American Nuclear Society
Fusion Energy Division
December 2005 Newsletter

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Letter from the Chair, Said Abdel-Khalik, Georgia Institute of Technology, Atlanta, GA.

With nearly 700 FED members and a strong financial balance sheet, I am pleased to report that the state of our Fusion Energy Division is strong. I would like to take this opportunity to thank our previous Chair, Professor Jake Blanchard (University of Wisconsin-Madison) for his tireless efforts on behalf of FED.

This letter summarizes some of the ongoing activities at ANS, plans for the 17th ANS Topical Meeting on the Technology of Fusion Energy (TOFE), and activities related to the Fusion Energy Science Advisory Committee (FESAC).

FESAC

As Chair of the ANS Fusion Energy Division, I am honored to serve as an Ex-Officio member of FESAC. During my tenure on the Committee, FESAC has so far met only once (July 19, 2005). Among the presentations given at that meeting was a report by the Facilities Panel chaired by Dr. Jill Dahlberg of NRL. The Panel was appointed following a request from Dr. Orbach in April of 2005 and charged with identifying the "unique and complimentary characteristics of each of the three major US toroidal fusion facilities" (C-MOD, DIII-D, and NSTX), how the three facilities contribute to fusion science and the vitality of the U.S. Fusion program, and what research opportunities would be lost by shutting down one of the major facilities. The Panel's main recommendation is that all three major U.S. toroidal magnetic fusion facilities should continue operation to "conduct important, unique, and complementary research in support of fusion energy sciences and ITER."

Presentations were also given by Dr. Anne Davies (Associate Director for DOE Fusion Energy Sciences), Professor Ray Fonck (University of Wisconsin-Madison), Dr. Ned Sauthoff (PPPL), and Dr. Orbach (Director, DOE Office of Science). Dr. Davies presented an overview of the FY06 FES budget status and highlights, along with near-term activities following ITER site selection. Professor Fonck presented a status report on behalf of the U.S. Burning Plasma Organization, a fusion research community-based effort to advance burning plasma science and optimize benefits from participation in ITER. It fosters the community's coordination of, participation in, and ownership of the BP program activities. Dr. Sauthoff presented a status report on the ITER program (see detailed report in this newsletter). Dr. Orbach presented DOE's perspective on the ITER program. He described the negotiations process leading to the Cadarache site selection, discussed FY06 House and Senate appropriations for the Office of Sciences, and provided an estimate of the ITER project costs over the next eight years, and its expected scientific and technological outcomes. Meeting minutes and copies of the presentations for all FESAC meetings can be found at
http://www.ofes.fusion.doe.gov/More_HTML/FESAC_Charges_Reports.html

ANS

Several actions have been taken by the ANS Professional Divisions Committee (PDC) since/during the June meeting. Most notable among these is the approval of the formation of a "Young Members Group" which is aimed at providing a vehicle for young professionals to become involved in activities that enrich their professional lives and to continue their involvement in the society after their period of student membership. The proposal was subsequently approved by the ANS Board of Directors. A petition was submitted to the PDC to form a Technical Group on Nuclear Production of Hydrogen; the effort is led by Dr. Ken Schultz of General Atomics. No action has been taken on the petition; it will be discussed again at the November meeting. Other activities include the development of "Standard Bylaws" for the various Professional Divisions, along with procedures for the founding of new Technical Groups and Working Groups (to be discussed at the November meeting).

17th TOFE

Consistent with our practice of alternating between "stand-alone" and "embedded" Topical meetings, the 17th Topical Meeting on the Technology of Fusion Energy (TOFE) will be held on November 13-16, 2006 in Albuquerque, NM as an embedded meeting within the ANS Winter meeting. Dr. Craig Olson is the General Chair and Dr. Gary Rochau is the Technical Program Chair (see detailed report in this newsletter). Final approval of the meeting is expected on November 14, 2005 during the ANS Winter meeting in Washington, DC. The Technical Program Committee, along with the list of sessions, will be published soon. We look forward to another highly successful TOFE meeting.

