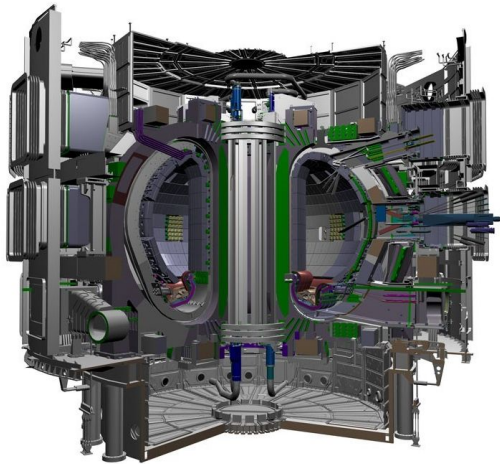


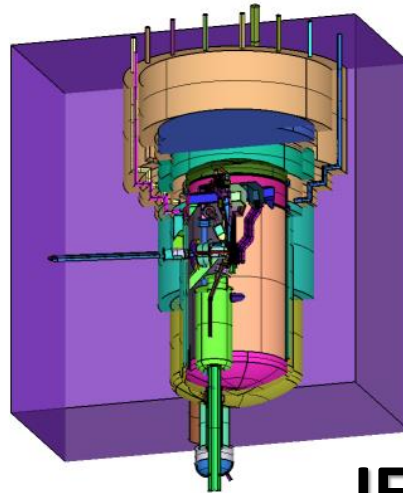
Nuclear Data Needs for Fusion – ITER, IFMIF, DEMO

U. Fischer

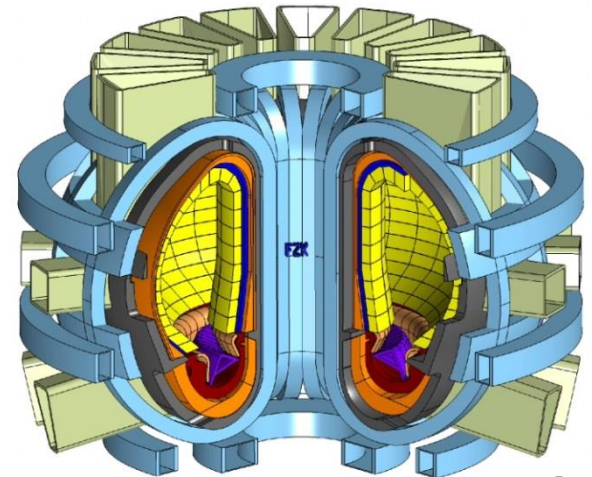
Association KIT-Euratom, Institute for Neutron Physics and Reactor Technology



