The Spherical Tokamak Components Test Facility

Rapporteured by Howard Wilson
representing

Plasma Science and Fusion Engineering Conditions of Spherical Torus Component Test Facility

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A Steady State Spherical Tokamak for Components Testing

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Plasma Science and Fusion Engineering Conditions of Spherical Torus Component Test Facility

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A Steady State Spherical Tokamak for Components Testing

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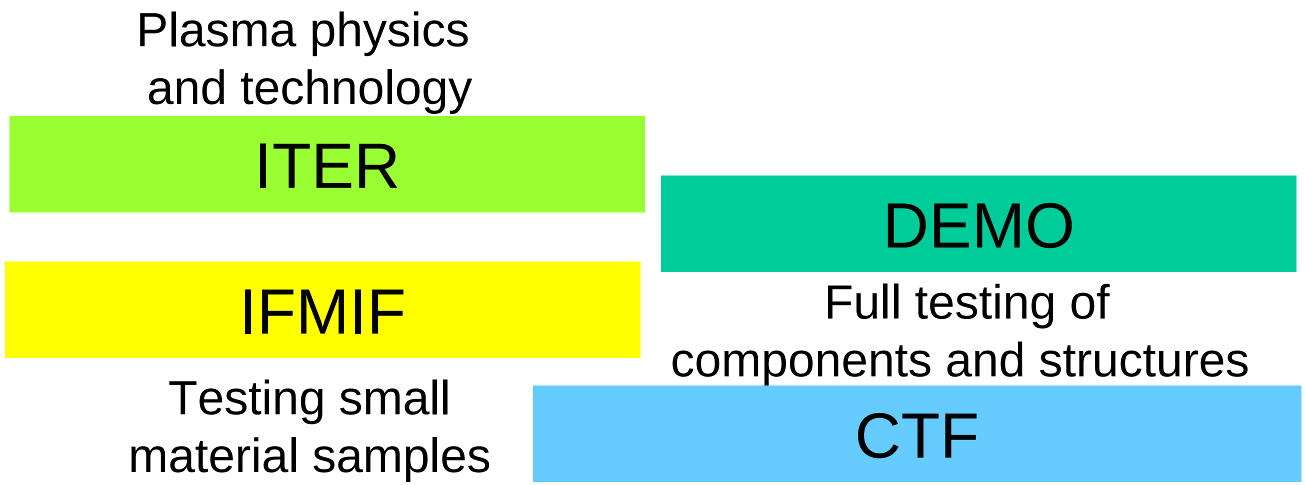
Outline

- Motivation
- Why a spherical tokamak
- Design features
- Plasma physics studies
- Conclusions

Motivation

- The present strategy for addressing plasma physics, fusion technology and materials is through ITER, IFMIF and DEMO:



- A dedicated, small scale Components Testing Facility would provide support for DEMO:
  - Greater flexibility
  - More rapid blanket-testing capability

The Goals of a CTF

- The conditions necessary for testing were identified by an international committee [1]:
  - A fusion neutron wall loading in the range 1-2MWm^{-2}
  - Steady state operation
  - A total neutron fluence of ~6MW-yrm^{-2} within ~12 years
  - Total test area exceeding 10m^2
  - Magnetic field strength exceeding 2T

- We explore the possibility that a driven burning plasma spherical tokamak can meet these requirements

[1] Abdou, et al, Fusion Technology ***29*** *(1996)1*

ORNL/PPPL and Culham strategies are complementary

The size of the device has implications for tritium management:

