INFORMATION BULLETIN

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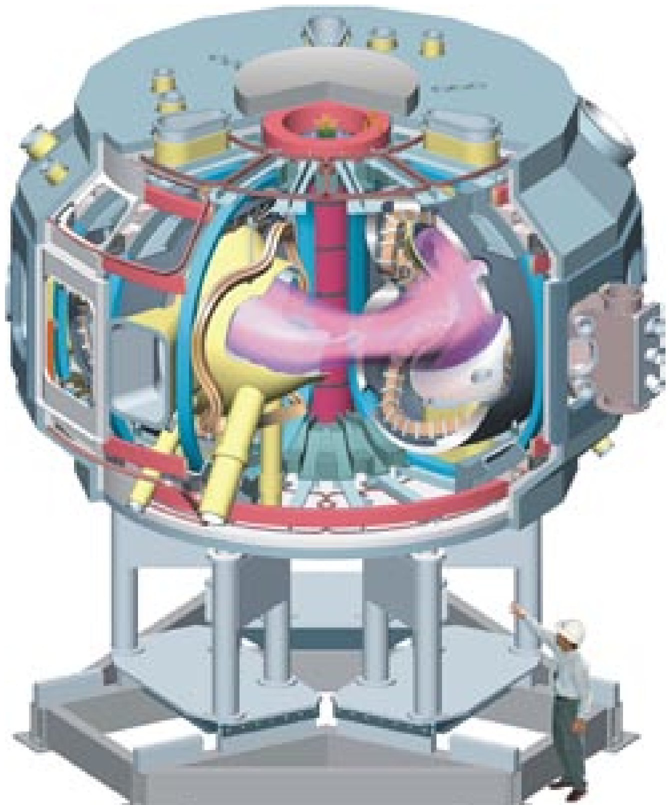
NCSX

National Compact Stellarator Experiment



National Compact Stellarator Experiment

Magnetic fusion energy researchers must find the best shape for the hot reacting plasma and the magnetic fields that hold it in place. Dramatic advances in magnetic confinement physics and computation capabilities have yielded a promising new configuration — the compact stellarator. A new experimental facility, the National Compact Stellarator Experiment (NCSX), is planned as the centerpiece of the U.S. effort to develop the physics and to determine the attractiveness of the compact stellarator as the basis for a fusion power reactor. NCSX will be built at PPPL in partnership with the Oak Ridge National Laboratory. First plasma is scheduled for 2008.

Scientific Foundations: Tokamaks and Stellarators

An attractive magnetic configuration is one that is passively stable and can be reliably sustained using little or none of the output power from the fusion plant. The success of the most widely studied magnetic fusion concept, the tokamak, has shown the advantage of bending the plasma into a toroidal, or doughnut, shape for achieving reactor-level plasma parameters for a short time. The tokamak can be made into a continuously sustained "advanced tokamak"configuration using the self-generated bootstrap current, but up to 20% of the plant's output power would still have to be recirculated to drive active plasma controls needed to prevent the disruption of a tokamak plasma. This prompted fusion physicists to search for configurations that would match the tokamak's good performance and, by reducing the recirculating power requirements, would be even more attractive.

A solution was found in another well-studied toroidal concept, the stellarator, invented by Princeton astrophysicist Lyman Spitzer, Jr. Spitzer realized that a stable, three-dimensional plasma torus could be formed and sustained continuously without active plasma controls. The cross-sectional shape of a stellarator plasma depends on where the torus is sliced, while that of a tokamak, a two-dimensional torus, is always the same. The third dimension provides physicists with an additional degree of freedom which they can use to tailor the plasma shape to obtain attractive physical properties (see Figure 1).

Advanced Physics and Computation

In the 1990's researchers began to study new stellarator designs with much lower aspect ratio than classical stellarator. This means that the new compact stellarators would produce plasmas that look more like truck tires when compared to classical stellarators in which the plasmas resemble bicycle tires.

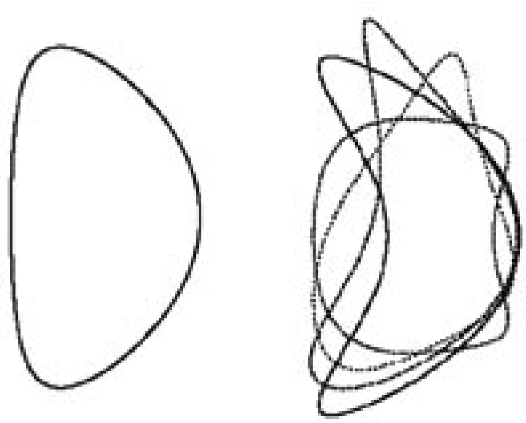


Figure 1. Compact stellarators are designed using powerful computers and sophisticated physical models to take a simple plasma shape and modify it to improve its performance. The two-dimensional toroidal plasma on the left requires an elaborate active control system to stabilize it, while the three-dimensional compact stellarator plasma on the right is passively stable in a steady magnetic field.

