AN INTRODUCTION TO FUSION RESEARCH
AT THE
PLASMA FUSION CENTER
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROF. RONALD C. DAVIDSON, DIRECTOR

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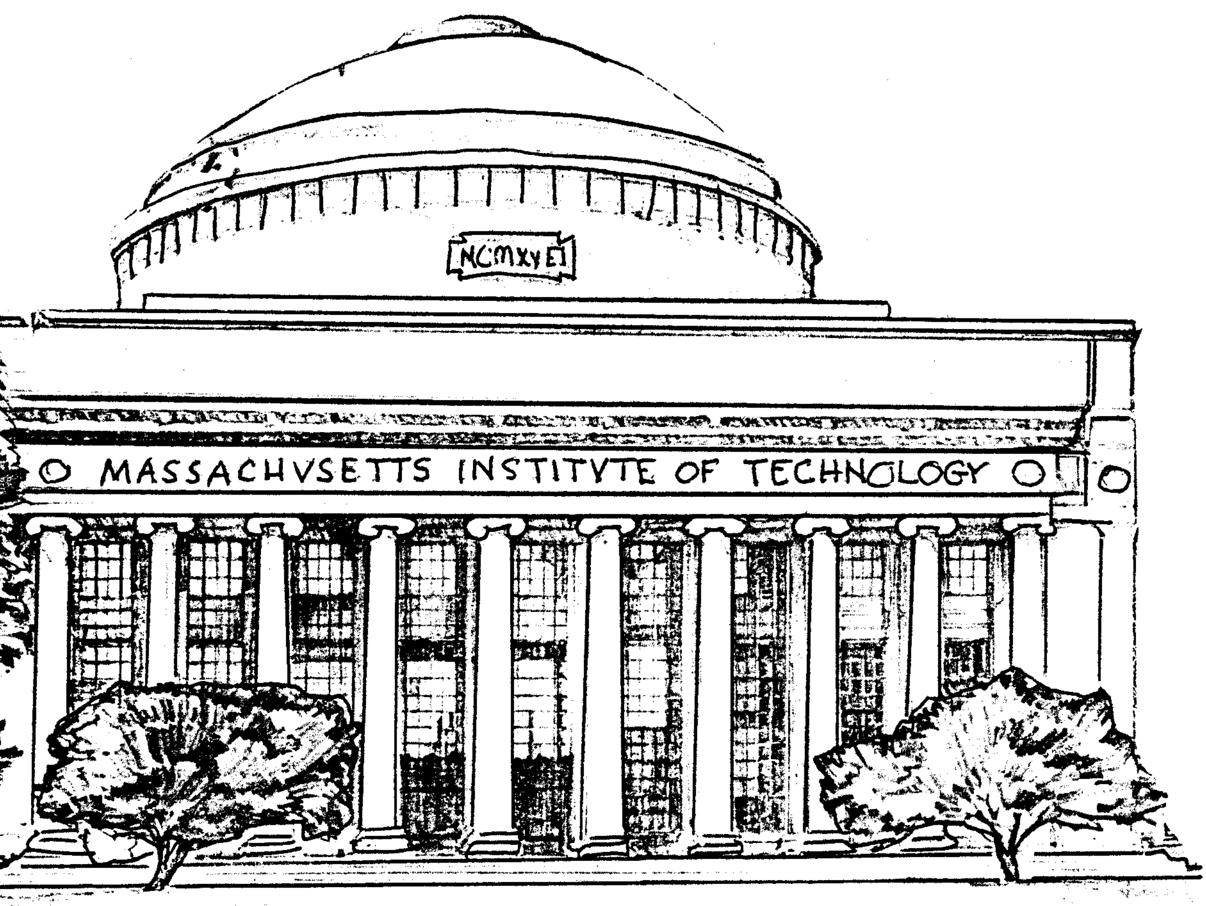


FUSION
POWER
AT
MIT

THE MIT PLASMA FUSION CENTER

INTRODUCTION

The primary objective of the Plasma Fusion Center (PFC) is to provide the strong intellectual and administrative leadership required for the effective coordination and execution of all fusion research activities at the Massachusetts Institute of Technology, including medium-scale confinement experiments, basic plasma physics, and activities related to fusion engineering and technology development. One of the Plasma Fusion Center's most prominent strengths, and more broadly speaking, a major strength of MIT as a whole, is the ability to provide a forum for blending excellent research programs within a university environment. This is important for training the students and researchers necessary for the successful development of fusion energy.

