Justification of Mission Need
for the
National Compact Stellarator Experiment
(CD-0)
Office of Fusion Energy Sciences
Office of Science

A. Mission Need

1. Fusion Energy Sciences Mission

The Mission of the Department's Fusion Energy Sciences Program, adopted in 1996 in a Congressionally-directed program restructuring, is to advance plasma science, fusion science, and fusion technology – the knowledge base needed for an economically and environmentally attractive fusion energy source. To achieve this, three policy goals are pursued:

- Advance plasma science in pursuit of national science and technology goals;
- Develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; and
- Pursue fusion energy science and technology as a partner in the international effort.

Since the 1996 restructuring, the fusion community and the Fusion Energy Sciences Advisory Committee (FESAC) have been developing an integrated program plan for fusion, including both inertial fusion energy (IFE) and magnetic fusion energy (MFE) elements, as a way of implementing the three policy goals. In MFE, because of the range of scientific ideas and approaches that exists, a number of confinement concepts are being studied. Depending upon its merits, each concept advances through a sequence of development stages: concept exploration, proof of principle, performance extension, fusion energy development, and ultimately demonstration power plant. The key element for developing the compact stellarator concept is a proof-of-principle experiment, the National Compact Stellarator Experiment (NCSX), which would experimentally test the key physics principles of the compact stellarator concept and provide unique opportunities to broaden the understanding of fusion plasma science.

The compact stellarator program was proposed to FESAC as part of its 1999 review of fusion program priorities and balance. In its plan that resulted from that review, the FESAC established a ten-year objective to "Determine the attractiveness of a compact stellarator by assessing resistance to disruption at high beta without instability feedback control or significant current drive, assessing confinement at high temperature, and investigating 3 dimensional divertor operation." This FESAC objective provides the basis for the NCSX project mission need.

2. Project Purpose and Relation to Program Strategy

The overall compact stellarator (CS) program addresses a critical issue for magnetic fusion energy (MFE), namely the requirement for a high-beta magnetic plasma configuration that can be continuously sustained without disrupting. It complements the existing advanced-tokamak (AT) and conventional stellarator thrusts in the development of an attractive steady-state configuration. The CS concept is an innovative hybrid of advanced tokamaks and stellarators that builds on the scientific foundations of both concepts and is projected to have distinct advantages. It uses the self-generated bootstrap current (as does the AT) in combination with three-dimensional stellarator magnetic fields from external coils to sustain a stable, high-beta toroidal plasma with a significantly lower aspect ratio than currentless stellarators. The stellarator magnetic fields are designed to tailor the plasma configuration so as to maintain a stable configuration without active plasma controls or current profile control systems and their attendant recirculating power. The CS concept would approach the AT in power density, while providing the stellarator's advantages of steady-state, disruption-free operation with low recirculating power.

The purposes of the National Compact Stellarator Experiment are to provide the experimental data base needed to resolve critical scientific issues, advance the scientific understanding of this concept and provide a basis for advancing the development of the compact stellarator concept to the next stage.

More specifically, NCSX will:

- Determine conditions for high-beta disruption-free operation, compatible with bootstrap current and external transform in a compact stellarator configuration.
- Determine beta limits and limiting mechanisms.
- Reduce neoclassical transport by quasi-axisymmetric (QA) design.
- Reduce anomalous transport by flow- shear control, using reduced flow damping by QA design.
- Stabilize equilibrium islands and neoclassical tearing-modes by design of magnetic shear.
- Test compatibility with stellarator power and particle exhaust methods.

