Toward a Fusion Nuclear Science Facility

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The Fusion Energy Sciences office has taken an important step by putting a Fusion Nuclear Science Facility (FNSF) on the table for FESAC's consideration. We agree that such a facility is needed and we agree with FES's assessment that it could make "absolutely central" contributions to world-leading science once it is built and operating. The opportunity to move forward with such an initiative does not exist at this time, but could materialize on short notice. If we hope to capitalize on any such opportunity (and not be caught flat-footed!), we need to be prepared with a plan and a convincing case for it. To prepare ourselves, we must:

1. Immediately undertake a funded national scoping study to develop the case for a DOE determination of FNSF Mission Need.
2. As part of such an effort, refine the priorities for fusion nuclear science and technology (FNS&T) research, identifying the subset of R&D issues that are critical for FNSF readiness, i.e., those needed to inform high-level design decisions.

Mission and Design

The possible missions for a next-step fusion nuclear facility span a wide space, encompassing basic materials research, blanket testing, tritium self-sufficiency demonstration, net electricity generation, and prototyping the design and maintenance scenario of a fusion power plant. The facility design options are correspondingly diverse. The U.S. community has studied a spectrum of designs, including a compact, low gain spherical torus (ST); a moderate gain advanced tokamak (AT); and net electricity-generating pilot plants based on ST, AT, and stellarator configurations. The optimum magnetic configuration choice is not *a priori* obvious. Similarly, the appropriate choices for key technologies are not obvious. The choices made for magnets; power exhaust; energy extraction and tritium breeding; plasma heating, fueling, and control; and maintenance are concept-level decisions linked directly to the choice of mission.

Technology Readiness

As noted in the FES 1-pager, the FNSF is an integrated facility, integrating a high-performance deuterium-tritium plasma with solutions for power and particle exhaust and for harnessing fusion power. In system terms, it will integrate a magnetic confinement device with technologies for power exhaust and tritium control (divertor, first wall), tritium breeding and energy conversion (blankets, tritium systems), plasma control (diagnostics, heating, current drive, and fueling), and maintenance and operations (e.g., remote handling, safety) compatible with the demanding requirements and nuclear environment (extreme neutron and ionizing radiation with high electromagnetic and thermo-mechanical fields and a wide range of operating temperatures) of an FNSF. What must be done before we are ready to take this integration step? The FES paper points out the need for research on FNSF-relevant plasma scenarios and control tools, but the critical path to FNSF readiness will likely run through the research needed to advance subsystems to a level of readiness for integration. The research needs have been amply documented, and now the U.S. must prioritize those needs so as to acquire the critical knowledge necessary to launch an FNSF project, as well as lay out the plans for tasks than must proceed in parallel with the FNSF as part of a sufficient FNS program.

First Step: A National FNSF Scoping Study to Establish Mission Need

What would the Mission Need case for an FNSF, a multi-$B facility, consist of? We can reasonably assume that at least the following would be needed:

- Mission description: knowledge to be generated via the proposed program, and how it will advance fusion science and technology relative to the objectives of ITER and DEMO.
- Concept design, operating plan, and rough cost: a convincing existence proof of at least one facility design and program execution plan showing that the mission can be accomplished, accompanied by a rough estimate of its cost and schedule.
- Readiness and risk assessment: the physics basis for the proposed magnetic configuration and operating scenario, and the technical readiness of the technologies to be used. To the extent that there are gaps in readiness, what is the associated risk and what are the mitigation measures?
- The degree to which the design and technology choices should prototype those of a commercial power plant. The tradeoff between DEMO relevance and operational advantages such as flexibility need to be evaluated.
- The roadmap to fusion energy and the associated timeline implied by the proposal. If the program is successful, how far will it take us? Would DEMO follow or would there need to be another step?
- International assessment: what is the relationship to ITER and the programs of other countries? Can the U.S. take advantage of opportunities for international collaboration such as participation in the ITER Test Blanket Module (TBM) program? How will a U.S. FNSF best enable a world-leading U.S. program?
- Alternatives assessment: why are the proposed mission and the proposed scientific and technical approaches the best choices among the available options?

To date the effort has been limited to mission and design studies carried out mainly by institutions using discretionary funds. Now a national design and mission definition effort, funded by DOE to develop options and evaluate them against common criteria, is essential if we are to go beyond institutional advocacy in making the Mission Need case for an FNSF.

Summary: Action is Needed Now.

An initiative to move forward with ReNeW Themes 2 to 4 is welcome indeed. Several other countries have reached similar conclusions, and are acting on them with R&D programs in materials and fusion nuclear technology and with national design and planning studies for next-step fusion nuclear facilities to address missions similar to those foreseen for an FNSF. The world-wide interest in this mission space underscores not only the potential for leadership roles in this important science, but also the reality of intense international competition for world leadership in the era of ITER and FNSFs. The U.S. can be a leader in this era, provided we move ahead now with the actions necessary to be prepared for opportunity. Even the preparatory R&D could make “absolutely central” contributions to world-leading science in the next decade, such are the scientific richness and the open opportunities in this area. A scoping study could transition smoothly into conceptual and engineering design activities and could position us to start construction of a world-leading fusion facility within the next decade.