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ENVIRONMENTAL ASSESSMENT

THE NATIONAL COMPACT STELLARATOR EXPERIMENT AT THE PRINCETON PLASMA PHYSICS LABORATORY

September 2002

U.S. DEPARTMENT OF ENERGY
ARGONNE, ILLINOIS 60439

THE NATIONAL COMPACT STELLARATOR EXPERIMENT AT THE PRINCETON PLASMA PHYSICS LABORATORY

1.0 PURPOSE AND NEED

If the United States is to meet the energy needs of the future, it is essential that new technologies emerge to compensate for dwindling supplies of fossil fuels, the eventual depletion of fissionable uranium used in present-day nuclear reactors, and the limitations of solar, hydro and wind alternatives. Fusion energy, the power source of the sun and other stars, has the potential to become a major source of energy for the future. Power from fusion would provide substantially reduced environmental impacts as compared with current forms of energy generation. Thus, the United States and other countries around the world continue to pursue development of fusion energy as one of a number of potential power sources for the long term.

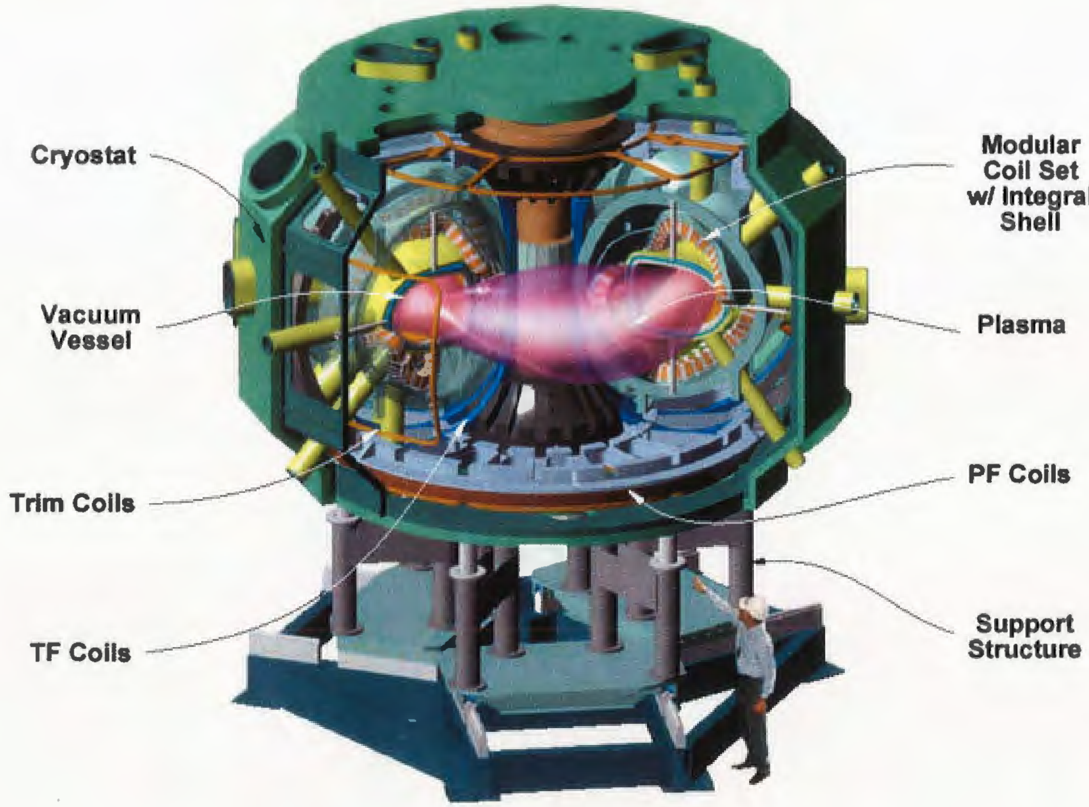
Fusion research, using various machine configurations, has been proceeding since the early 1950's, and significant progress has been achieved in performance and in understanding of the underlying physics. For most of this period, fusion machines called stellarators and tokamaks, which are toroidal (doughnut-shaped) devices, have been most frequently used to conduct experiments for producing controlled nuclear fusion. It is now desirable to take a next step in the fusion development program, by providing an experimental device to investigate the attractiveness of a compact stellarator as the basis for a fusion power reactor. This concept has the potential to build upon advances in understanding of stellarators and tokamaks, and to combine the best features of both. The goal is to build a compact stellarator that would be smaller than conventional stellarators and operate more efficiently than previous tokamaks. Such a device would broaden our understanding of magnetic fusion science while contributing to the development of a potentially attractive fusion reactor solution that may have cost advantages over other fusion concepts.