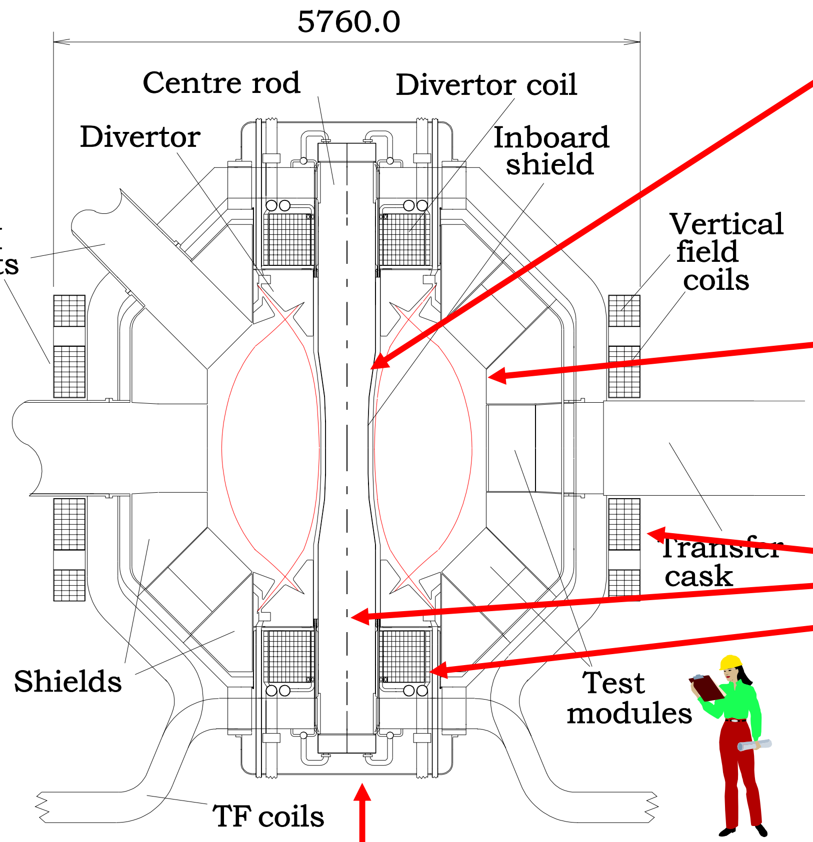
- Culham and ORNL/PPPL adopt complementary approaches

- The ORNL/PPPL study explores a larger device:
  - Benefit: able to test tritium generation towards self-sufficiency, including material composition of chamber systems
  - Cost: restricted range of suitable materials

- The Culham strategy is for a compact device:
  - Benefit: does not need to generate tritium
  - Cost: access to optimised regimes limited by tritium availability

Main advantages of an ST as CTF

Culham design (peaked current profile)



Tight aspect ratio means few neutrons absorbed on inner wall

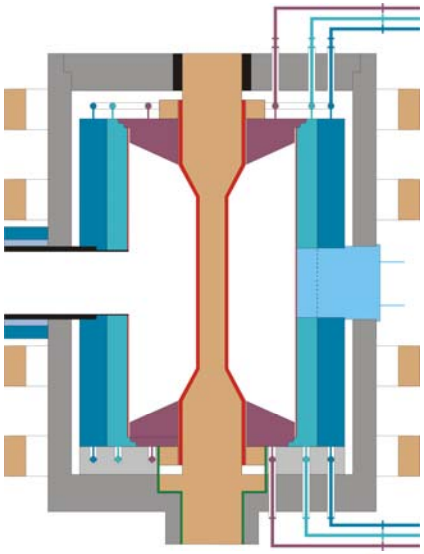
High volume-to-surface area ratio: high fusion power density

