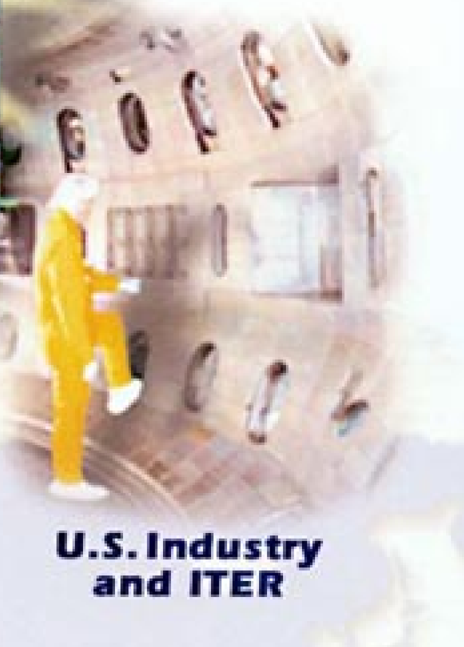
The U.S. and ITER

Science Opportunities

U.S. Direct Experience

ITER Design

Technology Opportunities



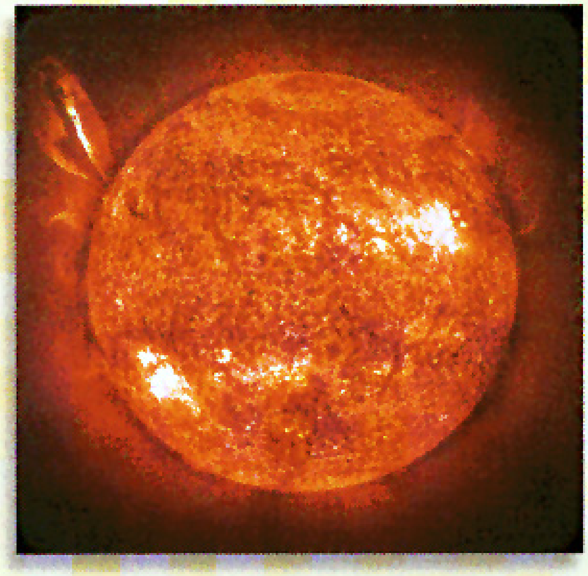
U.S. Industry and ITER

The Path to Fusion Energy

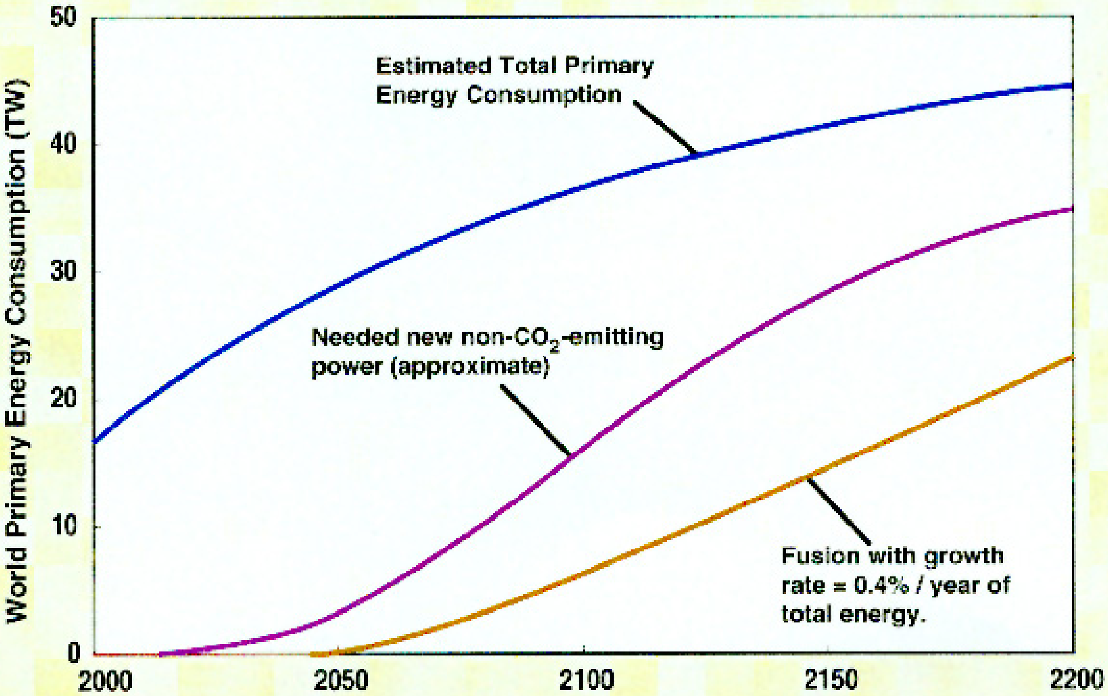
Office of Science
U.S. DEPARTMENT OF ENERGY

Why Fusion? If Successful, the Payoff is Enormous!