ITER



IFMIF



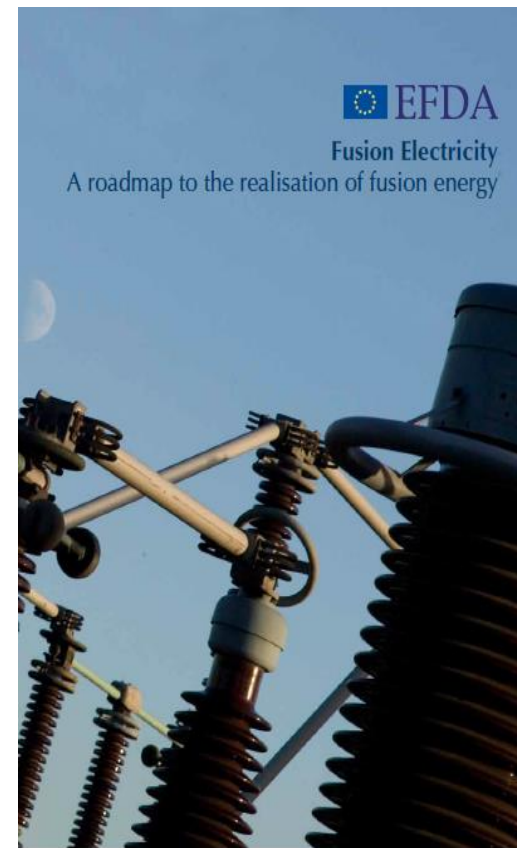
DEMO

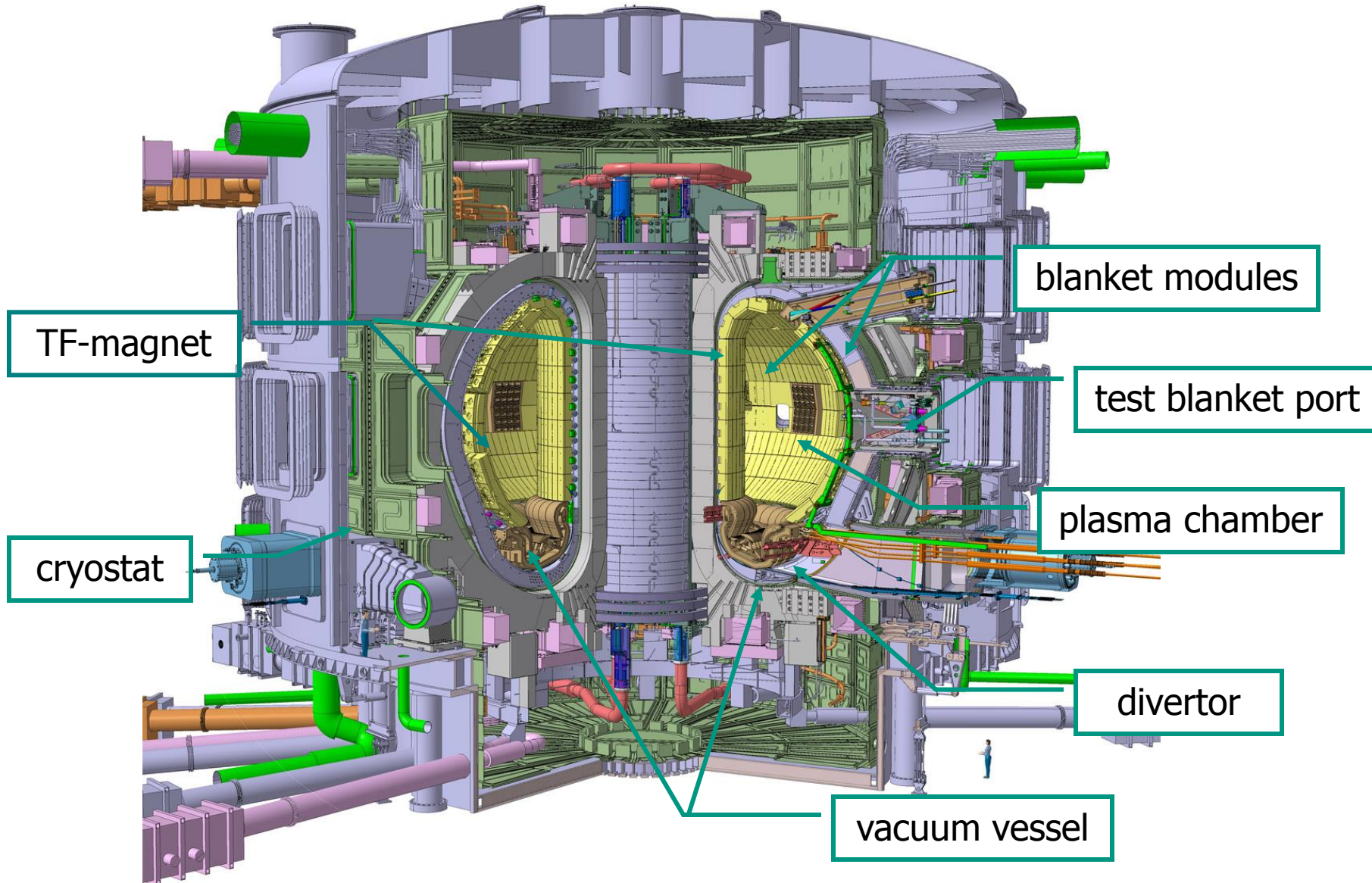
- EU fusion roadmap
- Nuclear data for fusion technology
 - What are we aiming for ?
 - What is required to this end ?
 - What do we have available ?
 - What need to be developed ?