2.0 DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVE

2.1 NCSX Project

The proposed action consists of the fabrication, assembly and operation of a National Compact Stellarator Experiment (NCSX) within the existing C-Stellarator (CS) Building at C-Site of the Princeton Plasma Physics Laboratory (PPPL). The NCSX would consist of a plasma confinement device made up of an assembly of several magnet systems and structures that surround a highly shaped plasma (see Figures 2-1 and 2-2). Plasmas are very hot gases whose atoms are ionized, i.e., have their electrons stripped off. The fuel (hydrogen, deuterium or helium) in a fusion device must be heated to high temperatures for the fusion reactions to take place. The plasma fuel is suspended and contained within these devices by a magnetic field and is heated by various means. Coils would be provided to produce a magnetic field for plasma control and shaping. A vacuum vessel would produce a high vacuum plasma environment with access for heating, pumping, diagnostics, and maintenance. The device would be enclosed in a cryostat to permit cooling of the magnets at cryogenic (very low) temperature (where resistance to current flow is small).

FIGURE 2-1 NCSX Device



Key features of NCSX relative to determining the attractiveness of the compact stellarator concept would include:

1. Plasma stability without active feedback control;
2. Capability for testing features favorable for steady state operation;
3. Enhanced efficiency for plasma confinement.

2.1.1 NCSX Fabrication and Assembly

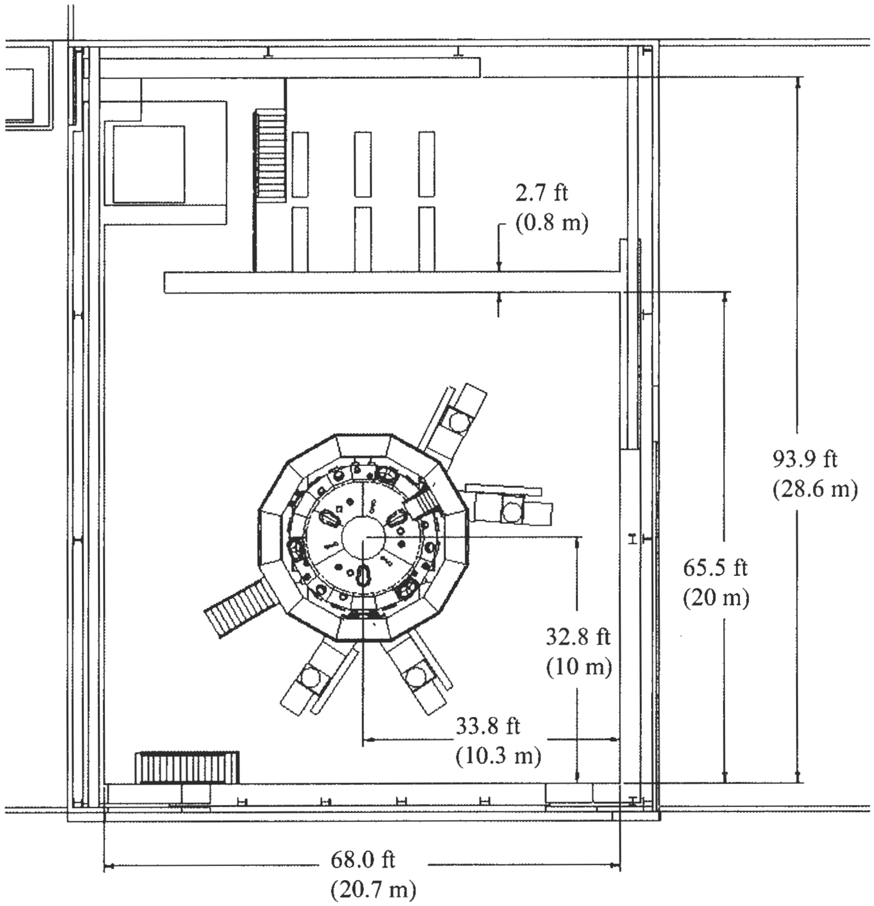
The NCSX device would be installed in an existing building formerly occupied by two other fusion devices (see Figures 2-3, 2-4 and 2-5). This test cell would be refurbished by:

1. Relocating the shield walls to combine two former experimental areas into a single, spacious area (Test Cell) for NCSX;
2. Raising the height of the shield walls by one to two blocks to further minimize radiation exposure during deuterium operation in the control room and adjacent offices; and
3. Reinforcing the shield walls to meet current DOE seismic requirements.