Economic fusion could be an ultimate solution to concerns about sustained growth of energy usage



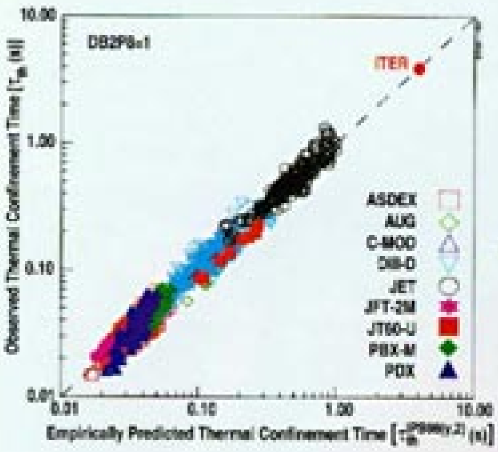
- Derived from sea water, fusion fuel is essentially inexhaustible. Its worldwide availability means that successful development of economic and environmentally acceptable fusion energy could guarantee true energy independence for all nations.
- The fusion process produces neither atmospheric pollutants nor long-lived, high level radioactive wastes. Structures and other components activated by fusion neutrons can be minimized by optimal choice of materials.
- A fusion reactor "can't blow up and can't melt down" owing to the nature of the fusion process. Furthermore, as it requires no fissionable materials, a fusion reactor is highly resistant to proliferation.
- As a primary energy source, fusion could power electricity, hydrogen production, or water desalination.



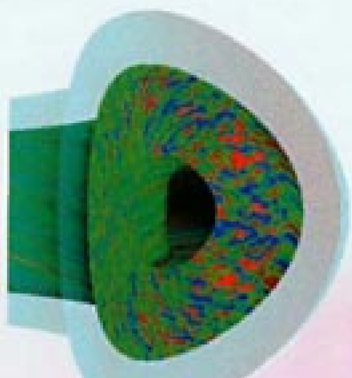
Growth in world population and energy needs, particularly in the developing world, will lead to continued increases in energy consumption. If greenhouse gas emissions limit the use of conventional fossil fuels, new energy sources will be required. Fusion energy can, in a timely way, play a critical role in filling the need for new sources.

Fusion Science has Come of Age!

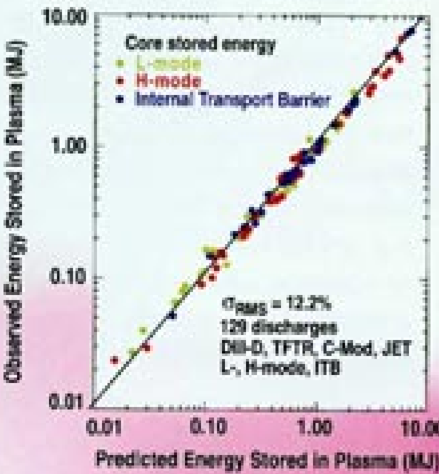
Advances in fusion research over the past decade have changed markedly the outlook for practical fusion energy. Through the course of the past 40 years, fusion research developed the fundamental science of a fourth state of matter – that of fully ionized gases, called plasmas. In the early years this research had a strong empirical aspect which, although useful, raised legitimate questions when used as a basis for prediction. Over the past decade, however, a true sea change in fusion research has been accomplished with the combination of increased detailed measurement instruments, deeper theoretical understanding, and large-scale computational tools enabling modeling of real configurations. The basic mechanisms have been identified, and the earlier empirical predictions have been put on more solid footing. Today, we can reliably create, measure, model, and predict experimental plasma behavior to such a degree that large-scale energy production can be designed with much improved confidence.



