Internal Components Research

FDF Will Complete the Technology Development Path to DEMO for Internal Components

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Internal Components are Those Items in the High Neutron Fluence Zone that are not Shield Blankets, PFCs or Divertors

- In general, Internal Components are structures or subsystems just behind the First Wall and inside the envelope of the Vacuum Vessel.

- **Internal Components are:**
  - The front end of Diagnostics
  - RF antennas
  - Microwave launchers
  - Control & stabilizing coils
Diagnostics will be Severely Challenged in the Burning Plasma Era of Fusion Energy Research

- **Environmental issues:**
  - Large nuclear radiation field (neutrons and gammas)
  - Large particle flux and fluences (ions and neutrals)
  - Large stray microwave field

- **Access:**
  - Limited number of access ports
  - Minimum penetrations through shielding (labyrinths)

- **Reliability:**
  - Robust systems (mechanical, electrical, etc)
  - Functional for long periods (e.g. weeks)
  - Capable of maintaining calibration without direct intervention or down time
  - Error-free systems as inputs to control systems
RF Techniques for Plasma Heating, Current Profile Control, Rotation Control, MHD Stability Control for DEMO Faces Significant Challenges

- **Compatibility with cw high heat loads**
  - Launchers will be required to operate at +700°C
  - RF launchers are large, requiring a significant penetration of the breeding blanket
    - Requires antenna to have high power density levels (arching concern)
- **Compatibility in nuclear environment**
  - Antennas will need to be from materials not presently used in launchers, and potential poor RF conductors
- **Low impurity generation**
  - Boronization to minimize impurity generation not feasible for DEMO
- **Sufficient EM-plasma coupling without arcing**
  - Good coupling to plasmas leads to close proximity of launching structure to the SOL
    - Increases the likelihood of arcing
    - Power coupled to the SOL ends up in concentrated spots which could experience damage and melting
- **RAMI**
  - Operational reliability and survivability are unknown and unproven
Present Designs of Microwave Antennas May Not Survive in a Fusion Reactor

• Microwave Antennas are complex structures
  – Tracking of NTM islands requires the final mirror to be steerable
    • Places rotating joints in a high heat, high neutron fluence environment
  – Final Mirror is close to the plasma edge and experiences the full EM loads from disruptions and VDEs
    • Steering mechanism has to be designed for high mechanical loads, which may compromise slew speed
  – Fusion reactors require ECH & ECCD frequencies of +200 GHz
    • Last mirror must have a high conductivity surface, owing to the shallow skin depth ~0.15 micron
      ❖ Surface is prone to neutron degradation and/or impurity contamination

ITER ECRF Upper Launcher
Are Control Coils Feasible in a Fusion Reactor Environment?

**Environmental issues:**
- High neutron fluences impacts the choice and use of high conductivity metals
  - Metals loose conductivity under neutron exposure
  - Metals are imbritted from neutron exposure
  - Nuclear heating adds to the heat load needing removal
  - Shielding of coils to reduce neutron exposure requires higher coil currents to create the effect of a coil near the SOL
    - Results in high loads and increased cooling requirements
- High neutron fluences may limit the choice of insulating material
- Coils may experience high electromagnetic forces from disruptions and VDEs

**Access:**
- Coils will need to be located under the shielding blocks making remote maintenance time consuming
- The more flexible the control coil system the more penetrations of the vacuum vessel will be required

**Reliability:**
- Robust systems required owing to the poor access for remote maintenance
- Functional for long periods (e.g. weeks)
Components Will Need to Be Qualified Prior to the Design of DEMO

- The licensing of DEMO will require a high level of documentation that components can meet all the safety requirements and has demonstrated effective reliability and maintainability
  - Materials will need to be prequalified for use in an neutron environment
  - Validation of theory and modeling on test stands
  - Validation of system design and performance on an operating device (most likely non-nuclear)
  - Validation of performance under high neutron and heat fluences
  - Accumulation of operational data for RAMI classification
Reliability, Availability, Maintainability and Inspectability

- RAMI is critical to DEMO in order to demonstrate the productive capacity of fusion power and validate economic assumptions.
  - Demonstrated high availability using Remote Maintenance is essential
    - Continuous operation of two weeks to a month at a time
      - Reasonable mean-time-between-failure
    - Availability of 20% to 50% must be achievable
      - ITER is 10%
    - Component replacement with short down time (mean-time-to-repair)
    - Full reparatory of specialized remote handling tools and end-effectors developed and available
    - Demonstrated ability of in vessel inspection
      - Erosion evaluation, leak detection, metrology, etc.
The Gaps in Internal Component Technology are Large and will Take an Integrated Program to be Successfully Closed

- All of the internal components to be used in DEMO must pass through a rigorous development cycle:
  - Physics, Theory & Modeling
    - Improve the science underpinnings of Internal Component (IC) technology
    - Including interaction of the ICs with the plasma
  - Technology Development
    - Exploration of potential solutions to key gap areas
  - Existing/Upgraded/New Test Stands
    - Validation of new concepts
  - Existing/Upgraded/New Non-DT Confinement Facilities
    - Validation of nuclear grade component performance in a reactor plasma environment (without the hassle of activation)
  - New DT Confinement Facilities
    - Integrated system testing in a neutron environment at cw conditions
To Complete the Internal Component Research Program a DT Facility that Produces Reactor Grade Plasmas is Needed

- The Fusion Development Facility (FDF) is an ideal device to validate the internal components needed for DEMO
  - Neutron fluxes of 1–2 MW/m²
  - Duty factor of 0.3
  - Auxiliary heating of ICRF, LH, ECRF and NBI
  - Internal coils for ELM and RWM suppression, and possibly plasma rotation
  - Diagnostics

- FDF can produce fluences of 3–6 MW-yr/m² in ten years of operation onto complete internal component prototypes
  - With these fluences FDF can make a significant contribution on relatively large, fully integrated and engineered components.
DEMO Relevant Internal Components will be Needed to Operate the FDF Tokamak from Day One

- It is expected that over the lifetime of FDF the internal components will evolve into designs with more capability and robustness.
- Other components can be validated in the test ports provided as part of the FDF mission,
  - This allows the testing of different designs for extended periods, and under different temperatures and cooling methods
  - Both liquid metals and gas cooling can be explored, with temperatures as high as 900°C