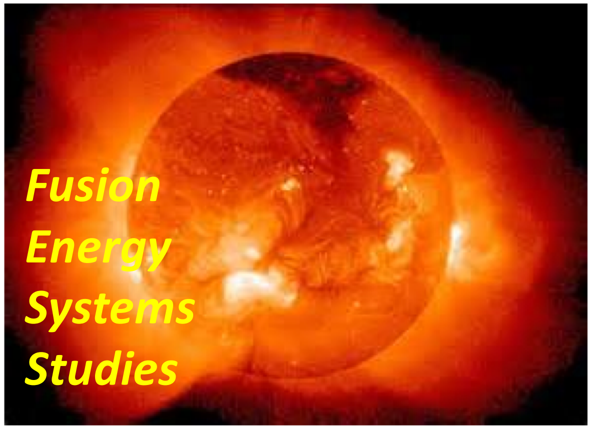
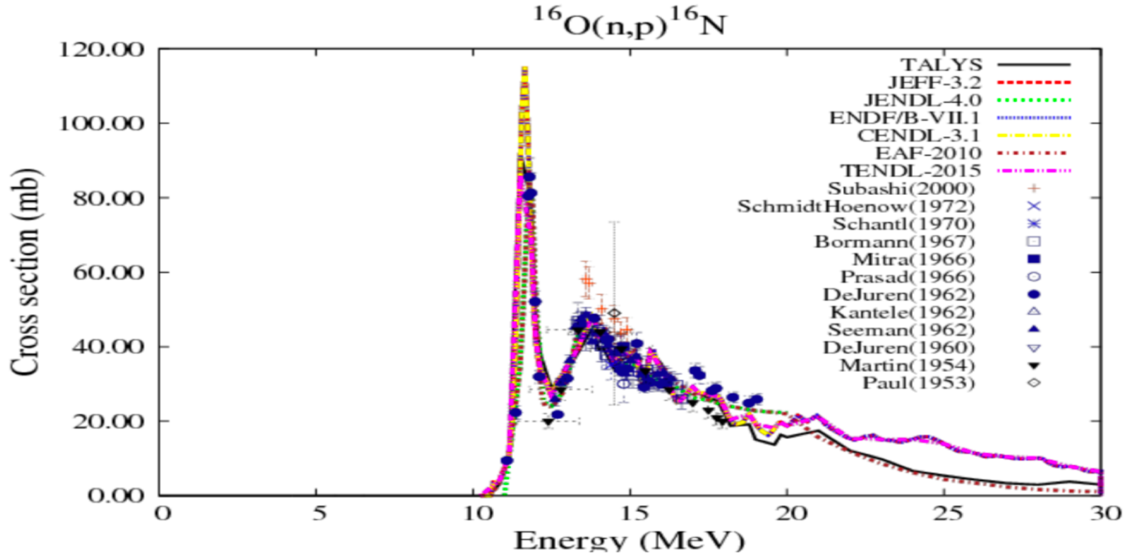




Fusion Nuclear Science Facility – *Nuclear Analysis and Data* are Central to its Design and Success

C. E. Kessel, ORNL

Workshop on Applied Nuclear Data Activities, GWU, Jan 22-24, 2019

We Hope to Build and Operate a Fusion Nuclear Science Facility by ~ 2040 - 2050

We have begun to explore what this "first" fusion nuclear facility will do in its program and what R&D is required before to prepare for this facility

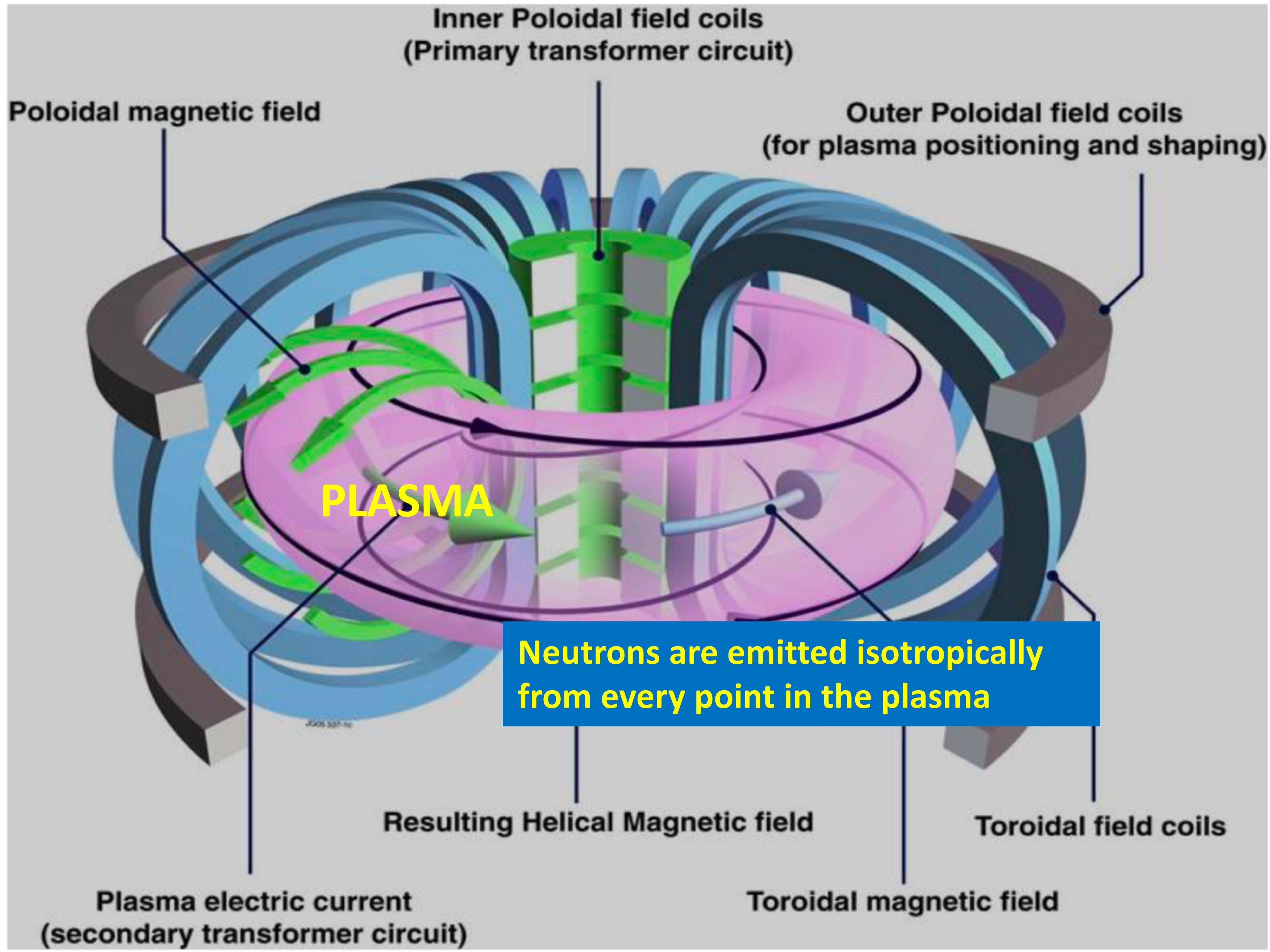
Fusion devices are generally toroidal in shape, like a donut