All coils are normal-conducting copper

Easy to maintain: centre column and divertor coils drop out through bottom

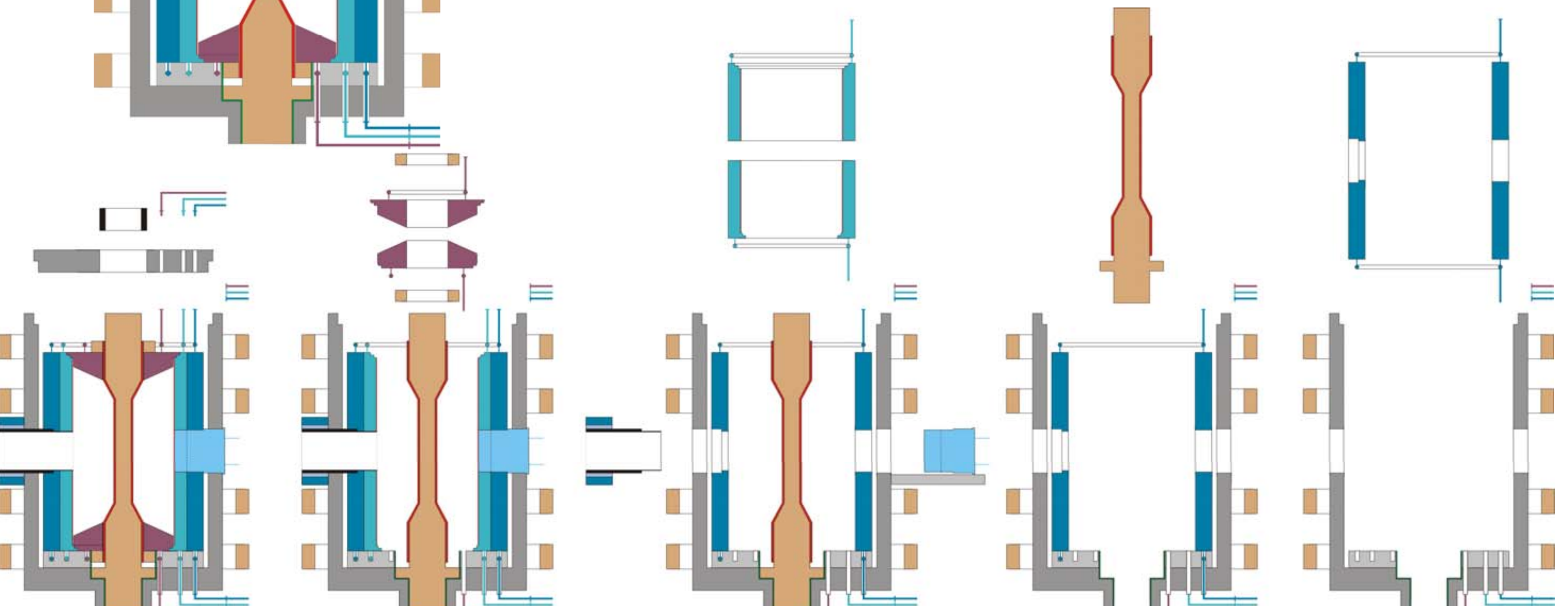
High availability requirement drives the design

ORNL/PPPL design



Machine Assembly/Disassembly Sequence Are Made Manageable

- **Hands-on connect and disconnect service lines outside of shielding and vacuum boundaries**
- **Divertor, cylindrical blanket, TF center leg, and shield assembly removed/installed vertically**



