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JA fusion neutronics activities toward JA-DEMO design and construction

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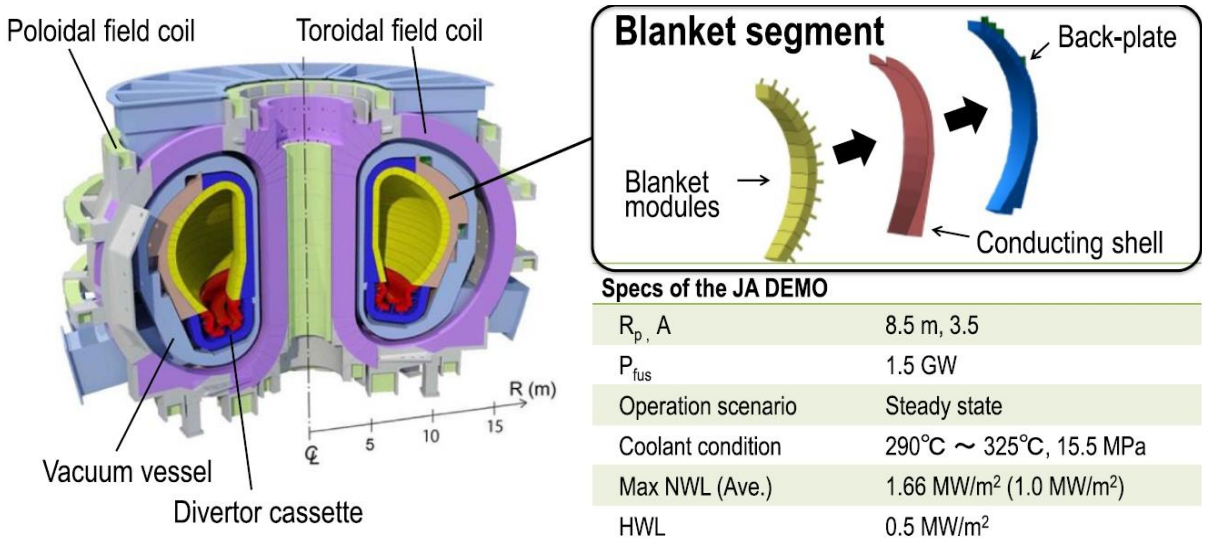
JA-DEMO Design and Nuclear Eng. Requirements

The design of the JA-DEMO reactor has recently been reviewed and updated with the aim of demonstrating power generation in the 2030s. Currently, a device scale that complies with the ITER class is being considered.

In order to achieve this goal early, JA-DEMO aims to gradually achieve self-sufficiency in tritium fuel and demonstrate power generation. To this end, downsizing of the thickness of the breeding region and shielding region is being considered from the perspective of securing the plasma cross section.



Specs of the JA DEMO	
R_p, A	8.5 m, 3.5
P_{fus}	1.5 GW
Operation scenario	Steady state
Coolant condition	290℃ ～ 325℃, 15.5 MPa
Max NWL (Ave.)	1.66 MW/m^2 (1.0 MW/m^2)
HWL	0.5 MW/m^2

Configuration and specification for JA DEMO reactor

Requirements of the JA DEMO blanket design.

Parameter	Value
Target of the overall TBR	≧1.05
Inlet and outlet temperature	290 °C–325 °C
Pressure tightness against in-box LOCA	17.2 MPa
Thickness of the radius direction	<0.65 m
Neutron multiplier	Beryllide

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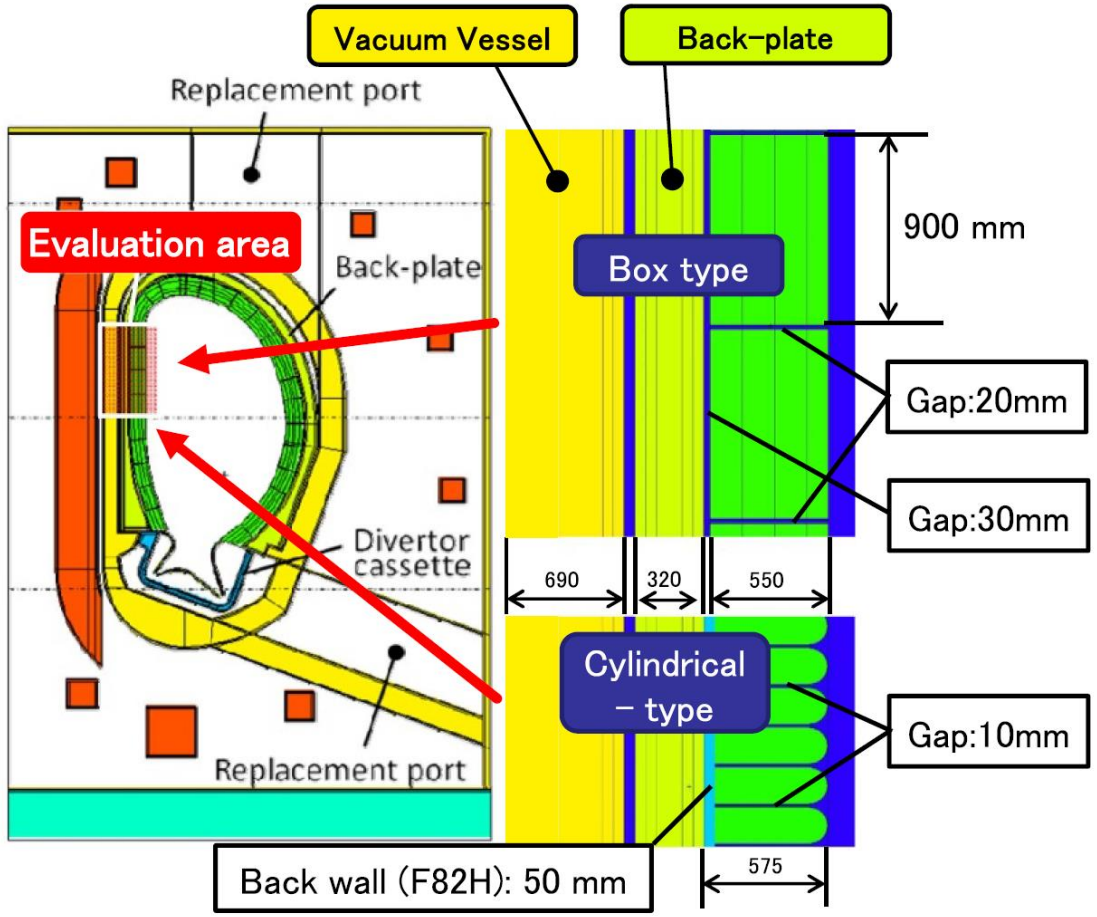
DEMO Design and Neutronics