A high temperature plasma composed of deuterium and tritium is used to generate fusion power via D + T → **He_4 (3.5 MeV)** + **n (14 MeV)**

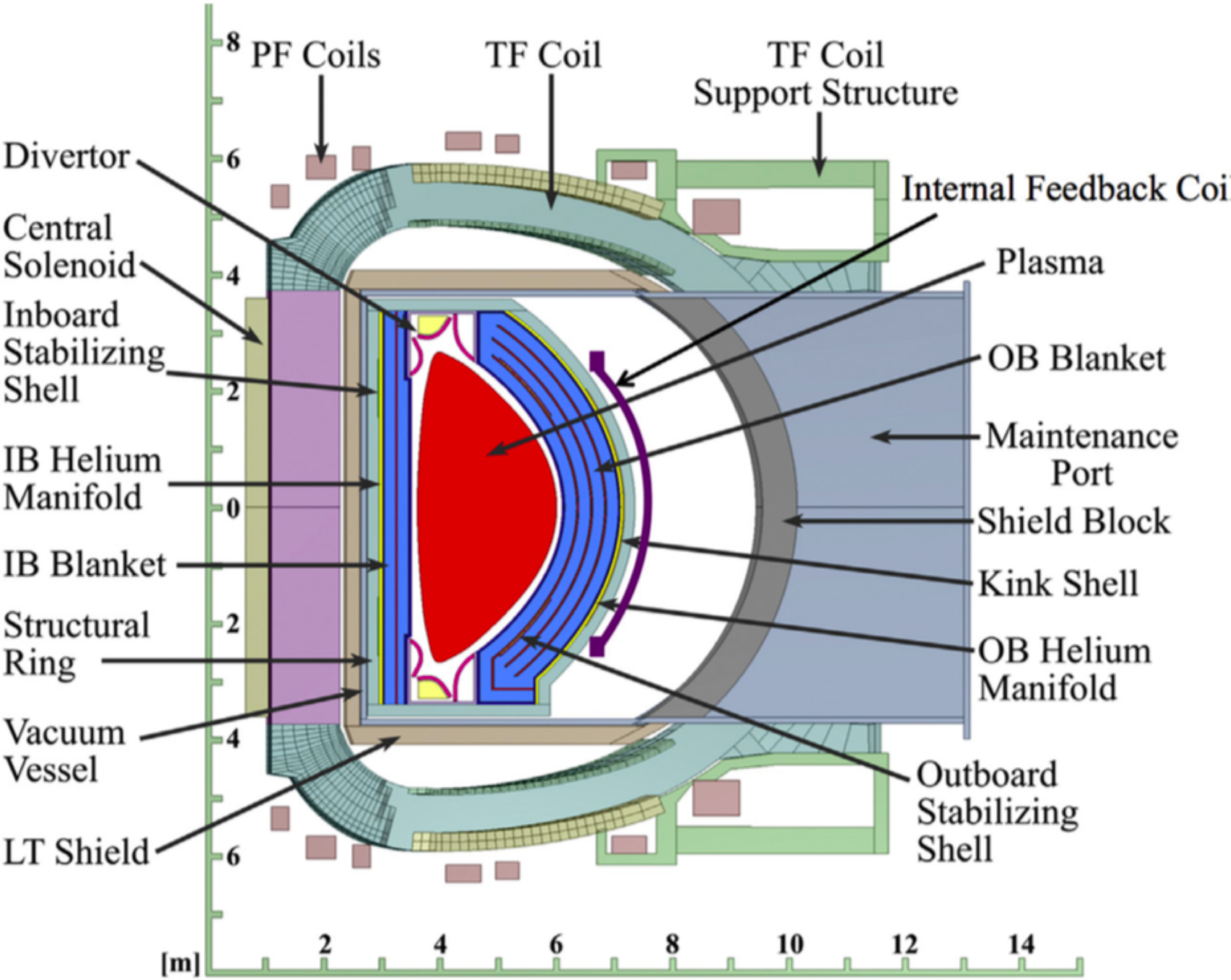
The plasma (neutron source) is surrounded by structures that provide various functions:

