Statement of Harold P. Furth
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before the
Subcommittee on Energy Research and Development
House Committee on Science, Space, and Technology
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Madame Chairman, Members of the Committee:

Since the initiation of the Tokamak Fusion Test Reactor (TFTR) project, in 1975, the fusion program has made steady progress toward the understanding of hot-plasma confinement and the production of useful energy. One way we measure our progress is by comparing the fusion power that is generated in a hot plasma with the power that is required to heat the plasma:* The experiments of the mid-70's still had a factor of a thousand or more to go towards the achievement of break-even conditions, where the fusion power equals the plasma-heating power. As of last year's TFTR run, there is less than a factor of five to go. I find it particularly encouraging that last year's TFTR results were achieved using only a fraction of the full TFTR plasma current and a fraction of the plasma-heating power that is now available. During this year's TFTR run, we hope to advance to within a factor of two of break-even conditions.

The Laboratory's plan is to introduce tritium onto the TFTR site this fall, have the tritium system fully operational by next fall, and carry out the D-T break-even demonstration during '90-'91. After '91, the TFTR experiment will be shut down to make available funds and facilities for the Compact Ignition Tokamak (CIT) experiment.

*Performance is usually calculated in terms of the reactor-relevant deuterium-tritium (D-T) fusion reaction, but pure deuterium or hydrogen has served as a substitute for D-T in plasma-confinement experiments to date.

The TFTR-CIT-ITER Sequence

As fusion research progresses from the study of ordinary plasmas to the study of burning D-T plasmas, scientists will be confronted with a number of new plasma phenomena as well as new technological challenges. In D-T operation, plasma-confining experimental devices become radioactive -- essentially on the first successful shot. While the amount of radioactivity is relatively small, it is sufficient so that remote handling and other special experimental operating techniques must be introduced.

The CIT experiment will provide necessary experience with the handling of burning plasmas for the benefit of reactor experiments of the future, such as the proposed International Thermonuclear Experimental Reactor (ITER). On the basis of the CIT experience, it will be possible to make well-formulated plans for the reactor operating phase prior to the activation of the machine -- thus safeguarding major investments. In the same way, successful entry of the CIT project into its burning-plasma phase will build on the experimental data and the practical operating experience gained in the D-T phase of the TFTR project. (The somewhat later D-T-experiments on the Joint European Torus [JET] would benefit similarly from the TFTR experience and would be valuable in strengthening the CIT data base.)

The new plasma-physics phenomena expected in burning plasmas are mainly due to the presence of alpha particles -- the energetic helium nuclei that are produced by D-T fusion reactions. The moderately dense, very-hot-ion plasma regimes that have been achieved in TFTR are particularly well suited to produce significant alpha-particle populations. The special diagnostics, neutron-shielding, and maintenance techniques being developed for D-T operation in TFTR are similar to those needed for CIT. The tritium-handling technology will also be the same: We plan to reuse the actual TFTR tritium systems for the CIT experiments.

The CIT design takes advantage of the last ten years of progress in the physics and technology of tokamak confinement to raise performance from the break-even level to the ignition level. The ignition capability of the CIT is based on two principal factors: (1) powerful machine parameters, such as high plasma current and magnetic field strength and (2) refined plasma-control techniques, such as special shaping of the plasma density profile and use of a magnetic divertor at the plasma edge.

The maximum attainable CIT plasma current and magnetic-field strength are several times higher than the currents and fields of the most powerful present-day tokamak devices. This combination of machine parameters gives the CIT a fundamentally superior plasma-confinement potential -- comparable to that proposed for engineering test reactors in recent design studies. In addition, the CIT design emphasizes the use of special plasma-control techniques to enhance the quality of confinement, because qualitative improvements will be particularly useful in minimizing the future development cost of tokamak reactors. The large parameter range and flexible experimental capabilities planned for the CIT will make it the preeminent research facility of the world fusion program during the latter part of the 1990's.

At present there is a spectrum of scientific opinion about how large an improvement factor in the quality of tokamak confinement will ultimately be achieved by special techniques. To help take both optimistic and pessimistic expectations into account, we are developing a flexible project strategy. The CIT experiments will begin at a plasma current and magnetic field level sufficient to reach ignition under favorable confinement conditions that are being achieved in present-day tokamak devices prototypical of CIT. This operating mode will utilize the available TFTR power supplies. Depending on the trend of confinement-physics results, the machine parameters can be raised toward their maximum values by increasing the input power to the magnet system.

The CIT conceptual design has been developed by a national team, led by PPPL. The design process has been guided by the Ignition Technical Oversight Committee (ITOC), which consists of distinguished U.S. fusion scientists and engineers.

CIT Plans for FY'88 and '89

In January 1988, the national CIT team completed a conceptual design study that integrates CIT plasma-physics models with the engineering of the machine components and the ancillary systems and facilities. The physics concepts and the engineering design of the individual CIT systems are now supported by extensive detailed analyses.

During the conceptual design study activity of the past year, the plasma major radius was increased, in order to maximize the physics and engineering margins of the basic CIT device. The change in size has had a limited impact on the design analyses, since the relative scale of the machine components has remained about the same.

