History of Mechanical Engineering for Fusion Research at Princeton

ASME Historic Mechanical Engineering Landmark Presentation

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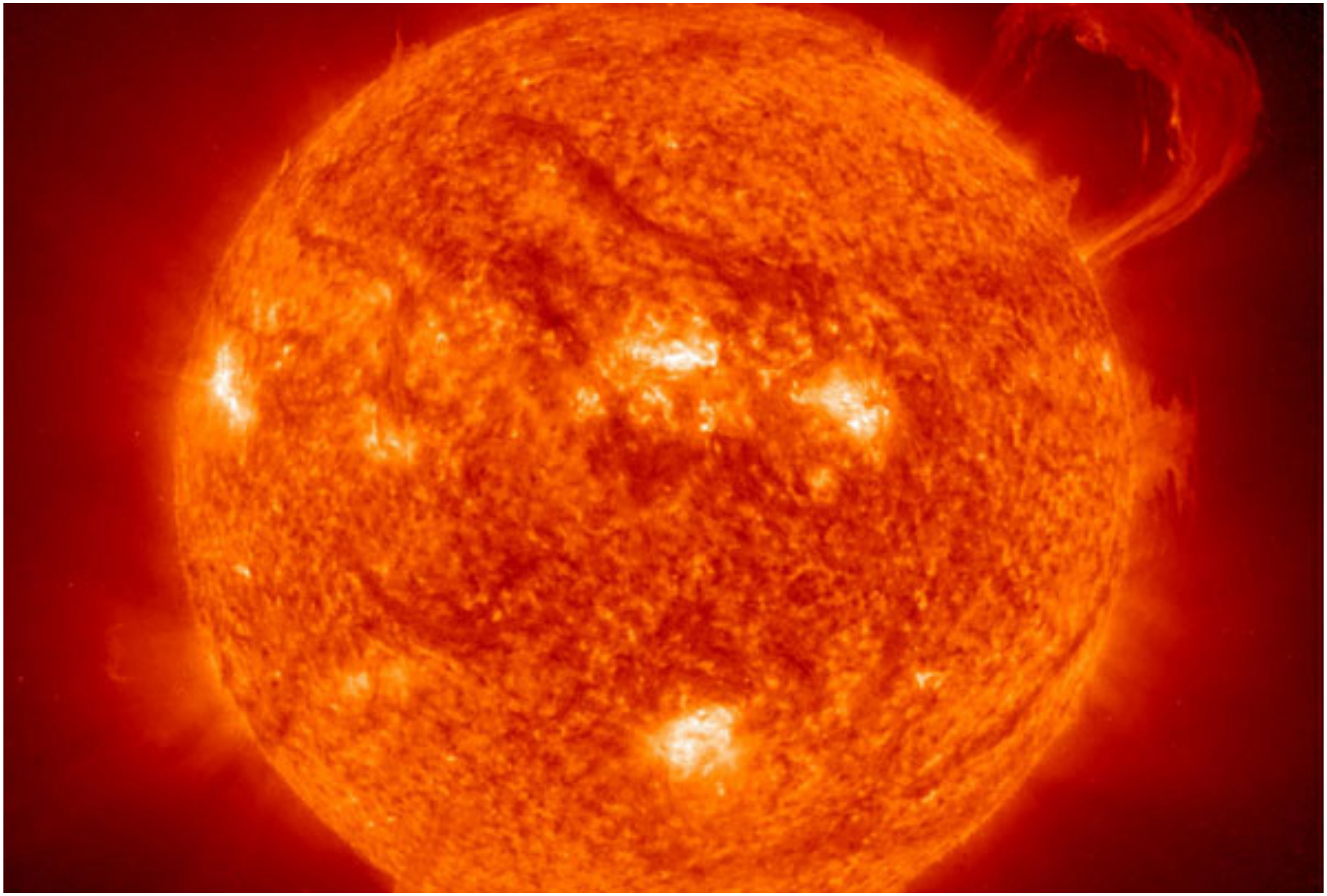
PRINCETON PLASMA PHYSICS LABORATORY
Project Matterhorn/PPL/PPPL