- Breed tritium fuel
- Absorb neutron heating
- Shield sensitive components from the neutrons
- Inject power into the plasma for heating and fuel for nuclear reactions
- Sustain the vacuum conditions required for plasma
- Create the strong magnetic fields required to confine the plasma
- Provide diagnostics for plasma and fusion core
- Control of plasma behavior

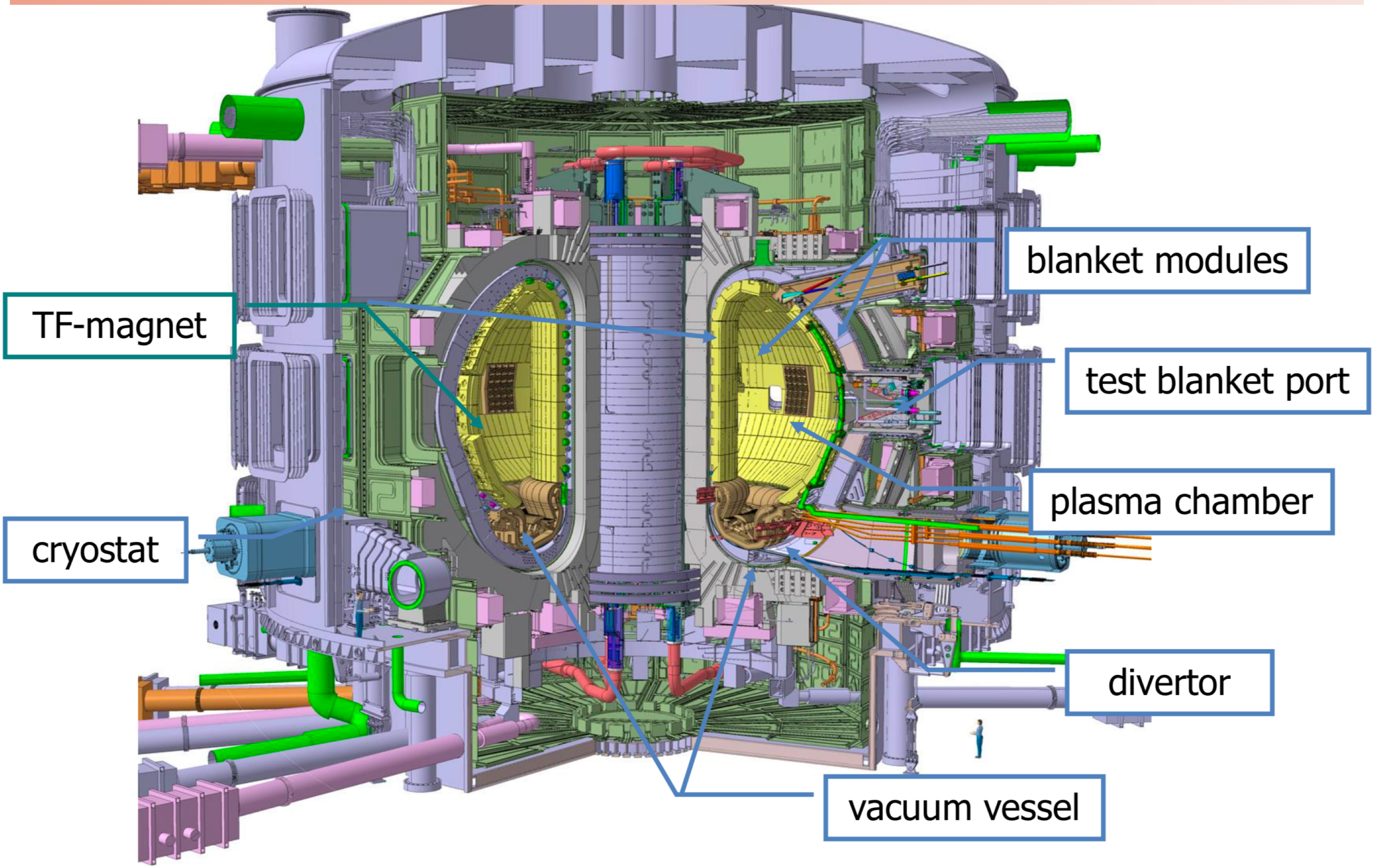
Tokamak


Inner Poloidal field coils
(Primary transformer circuit)
Poloidal magnetic field
Outer Poloidal field coils
(for plasma positioning and shaping)
PLASMA
Neutrons are emitted isotropically
from every point in the plasma
Resulting Helical Magnetic field
Toroidal field coils
Plasma electric current
(secondary transformer circuit)
Toroidal magnetic field