European Fusion Roadmap

Goal: *Realization of fusion as energy source for electricity by 2050 (Fusion Power Plant, FPP, to provide electricity to the grid)*

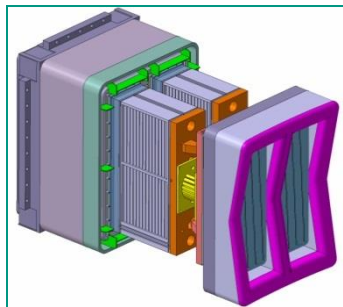
- Included in Strategic Energy Technology Plan (“SET-Plan”).
- “Horizon 2020”
 - Implementation of Fusion Roadmap
 - Aim: Achieve all know-how required to start construction of DEMO by 2030
- Requires three major facilities:
 - ITER – key facility for “next step” (2020)
 - Dedicated “elementary” neutron source for material development (2025)
 - “Early” DEMO (2030)





- HCPB and HCLL TBM test assemblies for equatorial test blanket port of ITER
- MCNP model of port plug includes:
 - HCPB TBM (developed by KIT)
 - HCLL TBM (developed by ENEA Frascati)
- TBM port plug model integrated into A-lite MCNP model of ITER

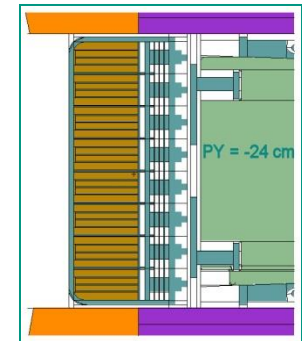
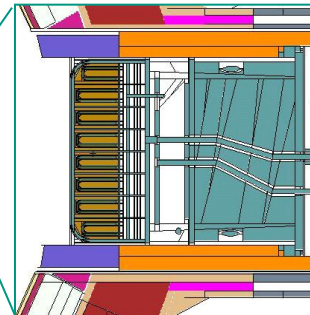
TBM port plug (CAD)



McCad



TBM port plug with
HCPB TBM (MCNP)



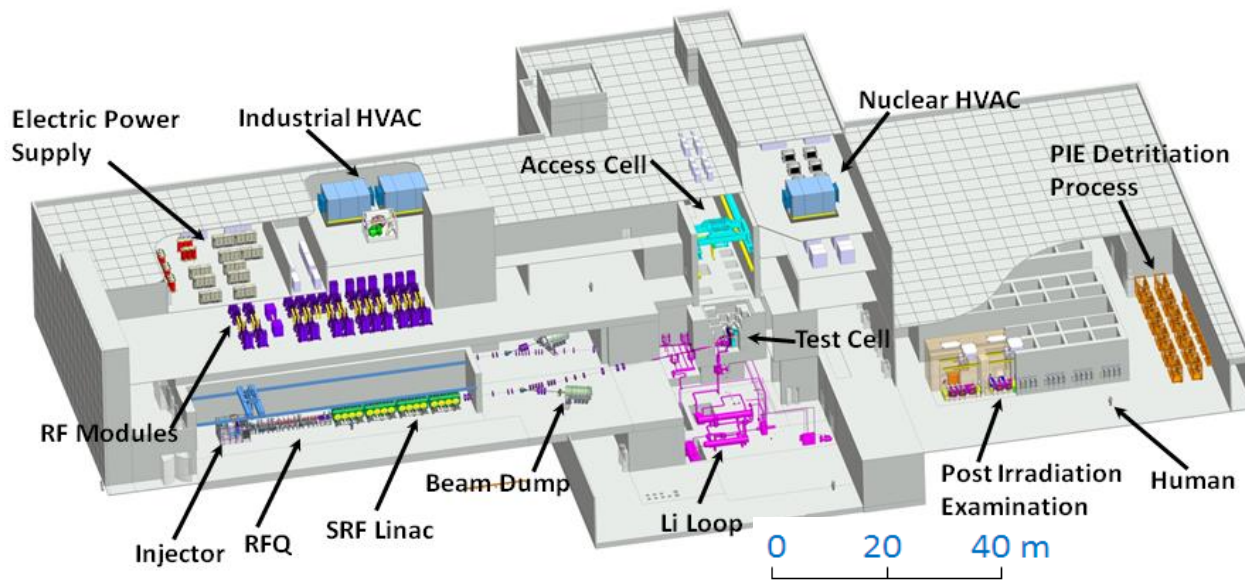
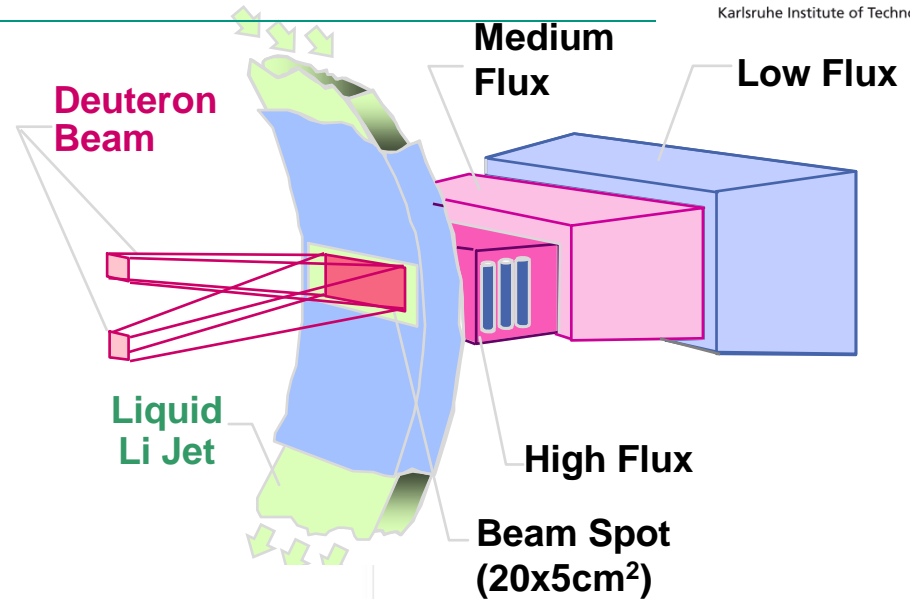
HCLL TBM
(vertical cut)