U.S. DEPARTMENT OF ENERGY
AEC/ERDA/DOE

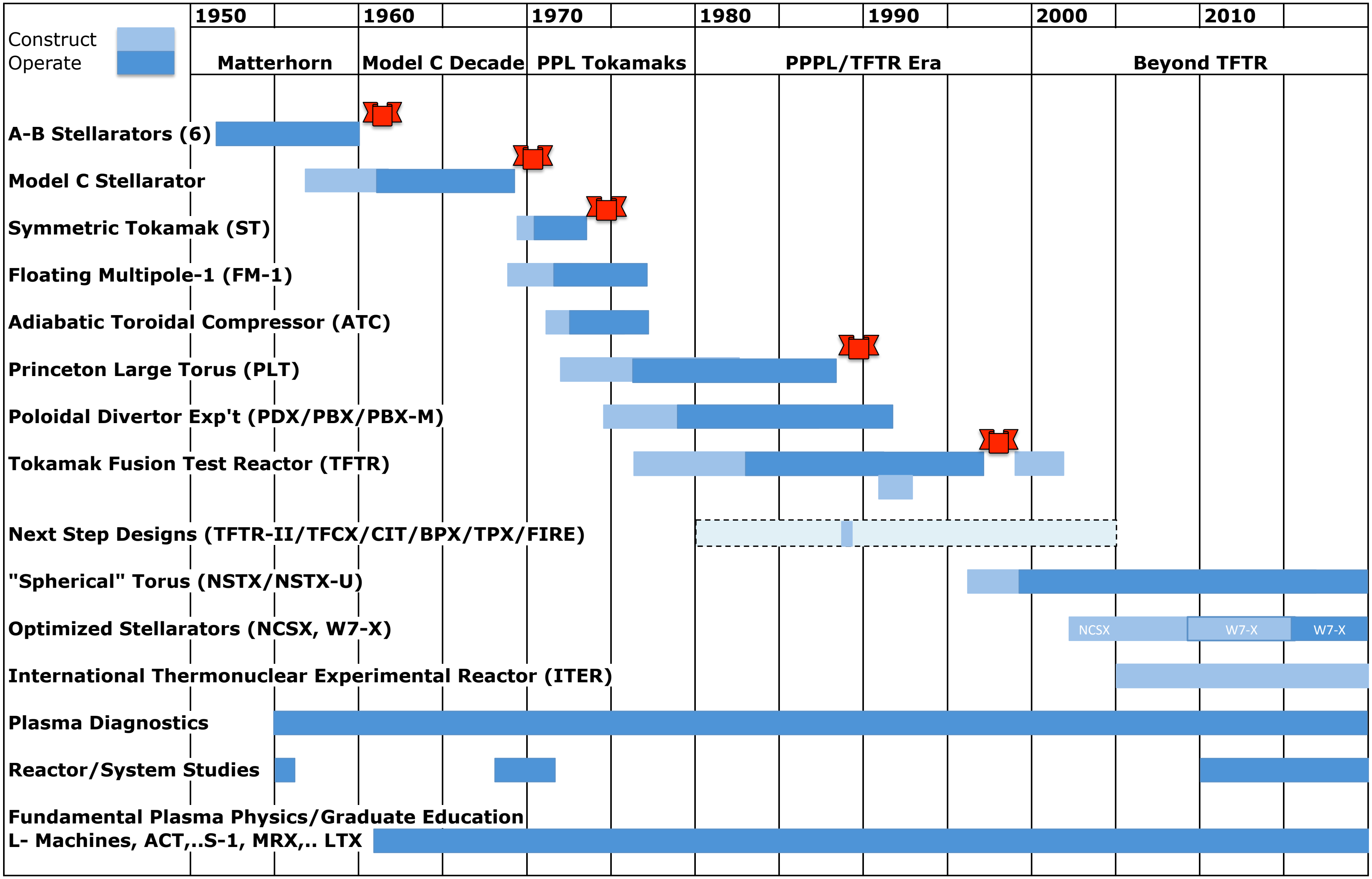
PRINCETON UNIVERSITY
Princeton University