This design requirement is extremely challenging from a neutron engineering perspective.This is because JA-DEMO is considering a design based primarily on a water-cooled ceramic blanket, and the trade-off with tritium breeding performance requires more stringent design accuracy for the TBR.

Regarding shielding performance, there is a possibility that increased nuclear heat generation from equipment or elevated radiation doses to equipment components could lead to premature failure of components.



Calculation model of the radiation shielding.

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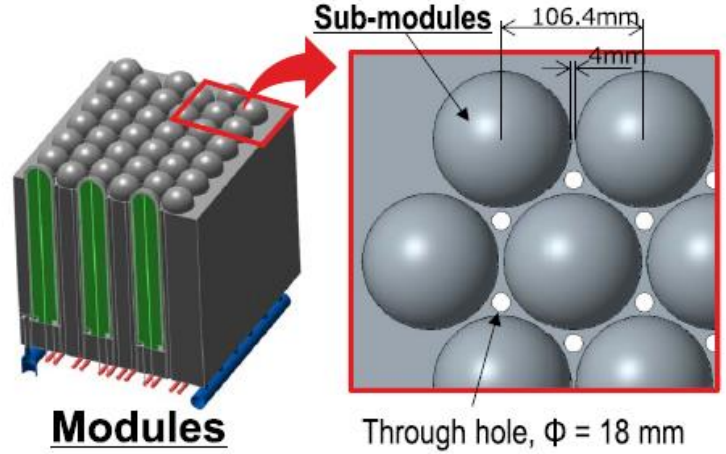
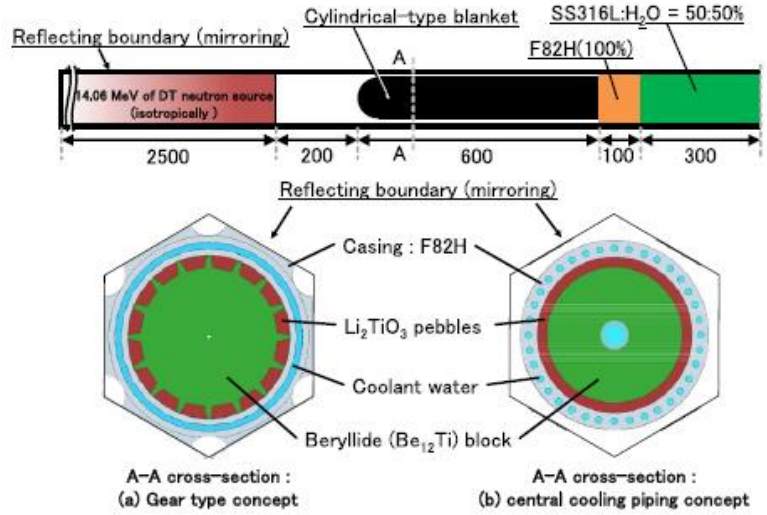
Candidate material and damage

Furthermore, in the social implementation phase, evaluating the lifespan of structural materials and divertor equipment materials due to material irradiation is critically important from an economic perspective.



Location of sub-modules and through-holes in the blanket module.

Irradiation data for low-activation ferritic steel F82H, a candidate structural material in Japan, up to high irradiation levels (100 dpa) will be necessary by the time of social implementation. Similarly, verification of tungsten and copper alloy cooling pipe materials, which are candidate diverter materials, is also important.



MCNP calculation model for the cylindrical submodule blanket

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Present activities for DEMO

Research and development on nuclear fusion neutrons in Japan is advancing activities for JA-DEMO reactor design by comprehensively addressing the following items.