Moreover, NCSX will provide answers to some critical questions in fusion plasma science, for example:

- Can pulse-length-limiting instabilities, such as external kinks and neoclassical tearing modes, be stabilized by external transform and 3D shaping?
- How do externally-generated transform and 3D shaping affect disruptions and their occurrence?
- Can the collisionless orbit losses typically associated with 3D fields be reduced by designing the magnetic field to be quasi-axisymmetric? Is flow damping reduced?
- Do anomalous transport control and reduction mechanisms that work in tokamaks transfer to quasi-axisymmetric stellarators? Do zonal flows saturate turbulent transport in a quasi-axisymmetric stellarator at levels similar to tokamaks? How does the transport scale in a compact stellarator?
- How do stellarator field characteristics such as islands and stochasticity affect the boundary plasma and plasma-material interactions? Are 3D methods for controlling particle and power exhaust compatible with good core confinement?

The NCSX proof-of-principle experiment is the central element of a program to develop the Compact Stellarator. As part of this national program, a considerably smaller experiment, the Quasi-Poloidal Stellarator (QPS), formerly the Quasi-Omnigenous Stellarator (QOS) is also being proposed by Oak Ridge National Laboratory. The concept-exploration-level QPS complements the PoP NCSX by exploring a much lower aspect ratio configuration, extending the configuration space for compact stellarators. While NCSX and QPS are both hybrid configurations, they emphasize different physics in their optimization, resulting in magnetic configurations with different properties and complementary missions. The national CS program also couples to the programs on small, already-approved facilities at the University of Wisconsin, the Helically Symmetrical Experiment (HSX), and at Auburn University, the Compact Toroidal Hybrid (CTH), as well as parts of the Theory and International Collaboration programs.

3. <u>Alternatives</u>

The main alternatives to the compact stellarator are the advanced tokamak (AT) and the conventional stellarator, as discussed above. Adding the compact stellarator to this portfolio of magnetic confinement concepts greatly increases the likelihood of finding the most attractive steady-state configuration for magnetic fusion energy.

B. Technical Objectives and Technical Progress

The key technical objective for the NCSX project is the fabrication and assembly of the NCSX experimental facility to be capable of accomplishing its physics mission at an affordable cost. The high-beta requirement determines the size and technical performance of the NCSX and its heating systems. To test the predicted stability limits and transport mechanisms requires a toroidal plasma with a major radius in the range of 1.4 m, a plasma radius of 0.33 m, magnetic field strength of up to 2.0 T with a ~1s pulse length at the maximum field, and beam heating power of 3 MW (upgradable to 12 MW). The NCSX experiment will be flexible and provide good access for diagnostics and other research tools.

Technical Progress and Current Status: Since 1997, the national compact stellarator design team has made good progress in the development of a magnetic configuration and a machine concept for the NCSX. Significant advances in the physics and technology of stellarators have been made, with attendant improvements in the design capability. In FY1999 a reference NCSX stellarator configuration was developed based on a plasma configuration (known as "C82") that was stable at β=4% and on the re-use of the TF and PF coils and neutral beams from the former PBX-M facility at Princeton Plasma Physics Laboratory. Though not a complete conceptual design for the NCSX, the 1999 reference design showed the potential for a practical device realization and highlighted issues needing further work.

In FY2000, further improvements in the design tools were made in order to incorporate all physics requirements into the NCSX design process. The range of evaluated configuration options (reference plasma and coil concepts) was broadened to provide a stronger basis for selecting the best configuration. A new reference plasma configuration and coil concept were chosen that represented a significant improvement over the 1999 design and provided an adequate basis for developing a design that meets all requirements. The evaluation of coil designs compatible with heating and diagnostic access requirements is nearing completion, the final step in establishing the pre-conceptual design basis for the project.

In March 2001 a panel of plasma physicists and engineers conducted a physics validation review of the NCSX design. The panel concluded that the physics approach to the NCSX design based on the quasi-axisymmetric stellarator concept is appropriate, that the physics requirements and capabilities of the pre-conceptual NCSX design are appropriate for the central element of the proof-of-principle program, and that the concept is ready for proof-of-principle designation.