The Goal: Achieve Attractive Fusion Power



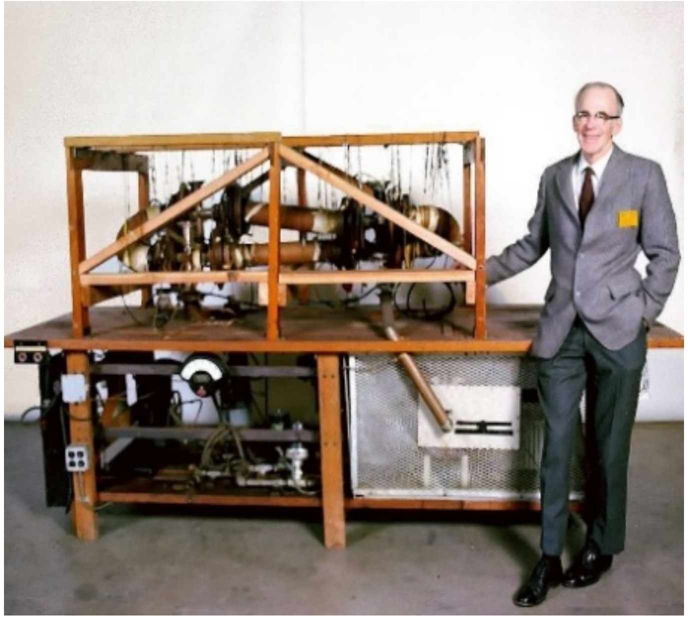
A Grand Challenge for Fusion Science
A Greater Challenge for Mechanical Engineering

Mechanical Engineering Activities at Matterhorn/PPL/PPPL



1951: The Birth of Princeton Fusion Energy Research

First fusion Lab at Princeton University, formerly a rabbit hutch

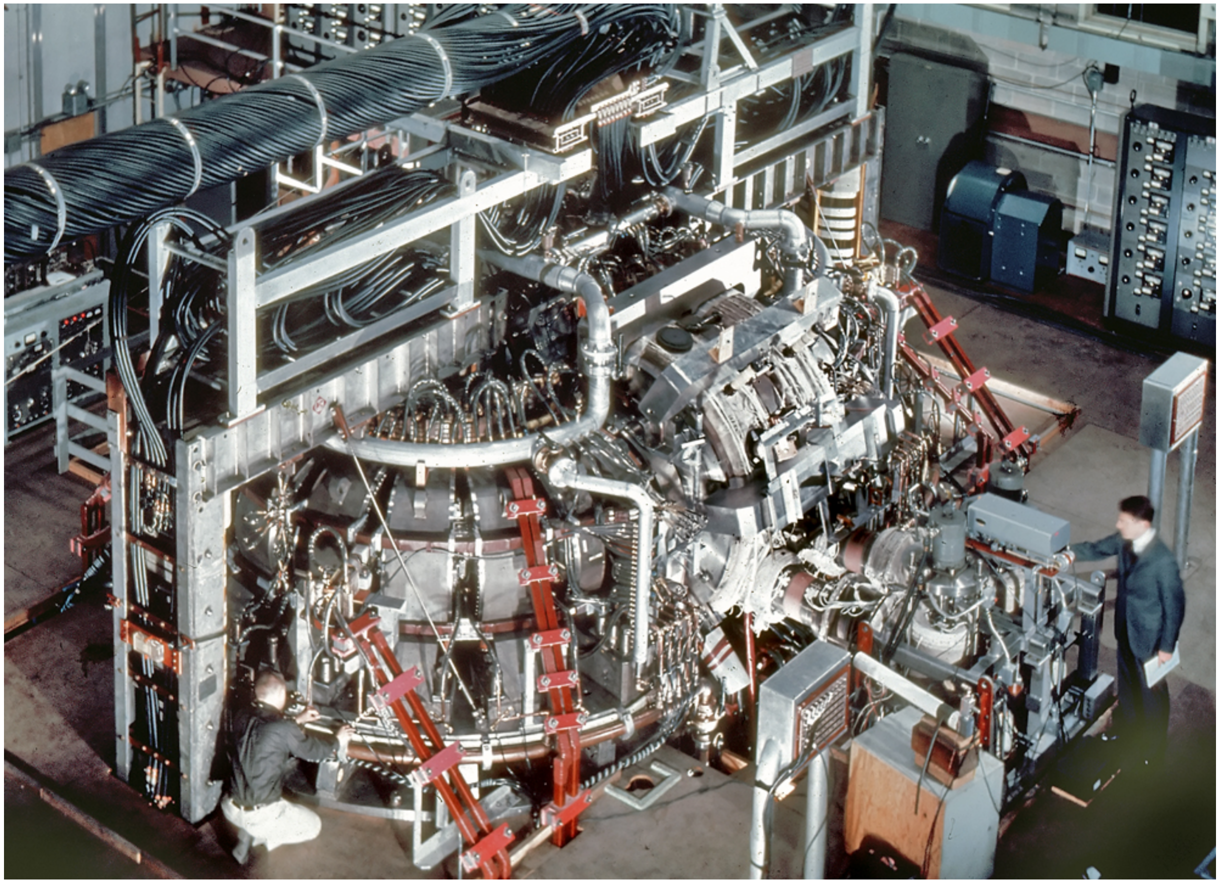


Model A Stellarator and Prof Spitzer

Historic Milestone #1: Spitzer receives a $50k grant from the AEC for stellarator research. Project Matterhorn is formed and located at Princeton University's James Forrestal Research Center B-site.