1. Nuclear Design Research of WCCB-TBM and system in ITER
2. Facility Design of Fusion Neutron Source for DEMO reactor
3. Irradiation plan and nuclear analysis of A-FNS
4. Nuclear data investigation and contribution

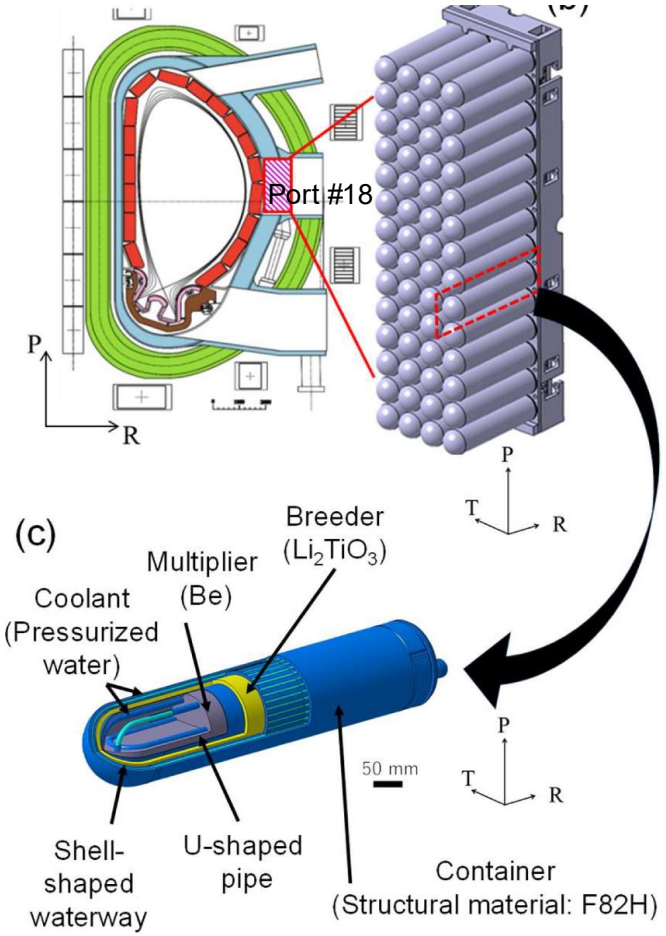
WCCB-TBM and system

The WCCB type blanket is planned to be tested as a test blanket module in equatorial port #18 of ITER.

- The cylinder-shaped sub-module uses Li-6 30% **lithium titanate pebbles** as the breeder material and the multiplier will be **beryllium**.
- Sub-module structural material is low-activation material **F82H** and so are the water cooling pipes.

The significance of this test from a DEMO Neutronics Design perspective is considered to be as follows,

- Verification of **tritium production and recovery** characteristics
- Verification of analysis for accurate **nuclear heating and TBR** estimation
- Structural study to obtain reliable **shielding performance**.
- **Nuclear activation** characteristics and dose evaluation of materials



Schematic drawing of current design of WCCB TBM located in ITER Cross section of ITER tokamak, WCCB TBM and Submodule.

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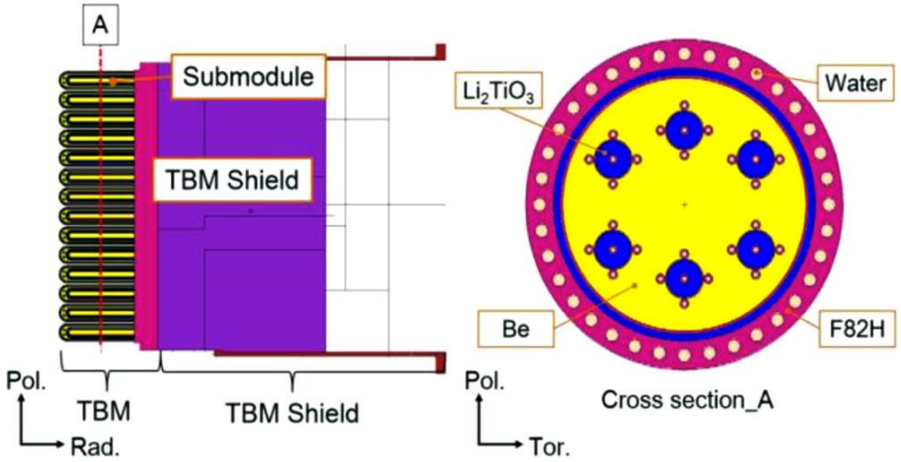
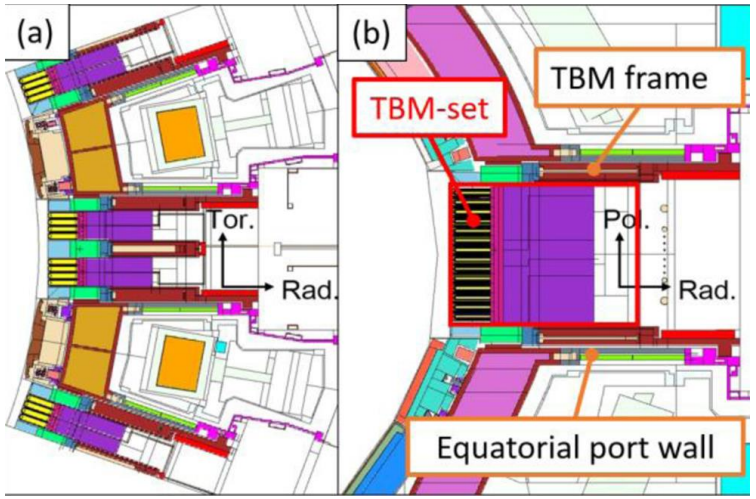
Nuclear design activity of WCCB-TBM and system

QST is conducting nuclear analysis for the design and manufacture of WCCB-TBS.