Slate of Candidates for 2006/2007 FED Executive Committee, Jake Blanchard, University of Wisconsin-Madison, Madison, WI.

All FED members will receive a ballot early in 2006 for the election of FED Officers and Executive Committee members. We all will benefit from a good turnout, so please take the time to fill out and return your ballot per the instructions supplied with the ballot. The outcome of the election will be announced before the June 2006 ANS annual meeting in San Diego. The FED is always looking for members who would like to become active in the operation of the division. If you are interested, please contact Said Abdel-Khalik (who will be chairing the nominating committee for next year's candidates) or any other member of the Executive Committee.

We have an excellent slate of candidates for the upcoming FED election and their willingness to contribute their time and effort to FED is much appreciated. The current Vice Chair/Chair-Elect, Jeff Latkowski (Lawrence Livermore National Laboratory), will become FED Chair at the end of the FED Executive Committee meeting in June. Also, Lee Cadwallader from Idaho National Laboratory will continue to serve as Secretary/Treasurer, as he is just one year into a two year term. The list of candidates (in alphabetical order) for the 2006 election consists of:

Vice Chair: Susana Reyes (LLNL)

Executive Committee (3 members to be elected):
- Mark Anderson (University of Wisconsin-Madison)
- Ben Cipiti (Sandia National Laboratories - Albuquerque)
- Brad Nelson (Oak Ridge National Laboratory)
- Shahram Sharafat (UCLA)
- Brian Wirth (UC Berkeley)

17th ANS Topical Meeting on Technology of Fusion Energy, Craig Olson and Gary Rochau, Sandia National Laboratories, Albuquerque, NM.

The 17th ANS Topical Meeting on the Technology of Fusion Energy (TOFE) will be held on November 13-15, 2006 in Albuquerque, NM, as an embedded meeting during the 2006 Winter ANS Meeting in Albuquerque, NM on November 12-16, 2006. The General Chairman of the TOFE meeting will be Craig Olson from Sandia National Laboratories, and the Technical Program Chair will be Gary Rochau from Sandia National Laboratories. Albuquerque is home to Sandia National Laboratories, the Air Force Research Laboratory, and the University of New Mexico. In addition, Los Alamos National Laboratory, the Very Large Array, and White Sands Missile Range are within easy travel distances. Albuquerque has numerous museums (National Atomic Museum, Natural History Museum, Albuquerque Museum, Maxwell Museum of Anthropology, etc), fiestas (the International Balloon Fiesta in October is the largest hot air balloon event in the world), the Sandia Peak Tram (the longest tram in the world; it connects to Sandia peak at 10,500 feet), Old Town, theatres, fine dining, music, sports, and extensive southwest culture. 2006 will be an especially interesting time because it is the Tri-Centennial (1706-2006) for the founding of Albuquerque, and several special events are planned. In addition, Santa Fe, Taos, and numerous Indian pueblos are within a short drive from Albuquerque.

The scope of the TOFE meeting is to provide a forum for the discussion of new results in fusion technology as they relate to present fusion research and to future fusion energy applications. This is a particularly exciting time for fusion technology due to the development of ITER and NIF, and many other fusion facilities world-wide. The TOFE organizing committee, technical program committee, and multiple sponsors are presently being developed. A website for TOFE has been created at www.TOFE17.org, and it will be available December 1, 2005. Please visit this website periodically, as it will be updated often.

Topics

Paper submissions are solicited in all areas of fusion technology that include, but are not limited to, the following topics:
- Engineering of experimental devices
- Power plant studies
- High heat flux components

IFE target fabrication, injection, and tracking
In-vessel components (blanket, shield, vacuum vessel)
IFE chamber dynamics and clearing
Magnets
Nuclear analysis and experiments (neutronics, shielding, and activation)
Structural and breeding materials
Material and component test facilities
Blanket testing
Safety and environment
Radwaste management
Tritium handling and processing
Plasma engineering, heating, and control
Diagnostics
Fabrication, assembly, and maintenance
Power conversion and conditioning
IFE drivers
Computational tools and validation experiments
Alternate, non-electric applications of fusion
Hydrogen production
Socioeconomics

Technical Program

The 17th TOFE will be a two and a half day meeting with plenary, oral, and poster sessions, with a mix of invited oral papers, and a substantial number of contributed oral and poster papers. In addition, special sessions are being planned on various topics (e.g., ITER).