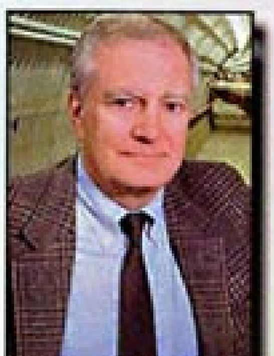
Confinement data collected from tokamaks worldwide has been the traditional technique for projecting the energy confinement time of new devices. Although empirical, these models have proved to be reliable and accurate tools; tools which point the way to the confinement needed for success in ITER.



Recent computational modeling advances now allow plasma turbulence calculations and confinement predictions to be made for the ITER plasma shape.



Theoretically based computational models now predict gross plasma characteristics very well and provide a basis for design beyond the range of empirical data. Shown is the gross energy stored compared to modeling prediction for several devices.

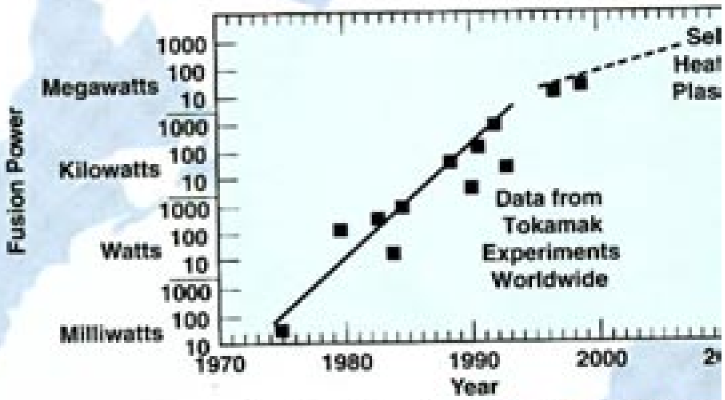


As Presidential Science Advisor John Marburger noted: "This [progress in fusion science] is an enormous change that is enough to change the attitudes of nations toward the investments required to bring fusion devices into practical application and power generation."

Assessments of U.S. Fusion Program Confirm a Burning Plasma Experiment as the Next Major Fusion Step

"Over the longer term, the U.S. must involve itself in the international experiments associated with burning plasmas," Secretary of Energy Advisory Board (1999)

Early experience with burning plasma phenomena was gained in the TFTR (U.S.) and JET (Europe) experiments using a full deuterium-tritium (D-T) fuel to produce fusion at power levels less than that required for self-sustainment. The scientific challenges of a self-heated plasma are twofold. First, the operating regimes studied in current devices must be extended to higher performance to assure that the D-T fuel can reach the conditions, e.g., energy confinement, which are a prerequisite for sustained self-heating. The second is to explore, understand, and quantify the phenomena resulting from the self-heating process.



Power production in international fusion experiments has grow from milliwatts in the 1970s to megawatts in the 1990s. T next step requires a burning plasma experiment such as ITE An international collaboration would allow the costs to be shar

ITER Constitutes an Important Stepping Stone Toward Fusion Power

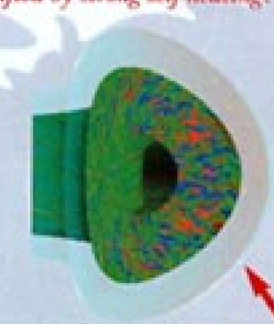
The new, lower cost ITER design with its increased scientific flexibility, presents a more attractive opportunity to the U.S. than the original design. There are numerous opportunities for U.S. involvement that draw on areas of historic U.S. strength and provide avenues for a wide spectrum of U.S. universities, laboratories and industries. For example, over the next decade and before actual ITER operation, it will be necessary to develop, design and test the variety of measurement, heating, and control devices determined in the negotiations to be part of the U.S. ITER contribution. After ITER begins operation, employing these same tools to measure or control the plasma becomes an integral part of the ongoing research that, in turn, requires the theoretical and modeling support that proved so successful over the past decade.

We have the tools, the knowledge, the need, the will and the WAY! (in Latin ITER = the way)

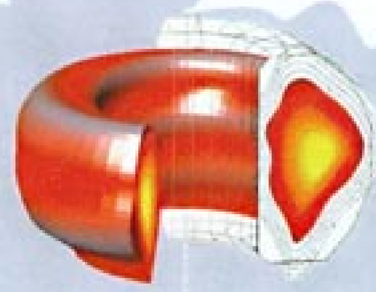
U.S. Role in ITER Would be Scientifically Exciting

How are plasma energy confinement and transport modified by strong self heating?

