration experiments using a compact D-T neutron generator for ITER in-vessel neutron diagnostics have been simulated by MCNP with the simplified ITER model.
- Angular neutron spectra from the compact D-T neutron generator have been evaluated for the source term of the MCNP calculation of the neutron calibration simulation.
- Point efficiencies for an idealistic D-T neutron source have been calculated for NFM, DNFM, and MFC.
- Point efficiency measurement using the compact D-T neutron generator facing to NFM in EQ#1 is effective method for the NFM calibration because the point efficiency curve for idealistic D-T neutron source can be derived from those for the compact D-T neutron generator. Finally, we will obtain the detection efficiency for the plasma neutron source.

Than you for your attention

Supplemental viewgraphs

Plasma size dependency

- To evaluate the discrepancy between 14 MeV line source and standard plasma source, plasma size dependency has been investigated.

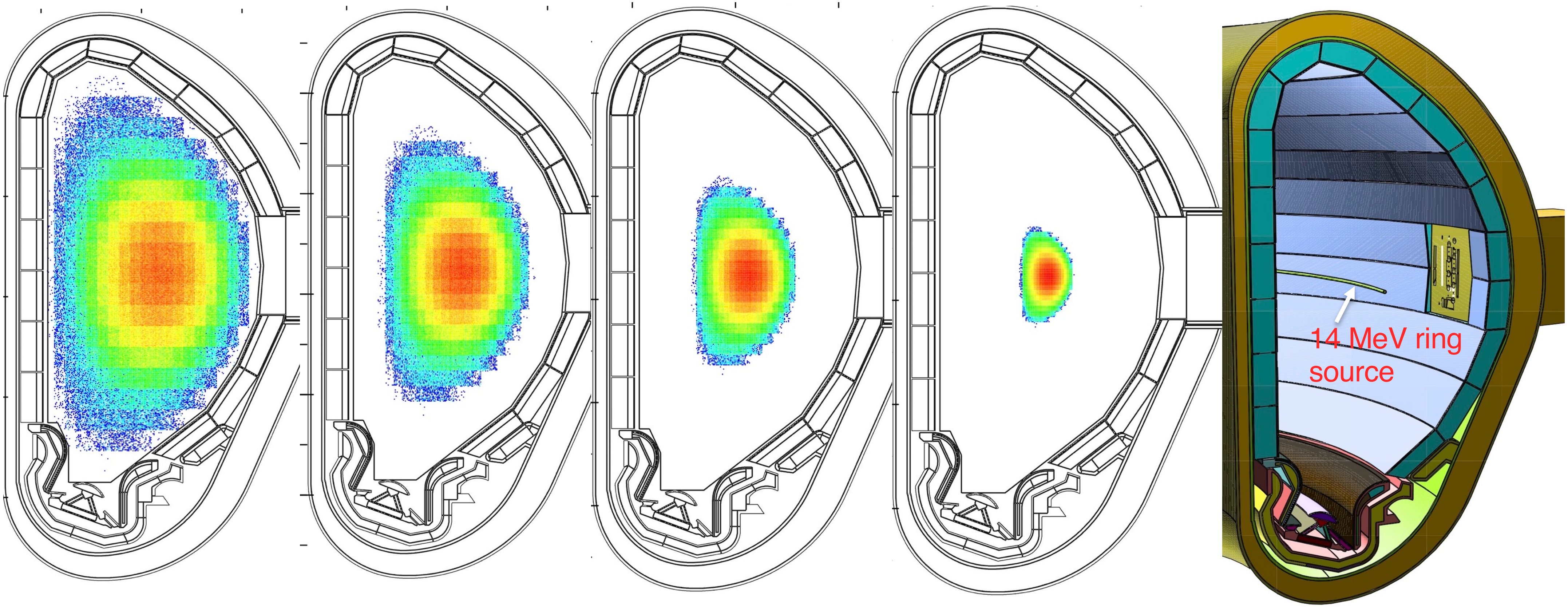
Standard plasma Neutron source a_p = 2.0 m

a_p = 1.5 m

a_p = 1.0 m

a_p = 0.5 m

14 MeV ring source



Plasma size dependency

Detection efficiencies of NFM have a week (negative) plasma size dependence.