The Plasma Fusion Center is organized in the following manner. The Director, Prof. Ronald Davidson, oversees all Plasma Fusion Center research acitivities and provides the administrative interface between the PFC and the Department of Energy. The Office of Resource Management, headed by John Cochrane, coordinates all administrative requirements for the PFC, both within MIT and with outside agencies and laboratories. The PFC Steering Committee, made up of the key research principal investigators, assist the Director in establishing priorities and coordinating research activities throughout the PFC, and the PFC Advisory Committee, made up of the heads of the affiliated MIT departments and laboratories, assists the Director in coordinating PFC research programs with other activities at MIT. The PFC is organized into five technical divisions:

- The Toroidal Confinement Experiments Division
- The Mirror Confinement Experiments Division
- The Fusion Systems Division
- The Applied Physics Research Division
- The Fusion Technology and Engineering Division

Included here is a brief summary of the PFC research activities within each Division, the organizational structure of the PFC, and an MIT campus map showing the PFC research locations.

THE PLASMA FUSION CENTER RESEARCH DIVISIONS

TOROIDAL CONFINEMENT EXPERIMENTS DIVISION (Alcator)

Prof. Ronald R. Parker, Head

The particular role of the Alcator experiments deals with the exploration of the use of extraordinarily high magnetic fields to contain plasmas in relatively small chambers. Literally, the three syllables of the word Alcator (Alto-Campo-Torus) are interpreted from Latin as High-Field-Torus.

Alcator A has been operating since 1973, and Alcator C, a more advanced device, began operation in 1978. In these tokamaks the toroidal plasma chamber is surrounded by current-carrying plates similar to the magnet designs of the late Francis Bitter, a pioneer in the design of high-field magnets. The Bitter magnet construction results in both a highly uniform and strong toroidal field because of the continuous distribution of magnet turns.

The Alcator tokamaks are unique in that they can operate at extremely high magnetic fields. Alcator C is designed to operate with magnetic fields up to 140,000 gauss (the earth's magnetic field is approximately .5 gauss). Due to this very high magnetic field, extremely high plasma densities are obtained. Since confinement quality has been found to improve at high density, the Alcator tokamaks have proved to be of strong interest in the race to harness fusion energy. Additionally, the compact nature of the Alcator approach may lead to economic advantages in later fusion research reactors.

Alcator A achieved record-breaking results in confinement quality in 1975 and again in 1978. Confinement quality is the value of the plasma density multiplied by the energy confinement time of the plasma, called "N-Tau". The "Lawson Criterion" states that a value of 10^{14} seconds per cubic centimeter is required to achieve net power production in a fusion reactor. In 1975, Alcator A achieved a confinement quality of 10^{13} seconds per cubic centimeter at a plasma temperature of 10 million degrees. That was 5 times better than that achieved before by any other tokamak in the world. "A" improved its own record by a factor of three (n-tau = 3×10^{13} cm^{-3} sec.) in February 1978. This world record value has been surpassed on Alcator C during its early mid-field operations. Very high field operation of Alcator C will begin this year and confinement qualities approaching the breakeven value are expected to be within reach.