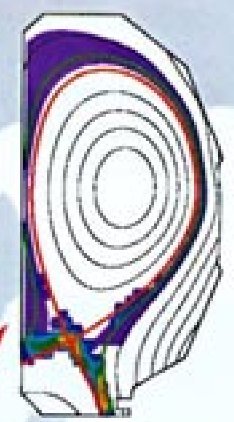
How can the high thermal power escaping from a fusion reactor be spread over solid, material walls?



Confinement and Transport

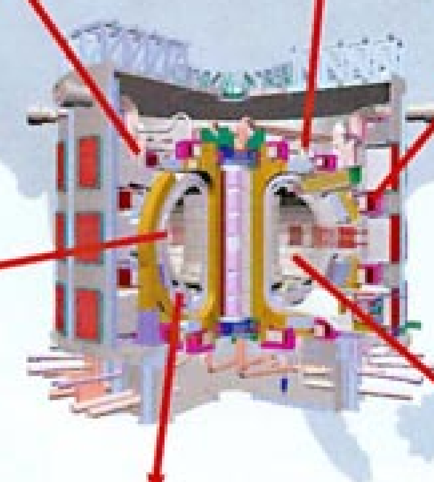


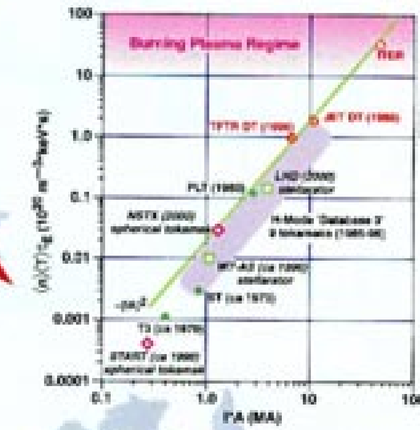
MHD Stability and Control



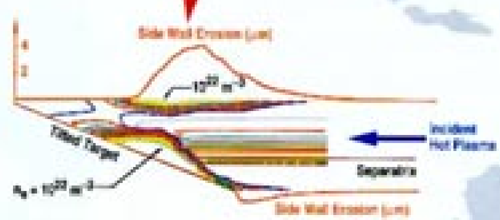
Boundary Physics

Burning Plasma Self-heating Effects





Integrated Performance



Disruption Effects

How can infrequent, but sudden, losses of internal plasma energy be avoided or mitigated under burning plasma conditions?

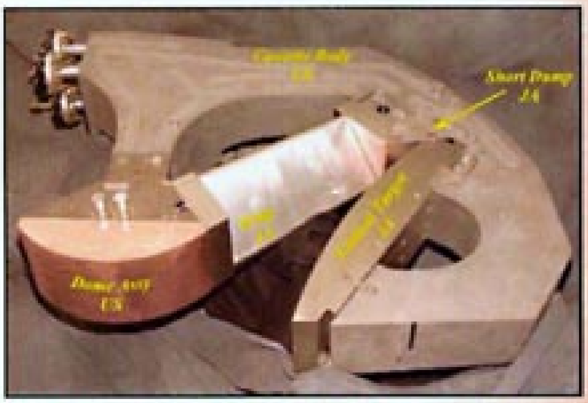
How do all of the physical phenomena recognized in non-burning plasmas play together under conditions of strong self heating?

Operation of ITER will draw upon and extend virtually all of the plasma science developed over the past decades and apply that science in an integrated manner to explorations in the burning, self-heated regime.

U.S. Role will Include Valuable State-of-the-Art Energy Technology

The U.S. was a major contributor to ITER Technology and Science during the previous first two phases i.e., the Conceptual Design Activity and the Engineering Design Activity. U.S. universities, national laboratories and industry collaborated to develop, design, and fabricate models and test components for several major components and a number of critical diagnostics.

Central solenoid for the ITER model coil was designed and fabricated in the U.S. (above left) as a collaboration between MIT, LLNL, and General Dynamics. The remaining components were fabricated by other ITER Parties and the fully assembled model coil was successfully tested in Japan (above right).



ITER divertor cassette was designed and fabricated as a collaboration between Sandia National Laboratory and Boring.