HCLL & HCPB TBM
systems
(horizontal cut)



IFMIF Intense Neutron Source

- Deuteron beams:
 - $2 \times 125 \text{ mA}$
 - $E_d = 40 \text{ MeV}$
- Neutron production:
 - $\approx 1.1 \times 10^{17} \text{ s}^{-1}$



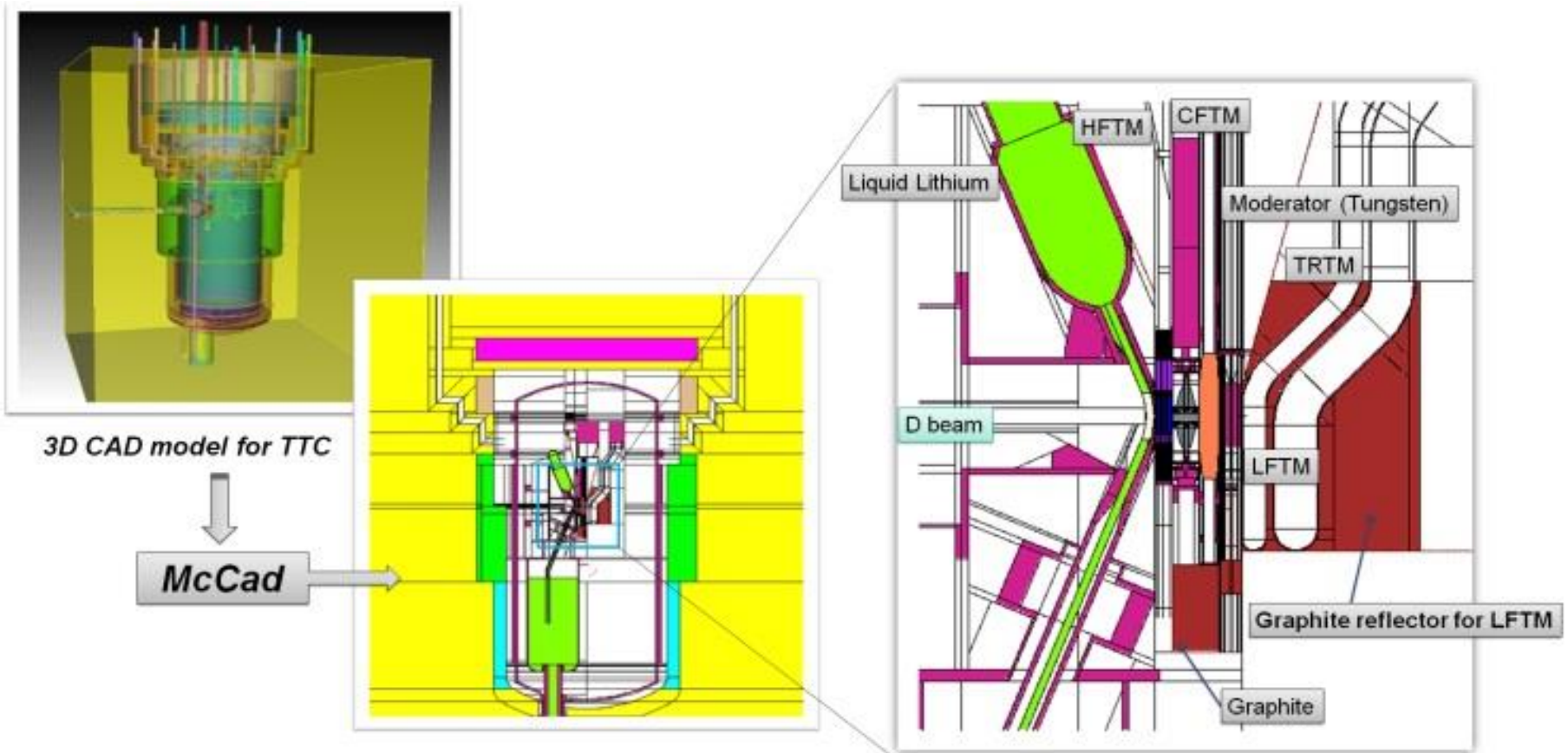
• Test volumes:

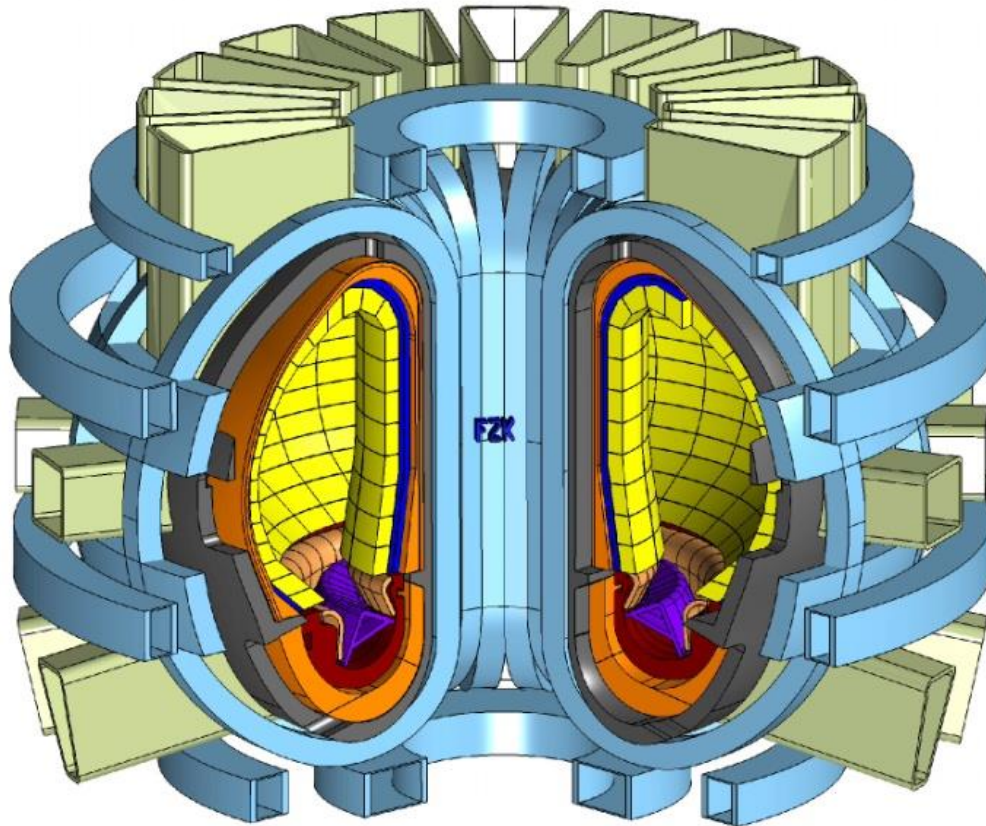
- high flux:
 $0.5 \text{ L} > 20 \text{ dpa/fpy}^{(*)}$
- medium flux:
 $6 \text{ L} > 1 \text{ dpa/fpy}$,
- low flux:
 $7.5 \text{ L } 0.1\text{-}1 \text{ dpa/fpy}$