- Monte Carlo transport calculation code MCNP (mainly Ver. 5) is used for neutron and gamma ray transport calculations.
- Tritium production rates and activation analyses were performed using EAF2007
- Shut down dose rate SDDR is being analyzed in D1S
- The calculation model is applied to “C-model” and the WCCB-TBM model is set up independently using a CAD conversion tool.
- The WCCB-TBM model was set up using a CAD conversion tool.



. A MCNP model of WCCB TBM-set with the cylindrical container,



Cross-section of C-lite with the cylindrical TBM-set:
(a) Horizontal cross section, (b) Vertical cross-section.

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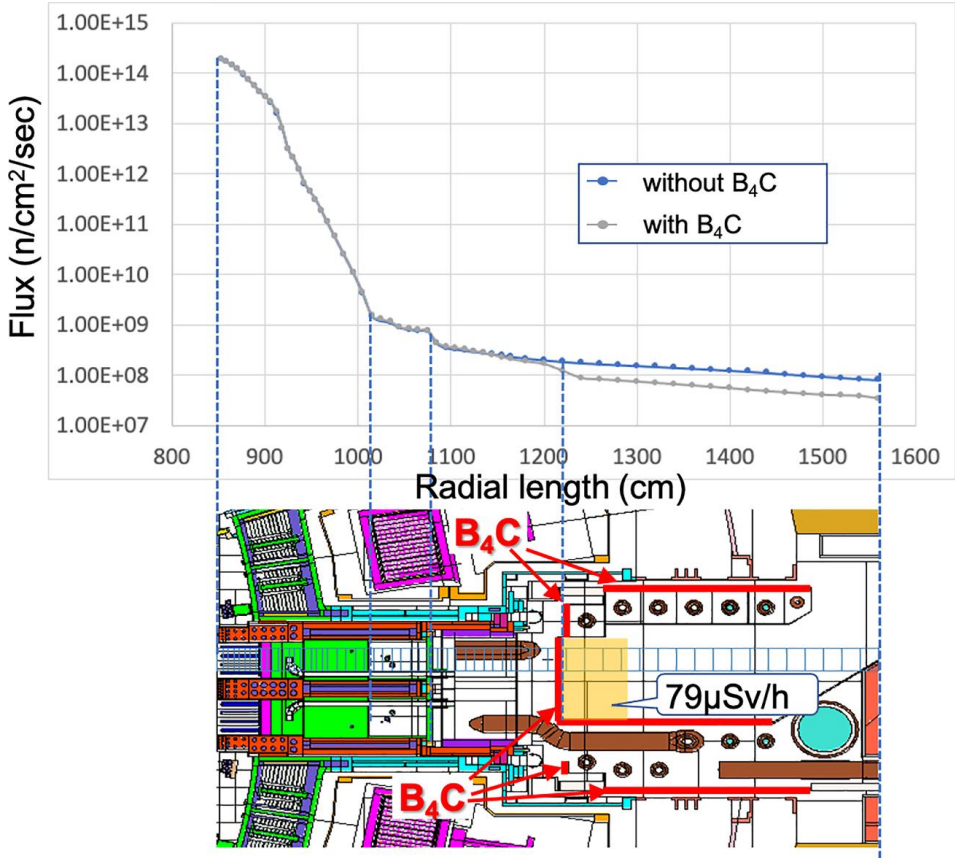
Example of analysis results

The analysis is conducted using ITER operation with 400 MW neutron source power and 400 s of DT operation as a unit shot.

- The incident neutron flux is closed to 1E14 n/cm2/sec.
- TPR of WCCB TBM will be 1.22E+17 T/s
- Nuclear heating of total number of WCCB-TBM will be 0.44 MW
- The heat generation in the breeding material and in the structural material was found to be 0.12 and 0.2 MW, respectively.
- Dose calculations for the rear area of the TBM shield, which is also in operationWe also propose to reduce the neutron field by B4C in order to reduce the wraparound from other regions.



Neutron Flux distribution and SDDR in the case with B4C.

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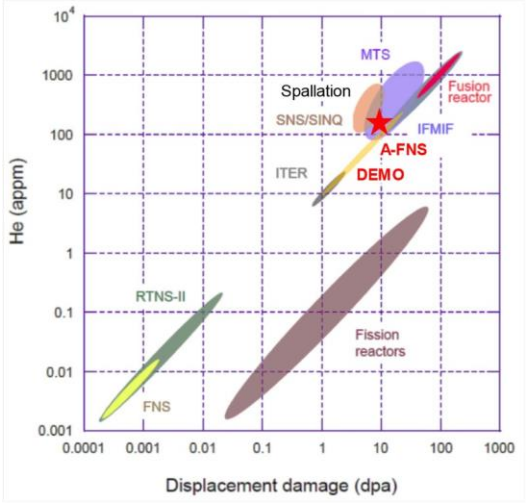
These analyses are being conducted based on the SA 2 operating scenario evaluated by ITER. Meanwhile, analyses according to the New Base Line, currently set for 2024, are also required.

Facility Design of Fusion Neutron Source for DEMO reactor

A neutron source using a heavy ion accelerator and a lithium target is necessary to generate DEMO-level neutron intensity.