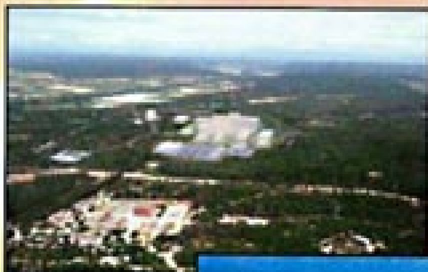
U.S. involvement in the construction phase will provide access to the international development of all ITER technological components. Additionally, the U.S. could take responsibility for development, design, and fabrication of selected systems such as diagnostics, advanced control, plasma heating systems as well as some larger tokamak components. Such responsibilities will allow the involved U.S. institutions to maintain their world leadership in key areas and allow U.S. industry to remain engaged in fusion energy development.

Fast gas injection equipment developed by ORNL has been demonstrated to significantly mitigate plasma disruption consequences in the DIII-D tokamak.

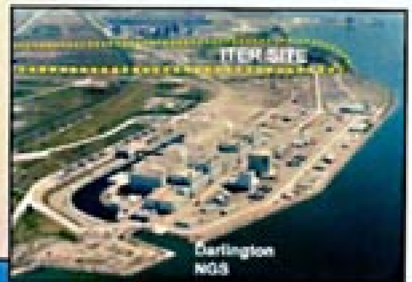
These skills will provide valuable spin-off applications and will be required to realize energy and economic growth from a successful fusion energy program

ITER: An Opportunity for International Collaboration and Cost Sharing

The U.S. fusion community has reached a consensus that the next major step for the U.S. program should be a burning plasma experiment. While several candidate experiments have been evaluated, ITER is recognized as the most comprehensive and capable candidate. Participation by the U.S. in ITER would reinvigorate our international collaboration, and it should result in advancing the U.S. program through the burning plasma step with the cost being shared among the international participants. The European Union, Japan, the Russian Federation and Canada began formal talks in November 2001. The negotiations schedule calls for a consensus on the preferred site to be reached before mid-2003. Potential sites have been offered by Canada, Japan, France and Spain.



France (Cadarache)



Canada (Clarington)

Japan (Rokkasho)

Spain Vandellos

Based on informal communications with the ITER Parties, the U.S. would be warmly welcomed if the decision is made to rejoin the ITER project. The U.S. was an original co-founder of ITER and would be "grandfathered" into the current talks. U.S. involvement would enable a number of highly qualified and internationally respected U.S. scientists to return to ITER. Other major countries are anticipating joining the ITER project during 2003.

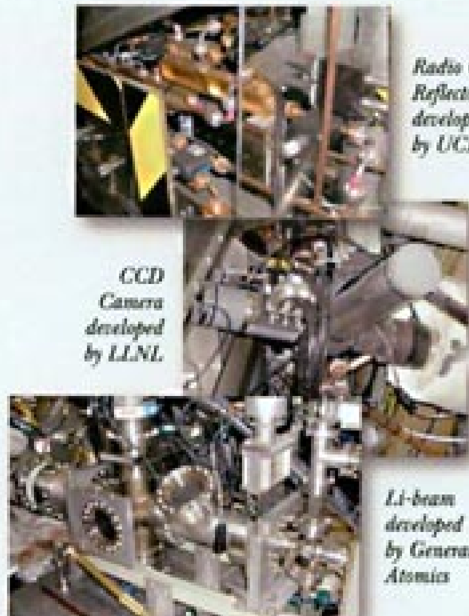
The ITER Construction Schedule is aggressive. Construction funding is to begin around FY06 and construction is to be completed seven years after the construction license is granted. The first plasma is scheduled one year later. Early deuterium-deuterium experiments will focus on plasma science and provide a basis for subsequent burning plasma experiments. The burning plasma activities will provide scientific and technological developments necessary for exploitation of fusion as an energy source. These developments cannot be accomplished without a burning plasma experiment.

Goal: *First plasma 8 years after construction start*

Productive U.S. Involvement

U.S. participation in ITER will advance the science and technology of the U.S. fusion program and will allow the U.S. to make important contributions to ITER. As an incremental activity having its foundations in the base fusion program, the U.S. fusion community can provide scientific and computational support that is not duplicated by current ITER Parties. The U.S. can also provide plasma physics experimental support from major facilities that have unique flexibilities and diagnostics. In addition, the U.S. can provide the diagnostics, control and subsystem components noted previously. A limited number of experienced scientists and technologists could be made available to ITER, including several who were major contributors to the project during the previous phases.

Each Party's contributions will be on an "in-kind" basis, with the bulk of funds being expended within the Party. Importantly, each Party would not be responsible for project cost overruns beyond its agreed commitments.