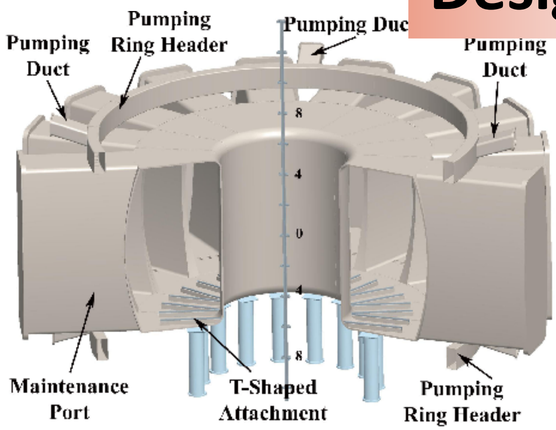
Fusion Nuclear Science Facility

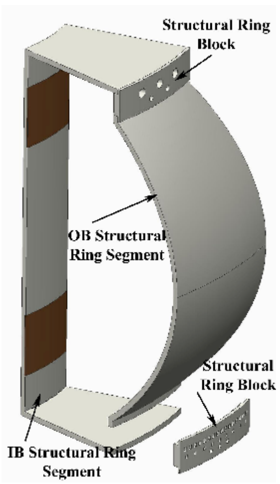


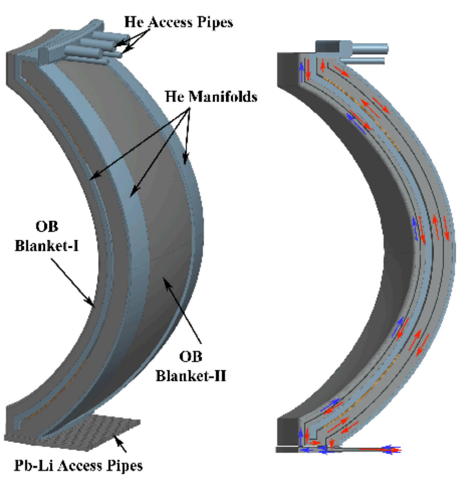
ITER (International Tokamak Experimental Reactor)



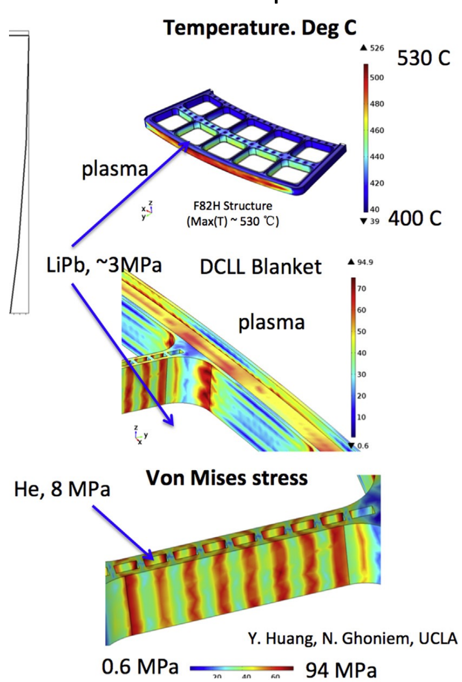
Design







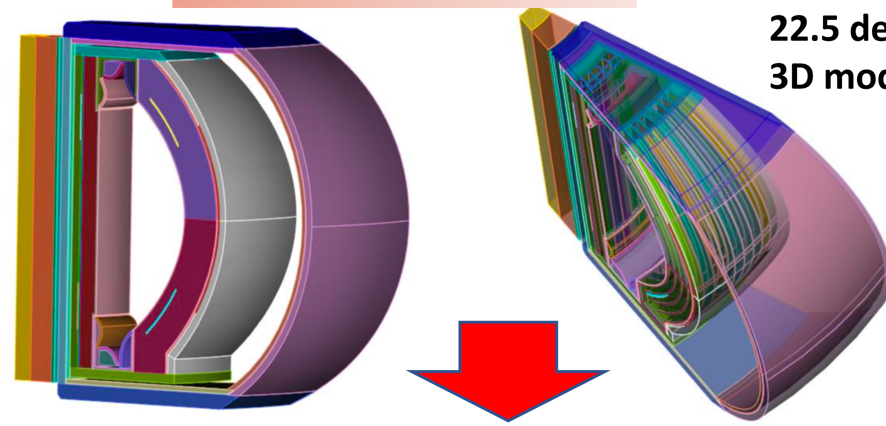
- Thermo-mechanics
- Materials
- Liquid metal/ceramics
- Thermal hydraulics
- Maintenance/hot cell
- Tritium fuel cycle
- Accident analysis, safety
- Waste and disposal