Remove top hatch

Remove PF coils and divertors

Extract NBI liner, test modules and blanket assemblies

Remove centerstack assembly

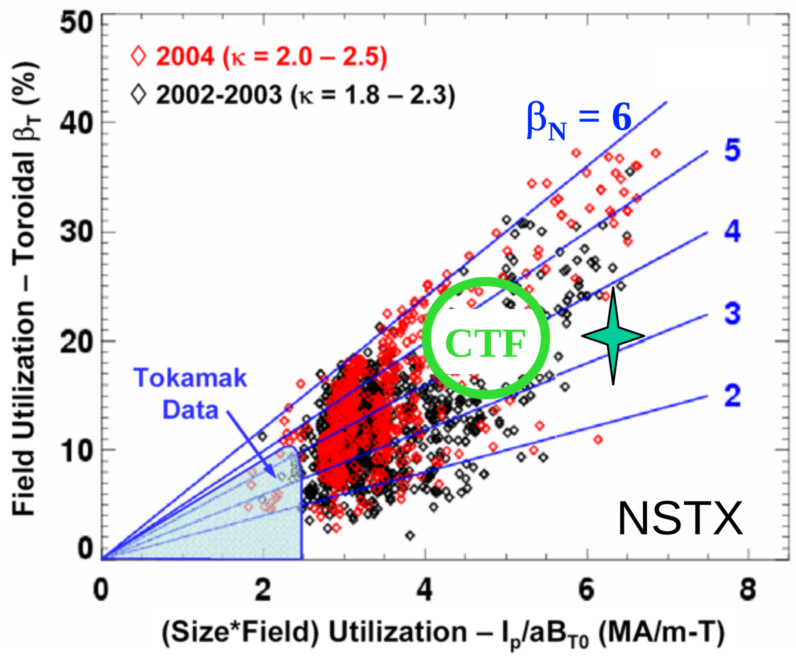
Remove shield assembly

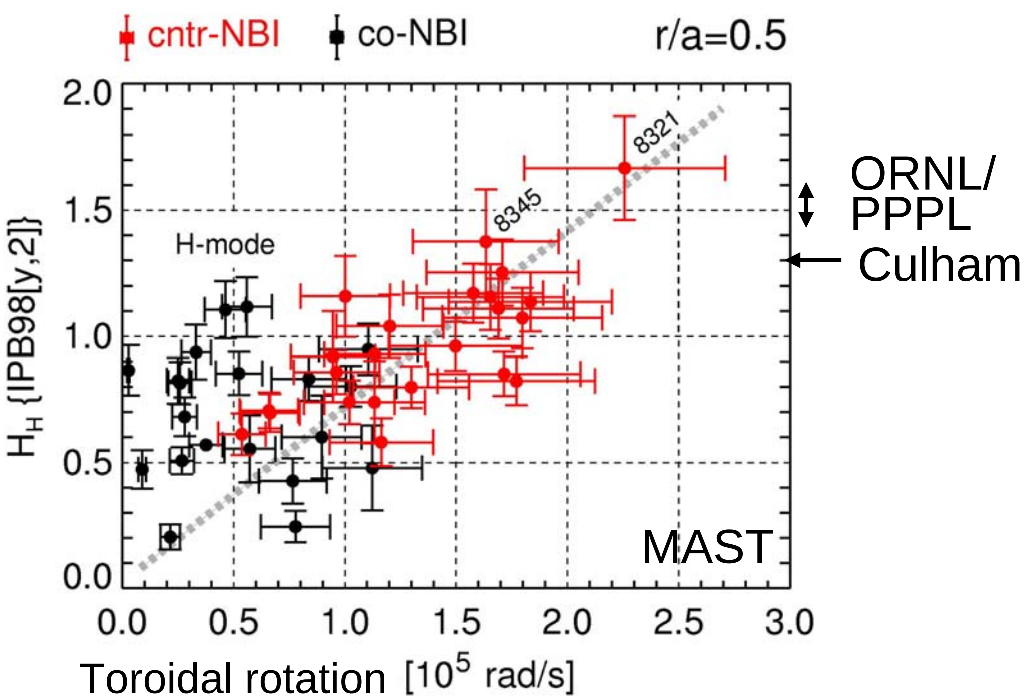
Parameters of the designs

- Key drivers for both designs:
  - High TF (~2.5T) and elongation to allow high plasma current at kink limit
  - Low density for efficient current drive
  - High beta and good confinement

Parameter	ORNL/ PPPL-led	UKAEA-led
Major/minor radius (m)	1.2/0.8	0.75/0.47
Elongation	3.2	2.5
Plasma current (MA)	9.1-12.8	8.0
TF rod current (MA)	15.3	10.5
Normalised toroidal β_N	3.1-3.9	3.5
Toroidal β_T (%)	14-24	21
Confinement $H_{IPB98(y,2)}$	1.6-1.5	1.3
Electron/ion $H_{IPB98(y,2)}$	0.7/4.0	—
Aux heating power (MW)	36-47	60
Fusion power (MW)	72-144	50
Wall loading (MWm^{-2})	1-2	1.5
n/n_{GW}	0.17	0.15

Based on modest assumptions regarding MHD and confinement





Culham design exploits high normalised current

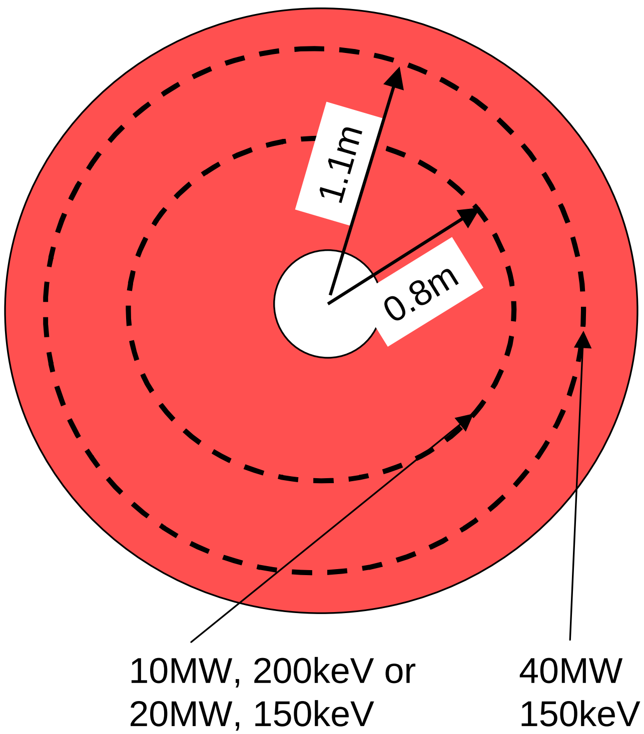
Range of ORNL/PPPL designs sits within NSTX data-set