NCSX would be equipped with neutral-beam heating systems (that heat the plasma using beams of hydrogen, deuterium or helium) with up to 6 megawatts (MW) of power, radio-frequency (RF) heating systems (that heat the plasma using radio waves) with up to 6 MW of power, pumps, fueling systems, diagnostics, control systems, and data acquisition systems. The NCSX plasma major radius (radius of the plasma "doughnut", i.e., distance from the center of the "doughnut" to the center of the plasma cross section) would be 4.6 feet (1.4 meters), with a cross-sectional shape that repeats itself around the plasma three times (see Figure 2-2). The design would include eighteen (18) modular coils, eighteen (18) toroidal field coils, six (6) pairs of poloidal coils located symmetrically about the horizontal midplane, and trim coils for configurational flexibility. The total height of the vacuum vessel and coils would be 11.2 feet (3.4 meters), and the total diameter of the device would be 18 feet (5.5 meters). A cryostat (see Figure 2-1) would enclose NCSX's toroidal, poloidal and modular coils, which would be cooled to 80 degrees Kelvin (-315.67 °F). Plasma-facing components (i.e., equipment inside the vacuum vessel that are nearest the plasma) would be bakeable (capable of being heated) to 350 °C (662 °F) to remove water vapor as necessary, thereby enhancing plasma purity, temperature and stability. A range of internal structures, including neutral-beam armor to protect vacuum chamber walls; and limiters, baffles, divertor, and pumps to control the size of the plasma and remove impurities, would be implemented over the life of the NCSX. Fueling would be provided at first by a gas injection system, while pellet injection fueling may be added later. High vacuum inside the NCSX vacuum vessel, to allow plasma formation, would be provided by an existing pumping system. The facility would be equipped at first with diagnostics (observational and data collection devices) needed for fine-tuning of major machine systems and the first few phases of physics operation. More diagnostics would be added during the ten-year operating life of the facility. Experimental results from the initial operating phases would help to optimize the selection of new diagnostic systems and their design characteristics.

FIGURE 2-2 NCSX Plasma Configuration

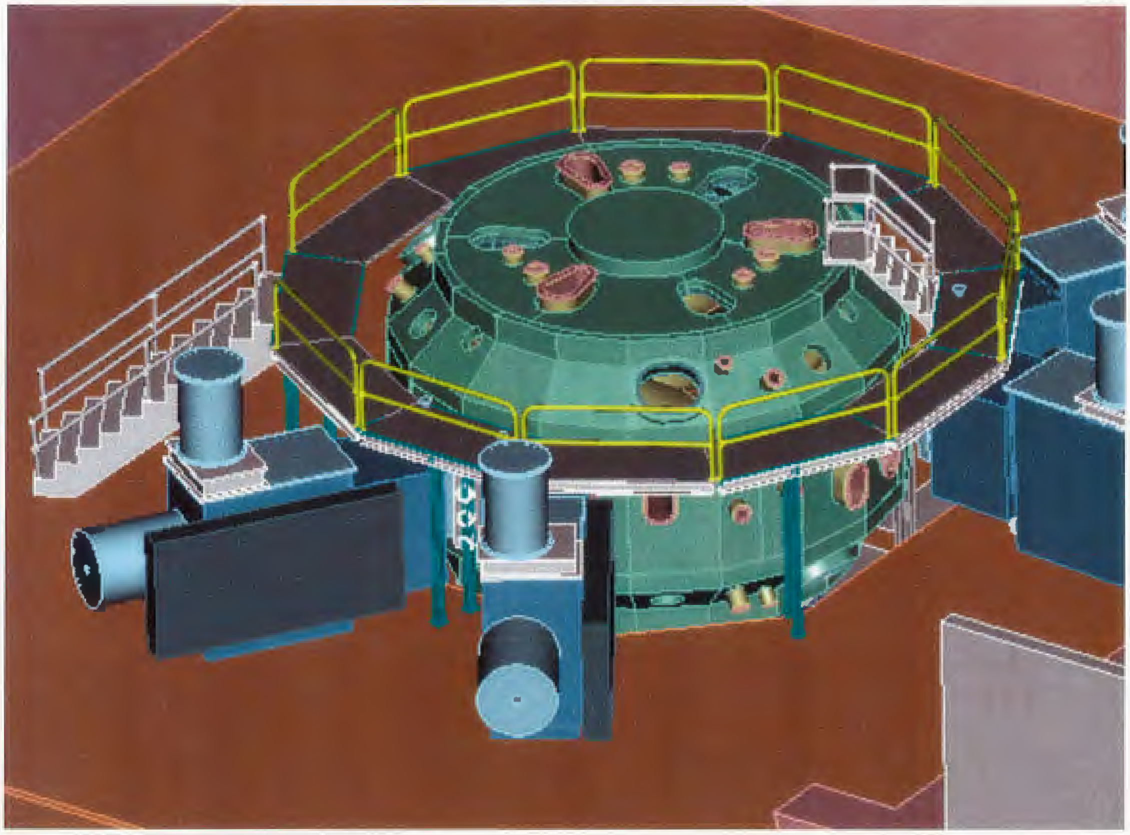
FIGURE 2-3 NCSX Test Cell



A platform with a ceiling height of approximately 9 feet (2.7 meters) would be installed around the NCSX device (see Figure 2-4) to provide a good working area in support of diagnostics and improve access to the machine. A catwalk would be installed in close proximity to the machine to allow access to the upper portions of the device. The platform would have exiting stairs from the southeast and northwest corners of the NCSX Test Cell. A walkway would extend completely around the machine to the entrance of the Control Room.

