INFORMATION BULLETIN

PPPL PRINCETON PLASMA PHYSICS LABORATORY

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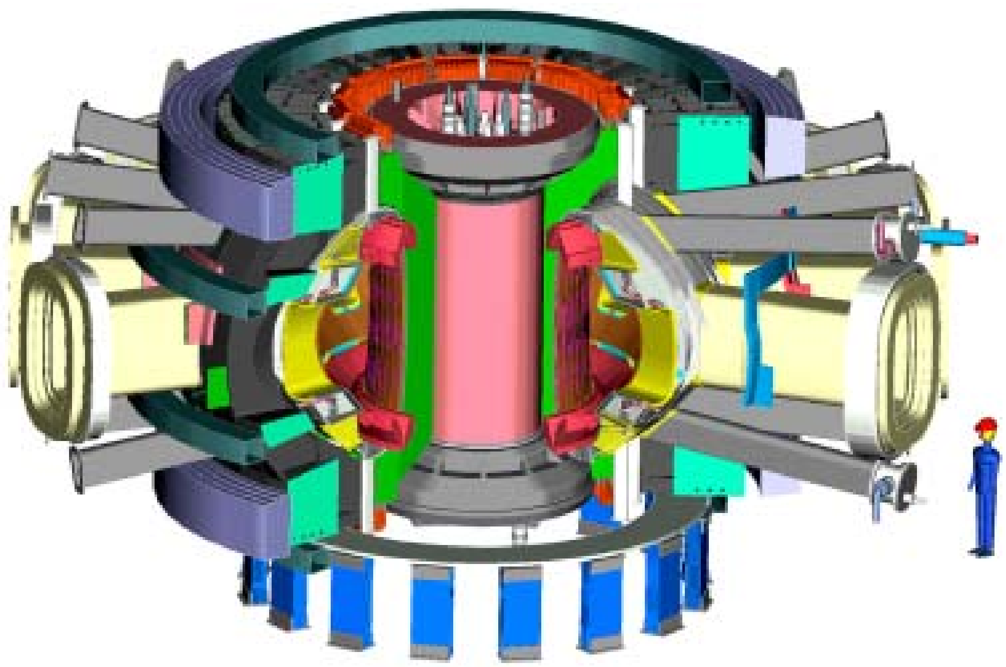
FIRE

Fusion Ignition Research Experiment

Exploring the Frontiers of Burning Plasma Science



Fusion Ignition Research Experiment

The next large-scale research step required to provide the scientific foundation for magnetic fusion energy is the creation and exploration of a burning plasma — a very hot fusion fuel that is dominantly sustained at high temperature through the power of its own fusion reactions. It is widely agreed that scientific progress in magnetic fusion research has established the technical basis needed to proceed with this step. For the past two years, a team consisting of scientists and engineers from more than 15 institutions in the U.S. fusion community has been designing a burning plasma experiment based on the advanced tokamak configuration known as the Fusion Ignition Research Experiment or FIRE. The primary mission of FIRE will be to study plasmas dominated by self-heating in an optimally sized (or "most cost-effective") experiment for understanding the critical scientific phenomena expected in a burning plasma. The work is managed through the Virtual Laboratory for Technology (http://vlt.ucsd.edu/) and is funded by the U.S. Department of Energy. The FIRE study is presently at the preconceptual level with the goal of being ready to begin conceptual design in October, 2002.

Self-Heated or "Burning" Plasmas

Plasmas are the hot ionized gasses that serve as the fuel for fusion energy production. The first generation of fusion power plants will likely employ plasmas consisting of a 50/50 mix of deuterium (D) and tritium (T), the heavy isotopes of hydrogen. One deuterium-tritium fusion reaction results in the production of a single neutron and an alpha particle (helium 4) — see Figure 1. In a fusion power plant, the kinetic energy of the neutrons will be converted to heat for the production of steam for the generation of electricity. The alpha particles, which are electrically charged and therefore remain trapped by the magnetic field, will transfer their kinetic energy to the deuterium and tritium ions, helping to maintain the plasma temperature.

Fusion power gain Q is the ratio of the fusion power produced by the plasma to the heating power required to maintain the plasma temperature. At Q values greater than 5, alpha heating begins to dominate auxiliary heating methods such as neutral-beam injection and radio-frequency heating. The FIRE will produce "burning" plasmas with Q values in the range of 5 to 20.

Table 1. Major Parameters of FIRE.

