Gaps and Facilities for the Spherical Torus

This brief note provides a perspective on Gaps and Facilities for the Spherical Torus, as requested from the fusion community by the FESAC Toroidal Alternates Panel. It is framed in terms of the gaps associated with the three Themes developed in the recent FESAC Priorities, Gaps and Opportunities (PGO) report.

The low-aspect-ratio tokamak, or Spherical Torus, offers a very simple accessible magnetic confinement system into which a great deal of heating power can be injected without reaching beta limits, and in which a great deal of fusion power may be able to be produced, again within beta limits. These features recommend it strongly as an instrument for addressing FESAC PGO Theme B: "Taming the Plasma Material Interface" as well as FESAC PGO Theme C: "Harnessing Fusion Power". The simplicity of the coil system and of the easy maintenance schemes that flow from it recommend the Spherical Torus both for such applications and ultimately as a fusion power system.

FESAC PGO Theme B presents a very major challenge, and indeed successful response to this challenge is a prerequisite for proceeding to resolve the gaps associated with FESAC PGO Theme C. With the current state of understanding, there is no known solid material that can withstand the power and particle fluxes anticipated in a Component Test Facility or Demo. Even leaving aside the unacceptable impacts of ELMs and disruptions on solid surfaces, the most promising material, tungsten, has problematic interactions with He, an unavoidable component of the plasma in a fusion divertor. As a result it appears that tungsten would exfoliate unacceptably in a Component Test Facility or Demo as currently conceived. The erosion rate of tungsten from sputtering by seeded impurities would also likely be unacceptable. The retention of tritium in tungsten is uncertain. Clearly more theoretical understanding and practical development of tungsten alloys as plasma-facing materials is needed. Physics solutions also need to be demonstrated that can dissipate and spread dramatically the heat and particle flux away from the divertor strike point. Ideas along these lines include highly radiative plasmas as considered in the EU power plant studies, as well as innovative divertor configurations with high magnetic flux expansion as have been proposed in the U.S. Another approach, possibly to be used in combination with these, is to employ liquid divertor surfaces. Such studies are in their beginning phases, but have shown very promising results. Extensive experimentation is needed to demonstrate their practicality, for example in divertor tokamaks. Theoretical and experimental results point to the possibility that low-recycling surfaces such as lithium can lead to significantly enhanced thermal confinement, a very valuable benefit which also requires further experimental validation.

The Spherical Torus, or low-aspect-ratio tokamak, is very well suited to host Theme B studies, due to its easy accessibility for heating, diagnostics, and maintenance, and its ability to absorb high amounts of heating power that are ultimately delivered to divertor surfaces. A facility capable of very high heat flux, for long pulses, with excellent access for extensive PMI diagnostics as well as advanced plasma diagnostics, and with wide access for heating and maintenance, could contribute strongly to filling the key gaps identified by FESAC within PGO Theme B: "Taming the Plasma Material Interface." Such a facility would need to be able to operate high performance steady-state plasmas with both solid and liquid divertor surfaces, with Demo-relevant hot walls, and with poloidal field flexibility to allow tests of innovative approaches to divertor heat flux dispersal. Thus it would need excellent access for change-out of internal components, as is afforded by the easy vertical access and wide horizontal access of a low-aspect-ratio tokamak. Such a facility would need to be supported by a strong boundary physics and technology program on existing confinement facilities and by aggressive efforts at materials and technology development for both solid and liquid walls. Research on confinement, stability, ramp-up and sustainment on existing and upgraded Spherical Torus facilities can contribute greatly to optimization of this device, as such studies on it can contribute to the physics basis for an ST-based Component Test Facility. This device can also develop materials and fusion technologies to be transferred to the Component Test Facility. In collaboration with IFMIF, or a device/program providing similar capabilities, this facility could test the effects of plasma bombardment on plasma-facing materials which are exposed to high 14 MeV neutron fluence, such as the retention of tritium in traps created by neutron damage. The combination in the ITER era of this facility with a facility having IFMIF-like capabilities would be very powerful.

As has long been recognized, the Spherical Torus is also very well suited to provide the basis for a Component Test Facility, with the goal of addressing the gaps identified within PGO Theme C: “Harnessing Fusion Power”. The Spherical Torus configuration is capable of producing intense amounts of fusion power from within a relatively small and simple magnet set, allowing good access for nuclear component development. Building on the results from IFMIF, ITER’s first-phase blanket testing program, and the high-heat-flux and other physics and fusion technology studies described above, a moderate-gain DT facility based on the Spherical Torus could be used effectively to test the blanket systems required for Demo. Such a facility could in principle be constructed as a very major upgrade to the Theme B device, or it could be built separately and phased in so as to overlap with it. The EU is considering a strategy in which a Component Test Facility operates in parallel with an accelerated Demo.

While the Spherical Torus can fill key gaps identified within PGO Themes B and C, as discussed above, this should not obscure the fact that it has similar potential, and similar challenges, to those of the conventional-aspect-ratio tokamak for addressing PGO Theme A: “Creating Predictable, High-Performance Steady-State Plasmas.” Indeed if it proves possible, through experiments on the facilities discussed above, to sustain stable, high-performance operation that projects to high gain in a Spherical Torus Demo, taking into account the recirculating power required, the inexpensive magnets and simple maintenance scheme associated with this configuration would recommend it highly. Note that if the ARIES-ST design had been equipped with the high-efficiency blanket posited for ARIES-AT, the same plasma would have produced 50% more electrical output power, 1500 MWe, at nearly the same total capital and operating cost.

In summary, the FESAC Toroidal Alternates Panel should consider deployment of the low aspect ratio tokamak, or Spherical Torus, in conjunction with an intense point neutron source such as IFMIF, to address FESAC PGO Themes B and C.

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