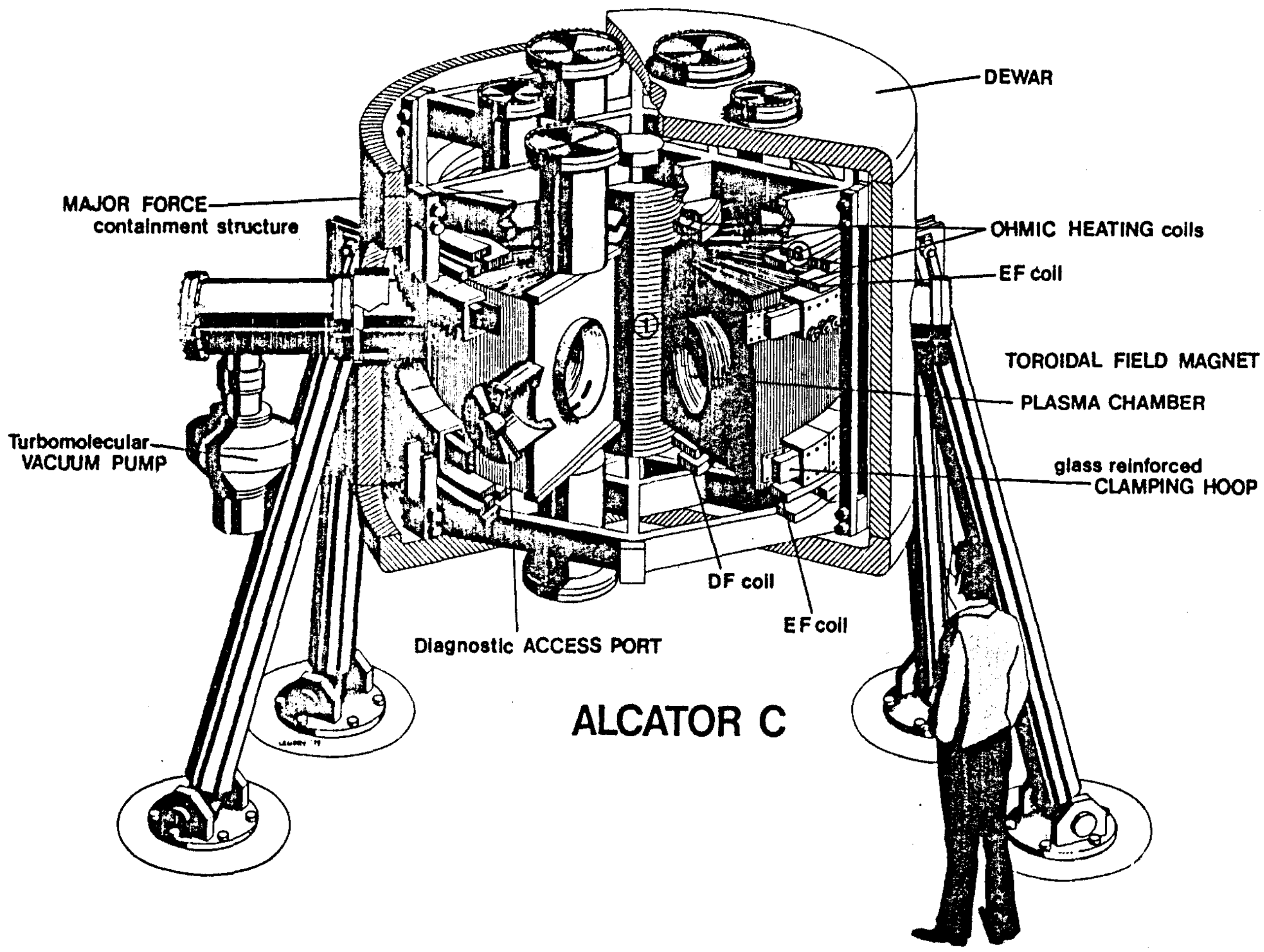
Microwave Experiments on Alcator C

An ambitious program is now underway using microwave heating on Alcator C. Fusion reactors will operate at temperatures far exceeding the core of the sun (50,000,000°C - 100,000,000°C). Since resistive (ohmic) heating alone cannot heat the plasma to these levels, a supplemental form of heating is necessary to reach reactor-like conditions. Experiments have just begun for the injection of microwave energy into the Alcator C plasma (a 4-million watt power supply is used for these experiments).

Additional experiments are underway to use microwave power to produce a continuous plasma current in Alcator C. It is widely known that one of the key drawbacks of the tokamak approach for use as a power-producing reactor is that tokamaks are not steady-state devices, i.e., they are pulsed. Successful RF current-drive experiments could transform the tokamak into a continuously operating device, thus making it more attractive to utility companies as a practical electrical power source.

Alcator A Modification

A design effort concerned with modifying Alcator A is underway. The primary aim is to develop an experimental facility for the study and control of plasma instabilities. The important feature is a helical winding, which, when combined with the magnet windings of a conventional tokamak, leads to a device with the ability to be either a pure tokamak, a pure stellerator or a hybrid of both. The increased size and lower design field allows for easier access of additional diagnostics and RF heating capabilities.