Site infrastructure such as cryogenic systems and utility services would be used. Major site credits (existing equipment and facilities) to be used would be the neutral beam injectors, vacuum pumping and gas injection systems used for a previous C-Site fusion device; D-site magnet power supplies originally used on the former Tokamak Fusion Test Reactor (TFTR) experiment; some C-site power supplies; the NCSX test cell and associated infrastructure; and the adjacent control and computer rooms formerly used for previous C-Site fusion devices. As part of the project, the facilities and equipment to be re-used would be reconfigured or refurbished as needed to meet NCSX requirements.

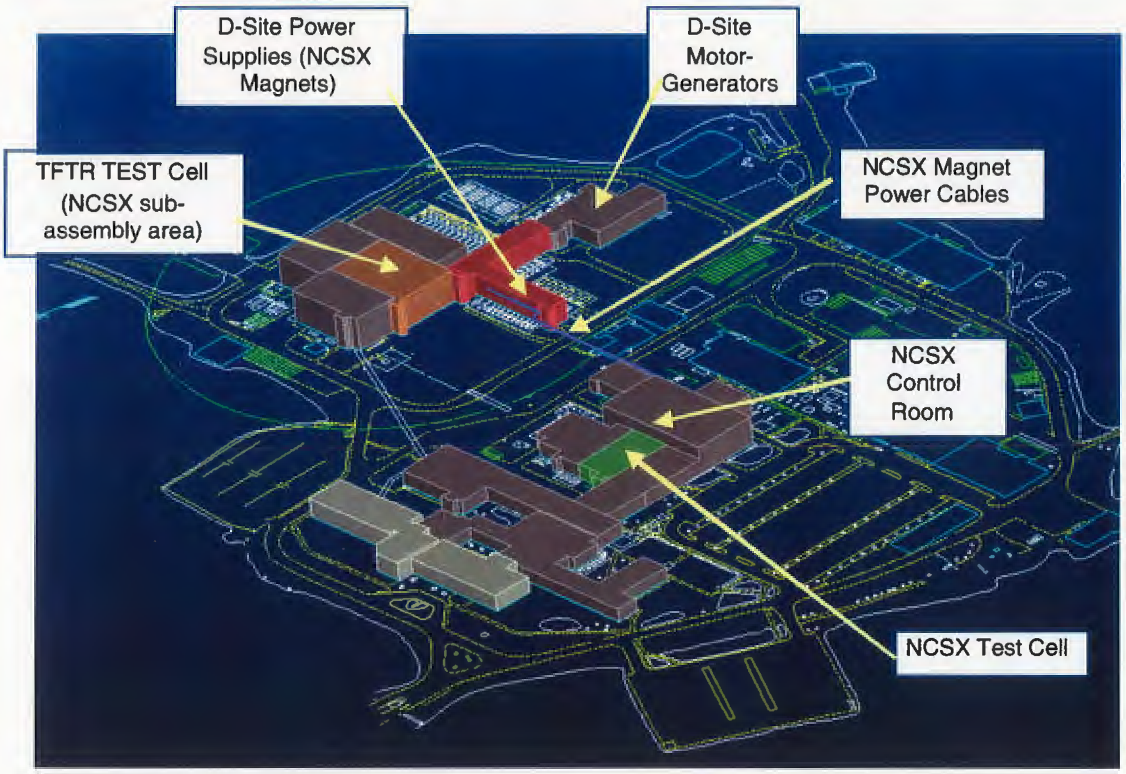
FIGURE 2-4 NCSX in Test Cell



The formerly used computer and control rooms, which are contiguous to the NCSX Test Cell, would be refurbished and utilized by providing new lighting, ceilings and floors, and through installation of new control and computer equipment. Power supplies currently located at D-site would be used by running approximately 500 feet (152.4 meters) of copper transmission lines from equipment in the D-Site Field Coil Power Conversion (FCPC Building) to the C-Site Equilibrium Field/Ohmic Heating (EF/OH) Building, and then to NCSX (see Figure 2-5). The second floor of the FCPC Building, which presently houses a number of offices and a Vacuum Preparation Laboratory, would be reconfigured. The laboratory would remain but the offices would be relocated. Additional modifications would include the core boring of penetrations between the FCPC Building first and second floors to provide routing for the power cables, along with a large weatherproofed wall penetration at the end of the FCPC building for the power cables exiting the building.