Major Radius, R_0	2.14 m
Minor Radius, a	0.595 m
Magnetic Field on Axis, B_0	10 T
Q	~10
Plasma Current, I_p	7.7 MA
Fusion Power	150 MW
Flattop Time, Coil Limit	20 sec
Triangularity, δ_{95}; δ_x	0.4; 0.7
Elongation, κ_{95}; κ_ε	1.8; 2.0
Tokamak Cost	~$0.37 B
Base Project Cost	~$1.2 B

Goals

The FIRE will be used to attain, explore, understand, and optimize alpha-dominated plasmas. A major goal is to develop a design concept that could meet these physics objectives with a construction cost in the range of $1.0 billion. The FIRE design activities have focused on the physics and engineering evaluation of a compact, high-magnetic field tokamak with features that include: strong plasma shaping, double-null poloidal divertors, low toroidal-field ripple, internal control coils, and space for wall stabilization capabilities. The ratio of the minor radius to the major radius (the aspect ratio) of FIRE will be 3.6. The major FIRE parameters are given in the Table. This design point is projected to achieve a fusion power gain of Q > 10, using design guidelines similar to those being employed by the International Thermonuclear Experimental Reactor (ITER).

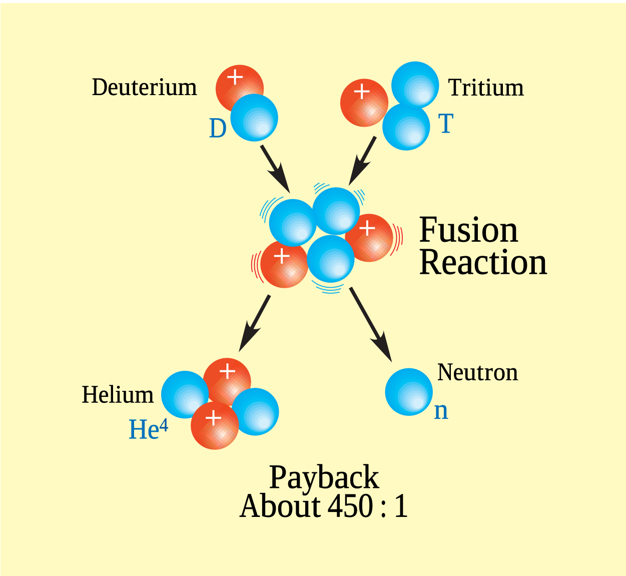


Figure 1. Deuterium-tritium reaction.

Burning Plasma Physics

Theoretical simulations predict that FIRE will be able to access the high-confinement mode (H-Mode) and sustain alpha-dominated plasmas with burn phases that are long enough to study plasma profile evolution, helium ash accumulation, techniques for burn control, and the effect of self-heating on the bootstrap current. Scientists believe that the bootstrap current — which is self-generated when the plasma pressure is highest at the center and falls off rapidly toward the vacuum vessel walls — may allow steady-state operation in a fusion power plant. In addition, the duration of FIRE plasmas will be sufficient to allow controlled shutdown to avoid plasma disruptions. The evolution of a burning plasma in FIRE is shown in Figure 2.

A longer-term goal for FIRE is to explore advanced tokamak plasma regimes similar to those envisioned for the advanced fusion reactor ARIES (Advanced Re-

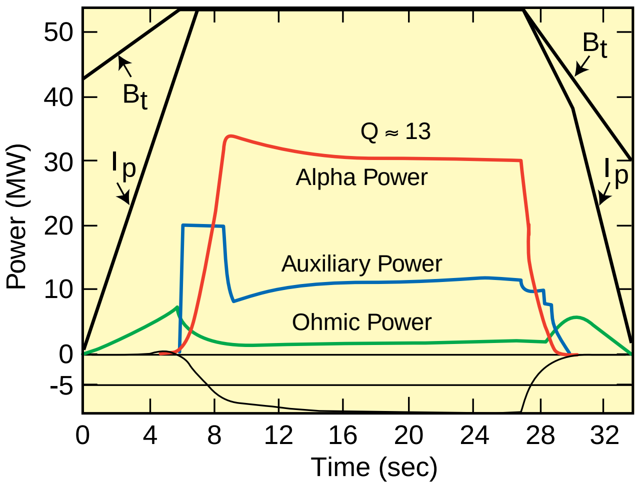


Figure 2. Evolution of a burning plasma in FIRE with major radius R = 2.14 meters, aspect ratio A = 3.6, toroidal magnetic field B_t = 10 tesla, plasma current I_p = 7.7 mega-ampere, and an approximately 20 second flattop.

actor Innovation Evaluation Study). The initial advanced tokamak experiments would use pellet injection and current ramps to create reversed-shear plasmas — a configuration with increased central ion densities and substantially reduced particle leakage. In later stages of the experiment, lower-hybrid current drive utilizing microwaves could be added to sustain the plasma current profile required for the reversed-shear regime. In addition, feedback stabilization using coils placed near the first wall would be employed to increase the plasma beta and bootstrap current to simulate ARIES plasma regimes.