ALCATOR C

MIRROR CONFINEMENT EXPERIMENTS DIVISION (TARA)

Dr. Richard S. Post, Head

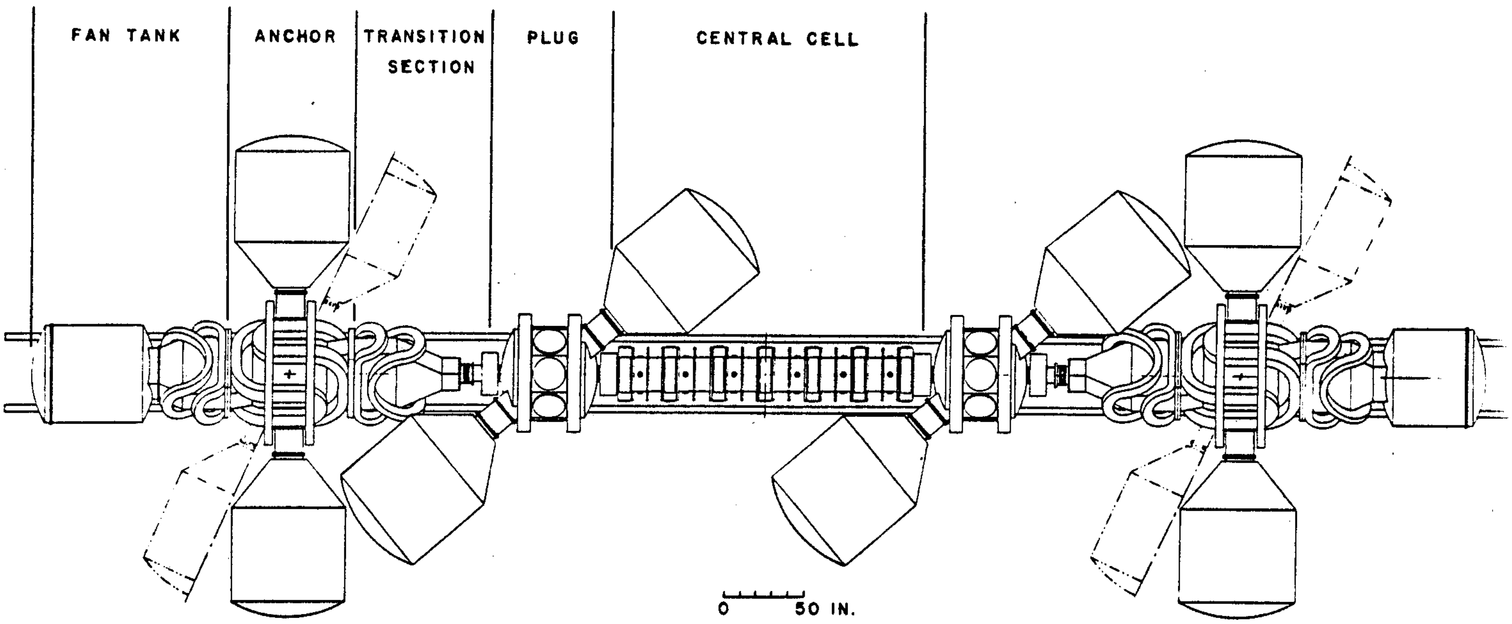
The proposed TARA tandem mirror experimental facility is the second major tandem mirror experiment being constructed in this country. Its purpose is to increase the understanding of tandem mirror physics, and it will significantly complement the research activities of the other large tandem mirror being built at Lawrence Livermore National Laboratory called MFTF-B, which will attempt to produce fusion reactor-like conditions.

A tandem mirror is a so-called "linear" plasma containment device. In this scheme, a large cylinder of plasma, termed the central cell, is "plugged" at each end by mirror cells. These mirror cells, the object of research that dates back 30 years, do not sufficiently confine the plasma well enough to be used by themselves as reactors. However, they have been observed to charge up positively, and this tendency makes them ideal to serve as plugs for the central cell plasma.

The TARA experiment will be a highly versatile facility which will focus on several physics issues critical to the success of tandem mirrors. First, is the reduction of radial (or cross-field) plasma losses from the central cell plasma due to a unique design which incorporates a high degree of symmetry into the plugs. Additionally, TARA will explore the enhancement of the stability of the mirror end plugs by exploring the generation of unusual ion density profiles within these cells known as "sloshing" or bellyband distributions. TARA will also focus on optimum use of RF heating to produce high temperature plasmas. A particularly promising application of this heating would involve electron heating in the outermost part of the plugs known as "anchors," which could prove much simpler and cost effective compared with the alternative heating approach of injecting energetic neutral particle currents. Lastly, TARA will permit exploration of a so-called thermal barrier in the end plugs. A thermal barrier is a method of producing a hotter electron component in the plugs as compared with the central cell plasma, which has been shown to greatly enhance the reactor potential of tandem mirrors.