Fabrication and assembly activities would involve the removal of previously used fusion experiment equipment including approximately 160 tons of stainless steel, 80 tons of copper and 5 tons of aluminum (all non-radioactive) that would be recycled to the maximum extent possible onsite, at other Department of Energy (DOE) sites, or commercially, and several tons of non-metals (plastics, wood and fiberglass) that would be disposed of as domestic waste. Modifications (e.g., penetrations) in existing walls and floors of the NCSX Test Cell could result in asbestos waste, which would be handled by a certified asbestos subcontractor. About 140 tons of material (stainless steel, copper, inconel, graphite, aluminum, glass & foam) would be used to fabricate the NCSX device, and 30-35 tons of copper cable would be run between D-Site and C-Site to power the coil systems. Some digging for footings covering about 0.2 acres in a previously disturbed non-sensitive area (see Figures 2-5 and 3-1) would be required for the power cable runs between D-Site and C-Site. Sheet rock, new lighting, and new floors and ceiling would be used to construct the NCSX Control Room.

FIGURE 2-5 NCSX Locations at PPPL



It is planned to fabricate the NCSX device from three (3) identical sections, each comprised of one third of the vacuum vessel plus six (6) Toroidal Field (TF) and modular coils. These sections (called "field periods") would be pre-assembled in the TFTR Test Cell at D-Site (see Figure 2-5), where they would be baked out (heated) using the existing National Spherical Torus Experiment (NSTX) Bakeout System and vacuum leak checked. This would require that the existing bakeout lines be extended approximately 100 feet (30.5 meters) from the Bakeout System, which is located in the adjacent NSTX Test Cell, to the Field Period Assembly Area in the TFTR Test Cell. Each field period would then be transported to the NCSX Test Cell for final machine assembly. After completion of assembly and installation, an integrated testing program would be carried out and a plasma ("first plasma") would be produced in the device to demonstrate readiness for experimental operations.

2.1.2 NCSX Operation

Design, fabrication and assembly of NCSX would occur in fiscal years (FY) 2003-2007, with initial operations ("first plasma") scheduled for June 2007. NCSX operations would be conducted over approximately a 10-year period. The NCSX mission would be pursued in a series of planned phases currently projected to proceed as follows:

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I. Initial Operation - initial plasma operation and system checkout. Short ohmic (resistive) pulses would be used to achieve the first-plasma milestone and carry out a brief campaign intended to test the ability to initiate the plasma and checkout the operation of the initial diagnostics.

II. Field-line Mapping - validation of the coil manufacture and assembly. This campaign would test the accuracy of the stellarator magnetic field generation by measuring the magnetic surface shapes in vacuum.

III. Ohmic - operation with inductive current and ohmic heating only. This phase would establish good control of the magnetic configuration as well as good vacuum and wall conditions. Physics results on various properties at low beta and temperature would be pursued. Beta is the ratio of the plasma pressure to that of the confining magnetic field, a measure of plasma confinement efficiency.

IV. Auxiliary Heating - operation with 3MW of neutral beam injection (NBI). This campaign would explore the flexibility, plasma confinement, and stability of NCSX, starting at the initial heating power (3 MW from two neutral beams), magnetic field (at least 1.2 Tesla) and pulse length (at least 0.3 seconds).

V. Operation at High Confinement and Beta - operation with about 6MW of auxiliary heating and upgraded plasma-facing components (PFCs). This phase would attempt to extend enhanced confinement regimes and investigate high-beta stability issues with a full neutral-beam complement (6 MW from four beams) and/or megawatt-level radio-frequency heating.

VI. Long Pulse - plasma and heating pulse lengths of at least 1.1 seconds, pumped divertor, possible further upgrade of heating power. This phase would be preceded by an upgrade to the heating systems (to allow pulse lengths of about 1 second, and power of as much as 12 MW) and a possible upgrade of the plasma-facing components for improved power and particle exhaust handling for long pulses.

Experiments would be carried out using hydrogen, helium and deuterium gases; no tritium fuel would be used. Emissions to the environment would consist of very small amounts of these gases. Tritium would be produced by D-D fusion experiments and would be released to the atmosphere in amounts estimated to be less than 0.014 Curies/yr. Approximately 10,000-30,000 gallons per week of nitrogen gas (the main constituent of air) would be released to the atmosphere from the heating of liquid nitrogen in the cryostat after cooling of the NCSX magnetic field coils. NCSX would generate neutron and gamma radiation during plasma operations, but little or no detectable neutron activation of components or building air would be expected. Wastes may include small amounts of hazardous wastes (i.e., machinist coolant, used vacuum pump oil, epoxy/cements, waste solvents, and solvent soaked rags), and very small amounts (< 0.001 Ci per year) of tritium contaminated vacuum pump oil (produced from pump oil absorption of some of the tritium generated by deuterium fusion reactions in NCSX).

The NCSX program would be conducted at PPPL by a nationally based research team.

2.2 Alternative To The Proposed Action

The only alternative to the proposed action considered was the "no action" alternative, i.e., not constructing NCSX for plasma research. This alternative would preclude efforts to investigate a potentially attractive fusion reactor solution that would also broaden our understanding of magnetic fusion science. In this case, activities at PPPL would proceed at about current levels with continued operations of existing fusion and plasma physics experiments.