Assumed confinement enhancement factors are consistent with MAST high rotation plasmas

Consistent with NSTX data, separating electron and ion confinement

Current Drive

- Neutral beam injection provides the main CD for both designs
  - ORNL/PPPL design exploring EBW for off-axis CD (~10MW, 140GHz)
  - Culham design exploring ECCD for on-axis CD (20MW, 160GHz)

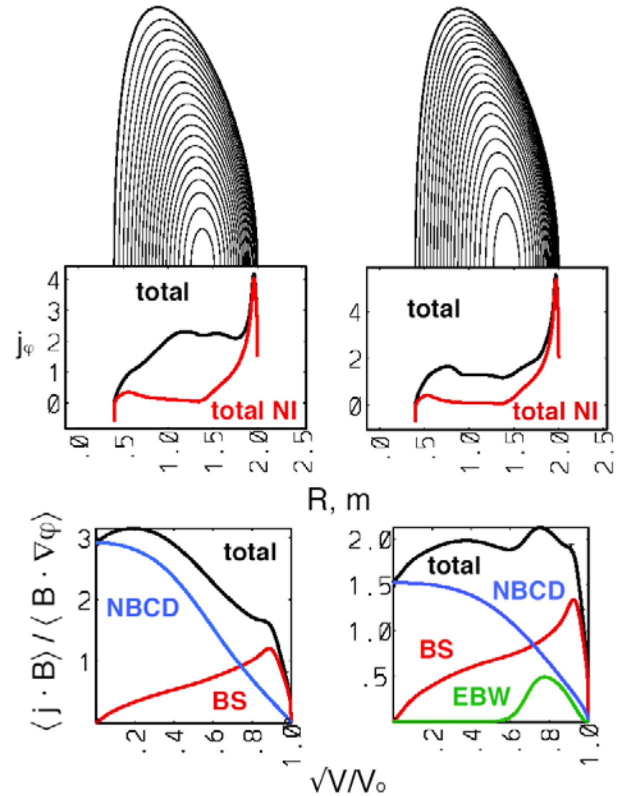


Culham 150keV NBI system