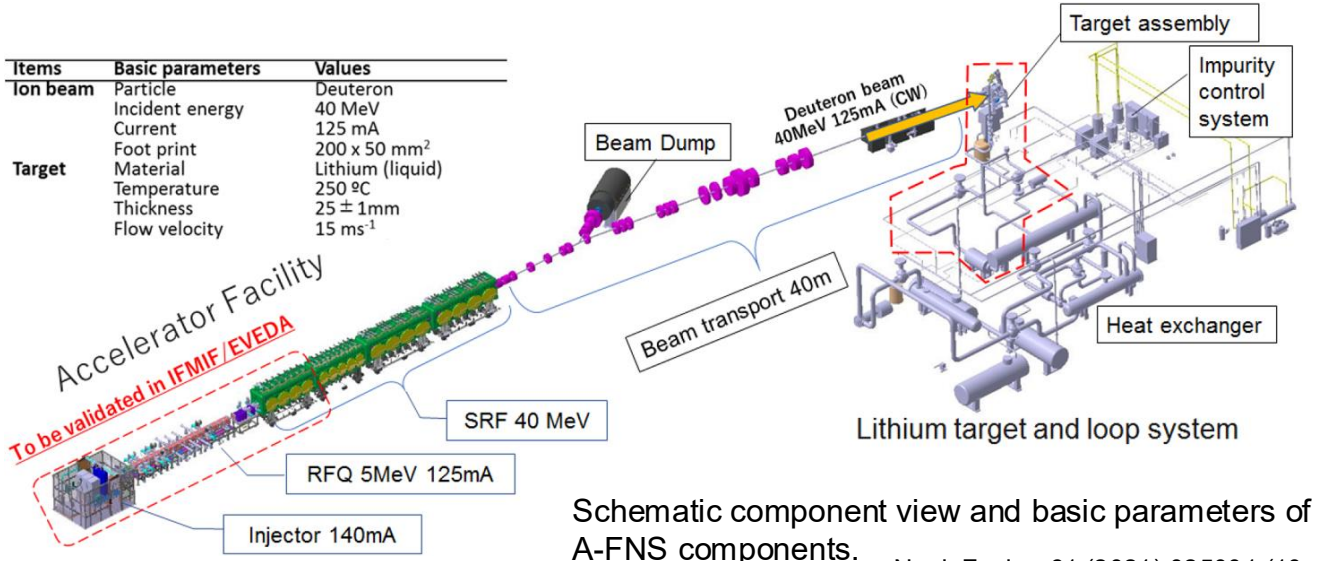
Currently, LIPAc as a prototype accelerator are being conducted by IFMIF/EVEDA as part of cooperation between Japan and European BA countries. Development of a lithium target is also underway.



Correlation of DPA and helium production for each neutron facility.

Finally, it is estimated that structural materials capable of withstanding approximately 100 dpa will be required for commercial reactors. In Japan, nuclear analysis of the A-FNS and nuclear design of the facility itself are being independently investigated.

Items	Basic parameters	Values
Ion beam	Particle	Deuteron
	Incident energy	40 MeV
	Current	125 mA
	Foot print	200 x 50 mm^2
Target	Material	Lithium (liquid)
	Temperature	250 ºC
	Thickness	25 ± 1mm
	Flow velocity	15 ms^{-1}



Schematic component view and basic parameters of A-FNS components.

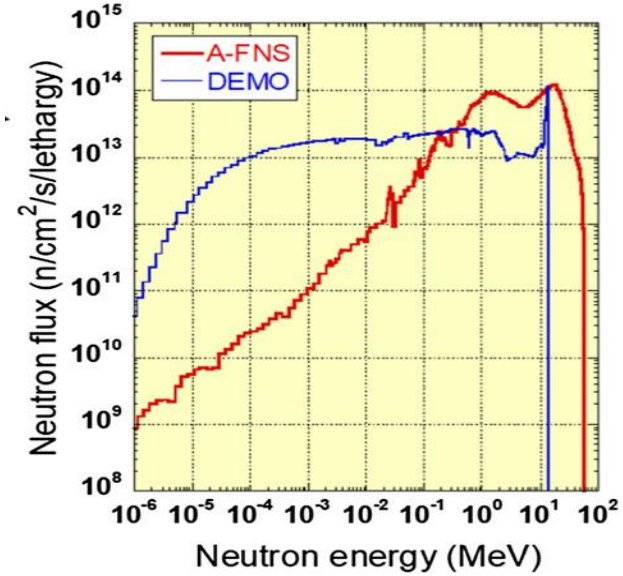
Nucl. Fusion 61 (2021) 025001 (10pp)