While the NCSX or a similar device could conceivably be constructed at another facility, the value of the PPPL "site credits" (estimated to be comparable to the total estimated project cost of about $70-75M) would make this project much more costly than the proposed action, with no apparent programmatic or environmental benefits. Thus, this latter option was considered unreasonable and therefore was rejected.

Consideration was given to locating the proposed NCSX at several other locations on the PPPL site, but the selected location would involve the least amount of modifications to existing facilities or impacts on existing fusion experiments.

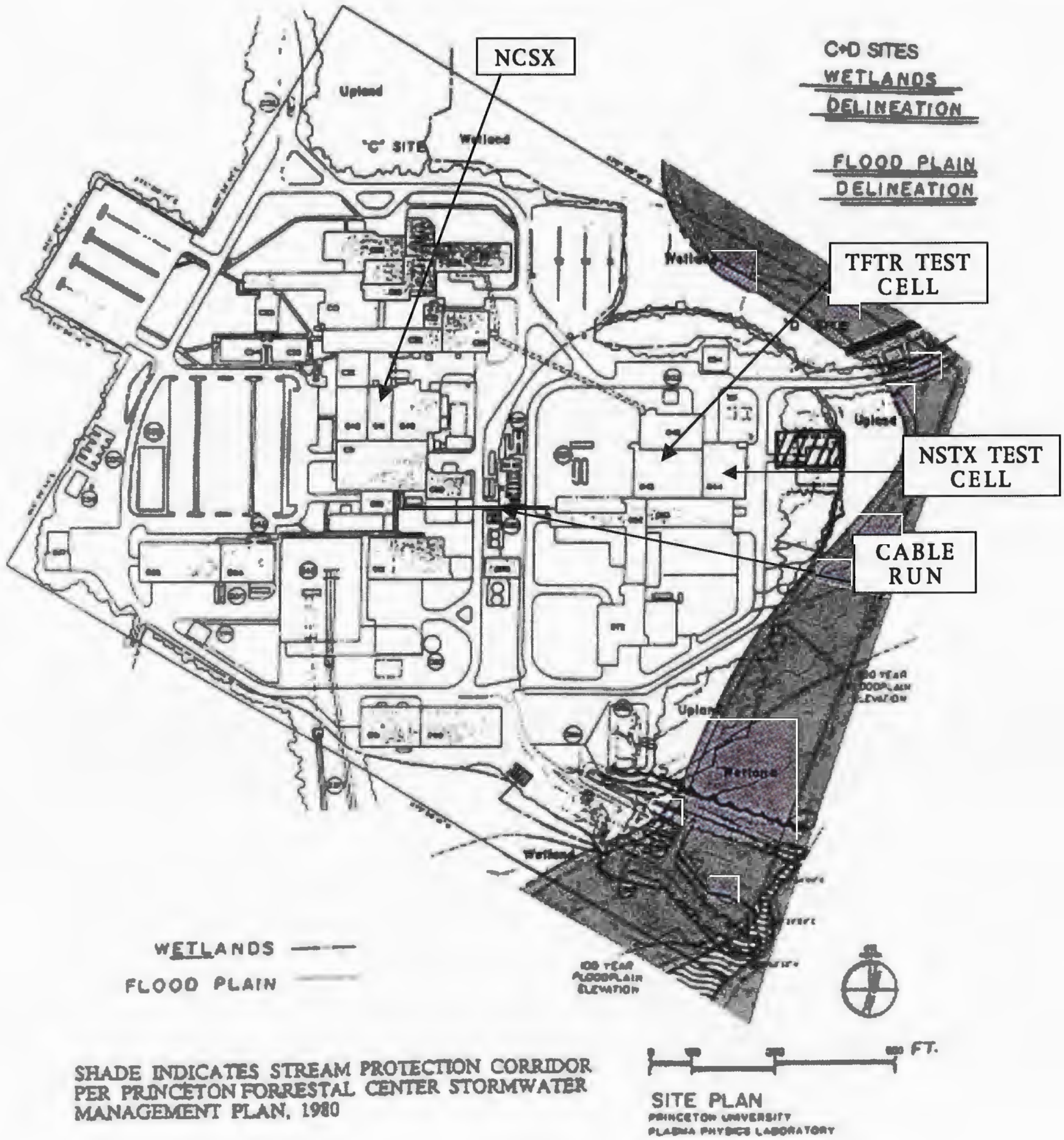
A key challenge for magnetic fusion energy research in the development of an attractive fusion power plant is finding a toroidal plasma configuration that has high power density, can be sustained with little or none of the output power from the fusion plant, and can be continuously operated. Depending solely on participation in existing and planned stellarators in the US, Europe and Japan would be less meaningful than fabricating and operating the proposed NCSX because these other machines address some of these features but not all. NCSX would be designed to investigate all of these aspects in a single experimental device.