Awards

In the continuing TOFE tradition of promoting professional recognition, the ANS-FED will offer three awards to provide technical recognition in the fusion area. These are the Outstanding Technical Accomplishment Award, Outstanding Achievement Award, and Best Student Paper Award (see the ANS-FED awards article in this Newsletter).

Registration and Publications

The process of registration and abstract and full paper submission/review will be done electronically. You may register for the TOFE meeting through either the TOFE website or the ANS website. You are invited to submit abstracts describing work that is new, significant, and relevant to both MFE and IFE technologies (check the TOFE website for abstract submission instructions). Full papers will be due at the meeting. Papers that are accepted by the peer review process will be published in Fusion Science and Technology journal. Registration at the ANS Winter Meeting includes admittance to all TOFE technical sessions. A separate fee will be required for tickets to the TOFE banquet.

Key Deadlines

Abstracts due	June 2006 (see ANS Winter Meeting)
Notification to authors	August 1, 2006

Early registration deadline	(See ANS Winter Meeting)
Hotel reservation deadline	(See ANS Winter Meeting)
Full papers due at the meeting	November 13, 2006

Please visit the TOFE website for additional details at www.TOFE17.org, and mark your calendars to attend the 17th TOFE in Albuquerque, NM on November 13-15, 2006. We're looking forward to seeing you in Albuquerque next fall!

Call for Nomination, ANS-FED Awards, Farrokh Najmabadi, University of California-San Diego, San Diego, CA.

The Honors and Award Committee of FED/ANS is seeking nominations for Fusion Energy Division of ANS Awards:

1) **Outstanding Achievement Awards:** This award is for recognition of a continued history of exemplary individual achievement requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.

2) **Technical Accomplishment Award:** This award is for recognition of a specific exemplary individual technical accomplishment requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.

Detailed descriptions of the awards and past recipients can be found at http://fed.ans.org/awards.shtml

Deadline for nominations is September 1, 2006 for the awards to be presented at the 17th ANS Topical Meeting on the Technology of Fusion Energy, to be held in Albuquerque, NM on November 13-15, 2006.

Nominations can be made by individuals and submitted at anytime to the FED Honors and Awards Committee Chair. Nomination package should include a) nominee's CV and b) a description of exemplary achievements. Support letters (and/or co-signature on the nomination form) are greatly encouraged.

Please send nominations to:
Prof. Farrokh Najmabadi
460 EBU-II
UC San Diego
La Jolla, CA 92093-0438
fnajmabadi@ucsd.edu

2005 Fusion Award Recipients, Laila El-Guebaly, University of Wisconsin-Madison, Madison, WI.

Fusion awards have been established to formally recognize the outstanding contributions to fusion developments made by members of the fusion community. The following awards (listed in alphabetical order) were available to the newsletter editor at the time of publishing this newsletter. We encourage all members of the fusion community to submit information on future honorees to the editor (elguebaly@engr.wisc.edu) to be included in future issues.

The ANS-FED officers and executive committee members congratulate the honored recipients of the 2005 fusion awards on this well-deserved recognition and our kudos to all of them.

ANS Awards

Mark H. Anderson (University of Wisconsin-Madison) received the Young Member Engineering Achievement Award in recognition of his innovative and pioneering achievements in the field of experimental diagnostics for fluid flow and heat transfer in nuclear fission and fusion technologies.

Everett E. Bloom (Oak Ridge National Laboratory) received the Mishima Award in recognition of his development of advanced radiation-resistant structural materials for fast breeder reactor and fusion energy systems.