()fpy = full power year*

IFMIF Target & Test Cell

- Target & Test Cell (TTC) including TTC vessel, target assembly, test modules (HFTM, MFTM, LFTM), cover, coolant pipes, deuteron beam ducts
- Model for neutronics calculations with MCNP/McDeLicious Monte Carlo code





Main DEMO parameters

Major radius [m]	9.0
Minor radius [m]	2.25
Fusion power [MW]	2119
Gross Electric [MW]	849
Net Electric [MW]	500
Auxiliary heating [MW]	51.8
He pumping power [MW]	200
Magnetic field B [T]	7.2
Plasma current [MA]	16.44
Elongation, k_{95}	1.66
Triangularity, δ_{95}	0.33

Breeder Blanket Development

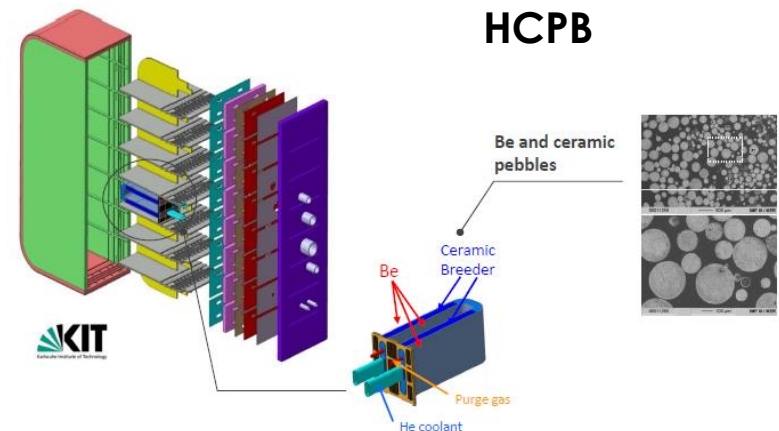
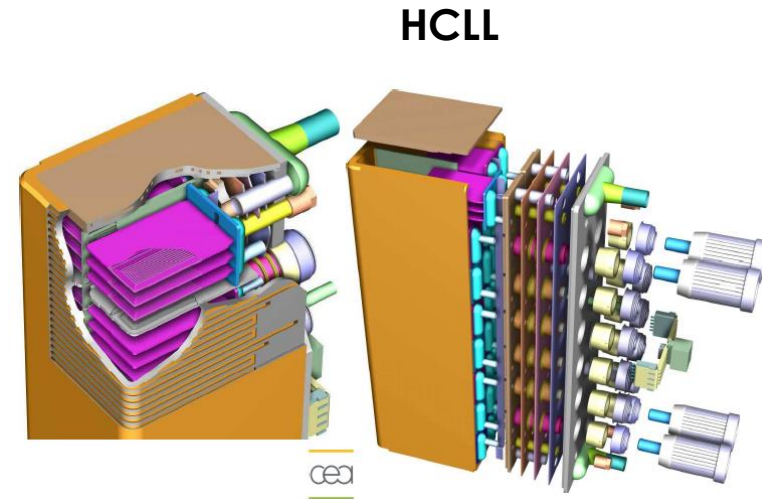
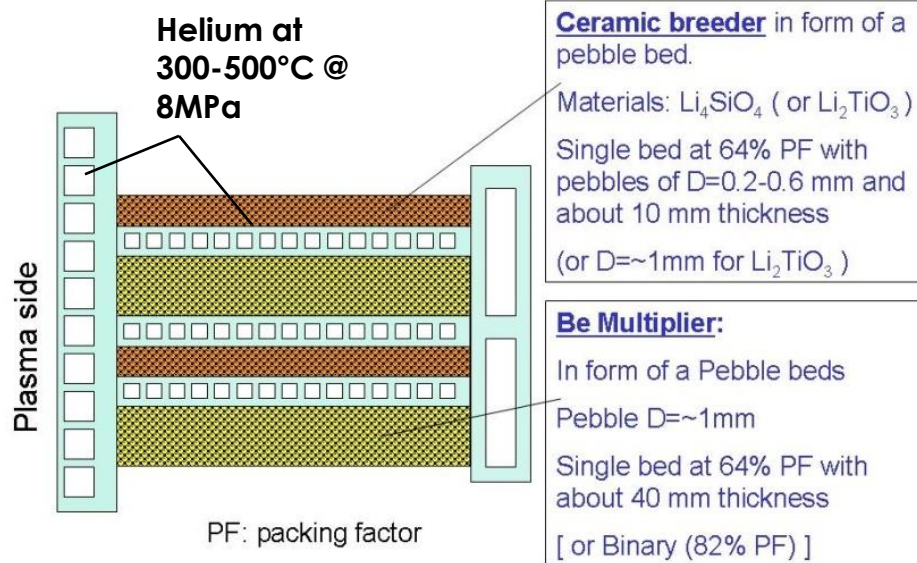
Reference designs considered for testing in ITER