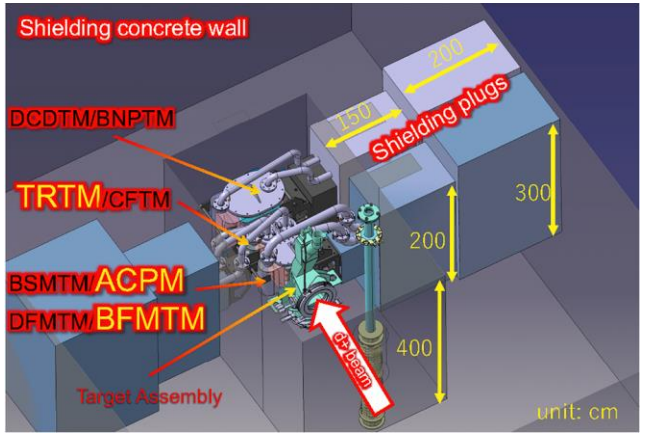
Material irradiation and neutron source

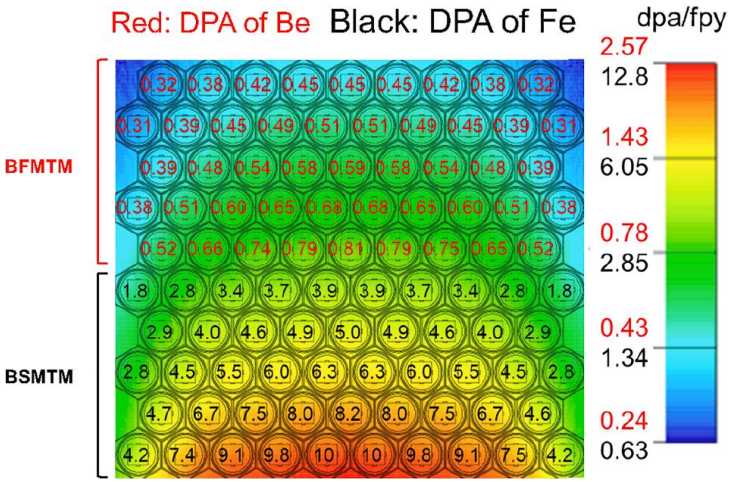
The neutron generation rate of the A-FNS is about 6.6E16/s, which allows irradiation at the surface of the irradiation module with a flux of the 14th power.

This means that irradiation with DEMO furnace class fluxes is possible, which in terms of iron can be up to 10 dpa.

In addition to F82H, A-FNS has also analyzed the irradiation of tungsten as a divertor material, copper alloys for cooling pipes, and beryllium as a multiplier material.







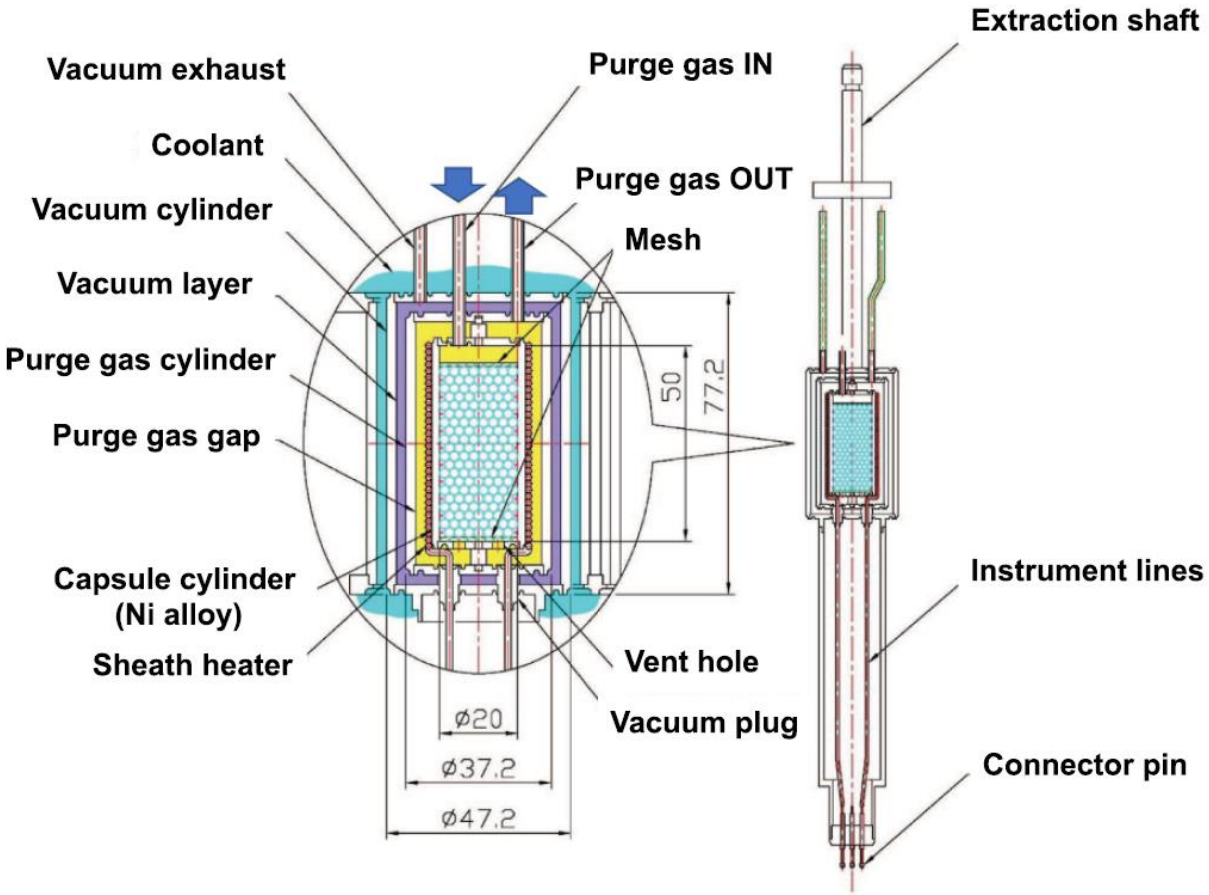
Map of the helium production rate at the horizontal cross section in the BSMTM for 5 cm distance from the TA to the capsules.