Terry Kammash (University of Michigan) received the Special Award for Space Nuclear Power in recognition of his pioneering contributions as a researcher and educator in plasma physics and its applications to advanced space nuclear power and propulsion systems.

Joseph Kilkenny and **Max Tabak** are the winners of the 2005 Edward Teller Medal, presented by the ANS for achievements in inertial fusion. The prizes were awarded last September at the IFSA-2005 meeting in France. **Kilkenny** (General Atomics; University of Rochester’s laser laboratory) is recognized for his initiation of experiments that were the basis for the National Academy of Sciences’ go-ahead for the National Ignition Facility at the Department of Energy’s Lawrence Livermore National Laboratory (LLNL). **Tabak** (LLNL) was recognized for the role he played in developing the fast-ignition process.

APS Awards

Nathaniel Fisch (Princeton Plasma Physics Laboratory) is the 2005 recipient of the American Physical Society's prestigious James Clerk Maxwell Prize for Plasma Physics. **Fisch** is cited for theoretical development of efficient radiofrequency-driven current in plasmas and for greatly expanding our ability to understand, to analyze, and to utilize wave-plasma interactions.

William Tang (Princeton Plasma Physics Laboratory) is the recipient of the Chinese Institute of Engineers USA Distinguished Achievement Award. **Tang** is cited for his outstanding leadership in fusion research and contribution to fundamentals of plasma science.

IEEE/ NPSS Fusion Technology Awards

These awards recognize outstanding contributions to research and development in the field of Fusion Technology.

Charles C. Baker (Sandia National Laboratories) was recognized for his leadership in the development of fusion technology and the quest to build future fusion power plants, for his leadership of the U.S. ITER fusion efforts, and for his leadership of the U.S. Virtual Laboratory for Technology.

Bradley E. Nelson (Oak Ridge National Laboratory) was recognized for his innovative technical contributions to the engineering of fusion experiments and his exceptional leadership in the design and construction of experimental fusion facilities.

FPA Awards

Charles C. Baker (Sandia National Laboratories) and **Dale M. Meade** (Princeton Plasma Physics Laboratory) are the recipients of the Distinguished Career Awards for making distinguished, lifelong career contributions to fusion development. **Baker** was recognized for his decades of outstanding contributions to the fusion effort, including but not limited to his roles in leading the fusion technology program and his inspirational leadership of several important planning and FESAC panel activities. **Meade** was recognized for his decades of outstanding contributions to the fusion effort, including but not limited to his roles in leading the TFTR and Next Step Options programs and his inspirational guidance in the search for an affordable path to fusion power.

Neil Morley (University of California-Los Angeles) received the Excellence in Fusion Engineering Award for his outstanding technical contributions to fusion development in areas such as high heat flux components, liquid walls and MHD fluid flow, and heat transfer and for his leadership qualities in such areas as the U.S. program for the ITER Test Blanket Module and the liquid surface divertor module on the NSTX facility at the Princeton Plasma Physics Laboratory.

Ronald D. Stambaugh (General Atomics) received the Leadership Award for his outstanding leadership qualities in accelerating the development of fusion, for his outstanding leadership of the DIII-D tokamak program at General Atomics over many years, resulting in many important scientific contributions to the fusion venture, and for his focus on finding ways to improve the ultimate fusion product, an economic fusion power plant.

Presidential and DOE’s Early Career Award

The Presidential award is the highest honor bestowed by the U.S. government on outstanding scientists and engineers who are beginning their independent careers. **Hong**

Qin (Princeton Plasma Physics Laboratory) was among six from DOE national laboratories to receive the Presidential award as well as the DOE's Office of Science Early Career Scientist and Engineer Award. Both the Presidential and DOE awards cite **Qin** for his contributions to the physics of high-intensity particle beams, with application to ion-beam (inertial) fusion energy (IFE), and for his work on electromagnetic effects in magnetically confined plasmas, with application to magnetic fusion energy.

News from Fusion Science and Technology (FS&T) Journal, Nermin A. Uckan, FS&T Editor, Oak Ridge National Laboratory, Oak Ridge, TN.