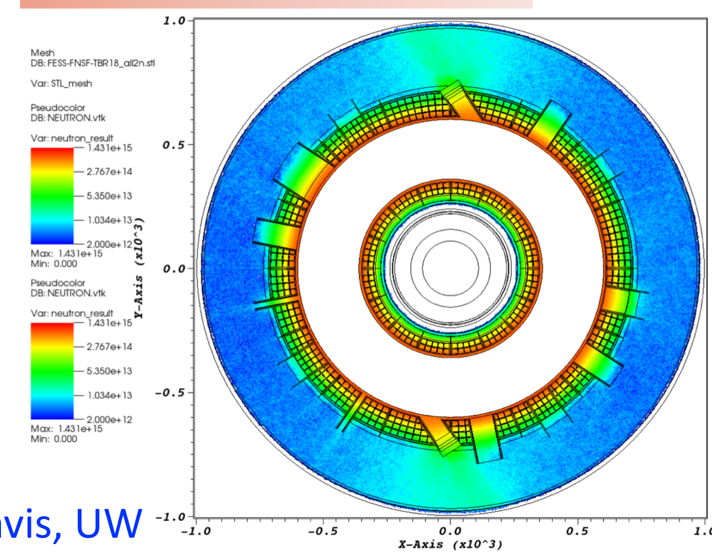
T. Bohm, UW

Nuclear Model

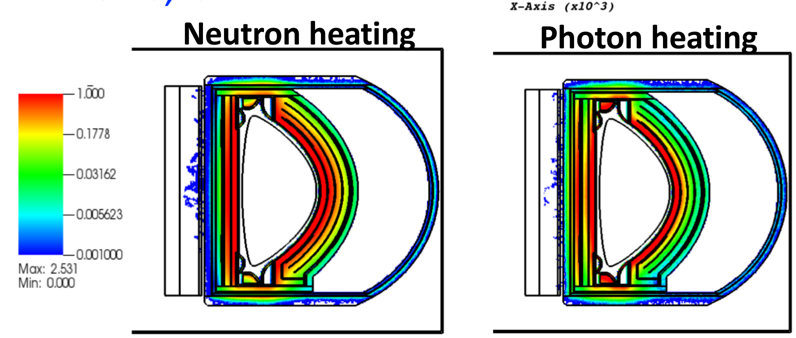
DAGMC/MCNP5
FENDL 2.1
22.5 deg
3D model



Nuclear Analysis



A. Davis, UW



What we want to know, and why

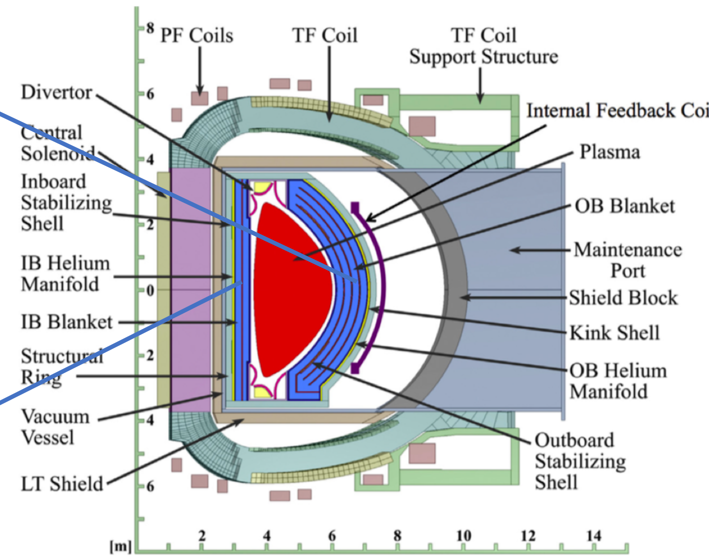
Nuclear Heating	Designing numerous components in the fusion core and beyond
Tritium Breeding Ratio	Wide range of different materials in affected nuclear zone
Material damage, displacements per atom (dpa)	Strong variations in n-flux and n-energy spectrum through thick components, and close and far components from the neutron source
He and H production	
Transmutations production	Optimize the materials for their environment (ϕt, dpa, He, H), long lives and functionality
Photon fluxes	
Shutdown dose	Accident scenarios, targeting passive safety
Decay Heat	
Waste management	Waste reduction, targeting shallow land burial for all waste