- Helium-Cooled Pebble Bed (HCPB) Blanket
- Helium-Cooled Lithium Lead (HCLL) Blanket

Other options considered for DEMO

- Water Cooled Lithium (WCLL)
- Dual Coolant Lithium Lead (DCLL)

⇒ *Development being conducted within
Eurofusion project on DEMO (1/1/2014)*



What are we aiming for ?

Implications for the Development of Nuclear Data for Fusion Technology

- Nuclear Data required for:
 - Design and optimisation analyses of components/materials and entire facilities/plants
 - Evaluation of nuclear performance of components (at facility operation)
 - Evaluation of safety performance at operation and during shut-down periods
 - Nuclear waste strategies and environmental impact analyses
- ITER, IFMIF, DEMO

Which kind of nuclear data ?

- Particle transport simulations
 - General purpose neutron cross-section data incl. secondary energy/angle distributions
 - Photon production and interaction cross section data
 - Nuclear responses: reaction cross-sections, energy deposition
- Nuclide inventory calculations
 - Activation/transmutation cross-sections (excitation functions)
 - Gas production cross-sections
 - Radioactive decay data
- Radiation damage
 - Displacement energy and damage cross-section data
 - Secondary particle energy spectra
- Uncertainty assessments
 - Co-variance data
- n-induced + d (and p) induced data for IFMIF

Which materials ?

Materials/Elements for ITER Nuclear Analyses

- Test Blanket Modules (TBM)
 - Be (multiplier, first wall armour)
 - Li_4SiO_4 (Li_2TiO_3), Pb-Li
 - **Eurofer** (Fe, Cr, W, Ta, V, Mn, C,)
 - He (coolant)
- Plasma facing components
 - Be, W
 - Cu/Cu alloy (CuCrZr, CuAl25)
- Shield modules, vacuum vessel
 - SS-316L (N): Fe, Cr, Ni, Mo, Mn, C, N, ..
 - SS 30467 (2w% B): Fe, Cr, Ni, Mo, Mn, B, C, N, P, S, ..
 - H_2O

Which elements ?

Element Priority List for TBM Nuclear Analyses

Required elements for TBM design:

- Be, Pb, Li, Si, O, Fe, Cr, W, Ta, Cu, Ti, ...

Requirements for data evaluations:

- DDX data for multiple particle emission reactions
 - Secondary particle & recoil spectra (\Rightarrow kerma, dpa)
- Co-variance data for uncertainty analyses
 - \Rightarrow *high priority for TBM design assessment*
- γ - production data for heating calculations
- Isotope evaluations
- Qualified by benchmark analyses

- Highest priority: structural materials of the reduced activation ferritic-martensitic (RAFM) type (Eurofer, F82H).
 - ⇒ A variety of Eurofer specimens will be irradiated in the high flux test module (HFTM) up to the target fluence of 150 dpa.
- Other materials of (possibly) lower priority:
 - SiC, V/V-alloy, divertor materials (e. g. W)
 - Breeder materials, neutron multiplier
 - Ceramic insulators and others