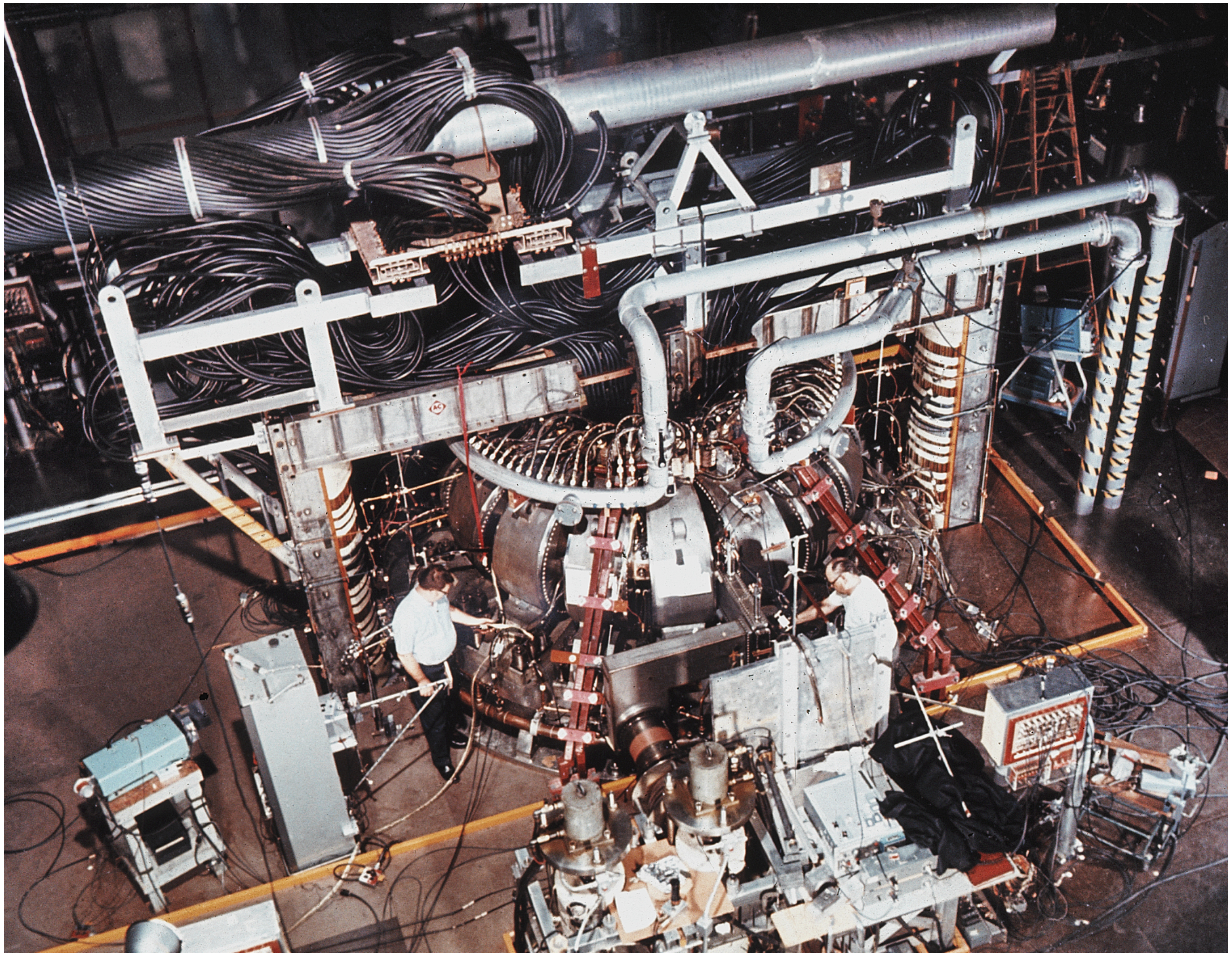
A series of five larger B stellarators were built before 1958. All secret fusion efforts are beset by plasma instabilities and make little progress. The world's fusion energy programs are declassified in 1958.