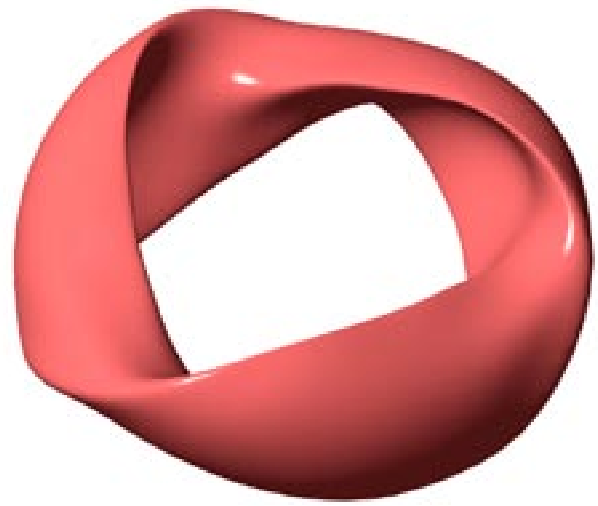


Figure 2. NCSX Reference Plasma Configuration.

Even though the geometry of a compact stellarator is three-dimensional, its magnetic field structure is designed to be "quasi-symmetric," which makes it tokamak-like in its underlying physics and confinement performance. Projections for these new "compact stellarator" reactor designs have higher power density, and are therefore more economical than classical stellarators. This exciting new concept is due not only to breakthroughs in physics, but also to a new way of designing fusion experiments made possible by the advent of modern, massively parallel computers.

Sophisticated computer programs using detailed mathematical models of the stellarator's performance allow dozens of stellarator shapes to be calculated simultaneously, then compared with each other to find the best, in a process repeated hundreds of times, until the most attractive shape is found. In a year, the designers compute and quickly evaluate as many as 100,000 different designs this way. Figure 1 shows how a two-dimensional torus is deformed by this method into a three-dimensional torus with better performance. The final shape is determined by mathematical models for the physical mechanisms that govern plasma behavior, such as the spontaneous plasma disturbances which lead to sudden terminations.

NCSX Physics Design

Using these computational techniques, a national stellarator design team, with members from two U.S. Department of Energy laboratories and several universities, developed a reference configuration for the National Compact Stellarator Experiment. (See Figure 2 and 3.)

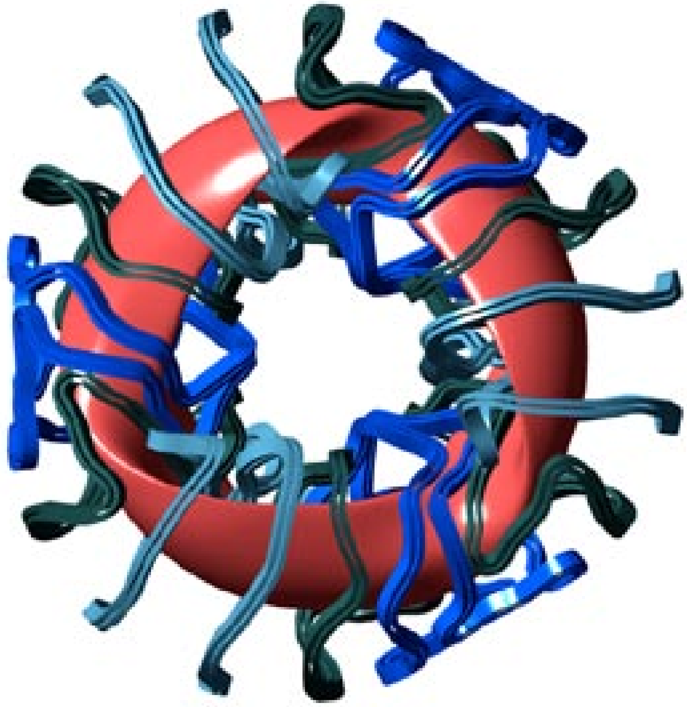


Figure 3. NCSX Plasma and Modular Coils.