TARA will be housed in the Nabisco Laboratory, which was donated to MIT by Nabisco, Inc. and will be in close proximity to the other major fusion research facilities at the PFC.

The TARA Tandem Mirror:



FUSION SYSTEMS DIVISION

Dr. Daniel R. Cohn, Head

This division investigates several problems of fusion reactor design, operation of fusion reactors, and develops new approaches. Also under development are new millimeter/submillimeter wave technologies for plasma heating diagnostics.

The goals of the reactor and safety studies programs are to develop conceptual designs for the next generation of test reactors, to deepen understanding and develop new concepts for commercial reactors and to provide guidance in the development of reactor technology. Present programs include scoping studies of tokamak reactors with high performance resistive magnets, tokamak-stellarator reactor design options; and improved torsatron reactor designs. In addition, there are investigations of reactor operation with advanced fuels; advanced first wall and blanket designs; and safety issues connected with possibilities of lithium fires and tritium releases. Design studies of tokamak reactors with high performance resistive magnetics have pointed out significant new possibilities for exploiting the potential of the tokamak as a compact device with low unit cost, high power density and high values of n-tau.

The millimeter/submillimeter wave technology programs include development of gyrotrons for plasma heating and advanced submillimeter wave and detectors for plasma diagnostics. The main goal of the gyrotron project is the development of a high frequency device. Submillimeter source development includes the construction of a high power laser for Thomson scattering and the study of compact solid state sources for low power diagnostic applications.

APPLIED PHYSICS RESEARCH DIVISION

Prof. Ronald C. Davidson, Acting Head

The primary objective of this Division is to develop the basic experimental and theoretical understanding of plasma heating and confinement properties. Current applied activities include those areas set out below as well as the following: development of the MACSYMA symbolic manipulation system for computing results and ascertaining theoretical equations, plasma diagnostics development, and basic experimental and theoretical research on intense charged particle beams.

Tokamak Research on the VERSATOR II

This is a medium-sized research tokamak used for the basic investigations of plasma heating and confinement properties, under the leadership of Profs.

George Bekefi and Miklos Porkolab. The lower-hybrid current-drive experiments are perhaps the most advanced in the world, and the pioneering results are drawing national attention. Continued research includes removing the ohmic current in order to study a fully RF-driven tokamak.

Mirror Research on the CONSTANCE II

This is a moderately sized mirror research facility under the direction of Prof. Louis Smullin, with primary emphasis on the basic experimental development of RF and beam-plasma techniques to produce hot electrons and stabilize the loss of plasma through the ends of the device.

Theory and Computations

The PFC theory groups under the direction of Prof. Jeffrey Freidberg and Prof. Bruno Coppi contain a large number of highly qualified senior faculty with a strong supporting research staff. The PFC theorists work on a wide range of problems critical to understanding plasma behavior and achieving controlled fusion. These range from studies of various forms of RF heating to theories of MHD stability, plasma turbulence and associated transport. In addition, the theorists actively investigate new ideas related to advanced fuels, and conceptual modifications to the stellerator tokamak and mirror configurations.

Advanced Fusion Concepts

Under the direction of Prof. Lawrence Lidsky, there has been a continued emphasis on the development of fusion reactor designs consistent with the best available models of plasma physics and technological capabilities. Concentrating on the torsatron/stellarator design (which uses only helical windings of magnets to confine the plasma), this group is looking in depth at the physics involved in systems that have better technological promise. In particular, the group is trying to understand the effects of the shape of helical windings on fundamental phenomena like particle confinement and heat transport.