- Breeder Blankets
 - **Eurofer** (Fe, Cr, W, Ta, V, Mn, C,)
 - Li_4SiO_4 (Li_2TiO_3), Pb-Li
 - Be (multiplier)
 - He, H_2O (coolant)
- Plasma facing components
 - W
 - Cu/Cu alloy (CuCrZr, CuAl25)
- Shielding and other materials
 - SS-316 (Fe, Cr, **Ni**, **Mo**, Mn, C, N, ..)
 - WC, B_4C , Nb_3Sn , Al_2O_3 , MgO
 - ... and more

Element	wt% [10^{-2} g/g]
Fe	balance
B	0.001
C	0.105
N	0.040
O	0.001
Al	0.004
Si	0.026
P	0.002
S	0.003
Ti	0.001
V	0.20
Cr	9.00
Mn	0.55
Co	0.005
Ni	0.010
Cu	0.003
Nb	0.005
Mo	0.003
Ta	0.12
W	1.10

Density: 7.87 g/cm³

Reference:

Final Report on the EFDA Article 7 contract EFDA/06-1903 on “Procurement of reduced activation ferritic-martensitic steel type 9CrWTaV (EUROFER) for the TBM fabrication technology trials and mock-ups”, Saarschmiede GmbH, July 2009

Data provided by M. Zmitko, F4E, September 4, 2012

What is available ?

- FENDL: Fusion Evaluated Nuclear Data Library
 - Developed for ITER under co-ordination of IAEA/NDS
 - FENDL-1.0 (1994), -2.0 (1998), 2.1 (2003)
 - FENDL-3.0 (2013)
 - *n, p and d general purpose cross-section data up to 150 MeV*
 - *Specific sub libraries for activation and transmutations calculations*
 - *Shadow library with complete co-variance data*
- General Purpose Nuclear Data Libraries
 - Suitable for fusion applications
 - **JEFF-3.1, -3.2 (EU/OECD)**, ENDF/B-VII (US), JENDL-4 (J), ...
- European Activation File – EAF (CCFE)
 - Activation/transmutation cross-sections with n- data up to 55 MeV, p- and d-data libraries generated by TALYS
 - Adopted by JEFF and FENDL as activation data library (2007/2010)
- TENDL - TALYS Evaluated Nuclear Data Library (NRG)
 - Complete general purpose data libraries for n, p-, and d- induced reactions up to 200 MeV based on (automated) TALYS calculations
 - TENDL-2011 current activation data library of EU fusion programme

What need to be developed ?

■ Nuclear data for ITER

- Developed/provided within FENDL project of IAEA/NDS
- To be improved/updated, validated, extended
- To be supported/"fed" by JEFF data evaluations (F4E/ND consortium)
- **EU focus**: Data relevant to TBM programme (F4E/ND Consortium)

■ Nuclear data for IFMIF

- Developed/provided now with **FENDL-3** (IAEA/NDS)
- To be improved/updated, validated, extended
- To be supported/"fed" by JEFF data evaluations (F4E/ND consortium)
- **EU focus (F4E/ND Consortium)**:
 - Data relevant to material degradation (gas production, damage)
 - Transmutation/activation data

■ Nuclear data for DEMO

- To be addressed by EU fusion programme (F4E/ND consortium) and provided to/ fed in JEFF data library
- Focus on general purpose data evaluations incl. co-variance data specific to DEMO and activation data for safety & waste assessment

- Supported by Fusion for Energy (F4E), Barcelona, with Framework Partnership Agreements (FPA) and Grants
 - Consortium on “**Nuclear Data Development and Analysis**” including CCFE (UK), CIEMAT (E), JSI (SL), KIT (D), NRG (NL), TUW (AUS), IFIN-HH (RO), led by KIT.
 - Consortium on “**Nuclear Data Studies/Experiments in Support of TBM Activities**” including AGH-UST (PL), CCFE (UK), ENEA (I), KIT (D), JSI (SL), NPI (CR), led by ENEA.
- Running grants awarded by F4E to the two Consortia:
 - Specific Grant on “**Nuclear Data Improvements and Development of Tools - Nuclear Data Evaluation**” (April 2012 - 2014).
 - Specific Grant on “**Nuclear Data Experiments and Measurement Techniques**” (July 2013-2015).
- Reporting and exchange with **JEFF community** through joint sessions (“Fusion Working Group”, FWG) and inclusion of data evaluations in the **JEFF data library**