Atoms for Peace: Model-C Stellarator, 1961-1969



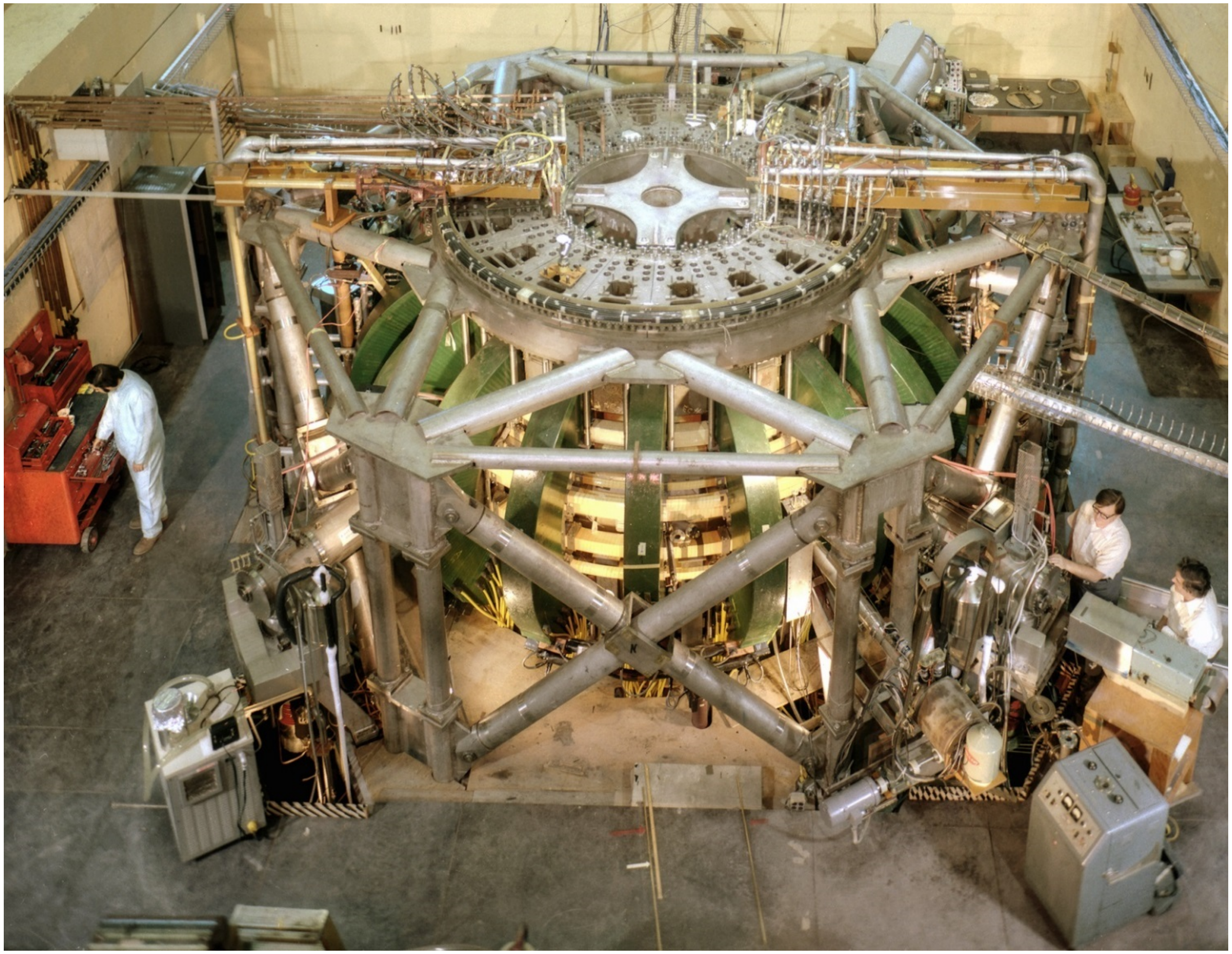
Historic Milestone #2: constructed in 4 years for $32M by Allis Chalmers, RCA with Westinghouse personnel. Confirmed that plasma instabilities were limiting progress, and that led to the creation of a Plasma Physics Program at PPPL. Provided engineering and physical infrastructure for the next 3 decades.

Symmetric Tokamak (1969 - 1972)



Historic Milestone #3: Converted from Model-C Stellarator by PPPL mechanical engineering in only 8 months. Confirmed Soviet breakthrough while increasing plasma performance and science understanding. Provided basis for a greatly expanded US magnetic fusion program.