Radiation Damage in the FNSF

Computations with 3D MCNP (DAGMC) on CAD geometry

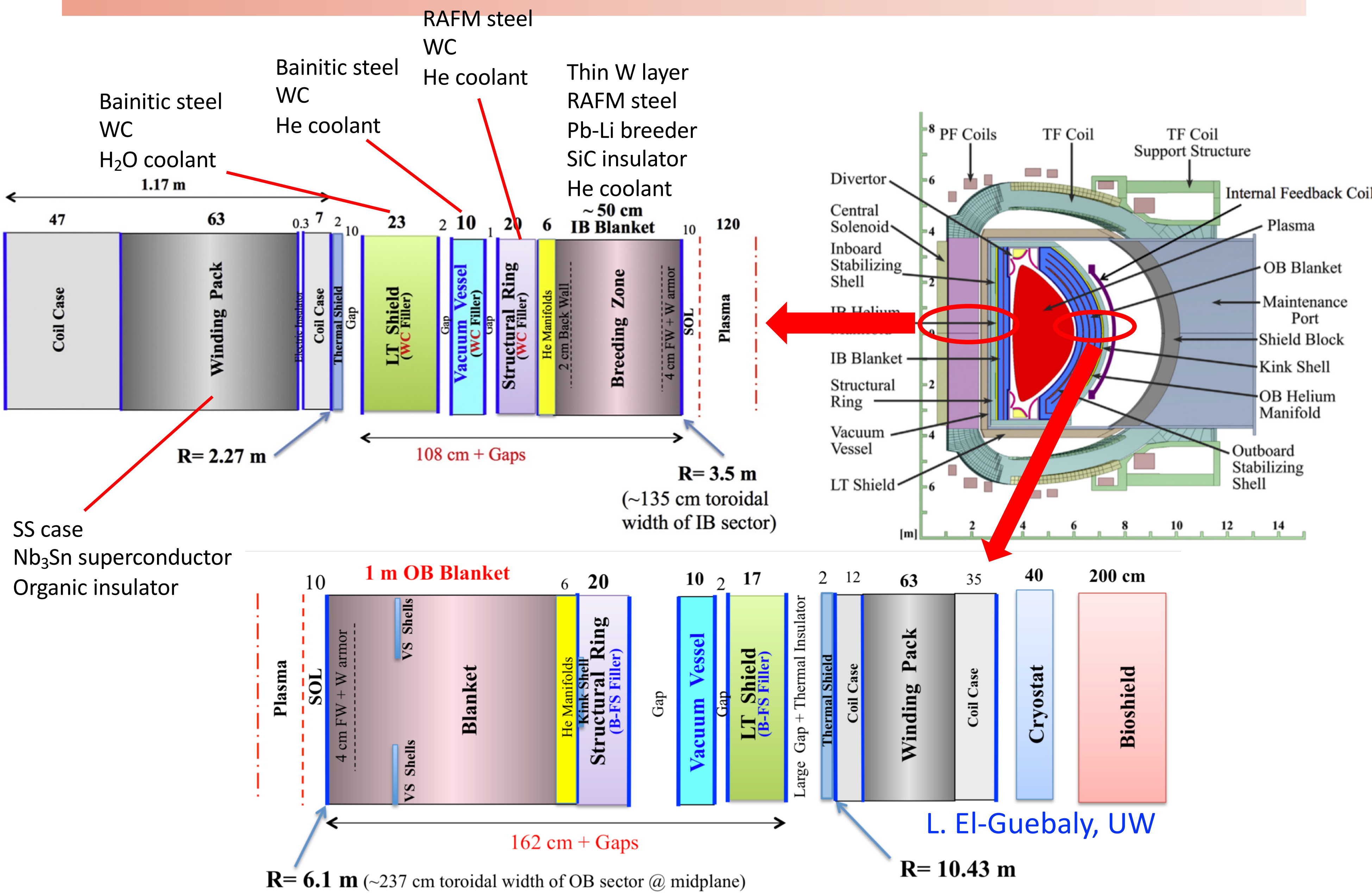
	Dpa/FPY	appm He/FPY	appm H/FPY
OB, first wall	15.30	154.6	692.0
OB, shield	0.120	0.010	0.050
OB, vacuum vessel	0.010	0.003	0.003
OB, LT shield	0.008	3e-4	1.2e-3
IB, first wall	13.70	137.3	613.5
IB, shield	2.600	1.700	7.900
IB, vacuum vessel	0.150	0.310	0.250
IB, LT shield	0.024	0.013	0.067

A. Davis, UW, FED2018



Dpa = displacements per atom
appm = atomic part per million
FPY = full power year

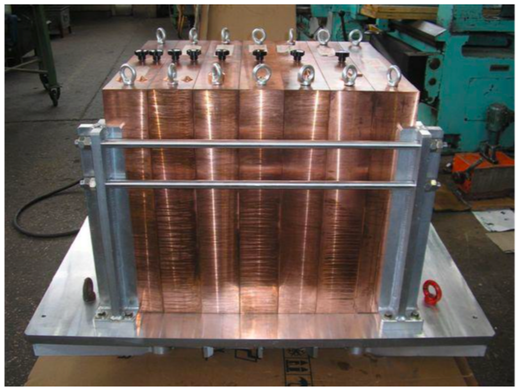
What is in the radial build of the FNSF?



Integral experiments are essential for checking the quality of nuclear data

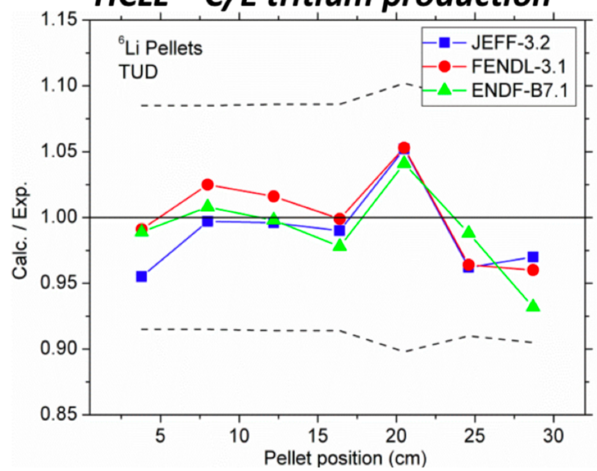
These activities are primarily done by EU

"point neutron source"