Technology Development

The baseline magnetic fields and pulse lengths for FIRE can be provided with beryllium-copper and oxygen-free high-conductivity copper toroidal-field coils and oxygen-free high-conductivity poloidal-field coils that are precooled to 77 degrees Kelvin prior to the pulse and allowed to warm up to 373 degrees Kelvin at the end of the pulse. The cross section of FIRE is shown schematically in Figure 3. The 16 toroidal-field coil system is wedged, with a compression ring to resist de-wedging at the top and bottom of the inner toroidal-field leg. Shielding is added between the walls of a double-wall vacuum vessel to reduce nuclear heating of the coils, limit insulation dose, and allow hands-on maintenance outside the envelope of the toroidal-field coils within a few hours after a full power, deuterium-tritium plasma discharge. Large (1.3 by 0.7 meters) midplane ports provide access for heating, di-

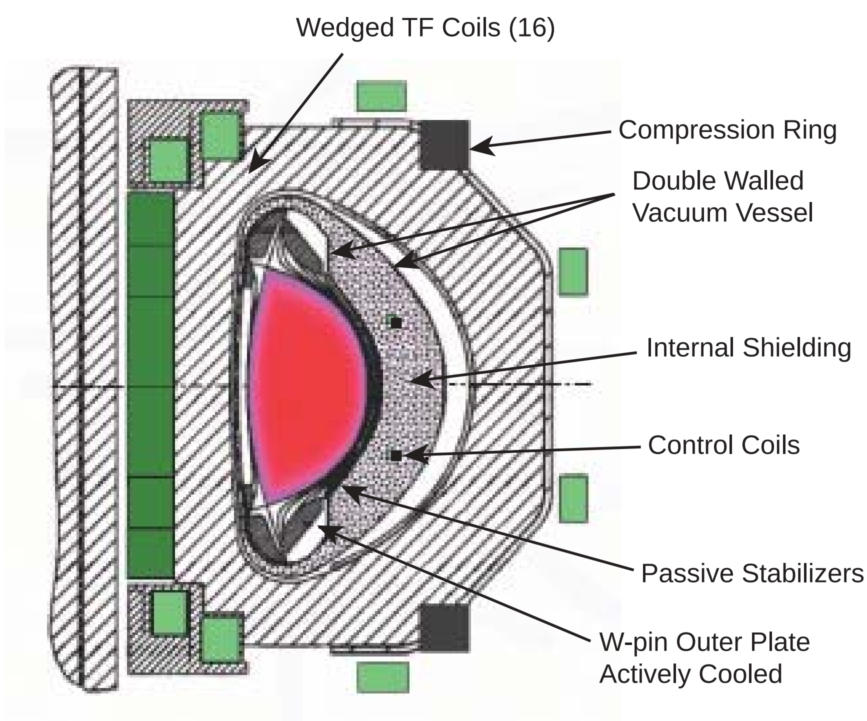


Figure 3. Cross section of FIRE.

agnostics, and remote manipulators, while 32 angled ports provide access to the divertor regions for utilities and diagnostics.

The FIRE is being designed mechanically to accommodate 3,000 full-field pulses and 30,000 pulses at two-thirds field. The repetition time at full-field and full-power pulse length will be about three hours, with shorter times at reduced field or pulse length. The fusion energy production of 5.5 terajoules produces a lifetime neutron dose to the toroidal-field insulating material at the inboard midplane of approximately 1.5×10^{10} Rads, which is consistent with the polyimide insulation being considered.

Plasma-facing components are tungsten "brush" targets mounted on copper backing plates, similar to a concept developed during the ITER Research and Development activity. Prototype tungsten brush target plates have been tested successfully up to 25 MWm^{-2}, the largest power density expected on FIRE components.

The first wall is comprised of copper tiles sprayed with a beryllium plasma. The high neutron wall loading (about 2 MWm^{-2}) at fusion powers of 150 megawatts contributes significantly to the first wall and vacuum vessel heating. Water-cooled copper plates inside the vessel alleviate excess heating of the stainless steel vessel due to neutrons. Sixteen cryopumps provide pumping for deuterium-tritium and helium ash during the pulse. Pellet injection scenarios will help minimize tritium throughput. The in-device tritium inventory will range from less than 2 grams for regeneration overnight to approximately 20 grams for monthly regeneration.

Additional information on the Fusion Ignition Research Experiment is available at: http://fire.pppl.gov

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 .