INFORMATION BULLETIN

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

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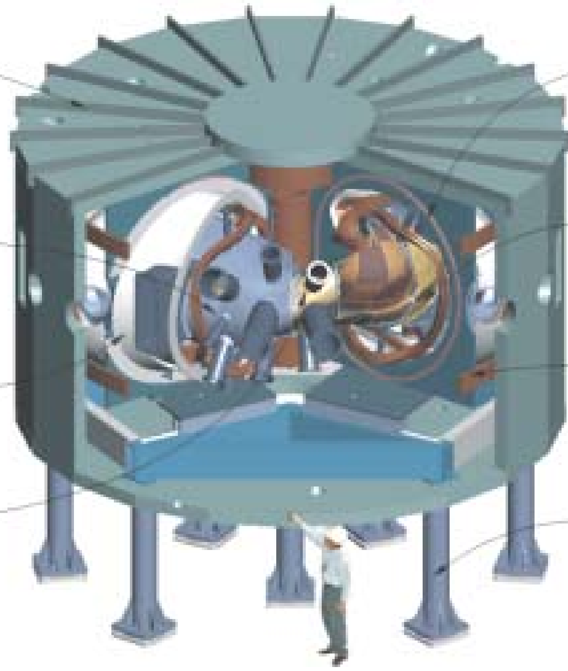
NCSX

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.

The NCSX project is now in conceptual design. Detailed engineering design is planned to begin in 2002 and construction is to be completed in September, 2006.

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. A crucial result from tokamak research was the experimental confirmation of a theoretically predicted self-generated "bootstrap current," that flows in high pressure plasmas. This effect can greatly reduce the power required to sustain the magnetic field. The bootstrap current can be used to make the tokamak into a continuously sustained "advanced tokamak" configuration, 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 1990s, researchers began to study new stellarator designs that take advantage of the bootstrap current to produce a stable plasma with a much lower aspect ratio than classical stellarators. These compact plasmas look more like truck tires when compared to classical stellarators, which resemble bicycle tires. 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.

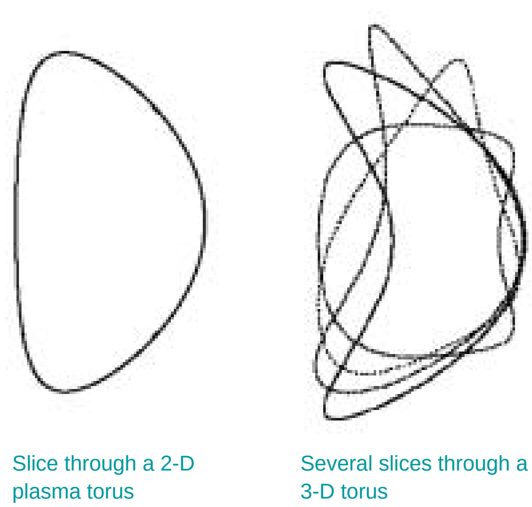


Figure 1. Compact stellarators are designed using powerful computers and sophisticated physical models to take a simple plasma shape and modify it to improve its performance. The two-dimensional toroidal plasma on the left requires an elaborate active control system to stabilize it, while the three-dimensional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

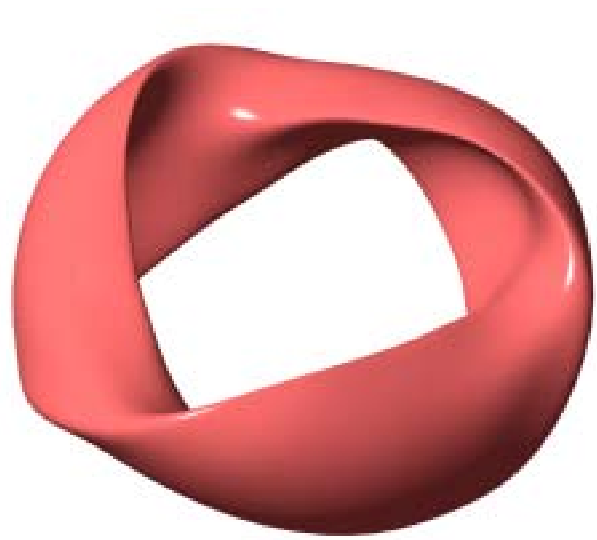


Figure 2. NCSX Reference Plasma Configuration.

