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A FUSION DEVELOPMENT FACILITY TO DEVELOP, FIELD AND TEST DIAGNOSTIC SOLUTIONS FOR DEMO

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GENERAL ATOMICS

The field of fusion energy science research has long benefited from the increasingly detailed understanding derived from scientific measurements (diagnostics). Over the years an increasing number of these measurements/sensors have been successfully introduced into elaborate and complex control schemes.

MEASUREMENT ISSUES

Such progress in fusion research is expected to encounter a series of new challenges starting with ITER and culminating with DEMO. It is largely expected that standard techniques used in today's experiments will not be employable or will require substantial adaptation or modification, or will suffer significant restrictions.

These challenges can be summarized into three broad categories:

1. Environmental issues
   a. Large nuclear radiation field (neutrons and gammas)
   b. Large particle flux and fluences (ions and neutrals)
   c. Large stray microwave field
2. Access
   a. Limited number of access ports
   b. Minimum penetrations through shielding (labyrinths)
3. Reliability
   a. Robust systems (mechanical, electrical, etc)
   b. Functional for long periods (e.g. weeks)
   c. Capable of maintaining calibration without direct intervention or down time
   d. Error-free systems as inputs to control systems.

Many of the plasma diagnostic techniques used in existing tokamaks will not be practical in a DEMO. R&D applied to the design and testing of ITER diagnostics has begun to address these issues, but will not provide the solutions for a DEMO. While plasma physics research may no longer be a major element in DEMO, development of highly reliable diagnostics and sensors capable of providing the inputs needed for plasma and burn control will be required and will be a major challenge.

TECHNICAL REQUIREMENTS

Environmental Issues

The large flux and fluence of neutrons and gammas near the plasma boundary of FDF will require the in-vessel sensors to be hardened or eliminated. A prime example of such a challenge consists of the large number of in-vessel magnetic probes normally required for basic plasma control. These sensors, as presently designed, would experience large spurious signals and/or be rendered inoperable after a short period.

Optical systems would also experience problems in which helium (alphas) and charge-exchange neutral flux would render first mirrors inoperable over a short period of time. One can envision that microwave-based diagnostics will become the workhorse in a burning plasma environment, but this development is still in its infancy.

Access Issues

Although ITER is a large device, diagnostic access to the plasma is severely limited due to the need for adequate radiation shielding (labyrinths). In a DEMO this access will be further limited by the need to maximize the tritium breeding capability at/near the first wall. Consequently, FDF will be uniquely positioned to optimize the diagnostic set based on ITER experience and progress in physics model validation. This model validation process will be especially important in order to reduce the needs for specific measurements and to reduce complexity. In addition, many diagnostic systems will need to share access, requiring additional R&D activity.

Reliability

This is an area, which would require a transformational approach to measurements. In today's experiments, diagnostics are expected to be operational for a few seconds over a day-long experiment. In ITER, they will be expected to perform for periods approaching 100s of seconds over a day. In a DEMO, they will be expected to perform reliably, with a good calibration for weeks at a time, a task that needs to be demonstrated in FDF. This is especially critical as a very large fraction of these measurements will be used for plasma and burn control, thus requiring a nearly perfect reliability. This challenge is made even more demanding since burning plasma devices will be remote handled exclusively.

RESEARCH THRUST

An intermediate step such as FDF will allow the development and testing of the diagnostics necessary for DEMO. In a research facility such as FDF, extensive plasma diagnostics will be required during the commissioning of the device, enabling and verifying the anticipated plasma performance. During the later phase, high power DT operations, FDF will serve as a test facility for diagnostics and sensor technology required in DEMO, within a burning plasma environment. In the diagnostic area, FDF is thus envisioned to serve as a bridge between the scientific needs for ITER and control needs in DEMO.

FDF is a facility and program to address the issues outlined above. FDF will be an experimental device designed for development and testing of techniques for use in DEMO.

To accomplish these goals FDF design includes the following features.

1. **Compact Design**. R ~ 2.5 m, a ~ 0.7 m, employing advanced tokamak features, high beta and confinement to achieve reactor relevant conditions.
2. **Helium Cooling**. Helium cooling for hot wall operation and avoided risk of water coolant accidents and impact on internal components and/or interfaces such as diagnostics.
3. **Steady State**. ~2 weeks of noninductive operation, testing the long-term issues (reliability and others) potentially impacting diagnostic performance.
4. **Normal Conducting Coils**. Large copper coils for low resistance and lower cost.
5. **Flexible Configuration.** The flexible port arrangement will enable rigorous testing of diagnostic solutions, while minimizing any down time.

FDF will employ a staged approach for its program plan. The stages of operation are currently envisioned as follows:

1. **First Phase**. Initial run period of ~5 years, ~12 dpa, to optimize the advanced tokamak aspects for high power density. This phase will require a larger set of diagnostics to validate the physics models and sensor inputs to control algorithms.
2. **Maintenance Period**. A ~2 year period for maintenance and change out of internal components, including any diagnostic. A number of options can be explored based on what is learned in the first operation period. This period would be also used to reduce the number of required diagnostic systems and optimize their configuration.

3. **Second Operaton Phase**. Currently envisioned to be about 5 years, providing ~25 dpa for diagnostic testing. Performance of reduced set of diagnostics is explored and environmental issues addressed.
4. **Maintenance Period**. This second maintenance period will be used to install the most advanced systems and retire non-performing ones.
5. **Third Operation Phase.** A 5 year run period with optimized parameters to achieve a neutron fluence of ~ 40 dpa. This operational period should accomplish the following.
   a. A final test of diagnostic sets (environmental, reliability) for utilization by DEMO.
   b. Optimized set of sensors for global and local control.
   c. Minimized access requirements.