Nucl. Fusion 61 (2021) 106026 (12pp)

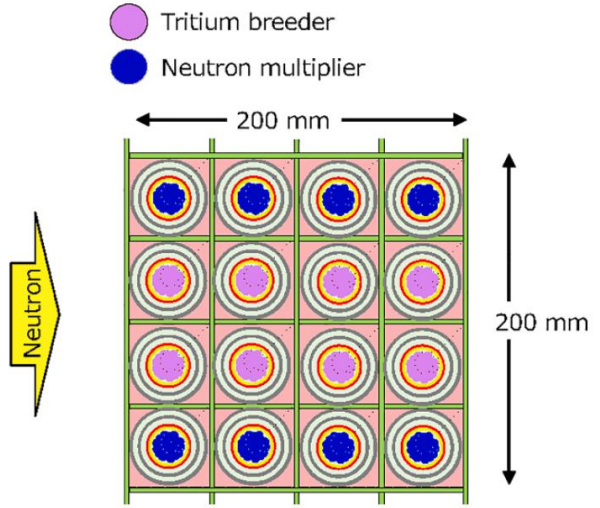
DEMO blanket materials test modules for A-FNS

Nuclear Materials and Energy 25 (2020) 100800

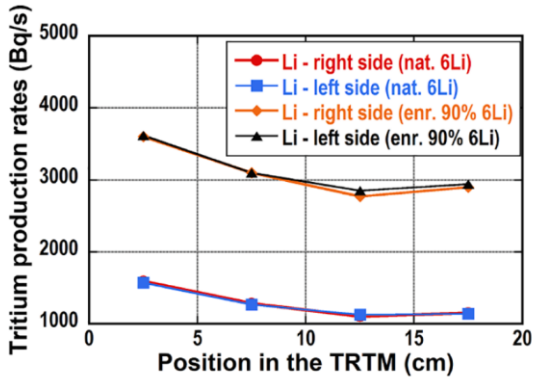
A-FNS is also implementing the nuclear design of a tritium recovery module with a d-Li neutron source.



Horizontal cross-sectional view of TRTM capsule.



A cross-sectional view of TRTM capsules.



Calculated tritium production rate of bulk Li in the TRTM capsule.

Nuclear analysis technique for A-FNS

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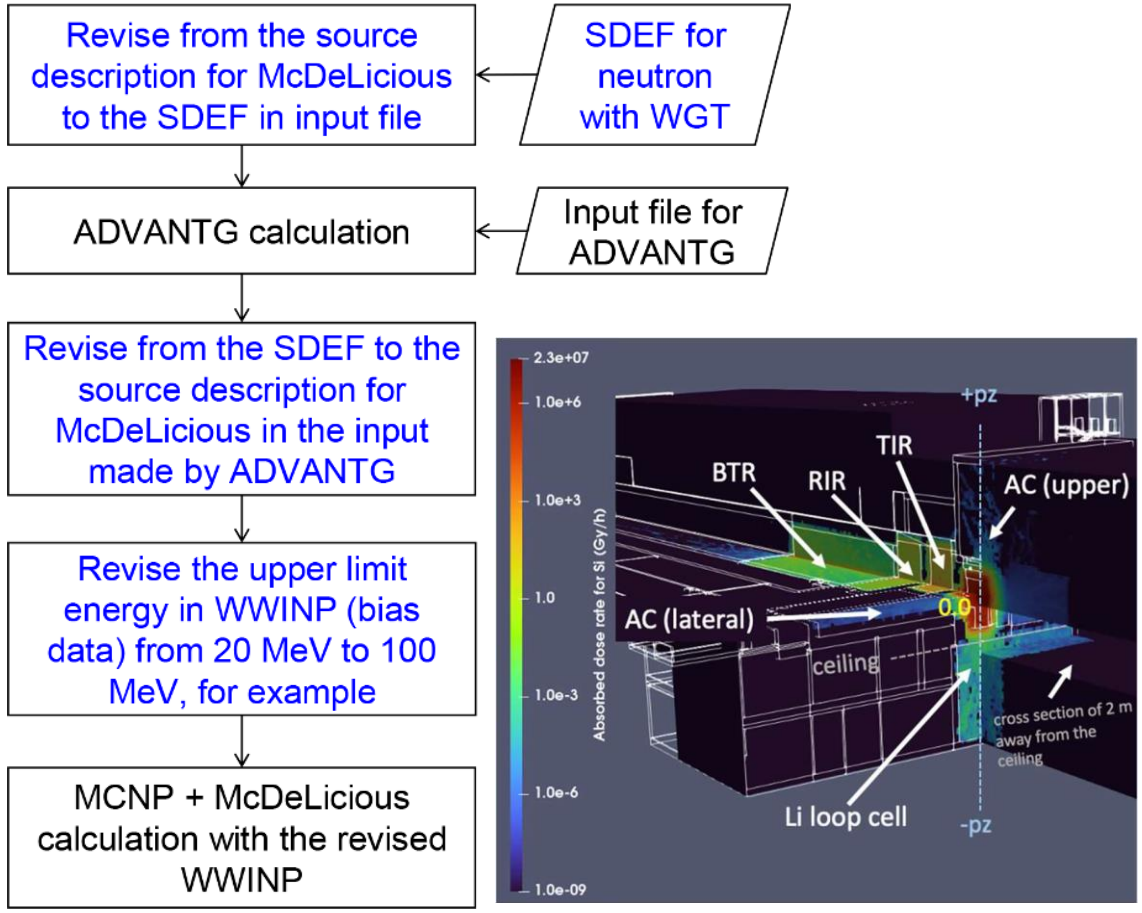
Fusion Engineering and Design 201 (2024) 114274

Nuclear analyses of the dose fields in the A-FNS facility and the development of code technology for these analyses are also being conducted.