Radio Correlator Reflectometer developed by UCLA

CCD Camera developed by LLNL

Li-beam developed by General Atomics

State-of-the-art diagnostic systems on the DIII–D National Fusion Facility have been developed by several members of the U.S. fusion community.

Electron cyclotron launcher developed by Princeton Plasma Physics Laboratory precisely controls heating profiles for improved plasma stability in DIII–D.

Megawatt high-frequency heating systems(such as this CPI gyrotron) will be important for plasma control in ITER.

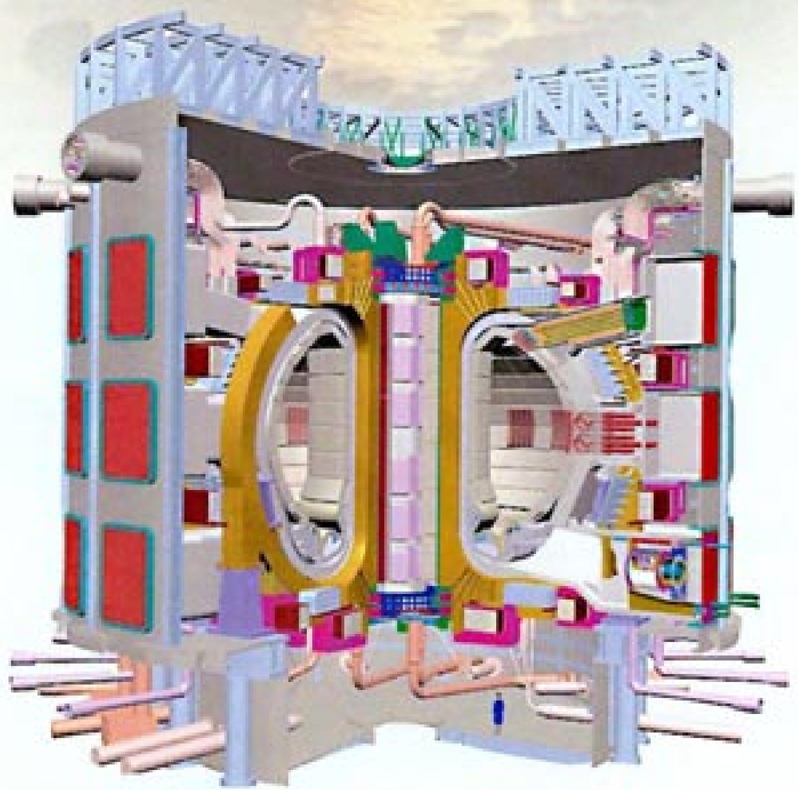
U.S. Participation will be beneficial for both the U.S. fusion program and ITER. Contributions of in-kind components for ITER will develop U.S. industry and labor skills.

U.S. Participation in ITER Would Be Rooted in a Robust Base Program

Underpinning U.S. Iter participation will be a spectrum of lower level research activities within the U.S. domestic program – e.g.,

- Providing ITER R&D support both in physics and technology and exploring new modes of improved or extended ITER performance
- Exploring confinement in alternative magnetic configurations,
- Developing the materials and technologies necessary for fusion energy, and
- Integrating all that is learned to look forward to power-plant applications

The sophistication of the underlying science, when evaluated using modern computational techniques, will enable the transference of lessons learned between such activities having such differing physical scales.



The combination of ITER plus a solid base program combines the opportunity to press forward into the burning plasma regime while retaining the ability of the nation to benefit from doing so.

U.S. Fusion Program Participants Spa

The U.S. Fusion Program employs the skills of many of the country's major universities, national laboratories, and selected industrial organizations. A broad range of expertise is required if the scientific and technological challenges inherent in the successful development of economic fusion energy are to be overcome.

he Country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Univ. of Wisconsin
ANL
Univ. of Chicago
Univ. of Iowa
Univ. of Illinois
Univ. of Missouri
Univ. of Michigan
Univ. of Rochester
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Florida A&M
Univ. of Florida
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Praire View A&M Univ.
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Excellent Science in Support of Attractive Energy

"I am pleased to announce that the United States will join ITER, an ambitious international research project to harness the promise of fusion energy. The results of ITER will advance the effort to produce clean, safe, renewable, and commercially available fusion energy by the middle of this century."

— President George W. Bush (January 2003)

Office of Science
Department of Energy
Washington, DC 20585

Visit the Office of Science Fusion Energy website:

www.ofes.fusion.doe.gov/iter.html

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