During the past 12 months, FS&T has been busy with publication and scheduling of several special issues and an excellent selection of contributed papers. The 2005 issues included the following special issues:

February 2005	TEXTOR Tokamak (Juelich, Germany) [Guest Editor: Philippe Martens]
April & May 2005	Proceedings of the 16th Topical Meeting on the Technology of Fusion Energy (16th TOFE, Parts I & II)
July/Aug 2005	Proceedings of the 7th International Conference on Tritium Science and Technology (Baden-Baden, Germany)
October 2005	DIII-D Tokamak (San Diego, CA)

Future (2006-2007) special issues will include: Fast Ignition (U.S., JA, EU), Alcator C-Mod Tokamak (MIT), JFT-2M Tokamak (JA), JET Tokamak (EU), 7th Carolus Magnus (EU), MFE Diagnostics (EU, JA, RF, U.S.), 15th IEA Stellarator Workshop (Madrid, Spain), 16th Target Fabrication Specialist's Meeting (Scottsdale, Arizona), 17th TOFE (Albuquerque, NM), and more.

Don't miss any of the present and future issues by signing-up for an individual ANS member subscription or through your libraries. Note that electronic access to FS&T is available from 1997-to-current. Tables of contents and abstracts of papers can be accessed at http://www.ans.org/pubs/journals/fst/. Individual and library subscribers can access the full text articles at http://epubs.ans.org/.

Over the past 5 years, the journal has grown and manuscript submissions have increased. Summary of paper statistics for October 1 – September 30 periods for this and the previous 5 terms are summarized in the tables below.

FS&T Manuscript Submission by Region 10/01 – through – 09/30/05					
Year	Total Ms Received	North America	Asia	Europe	Other
2004/05	363	156	89	114	4
2003/04	296	159	69	68	2
2002/03	232	126	66	40	47*
2001/02	140	53	55	30	2
2000/01	55	25	14	13	3
1999/00	68	23	20	21	4
*For 2002/03: Rejected/withdrawn papers from TOFE02 are included under Other – regions not sorted out in the ANS/FS&T database.					

FS&T Manuscripts in Progress 10/01 – through – 09/30/05				
Year	Total Ms Received	Accepted/ Scheduled	Rejected/ Withdrawn	Review/ Revision
2004/05	363	274	60	29
2003/04	296	249	47	0
2002/03	232	163	67	2 [NCSX]
2001/02	140	116	24	0
2000/01	55	34	21	0
1999/00	68	53	15	0

Looking forward to receiving your comments and suggestions on FS&T contents and coverage, and potential future topical areas that are timely and of interest. Contact e-mail: fst@ans.org.

Comments about New Book on Edward Teller Medal Award Lectures on Laser and Inertial Fusion Energy

by [1]George H. Miley and [2]Heinrich Hora,
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Introduction

The "*Edward Teller Lectures – Lasers and Inertial Fusion Energy*" book edited by Heinrich Hora and George H. Miley, with a foreword by E.M. Campbell, is now available in bookstores. This book is of special interest to ANS - FED members since it provides insight into the history of the Edward Teller Medal Award sponsored by FED.

In 1960, Edward Teller, along with John Nuckolls and others at the Lawrence Livermore National Laboratory, initiated research into laser fusion energy. Then, in 1969 a workshop series "Laser Interaction and Related Plasma Phenomena (LIRPP)" was begun to cover the basic physics associated with this area. In 1999 the conference was reorganized as the "Inertial Fusion Science and Applications (IFSA)" series. Starting in

1991, leading experts elected as "Edward Teller Medallists", an award of the ANS - FED, summarized their essential achievements in lectures presented at these conferences. Reprints of their award lectures, along with personal remarks by Edward Teller during the award ceremonies, are now collected in this new book, with a foreword by E. Mike Campbell. These lectures begin with the address of the first medallist, John Nuckolls, with Nobel Laureate Nikolai Basov (Moscow), and continue with awardees lectures up until 2003.