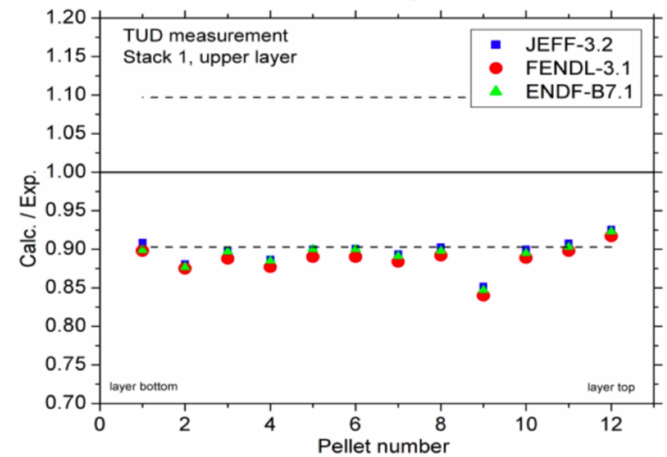


Frascatti Neutron Generator

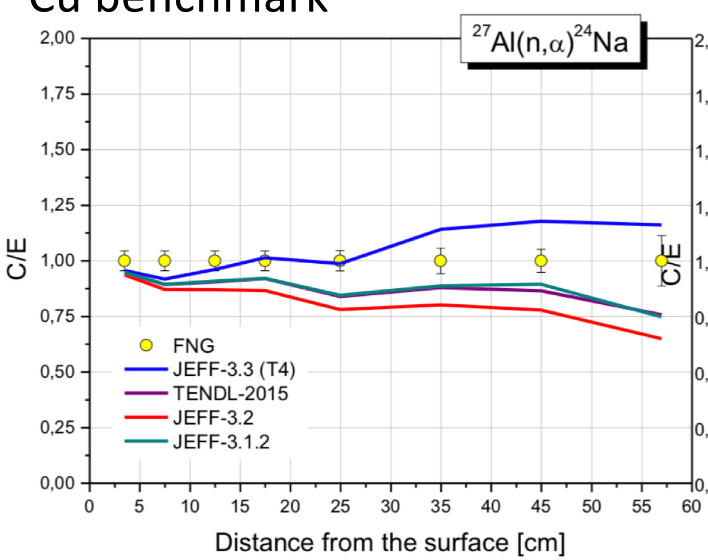
HCLL – C/E tritium production

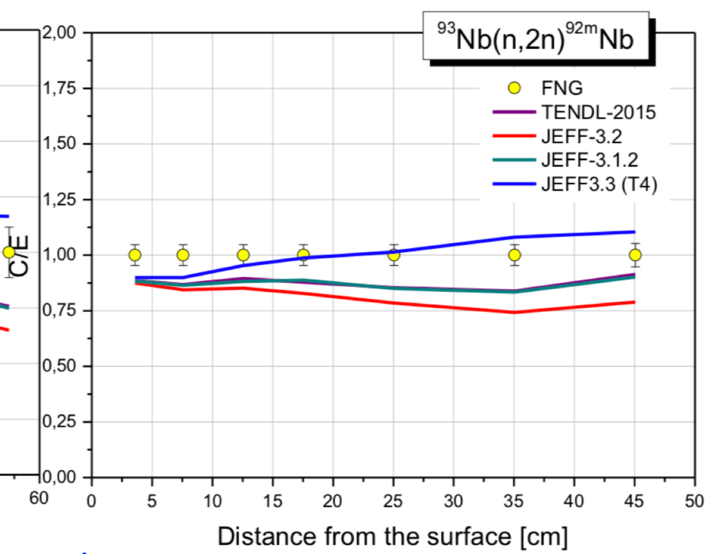


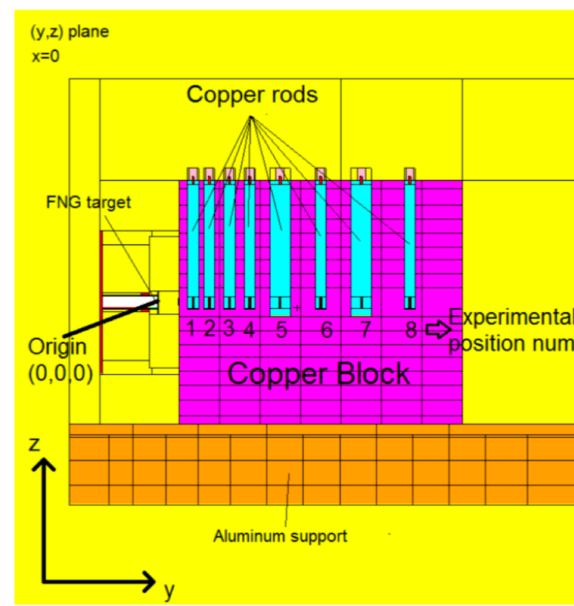
HCPB – C/E tritium production



Cu benchmark







U. Fischer

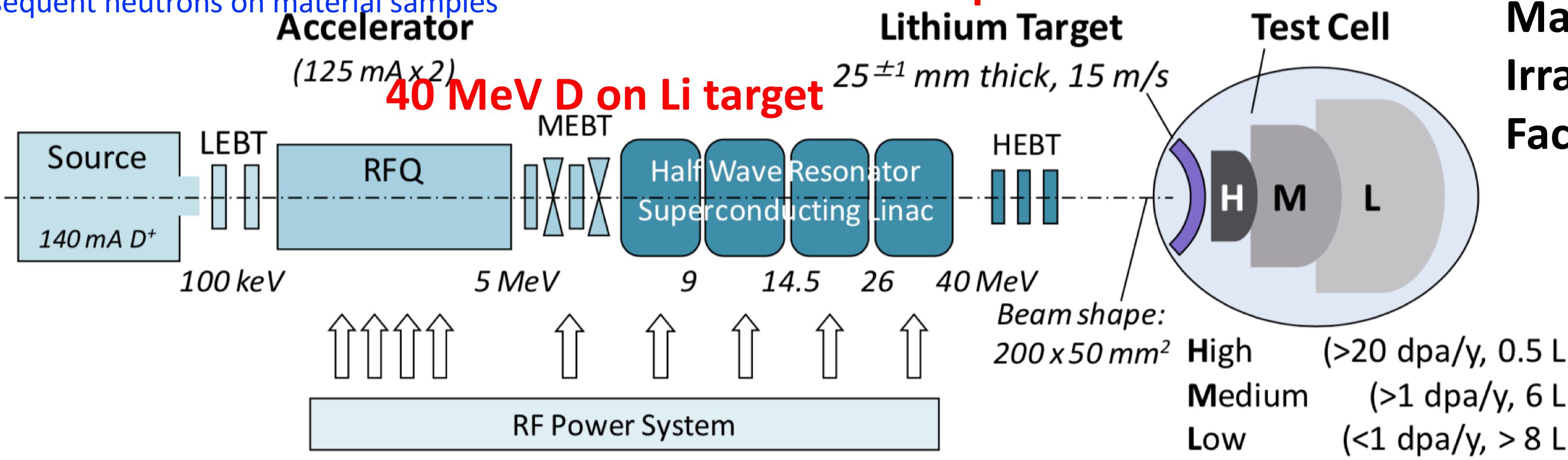
Fusion Requires a Fusion Prototypic Neutron Source to Explore Materials Behavior Before Moving to a Fusion Nuclear Facility