C. Schedule/Cost

The schedule objectives for the NCSX Project are summarized below:

- FY2001 – Document physics basis, complete pre-conceptual design, start conceptual design activities, continue R&D. Milestones are:
    - NCSX Physics Validation Review, March 2001.
    - NCSX Project Validation Review for start of Major Item of Equipment in FY-2003 (April, 2001).
- FY2002 – Continue R&D, Conceptual and Post-Conceptual Design Activities. Milestones are:
    - NCSX Conceptual Design Review (April, 2002) and Project Validation Review for FY-2004 (May, 2002).
    - Start of Post-Conceptual design activities, April, 2002.
- FY2003 – Start Title I design activities, October 2002.

- FY2004 – Start Major Item of Equipment (MIE) fabrication activities, October, 2003.
- FY2006 – First Plasma, September 2006.

It is premature now to commit to a cost estimate for NCSX because the project is just completing the pre-conceptual design stage, and design tradeoffs are still being evaluated. The current estimate appearing in the SC Project Validation is $65 million in as-spent dollars over the period FY2003 through FY2006. This would qualify the project as an "Other Project" in the new DOE Project Management Order because it is well below the $100 million upper threshold for this category. The cost estimate for NCSX takes advantage of extensive site credits at PPPL for experimental space in existing buildings as well as major subsystems such as power, heating, cooling and vacuum and includes allowance for contingency and inflation.

D. Acquisition Strategy

The Princeton Plasma Physics Laboratory will have lead responsibility for execution and hosting of the NCSX project. The Oak Ridge National Laboratory, as a partner to PPPL, will provide major support, including leadership in specific areas. A strong management organization for the NCSX Project is established within the PPPL organization, reporting to the Department of Energy through the PPPL Director. The NCSX program is being organized as a national effort led by PPPL and ORNL, with the University of Texas at Austin, Columbia University, the University of California at San Diego, Lawrence Livermore National Laboratory, and Sandia National Laboratories at Albuquerque collaborating. The national team organization facilitates cost-effective knowledge transfer and resource sharing within the DOE system of laboratories and helps broaden participation in the program nationally.

E. Risk Assessment/Mitigation Plans

The three-dimensional character of the magnetic configuration provides design flexibility but requires extra attention to modeling and computational accuracy as well as dimensional accuracy. These special requirements are being addressed in the design and analysis process by involving people with stellarator project experience in key physics and engineering roles and by making use of numerical design tools and concepts from previous stellarator projects around the world. In addition, R&D is planned to solidify the technical base. Small-scale tests already in progress are being used to establish the design criteria for the conductor and winding concept being considered for the three-dimensional magnetic field coils. In the future, prototypes of the three-dimensional coils and vacuum vessel will be constructed to provide information on manufacturing approaches, industrial capabilities, and costs. Finally, a conservative approach for assigning contingency at the system level will be applied. This recognizes the similar designs adopted from the recently completed NSTX Project and previous experiments, while appreciating the increased complexity involved. These three risk mitigation elements adequately address risk in a proactive manner.

F. Preliminary NEPA Strategy

The Department will comply with the requirements of the National Environmental Policy Act (NEPA) and its implementing regulations prior to taking any action on the proposed project that would have an adverse environmental effect or that would limit the choice of reasonable alternatives. However, a similar NEPA review process for the same site was completed for the NSTX Project just two years ago, without adverse findings. Accordingly, it is not anticipated that any adverse findings will result for the NCSX project. As with the NSTX Project, it is expected that an Environmental Assessment (EA) will be prepared for this Project and that a more extensive Environmental Impact Statement (EIS) will not be required.

G. Project Organization

The Office of Fusion Energy Sciences (OFES) in the Office of Science has the responsibility for the programmatic and technical overview of the Project. The Area Manager of DOE/CH Princeton Area

Office will assign a DOE Project Manager having primary responsibility to ensure that the Project is properly managed by PPPL and that its technical objectives are met within the baseline cost and schedule.

APPROVAL

This Justification of Mission Need for the NCSX Project is satisfactory, Critical Decision 0 (CD-0) is approved, and the Project is authorized to proceed with Conceptual Design activities.

Submitted by:

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Approved by:

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