The documentation in the book includes addresses by Edward Teller himself and provides a description of how he viewed world energy problems. In addition to fusion, there is a special documentation of Teller's future vision of an absolute safe fission breeder, free from problems of misuse of reaction products. Edward Teller is quoted in a lecture [see p.51 of the book] in 1993, saying "I do not know why ... the French have a really unjustifiable advantage over everyone else: they are logical! And that logic tells them that the nuclear way is the way to go". While Teller supported use of fission power, as seen from his other writings, laser fusion retained a special spot in his heart relative to future energy solutions.

His interest in lasers goes back to a correspondence with John von Neumann where he envisioned the laser scheme before Charles Townes demonstrated the very first microwave laser operation. Further documentation in the book shows how Teller was so important to promote laser development against highest ranking sceptics.

Is the Ultimate Goal of Fusion Energy by Lasers Near?

The lectures in this book provide a confidence that great progress has been made in the quest for fusion energy and that fusion may indeed issue in a new "golden age" for mankind. It has been known since experiments by Oliphant, Harteck and Lord Rutherford in 1934 that the nuclear reaction of heavy hydrogen is a real exception compared to other nuclear reactions. Usually fusion occurs only if the nuclei are smashed together after being accelerated by million volts of electric fields whereas the light nuclei (hydrogen to boron) require lower acceleration to react. This permits them to react at temperatures of a few tens of million degrees as shown in the sun and the myriads of stars.

In 1937, even before nuclear fission was discovered by Otto Hahn, Oliphant undertook a study of how fusion reactions could be used for energy production. Subsequently, this field has received much research. Much of the world-wide effort has studied how to confine the nuclear fuel at the necessary temperature and density by magnetic fields leading to the pioneering international ITER project at Cadarache, France, which has just commenced construction. ITER has taken longer than expected to overcome various technological and political problems, but ITER scientists predict that by 2040 this device will demonstrate whether or not the concept of using magnetic fields for confining the fuel as high temperature plasma will be of economic benefit.

An alternative hope for fusion energy came with the advent of the laser. Soon thereafter it was evident that the laser opened the possibility of achieving an extremely high concentration of energy within an extremely small volume during very short times, providing a way to compress and heat fuels to fusion conditions. Presently, lasers have an intensity which is ~10^{23} times higher than the sunlight at the earth's surface. Laser powers of several petawatts have been produced in pulses of a picosecond duration. Also, other "drivers" such as heavy ion beam accelerators and pulsed power pinches are under consideration for inertial confinement fusion.

After the first fusion neutrons were detected during laser-target irradiations in 1968, their number per laser shot has increased by more than ten billion, approaching break-even in energy production. Laser systems costing billions of dollars are now being built with the aim to prove the ignition of nuclear fuel. It has already been demonstrated that these techniques can achieve fuel compressions to a few thousand times solid-state density. Laser pulses of several MJ energy should achieve ignition and produce energy gains sufficient for a power station. This basic concept was first demonstrated by underground nuclear explosions (Centurion-Halite project 1986) and is now being studied with the new large laser NIF at the Lawrence Livermore Laboratory/California and the LMJ in Bordeaux/France.

Will Fusion Energy Lead to a New "Golden Age"?

The achievement of low cost fusion energy would help resolve many of the energy problems civilization on earth is currently facing. One may imagine that then vast amounts of water can be distilled from the oceans to make deserts green. Tropical forest would not need to give way to space for growing grain which can be harvested from the greened deserts. Any amount of water could be taken from oceans avoiding regional conflicts about water supply. Production of aluminum, titanium, magnesium and similar metals could be accomplished at a very low cost along with chemical production of polymers from petrol (assuming we don't consume it all for energy first!) allowing architects and town planners to develop unprecedented designs. For individual mobility, the present hybrid cars could be changed into purely electrical energy operation with or without fuel cells, the electrical energy coming from low cost, clean and safe fusion power stations with unlimited fuel. The only limit to this picture is that the total energy production on the earth must not exceed about 50 times of today's usage.