Princeton Large Torus (1972-1988)



Historic Milestone #4: PLT constructed in 4 years by PPPL Engineering.
Breakthrough ion temperature over 60 million °C, August 1978.
Provided confirmation of decision to build TFTR already under construction.

Bold Ambitious Goals for TFTR in 1976

TFTR Mission 1976

1. Study plasma physics of large tokamaks

2. Gain experience with reactor scale engineering

3. Demonstrate D-T fusion energy production. 1 to 10 MJ per pulse

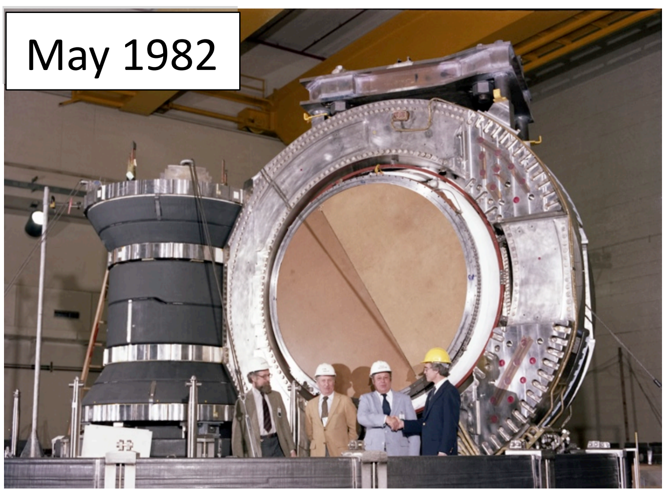
Engineering Challenges

Magnet Energy	increased by 100
Plasma Volume	increased by 10
Plasma current	increased by 10
Plasma Heating power	increased by 100
DD to DT Fuel	safety and environmental
Fusion Power	increased by 10^8