FUSION TECHNOLOGY AND ENGINEERING DIVISION

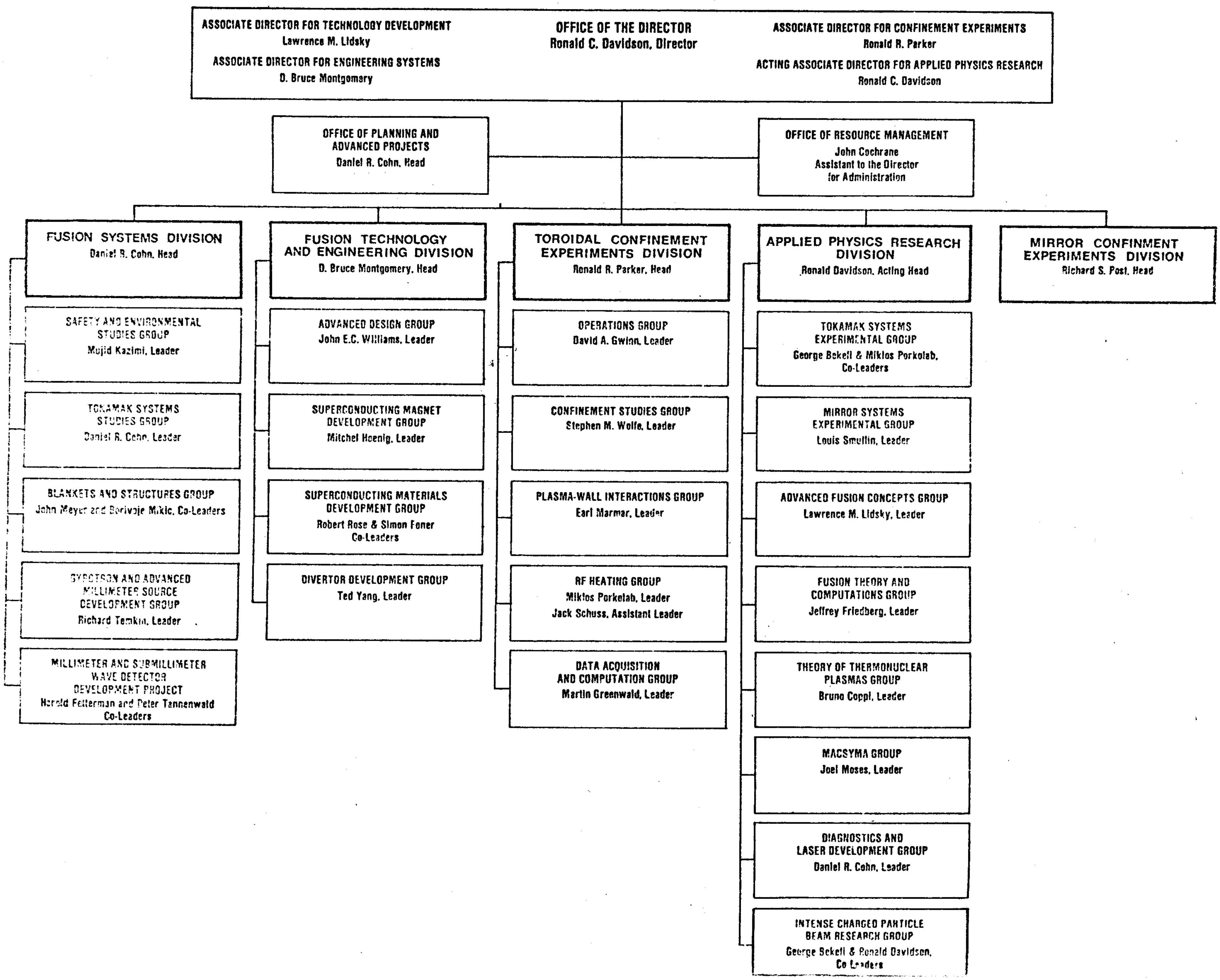
Dr. D. Bruce Montgomery, Head

This area provides engineering support for the advanced design projects and develops advanced superconducting magnet technology for the national fusion program. The Plasma Fusion Center was selected by the Department of Energy to take responsibility for the Magnetics Branch of the FED Design Center activities. The FED, or Fusion Engineering Device, is the next major step in the U.S. fusion program to prepare for the first demonstration fusion reactor. The PFC work is carried out in close cooperation with the Fusion Engineering Design Center Hq. at Oak Ridge National Lab., which has overall responsibility for systems integration and management of FED design activities.

Programs in superconducting magnet development involve construction and test of high-field superconducting materials, studies and experimental work on magnet safety, and studies of acoustic emission from magnet structural elements in order to predict possible failure conditions before they occur.