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The proposed NCSX would be located in the existing C-Stellarator (CS) Building at the C-Site of PPPL (Figure 3-1). The NCSX would be housed in the four story high bay NCSX Test Cell which has a floor space of about 6,400 square feet. All activities associated with NCSX fabrication, assembly and operation, with the exception of the D-Site-to-C-Site cable run, would take place within existing buildings. No NCSX activity would take place in or affect wetlands or floodplains, which are located near the northern and southern borders of the PPPL site.

PPPL is located in central New Jersey approximately midway between Philadelphia and New York City. It is adjacent to U.S. Route 1, in the Township of Plainsboro. The estimated resident population within 10 miles (16 kilometers) of PPPL for the year 2010 is projected to be about 499,000. The total estimated population for the year 2010 within a 50 mile (80 kilometer) radius of PPPL is projected to be approximately 16.4 million. The climate of central New Jersey is classified as mid-latitude, rainy climate with mild winters, hot summers, and no dry season. Temperatures range from below zero to above 100 degrees Fahrenheit (°F), -17.8°Celsius (C) to 37.8° C; the extreme temperatures occur about once every five years. The climate is moderately humid with a total average annual precipitation of 46.5 inches (118 cm). PPPL operates in compliance with air and water quality regulations, including the Clean Air Act (CAA), the National Emissions Standards for Hazardous Air Pollutants (NESHAPS), and the New Jersey Pollutant Discharge Elimination System (NJPDES).

FIGURE 3-1 PPPL Site Map



Additional information and details on the PPPL site and region can be found in the Annual Site Environmental Report (Finley 2001) and in a previous Environmental Assessment (DOE 1994).

4.0 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION AND ALTERNATIVE

4.1 Impacts of NCSX Fabrication and Assembly

As indicated in Section 2.1.1, some domestic waste (several tons of non-metals, i.e., plastics, wood and fiberglass) would be generated during the NCSX fabrication and assembly work. This waste material would be sent to a local landfill, which would not be adversely impacted due to the small volume of waste compared to the capacity of the disposal facility. Much of the material removed during the fabrication and assembly phase would be recycled for use on NCSX, recycled offsite as scrap metal, or stored onsite for future use. This material is not radioactive and is not located in a radiological area. Per regulatory requirements, a certified asbestos subcontractor would dispose of the small amount of asbestos waste that may be generated as a result of NCSX Test Cell wall and floor modifications. Since all work would take place within existing buildings or on small amounts of previously disturbed non-sensitive land on the PPPL site (see Figure 3-1), there would be no impacts from NCSX fabrication and assembly on environmental resources such as wetlands, floodplains, air quality, noise, water quality and quantity, aquatic and terrestrial ecology (including threatened and endangered species), visual environment, land use, historical, cultural, and archaeological resources, and socioeconomic environment. No new environmental permits are expected to be required for this work.

All fabrication and assembly projects have the potential for worker injuries, e.g., slips/trips/ falls, muscles sprains/strains, cuts, repetitive stress injuries, etc. Based on DOE Chicago Operations facilities (including PPPL) injury and illness data from 1997-1st quarter 2002 (DOE 2002), and a projected fabrication and assembly labor effort of about 59 worker-years for NCSX fabrication/assembly, there would be a statistical expectation of one lost work case (LWC) during the NCSX fabrication and assembly period. LWCs are away-from-work day plus restricted workday cases. An away-from-work day is a day an employee is absent from work because of an injury or illness at work. A restricted workday is a day an employee is present at work but restricted from normal activity because of an injury or illness at work. Environment, safety and health considerations would be integrated into all aspects of NCSX fabrication and assembly activities. These would include functions such as defining work scope, analyzing and controlling hazards, performing work within the defined controls, and providing feedback on lessons learned when a job is completed.

4.2 Impacts of NCSX Operation

During NCSX operations, small amounts of non-radioactive hydrogen, deuterium, helium and argon gases used in plasma experiments, as well as non-radioactive vaporized liquid nitrogen used in the cryostat to cool the NCSX magnetic field coils would be exhausted to the outside environment via a building vent. Venting of these types of gases has occurred during operation of PPPL's past and current experimental devices, and, as previous experience indicates, no adverse environmental impacts are anticipated from this operation.

It is planned that liquid nitrogen for NCSX needs would be delivered via truck to an existing large tank located outside, adjacent to the CS Building. Up to ten (10) truck deliveries per week of liquid nitrogen are estimated to be needed during NCSX operating periods. This would represent a very small fraction of the approximately 200,000 vehicles per week that travel U.S. Route 1 near PPPL (DOE 1994). Alternatively, re-liquefaction and reuse of the vaporized nitrogen would be considered, which may reduce or eliminate the need for these liquid nitrogen truck deliveries.