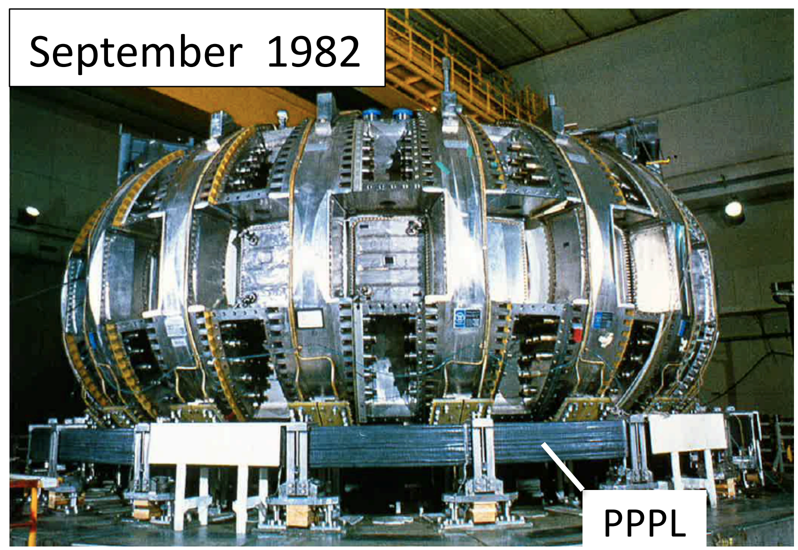
TFTR Constructed 1976 - 1982


October 1977


D-Site 1978

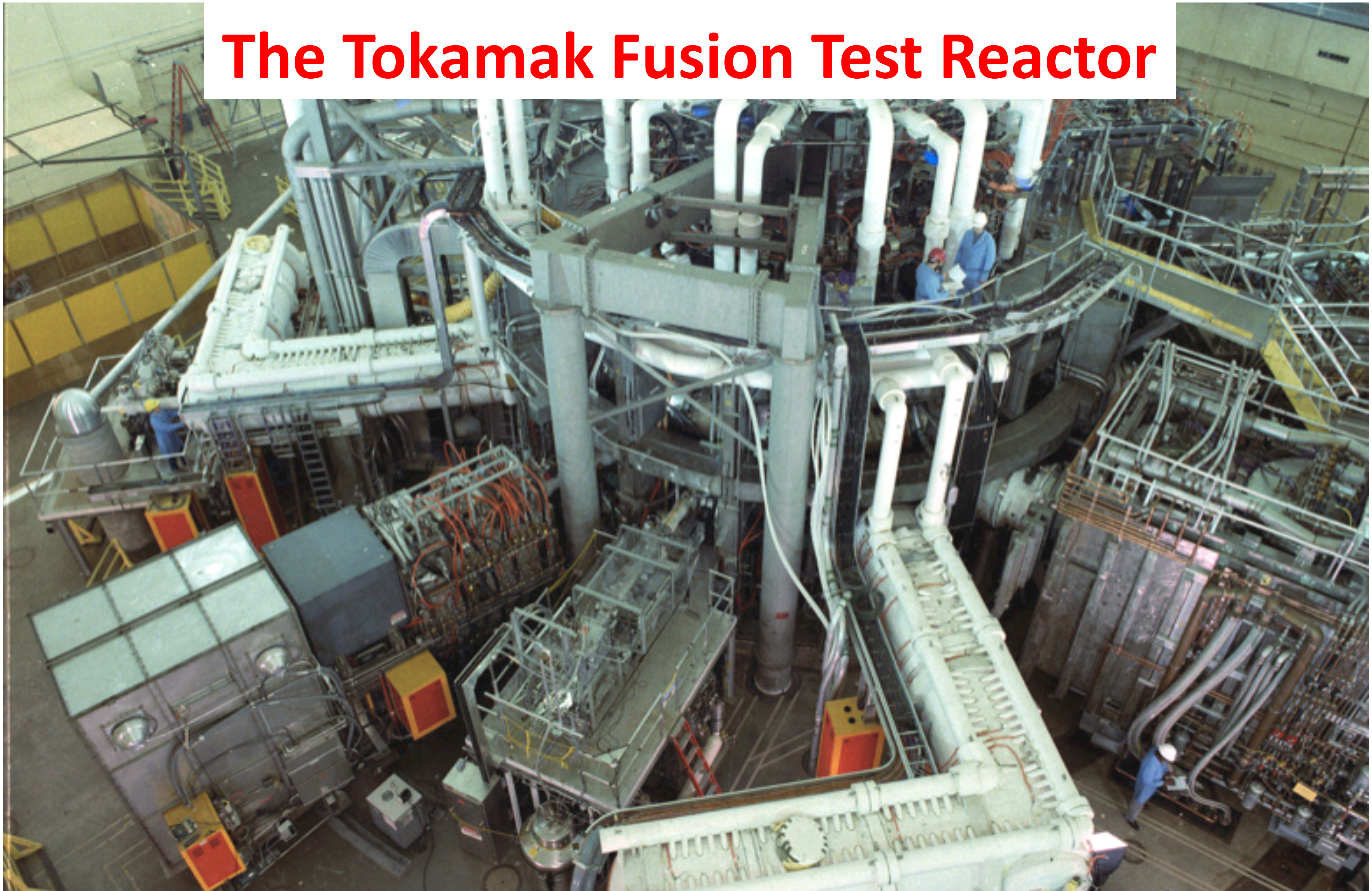

May 1982

Harold Furth, Don Grove, Paul Reardon, Milt Johnson



September 1982

The Tokamak Fusion Test Reactor



TFTR construction was completed in 6.5 years by an integrated team of PPPL, Ebasco and Grumman engineers. After 1st plasma on Dec 24, 1982, PPPL took control of the operation and additional hardware installation required for full performance and DT operation.

Countdown to the First High-Power DT Shot

December 9, 1993: After 9 years of optimization in deuterium operation, TFTR is running at full performance with high reliability.   The DT Prep Project is complete. All systems are go for DT.   10, 9, 8, 7…

The Reaction to the Reactions

DOE (Milt Johnson PAO Head, Steve Eckstrand FES TFTR Contract Monitor, John Willis FES Confinement Head) and Rich Hawryluk, PPPL TFTR Head, celebrate the 1st DT pulse on TFTR.

The New York Times

NEW YORK, FRIDAY, DECEMBER 10, 1993

75 cents beyond the greater New York metrop

Scientists at Princeton Produce World's Largest Fusion Reaction

By MALCOLM W. BROWNE

Special to The New York Times

PLAINSBORO, N.J., Dec. 9 — A huge experimental reactor embodying the process of the hydrogen fusion that fuels the sun unleashed a burst of energy tonight that broke all records and appeared to pave the way for eventual exploitation of abundant, cheap fusion energy.