Based on LOCUST calculations

Off-axis CD required for stability

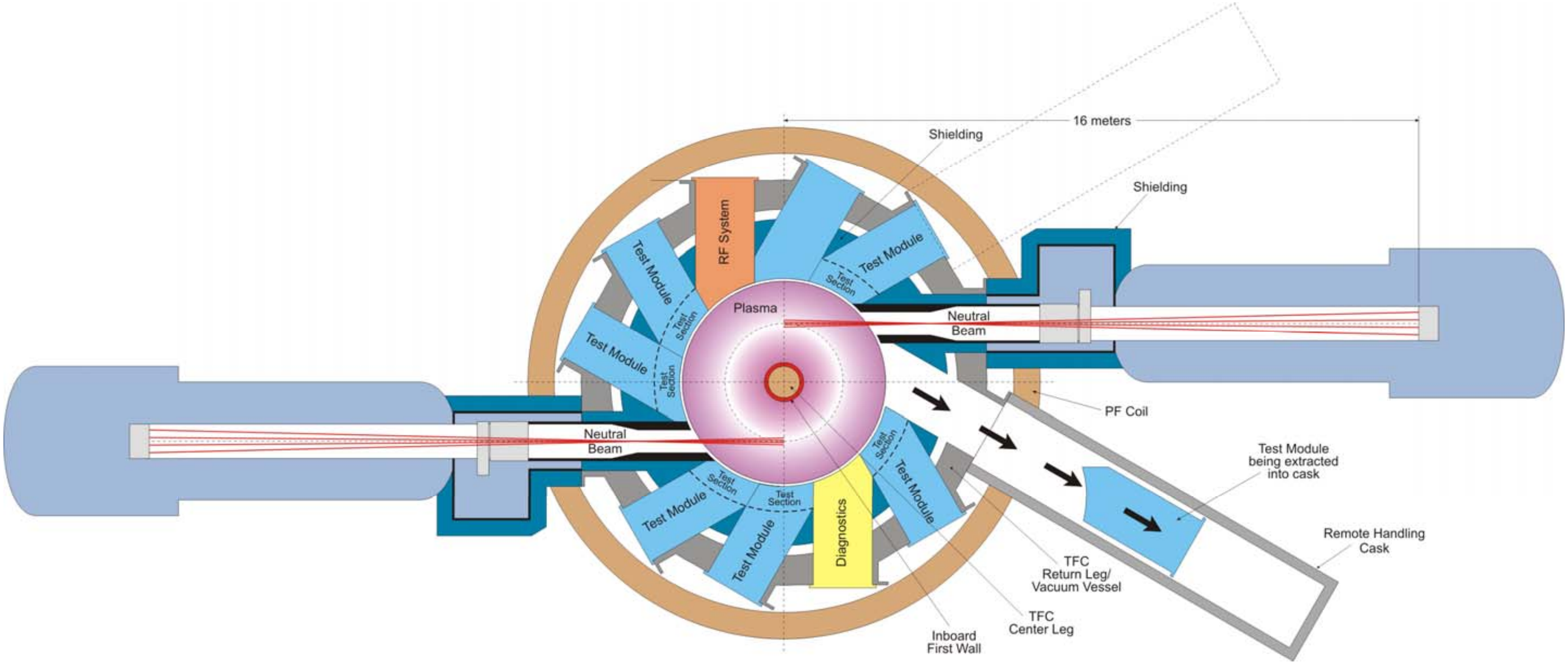
Could provide all fuelling



ORNL/PPPL 110keV NBI system

(from TSC, PEST2) appropriate for MHD-stable profiles (l_i=0.25-0.5)

Layout of ORNL/PPPL design, showing NBI injectors and scheme for removing test modules



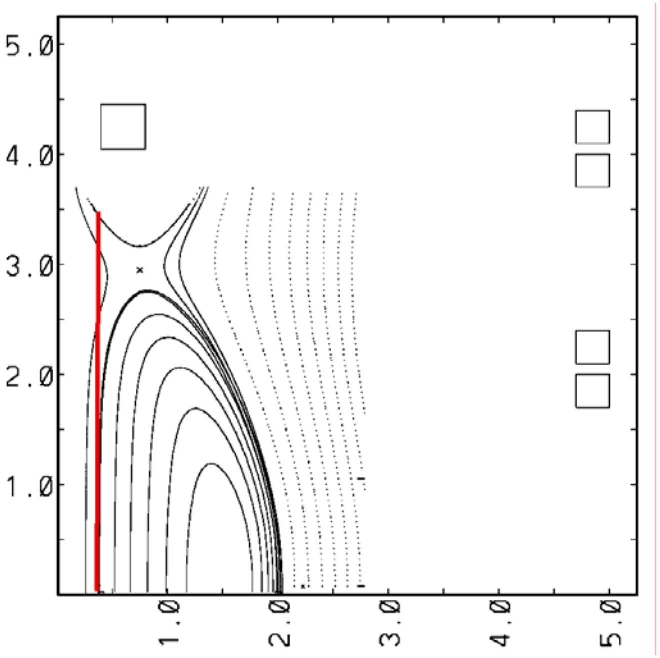
Top view

Handling the exhaust

- Two approaches:

ORNL/PPPL exploits

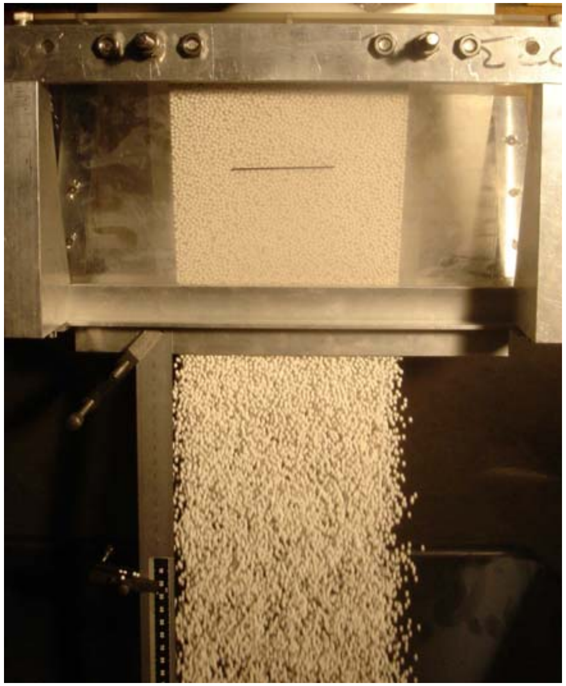
- "inboard-limited" configuration to spread heat load
- DND also possible



Resulting heat loads are ≤15MWm^{-2}

Culham adopts DND configuration:

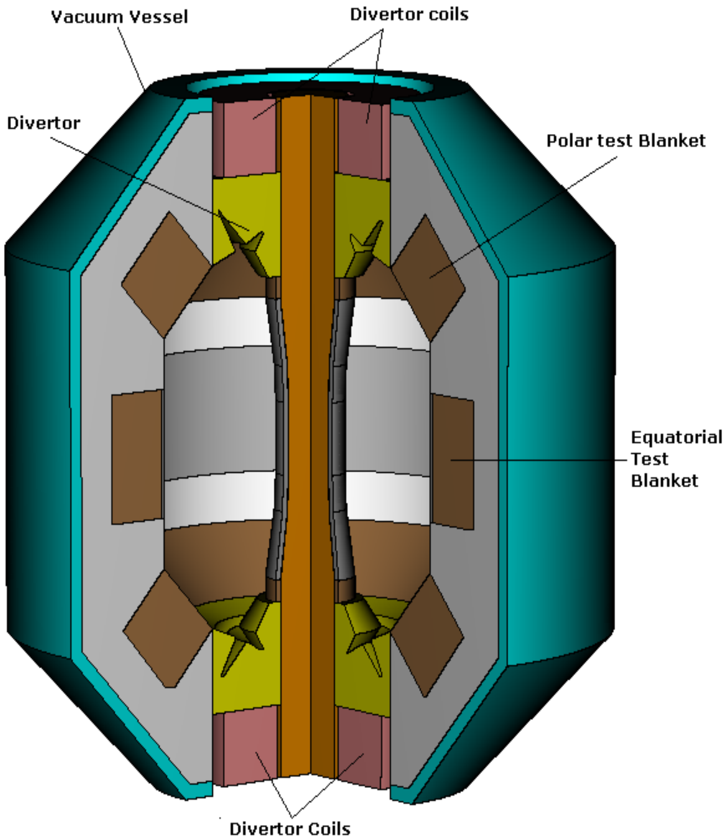
- Up to ~95% heat to outer target (MAST)
- High heat loads require novel scheme
- Exploring "pebble-divertor" (outboard)
  - reduces heat loads to ~10MWm^{-2}



Both designs rely on radiated power

Neutronics study

Study of Culham design using MCNP code shows:



Meets Abdou et al requirements:

- Equatorial test modules: 1.63MWm^{-2}
- Polar test modules: 1.40 MWm^{-2}
- 6MW-yrm^{-2} achieved in ~12 yrs with ~30% availability
- Tritium consumption is ~0.9kgyr^{-1}, so not reliant on ability to generate T

Tolerable radiation damage, except for divertor coils (need improved design, using cyanate ester resin)

Conclusions

- ORNL/PPPL and Culham have independently developed designs for CTF based on a spherical tokamak
  - The designs are complementary, with some similarities and some differences
  - It is encouraging that a range of solutions exist
  - Modest assumptions for the plasma performance have been made for the “baseline” regimes

- A CTF based on an ST looks feasible, but requires further research in a number of key areas:
  - Exhaust and divertor design
  - Influence of high momentum injection/fast particle content
  - Off-axis current drive
  - Start-up
  - First wall material

Please visit posters

FT/3-1Ra and FT/3-1Rb

for much more detail

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