Research Thrust on Magnets to Enable Low Aspect Ratio Fusion Nuclear Science Facility

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1. Purpose and motivation of white paper

The purpose of this white paper is to address the Tier 1 issues identified in the Report of the Fusion Energy Sciences Advisory Committee (FESAC) Toroidal Alternatives Panel. The basic objective of the panel was to "identify and justify a long-term objective for each concept". The panel addressed the ITER-Era goal for the U.S. spherical torus program which was to establish the knowledge base for a low aspect-ratio fusion component testing facility. The ST goal primarily is to extend fusion development beyond the ITER mission as opposed to achieving burning plasma conditions. The panel defined several high priority issues for the Spherical Torus which are identified as Tier 1 issues. A Tier 1 issue is based on a set of 6 ranking criteria which were adapted from the Greenwald Panel. One of the Tier 1 issues addressed the magnets.

The center-post magnets shown in FIG 1 had the highest technical risk. The center-post magnet consist of the initiation coil which is a single turn coil approximately 5cm x 5cm with approximately 108 turns with a vertical height of 5.4m. This coil will have resistive losses during the initiation of the plasma and then heating during operation from neutrons. The inside of the center-post contains the non-superconducting TF Coil which is a triangular shaped coil located inside the center-post consisting of copper conductor with an Inconel jacket (not shown). The panel had the following question "Can we develop reliable center-post magnets and current feeds to operate reliably under substantial fluence of fusion neutrons?"

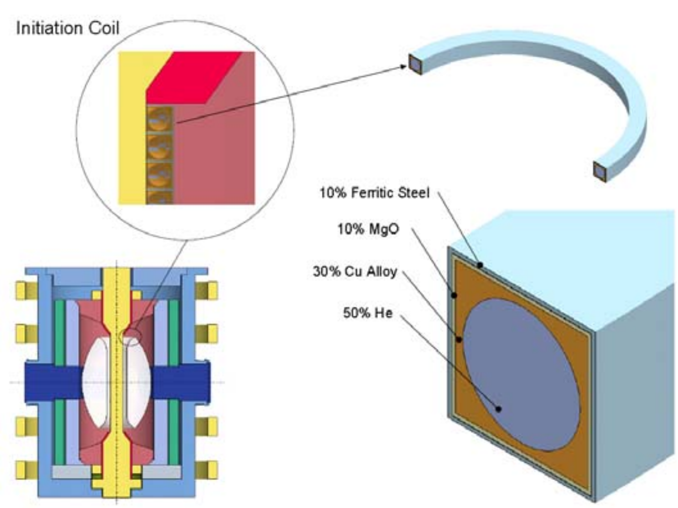

Fig 1 ST-CTF

In addition to the high neutron fluence (up to 1 MW-yr/m^2) additional issues are the expected high stress due to the high current single turn design and the high heat flux (~1 MW/m^2) from the plasma. A first wall design similar to the ITER first wall of Be tiles and cooling members will cover the plasma facing surface of the initiation coil.

2. Closing the Research Gap during the ITER era

The main issues from the TAP report that impact the ST-CTF will be the neutron fluence, the high heat flux from the plasma, high stresses from the initiation coil due to the high current single turn coil, and duty cycle. The ST-CTF will provide a full fusion nuclear environment for testing these components.

Mineral Insulated Conductor -To accommodate the high neutron fluence as well as thermal and magnetic loads on the coil the conductor will be insulated with magnesium oxide (or other suitable ceramic) powder and encased in ferritic steel. The ceramic insulation will provide high temperature and radiation resistance, while the ferritic steel casing will provide additional structural support. Prototype conductor must be designed, produced, and tested to assure a reliable fabrication technique and demonstrate that adequate strength can be achieved from the design.

Cooling of the initiation coil will be very challenging using He gas with a single conductor length of ~250m. Primary heat loads will be generated during the initiation of the plasma and then from the neutron fluence. Additional analysis is needed to finalize the design.

First Wall – The first wall concept developed for ITER is the design being considered for the ST-CTF. The cooling capability of the first wall will need to be improved to survive the high heat flux planned for the ST-CTF. Concepts are being considered to improve cooling by shaping the internal passages to simulate hypervapotrons. This approach may help meet the high heat flux expected in the ST-CTF environment.

The first wall will be assembled as part of the center post assembly and will be assembled/removed using the remote handling equipment. This should improve the duty cycle by reducing the number of components that must be handled separately.

3. Enabled R&D

3.1 Engineering Science issues

Prior to the operation of the ST-CTF the following engineering science issues should be addressed.

It is very important to determine what Nuclear Codes will be used during the design, construction, and operation phases as early as possible. The codes will have a significant impact on all phases of the project.

Fabricating the initiation coil using MgO, ferritic steel, and copper alloy needs to be prototyped for several reasons. The outside diameter of the center-stack is only 0.7m. Forming a coil with a cross-section 50.0mm by 50.0mm with an outer jacket of ferritic steel will require development to determine if this is possible. The exact dimensions of the ferritic steel, MgO, copper alloy, and helium cooling geometry will need to be optimized. The stiffness of the cable will also need to be determined and samples made to determine how difficult this is to form and if the conductor will move inside the casing and if it will provide extra stiffness for the conductor during operation.

While the mineral insulated configuration is not new the size and materials may be difficult to form. Vendors need to be surveyed to determine what capabilities exist. If the vendor's current technology is to form relatively small round wire we will need familiarize them with our concept, seek their advice, and work with them to develop the equipment to fabricate the coil. Once prototypes of the conductor are made the conductor can be tested to evaluate mechanical, thermal, and other material characteristics.

The design maturity is very preliminary at this time. Additional analysis and modeling is required in all areas.

3.2 R&D for Demo

Paying careful attention to the issues of remote handling and designing for long mean time between failures (MTBF) will be key to maintaining a high duty factor. To evaluate these issues requires a facility that provides a full fusion nuclear environment. This can best be determined by testing in the ST-CTF full fusion nuclear environment. Exposing the components to this environment and developing data on the MTBF of components is important to establish the duty factor for the demonstration facility