Extensive R&D has been carried out, particularly on magnet-coil materials. The development of principal machine components will be completed this year, and the project will proceed to full-scale prototyping and manufacturing studies. A complete logic network has been established for linking the tokamak component-development activities to the final machine design, as well as to the component-fabrication and assembly plans. During the present fiscal year, the preliminary design phase will begin and the engineering support contracts will be awarded.

The FY'89 project activities include the completion of preliminary (Title I) design of all major systems and the start of A&E design for the CIT buildings. Full-scale single-turn prototypes will be produced for the toroidal-field coil system. Full-scale poloidal-field-coil prototypes will also be produced, and a coil-testing program will be initiated, with completion scheduled for FY'90.

The activities planned for FY'88 and FY'89 will create the basis for initiation of the component-fabrication and site-construction phase of the CIT project in FY'90.

The Magnetic Fusion Base Program

While my presentation responds primarily to the Committee's questions concerning the burning-plasma aspect of fusion research, I would like to emphasize the crucial role that the development of basic fusion science and technology continues to play in support of our advance towards fusion energy. Our major operating fusion devices owe much of their success to insights derived from plasma theory and smaller experiments. The direct dependence of the CIT design on theoretical understanding and innovative experimental techniques has been brought out in the previous discussion.

I would like to note, furthermore, that important experimental advances are being achieved not only by tokamaks, but also by other confinement schemes -- notably the reversed-field pinch and the stellarator. There is a strong case for the continuing exploration of these concepts alongside the tokamak, as well as for the pursuit of the theoretically indicated opportunities to optimize the tokamak concept itself. A well-balanced fusion program should include substantial efforts along all these lines.

MFE Budget for FY'89

The President's FY'89 budget of $360M supports the most essential steps needed to advance towards the TFTR break-even objective and the construction of the CIT, while maintaining a vigorous base program.

Some significant negative impacts of the FY'89 budget are: (1) TFTR experimental approaches to break-even are being narrowed -- for example, we have lost support for construction at ORNL of a tritium-pellet injector. (2) The CIT construction schedule is being stretched out.

Projected MFE Budgets for FY'90-93

In response to a congressional request, OFE has prepared a budget study that shows how the construction of CIT could be accommodated within a set of MFE budgets that remain constant in '89 dollars (escalating to $375M in FY'90 and to $426M in FY'93). To fit within this difficult budgetary constraint, the CIT construction schedule is stretched out, at the cost of opening a five-year gap in frontline fusion research between the shut-down of TFTR in '91 and the start-up of CIT in '96. The incremental funding that is needed to make the transition from TFTR to CIT is generated by "taxing" the balance of the MFE program: there is a purely funding-driven two-year hiatus in the highly productive research program of Princeton's PBX-M device (during FY'90-91); painful constraints are imposed on other innovative experimental programs; and there is a general dearth of new initiatives, aside from the CIT project itself.

The DOE budget study is important and welcome in that it makes a clear statement concerning the central role of the CIT project within the fusion program. The five-year "flat-budget" illustration is also helpful in demonstrating that no really major capital-construction supplement is needed to help us make the transition from TFTR to CIT. From the point of view of maintaining the vitality and productivity of the US fusion community, however, an actual policy of trying to raise the entire CIT construction cost from within the existing program would be quite problematical. Such an approach tends to subject the CIT construction schedule and the MFE operating budgets to levels of pressure that seem to go beyond the point of cost-effectiveness.

Is MFE an Energy Program?

In planning the future of U.S. fusion research, one basic question is whether fusion should be thought of as a science program or as an energy program. I would like to conclude my remarks by addressing that question.

During the first decade of fusion research, a major program goal was to produce at least some measurable fusion energy release. This goal was reached at the end of the 1950's, with the production of about a million fusion reactions per experimental "shot". That corresponds to an energy release of about one millionth of a joule -- or equivalently, the work done by a horse in about one nanosecond (one billionth of a second). During this same era of fusion research, the field of modern plasma physics was founded and most of the basic discoveries and inventions of plasma-confinement theory were made -- but one may well hesitate to describe this fruitful activity as an "energy program".

Last year, TFTR produced two times 10^{16} fusion reactions per shot in deuterium plasma -- which corresponds to a horse working for twenty seconds. If D-T fuel were introduced right now, the horse would be working for more than an hour. When TFTR reaches break-even in D-T plasma, the energy released during each one-second shot will correspond to fifteen horses working for an hour. I would call that at least the beginning of an energy program.

The CIT will release about one gigajoule of fusion energy during a five-second burn, which is equivalent to five hundred horses working for an hour. The reactor objective of the ITER corresponds to about one million horses working a good part of the time. As you consider all those horses hard at work, I hope you will agree with me that fusion research is at least a bit of an energy program right now, and has the opportunity to become much more of an energy program in the fairly near term.

I should like to express my appreciation to the Committee for its confidence in the future of magnetic fusion, and particularly for its far-sighted support of the TFTR and CIT projects. Adoption of the President's FY'89 budget, along with modestly rising funding during the next few years, will permit us to make a significant start on the burning-plasma phase of fusion research. With the help and encouragement of the Congress, the magnetic fusion program can continue to evolve into a powerful and economically relevant energy program, while remaining a first-rate science program as well.