The PFC is also active in developing improved magnetic divertor concepts. A long-burning fusion reactor must deal with the build-up and removal of helium "Ash" and impurities, and magnetic or mechanical divertors are considered to be an extremely demanding but necessary component. The PFC has recently completed the major construction of a high-field divertor for the ISX-B tokamak at ORNL.

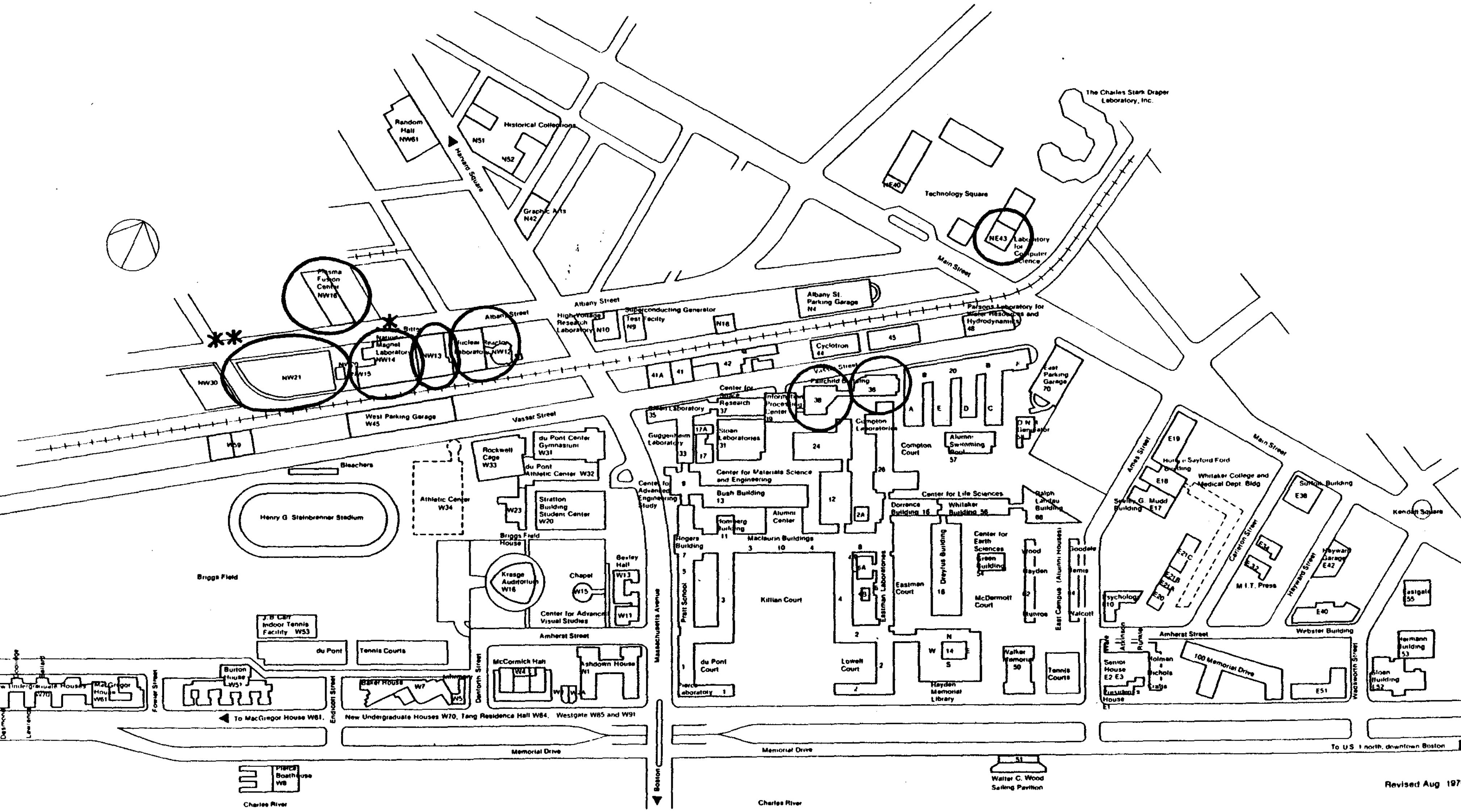
MIT PLASMA FUSION CENTER



◯ = Plasma Fusion Center Locations of Research

* = Location of Alcator Tokamaks

** = Location of Proposed TARA mirror



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