NCSX physics and machine parameters are listed in the Table on page 4. The design features 18 modular coils, 18 toroidal-field coils, and 6 pairs of poloidal coils located symmetrically about the horizontal midplane. NCSX will also have trim coils for configuration flexibility. The 18 modular coils (of which there are only three different shapes) are shown in Figure 3. The coils are designed to allow tangential access for neutral beams and diagnostics, to produce the physics properties of the reference plasma, and to provide experimental flexibility to test compact stellarator physics. The coils can provide good configuration properties over a wide range of plasma current, profiles shapes, and beta — the ratio of the plasma pressure to the pressure of the confining magnetic field. Beta is a measure of the efficiency with which the plasma is confined, and the plasma current provides some of the magnetic field for confinement. Start-up simulations have demonstrated the evolution from an initial vacuum state to a high-beta target state along a stable path, consistent with planned equipment capabilities.

A total of 12 MW of auxiliary heating can be accommodated in the NCSX design, 6 MW of tangential neutral-beam injection (NBI) and 6 MW of radio-frequency heating. Up to 3 MW of electron cyclotron heating can be added. The facility will use NBI from one of the four existing Princeton Beta Experiment (PBX-M) neutral-beam lines at first. The remaining beams can be added to upgrade the NBI power to 6 MW.

Carbon plasma-facing components will be bakeable in situ to 350 °C to remove water vapor as necessary. A range of internal structures, including neutral-beam armor to protect vacuum chamber walls, limiters, baffles, divertor, and pumps to control the size of the plasma and remove impurities, are expected to be implemented over the life of the experiment. Fueling will be provided at first by a gas injection system which can provide feedback control on the density. Pellet injection will be added later. High vacuum will be provided by an existing turbomolecular pumping system. The facility will be equipped at first with diagnostics needed to begin the research program, starting with characterizing the magnetic topology. More diagnostics will be added during the operating life of the facility. Experimental results from the initial operating phases will help to optimize the selection of new diagnostic systems and their design characteristics.

NCSX Engineering Design

The NCSX engineering design has been developed for a plasma with a major radius of 1.4 meters and a cross-sectional shape that varies periodically around the plasma three times (see Figure 2). A cryostat encloses all of NCSX's coils which will be precooled to 80 degrees Kelvin. The modular coils, toroidal-field coils, and vacuum vessel will be assembled in 120° segments. Each segment will have ports for heating, pumping, diagnostics, and maintenance access.

The NCSX will be assembled in the area at PPPL that formerly housed the Princeton Large Torus and the PBX-M. Hardware from the PBX-M, including the neutral-beam, vacuum pumping, and water systems will be reused. Power supplies formerly used on the Tokamak Fusion Test Reactor will also be used.

NCSX Has Passed Key Reviews

A Department of Energy Physics Validation Review was conducted in March 2001. The fourteen-member peer review committee, chaired by Professor Gerald Navratil of Columbia University, reviewed the soundness of the NCSX physics basis and physics design approach, and concluded, "The consensus of the Panel is that the physics requirements and capabilities of the preconceptual design of the NCSX experiment represent an appropriate approach to developing the design of a Proof-of-Principle scale experiment that is the central element in a program to establish the attractiveness of the Compact Stellarator (CS) concept."

At its May 2001 meeting, the Fusion Energy Sciences Advisory Committee (FESAC) endorsed the recommendations of the NCSX Physics Validation Review. The Committee noted that the potential fusion gains "earn for the compact stellarator an important place in the portfolio of confinement concepts being pursued by the U.S. Fusion Energy Sciences Program."

An NCSX Conceptual Design Review in May 2002 found the project to be on a sound basis in all respects. In late 2002, the U.S. Department of Energy approved the NCSX funding plan.

In April 2003, the fabrication project formally started with development of engineering design details and fabrication processes. A Preliminary Design Review was held in October 2003. Reviewers found that the design progress was commendable and that it provided a sound basis for the project's cost and schedule estimates. Fabrication of prototypes of major components began at about the same time. A successful Final Design Review was held in May 2004.

National Compact Stellarator Experiment Parameters

Parameter	Value	Comments
Major Radius	1.4 m	Radius of the plasma ring (distance from the center of the ring to the center of the plasma cross section).
Nominal Beta	4.0%	Ratio of plasma pressure to magnetic field pressure.
Aspect Ratio	4.4	Ratio of major radius to average plasma radius.
Magnetic Field	1.2 - 1.7 T	>2 T at reduced rotational transform.
Plasma Heating Power	Up to 12 MW	Neutral-beams and radio-frequency waves.

The Princeton Plasma Physics Laboratory is operated by Princeton University under contract to the United States Department of Energy. For additional information, please contact: Information Services, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08543. Tel. (609)-243-2750, e-mail: pppl_info@pppl.gov, or visit our web site at: http://www.pppl.gov .