The achievement crowned a day of lesser landmarks, in which the Princeton Plasma Physics Laboratory gradually increased the power of its Tokamak Fusion Test Reactor by mixing increasing proportions of tritium into the machine's fuel.

In the final "shot" of the night, the machine achieved a fusion power equivalent to about three million watts — double the power achieved two years ago by the Joint European Torus, a somewhat similar machine in England.

As the vast power of the seven-second burst manifested itself on computer screens in the control room and auditorium, it became apparent that the experiment was a success, about 500 scientists who had worked on the project for up to 20 years cheered and applauded, a few with tears in their eyes.

In the next several months, the Princeton group expects to increase the power of its reactor to five megawatts, and by the end of next year, to 10 megawatts. The machine consumes about twice as much energy as it produces, but this ratio is a vast improvement over previous types of fusion experiment.

Physicists and engineers had packed the huge control room of Princeton's tokamak fusion test reactor to run the machine on a fuel never before used in a reactor: a full-strength mixture of deuterium and tritium.

Fusion is the joining together of the nuclei of hydrogen atoms, each of which contains one proton. The fused nucleus resulting from this reaction is that of helium, which contains two protons. This process is the opposite of fission, the phenomenon that powers conventional nuclear reactors; fission involves breaking apart heavy nuclei, like those of plutonium atoms.

Although radioactive tritium fuel is used in the tokamak reactor, scientists say there is no danger of any accidental release of the tiny quantity used in the experiment — five grams. Unlike nuclear fission reactors, a fusion reactor cannot melt down, and if anything goes wrong, the fusion reaction, which is very difficult to keep going, simply stops.

Physicists believe that if the current series of high-power experiments is successful — and two more advanced fusion reactors are completed — the first commercial fusion power reactors could begin operating around the year 2030.

New Age of Cheap Energy Is Seen As Fusion Experiment Succeeds

The atmosphere in the huge control room here was reminiscent of a control room at the National Aeronautics and Space Agency preparing for a major space launching. As occasional snags in the countdown for the main fusion "shot" developed, scores of news reporters, officials and scientists watched the tense procedings from the windows of a balcony surrounding the control room.

Before trying a full-strength shot using the full charge of deuterium and tritium, the physicists conducted several lesser shots, each one more powerful than the last, and each "exploring a virgin field of physics," according to Dr. Dale M. Meade, deputy director of the laboratory. Onlookers heard a loud whine with each shot, as the 50-foot-high machine vibrated after being suddenly exposed to a powerful magnetic field.

The audience, which included officials of the Department of Energy, was also treated to spectacular views of the interior of the reaction chamber. Closed-circuit television vividly displayed the white-hot fuel confined in the machine, and could see the bright flash swiftly fade as the temperature rose above that at which visible light is emitted.

Dr. Meade said a crucial goal of tonight's series of runs was the measurement of the number and energy of neutrons emitted by the fusion reaction, which are an indication of the reaction's power. In a commercial reactor, these neutrons would be harvested by an external metal "blanket," which would heat up as neutrons hit it. This heat would be transferred to a gas that would turn the turbines of electric generators.

Scientists said that the deuterium-tritium fuel used in the current experiment would achieve a temperature of several hundred million degrees — modest by fusion standards, but far higher than the temperature at the core of the sun.

In the last 10 years, it has cost about $1.4 billion to build the tokamak reactor at Princeton's Plasma Physics Laboratory and conduct dry runs using deuterium fuel. Nearly all the money was provided by the Federal Department of Energy. The Princeton laboratory hopes to gain financing for a new tokamak reactor in which a continuous fusion reaction could be maintained.

The term tokamak is derived from a Russion acronym for toroidal magnetic chamber, which describes the design of the device.

Historic Milestone #5: Tokamak Fusion Test Reactor

- First use of DT fusion reactor fuel
- First to produce > 10 MW of fusion power
- First to document alpha particle physics
- First closed cycle tritium reprocessing system
- Record density x confinement time -1986
- First to achieve 100 M°C, 300 M°C, 500 M°C
- Record neutral beam heating power 40 MW (33 MW spec.)
- Toroidal magnet operated beyond original specification
- 1 MCi of tritium was processed for 1,000 DT exp'ts over 3 years of safe, reliable DT operation
- Successfully decommissioned and decontaminated 1999-2002

These Historic Milestones are a measure of progress toward fusion energy, and represent the importance of the essential contributions of PPPL mechanical engineering.

Princeton Plasma Physics Laboratory (PPPL)