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, has developed a reference plasma configuration for the National Compact Stellarator Experiment. (See Figure 2.) NCSX is being proposed for construction at PPPL in partnership with the Oak Ridge National Laboratory.

NCSX physics and machine parameters are listed in the Table on page 4. The design features 18 modular coils, 18 toroidal-field coils, and 5 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 types) are shown in Figure 3. The coils are designed to allow tangential access for

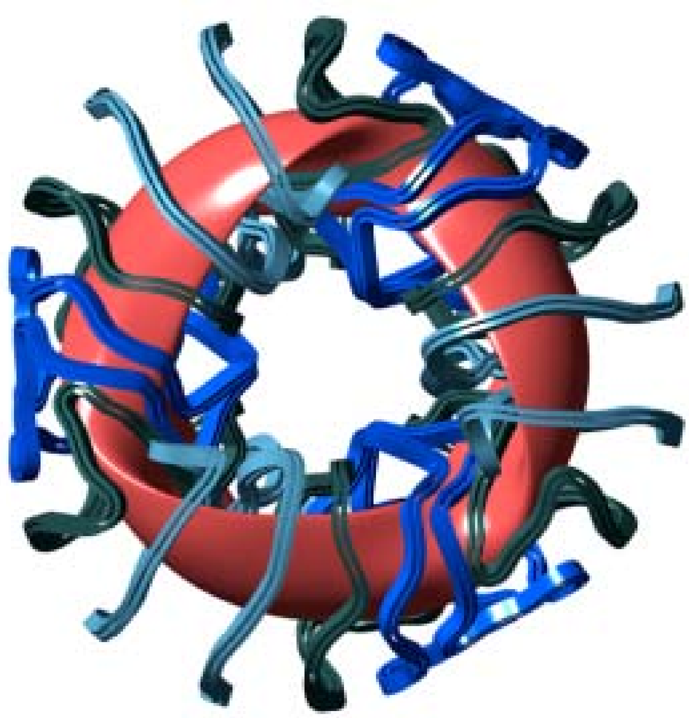


Figure 3. NCSX Modular Coils.

neutral beams and diagnostics, to reconstruct 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 that 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 been carried out, demonstrating 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. Initially the facility will be equipped with 3 MW of tangential NBI, using two of the four existing Princeton Beta Experiment-Modification (PBX-M) neutral-beam lines. The remaining two can be added to upgrade the NBI power to 6 MW.

Plasma-facing components will be made of carbon, 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 for shakedown of major machine systems and the first few phases of physics operation, including first plasma, electron-beam mapping of flux surfaces, ohmic plasma experiments, and initial heating experiments. 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 preconceptual 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). The NCSX vacuum vessel will have an internal structure that can support molded carbon-fiber-composite panels for power and particle control. The panels are bakeable to 350 °C. A cryostat encloses NCSX's toroidal, poloidal and modular 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, power supplies, and water systems will be reused. Power supplies formerly used on the Tokamak Fusion Test Reactor will also be used.

NCSX Passes Key Reviews

The successful completion of two critical physics reviews in Spring of 2001, significantly boosted NCSX's prospects. A Department of Energy Physics Validation Review was conducted March 26-28, 2001 at PPPL. 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, using documents and briefings presented by the NCSX design team. In its report, the Navratil Committee 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." The report also made a number of recommendations on design requirements, physics analysis, and management. Following this favorable review, the NCSX project was authorized to proceed with conceptual design, incorporating the review recommendations into its plans. A conceptual design review is planned for the Spring of 2002.

At its May, 2001, meeting, the Fusion Energy Sciences Advisory Committee (FESAC) endorsed the recommendations of the NCSX Physics Validation Review, citing the compact stellarator's potential to resolve significant issues for fusion energy, to complement existing tokamak and stellarator research, and to advance the science of three-dimensional magnetized plasmas. The FESAC said 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."

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	3 - 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 .