There would be no impacts from NCSX operation on environmental resources such as wetlands, floodplains, air quality, noise, water quality and quantity, aquatic and terrestrial ecology (including threatened and endangered species), visual environment, land use, historical, cultural, and archaeological resources, and socioeconomic environment. No new environmental permits are expected to be required.

The estimated radiation dose to the maximally exposed onsite individual (expected to be a worker in the adjacent NCSX Control Room) from neutron and gamma radiation generated during NCSX plasma operations would be less than 0.5 rem per year (Kugel 1998). This occupational dose would result in an increased probability of fatal cancer of less than 0.0002 (or 2 chances in 10,000), based on the methodology used in DOE 1994. Personnel exposures would be controlled through the use of administrative controls, monitoring, and precautionary measures (e.g., use of dosimeters within areas and on personnel; and evaluation, assessment, and preplanning of activities prior to entry to radiologically controlled areas and following radiological assessment by PPPL Health Physics). Radiation exposures to workers are required to be controlled and maintained below the annual DOE standard of 5 rem effective dose equivalent (EDE), as well as the PPPL administrative limit of 1 rem per year.

Worker exposures to radio-frequency (RF) and magnetic fields would be precluded by a safety interlock system that would prevent access to the NCSX Test Cell during plasma operations, and would prevent RF transmission into the Test Cell when personnel have access. In addition, systems transmitting RF energy to the NCSX Test Cell would be designed to limit leakage levels in compliance with Institute of Electrical and Electronic Engineers (IEEE) Standard C95.1 ("Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields"), and would be routinely checked for leakage. If access to the Test Cell is required for test purposes while coils are energized but plasma formation is prevented, worker exposures to magnetic fields would be restricted to the occupational exposure limits established by the American Conference of Governmental Industrial Hygienists (ACGIH).

Wastes may include small amounts of machinist coolant, used vacuum pump oil, epoxy/cements, waste solvents, and solvent soaked rags. The small amounts of tritium contaminated pump oil (< 0.001 Curies per year) that would be produced during NCSX D-D operations would be disposed offsite as low- level radioactive waste. It is assumed that such waste would be sent to the low- level waste disposal facilities at either the DOE Hanford Site in Richland, Washington or the DOE Nevada Test Site, as is current PPPL practice.

Workers would be protected from a large release of nitrogen from the cryostat to the NCSX Test Cell (which would be hazardous due to oxygen displacement) by mitigation features such as low oxygen concentration alarms, room egress pathways, and administrative controls that would be incorporated into NCSX design and operations. The integrated safety management features indicated in Section 4.1 would also be applied to NCSX operations, including maintenance and modifications.

Offsite doses from direct and scattered radiation and tritium gas vented during NCSX operations would be small, < 0.002 rem per year, resulting in an increased probability of fatal cancers of less than 0.000001 (or 1 chance in 1 million) to a member of the public (Kugel 1998 and DOE 1994). No accident scenario has been identified that would cause a release of hazardous material from NCSX to the offsite environment.

Eventual dismantlement of NCSX following the end of experiments on this device may produce small amounts of low level radioactive wastes which would be sent to an offsite DOE disposal facility as indicated above for tritium contaminated pump oil produced during operations. Worker exposures during dismantlement would be limited to less than the PPPL requirement of 1 rem per year, and an increased probability of fatal cancers of 0.0004 (or 4 chances in 10,000).

Unavoidable adverse impacts from the proposed action would include small radiation exposures to workers and the public, the potential for a small number of occupational injuries during NCSX fabrication and assembly activities, and small quantities (relative to disposal capacity) of waste requiring disposal. Irreversible and irretrievable commitments of resources would include utility use (e.g., electricity, water), the beneficial expenditure of 59 worker-years during NCSX fabrication and assembly activities, use of an estimated 2,600,000 to 7,800,000 gallons of liquid nitrogen over 10 years of NCSX operations, the use of some materials for NCSX fabrication/assembly which may not be fully recoverable, and land or space elsewhere for receiving waste generated during NCSX fabrication, assembly, operation, and dismantlement. No adverse cumulative or long term impacts from the proposed action are anticipated based on NSTX operating experience, the current absence of measurable cumulative impacts between PPPL and other facilities in the region, and the very low potential impacts from the proposed action. There would be no environmental justice issues, as there would be no environmental effects on minority populations, low-income populations, or Indian tribes.

4.3 Impacts of No Action Alternative

There would be no additional environmental impacts from the no action alternative. Efforts to investigate a potentially attractive fusion reactor solution that would also broaden our understanding of magnetic fusion science would be precluded. Activities at PPPL would be expected to proceed at about current levels with continued operations of existing fusion and plasma physics experiments. The space planned for NCSX would be available for other uses.

5.0 REFERENCES

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