In order to perform effective shielding calculations, a variance reduction method using valid bias data is necessary to reduce statistical errors.
In the analysis using the MCNP code and McDeLicious source subroutine, the ADVANTG automatic variance reduction parameter generation code is introduced into the calculation, and the generation of neutrons and photons in the McDeLicious source subroutine is approximated to perform a reasonable analysis method with low statistical error using the ADVANTG code.



Procedure by using ADVANTG code and Dose rate analysis of A-FNS facility.

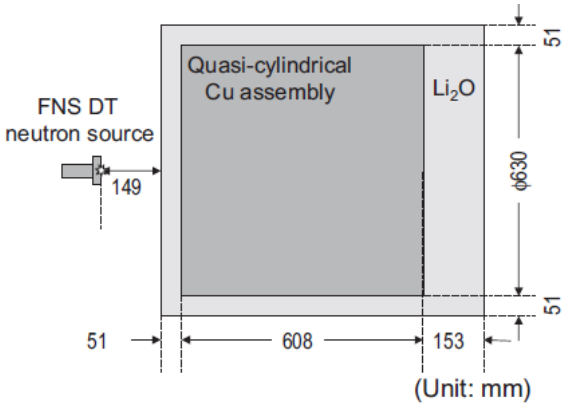
Nuclear data investigation and contribution

Reliability of nuclear data and its improvement is one of the essentials of improving nuclear analysis.

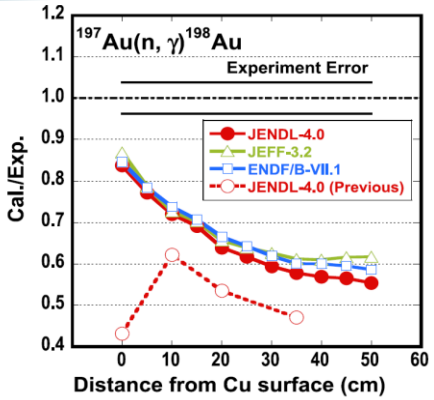
The evaluation of nuclear data is verified through nuclear data benchmark experiments and comparisons with evaluated nuclear data from other countries.

We have been conducting experiments on the Japanese DT neutron source FNS and comparative verification of the updated JENDL, ENDEF, JEFF, and other FENDL libraries.

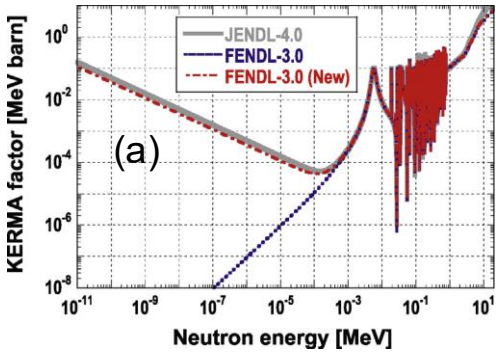
These verifications are shared globally through the IAEA-ND community and contribute to nuclear design techniques for fusion reactors and fusion neutron sources.

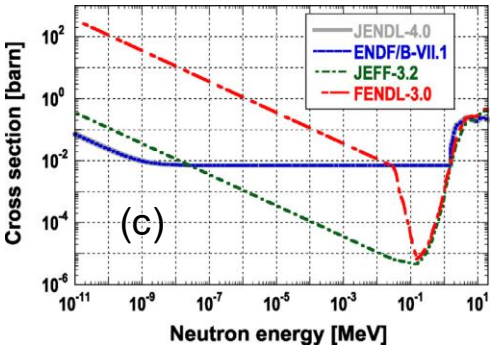


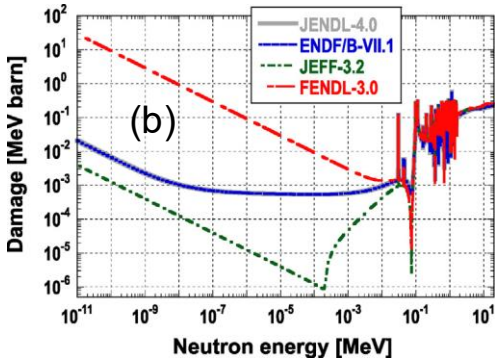
Schematic view of the experimental assembly.



C/E of reaction rate of 197Au(n,g)198Au







(a) KERMA factor of 50Cr (revised)
(b) DPA cross section of 32S.
(c) Helium production cross section of 32S

Fusion Engineering and Design 109–111 (2016) 1658–1662
Fusion Engineering and Design 109–111 (2016) 1649–1652

Summary

- In Japan (QST), the following items are being implemented as part of the nuclear design of the JA-DEMO reactor.
  - Neutron engineering research on ITER-TBM (WCCB) and its surrounding area
  - Nuclear analysis on irradiation of candidate materials by fusion reactor material irradiation neutron source
  - Nuclear analysis of fusion reactor material irradiation neutron source facilities
  - Nuclear data verification and its international cooperation
- These activities will be more important for the nuclear design of JA-DEMO, which will be analyzed in detail in the future, as a presentation of design data and improvement of analysis techniques.