IFMIF (Int'l Fusion Materials Irradiation Facility

Nuclear data needs for accelerated particle and target, and subsequent neutrons on material samples

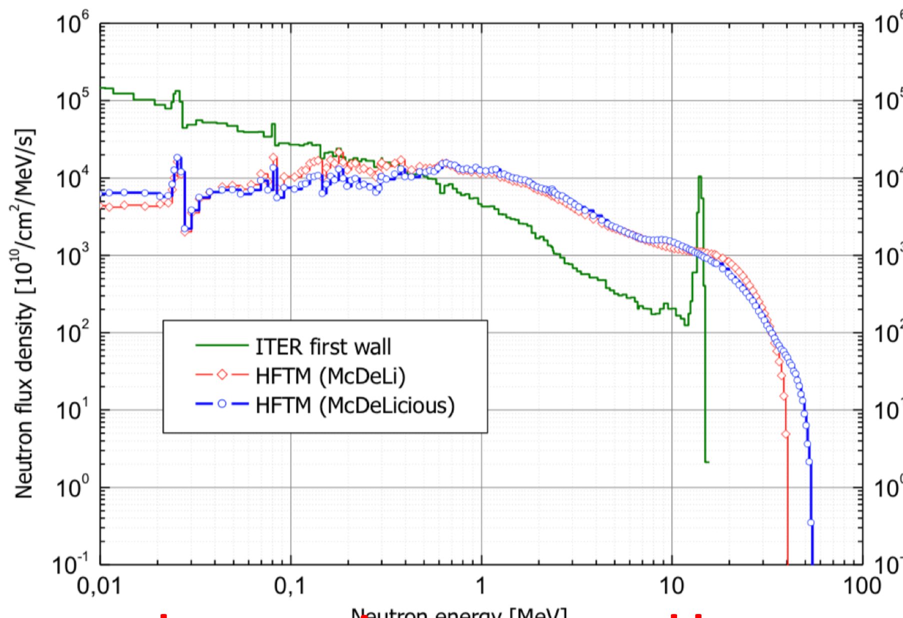
Up to 55 MeV neutrons

40 MeV D on Li target



- Deuteron beams:
  - 2 x 125 mA
  - E_d = 40 MeV
- Neutron production:
  - $\approx 1.1 \times 10^{17}\ s^{-1}$
  - *Max. neutron flux density (at back plate): $1.2 \times 10^{15}\ cm^{-2}s^{-1}$*

U. Fischer



Other ideas include spallation, other low energy nuclear reactions, e-γ-n, and beam reactions

Design of Fusion Nuclear facilities requires intensive nuclear analysis to optimize performance

Materials "damage" is one of several nuclear responses that **seriously impact fusion** nuclear systems, overall it determines **when a material has reached its end of life**

The **fusion environment** is complicated with **varying materials, neutron fluxes, n- energy spectra**, …. AND operating temperatures, operating stresses, corrosion, and their gradients

Gas production (transmutation, He and H) is a major contributor to material degradation

Displacement damage cross-section is based on NRT formulation, more accurate approaches may exist (NEA/NSC/DOC(2015)9, www.oecd-nea.org), but displacement damage is found to be similar to fission

Fusion will require a **Fusion Prototypic Neutron Source (FPNS)** (important nuclear data needs) to establish individual material behavior (coupons) in a neutron environment, in order to qualify materials for use in a FNSF……

but the complex in-service environment of the **FNSF is expected to provide new material behaviors**, providing another necessary step in **material qualification requiring detailed nuclear simulations and accurate nuclear data**

FNSF Program

Phase	1	2	3	4	5	6	7	
	He/H	DD	DT	DT	DT	DT	DT	PP
years	1-2	2-3	2.75	4.5	5.0	6.5	6.5	40 FPY
N_w^{peak}, MW/m^2			1.75	1.75	1.75	1.75	1.75	2.25
Plasma on-time, %/year		15-50	15 55 d	25 91 d	35 128 d	35 128 d	35 128 d	85 310 d
Plasma duty cycle, % (pulse/dwell)			33 (1d/2d)	67 (2d/1d)	91 (5d/.5d)	95 (10d/.5d)	95 (10d/.5d)	100%
Peak dpa Peak He, appm Peak H, appm			7.2 73 325	19.7 200 894	30.6 310 1388	39.8 403 1806	39.8/79.6 403/806 1806/3612	150-200
Max/min blanket structure op temp, °C	< 550	< 550	550/400	550/400	600/450	650/500	650/500	650/500
Blanket Structure material	RAFM Gen1	RAFM Gen1	RAFM Gen1	RAFM Gen1	RAFM-CNA	RAFM-CNA & ODS	RAFM-ODS	

25.3 years DT, 7.8 years neutrons, 650 plasma pulses