Energy "too cheap to meter" was originally envisioned for fission power plants, but unforeseen events prevented this goal. Now fission power is undergoing a "rebirth". Hopefully, due to its unique features and the use of "lessons learned" from fission's history, fusion energy development can avoid such problems.

In summary, this book provides important insight into Edward Teller's views on energy development and on the work of early pioneers in laser fusion who helped initiate research leading towards the "Golden Age" of fusion. We are confident that the fusion community members will find it most interesting. The book is published by Imperial College Press, UK and distributed by World Scientific Publishing Co., Singapore. Copyright © June 2005. The price is US $63. ISBN 1-86094-468-X.

Highlights from SOFE-05 Meeting, Nermin Uckan and David Rasmussen, Oak Ridge National Laboratory, Oak Ridge, TN.

The 21st IEEE/Nuclear and Plasma Sciences Society Symposium on Fusion Engineering (SOFE05) was held September 26 - 29, 2005 in Knoxville, Tennessee. The Symposium is dedicated to the scientific, technological and engineering issues of fusion energy research.

The meeting was sponsored by IEEE/NPSS and hosted by Oak Ridge National Laboratory (ORNL). The SOFE05 exhibitors, General Atomics, Major Tools and Machine, Spincraft, Mega Industries, and ORNL, contributed additional support.

About 240 participants, 40% of whom represented ten countries outside the U.S. and 15% of whom were students, attended the meeting. The decision to site ITER in Cadarache, France, was recently announced and SOFE05 was the first international technical meeting to highlight this exciting future. A special plenary session included presentations from two of the ITER Participant Teams: the deputy director of the ITER International Team and the leader of the U.S. Burning Plasma Organization. This is a period of great activity in the worldwide fusion program and increased international participation and presentations at the meeting reflected a renewed enthusiasm in fusion research. Presentations on new experimental facilities included the EAST superconducting tokamak in China, the SST-1 superconducting tokamak in India, the KSTAR superconducting tokamak in South Korea, W7X stellarator in Germany, the NCSX compact stellarator at PPPL, the National Ignition Facility at LLNL, and upgrades to the Z-Accelerator at SNL. Multiple invited paper sessions highlighted the progress on these devices. Additional invited paper sessions informed participants about the recent results and upgrades to major operating inertial and magnetic fusion devices (ASDEX, Alcator C-Mod, DIII-D, JET, JT-60), and about developments in fusion related technology research in materials, chamber technology, plasma technology, blanket technology, and power plant studies. Contributed oral and poster sessions provided an excellent opportunity for informed dialog and exchange of information. Technical summaries and highlights of the poster and oral sessions provided by the session chairs can be accessed on the SOFE05 website: http://www.ornl.gov/fed/sofe05/seschairs/

There were 249 papers accepted for presentation and 152 were submitted by the paper submission deadline to be included in the proceedings. The papers will be published as IEEE/SOFE05 proceedings on CD-ROM only; there will be no printed copy. They will also be included in the IEEE Xplore database and will be accessible online. An abstract booklet was distributed at the meeting and posted at the SOFE05 website: http://www.ornl.gov/sci/fed/sofe05.

Following the tradition, the IEEE/NPSS Fusion Technology Awards were presented at the meeting. This year, there were two awards. The 2004 award was presented to Charles C. Baker for his leadership in the development of fusion technology and the quest to build future fusion power plants, for his leadership of the U.S. ITER fusion efforts, and for his leadership of the U.S. Virtual Laboratory for Technology. The 2005 award was presented to Bradley E. Nelson for his innovative technical contributions to the engineering of fusion experiments and his exceptional leadership in the design and construction of experimental fusion facilities.

Nermin Uckan from ORNL was the General Chair and David Rasmussen from ORNL was the Technical Program Chair. David Swain (ORNL) was the Publication Chair, assisted by Phil Ryan (ORNL). For information on the technical program committee, local organizing committee, and other meeting details, visit the SOFE05 website at: http://www.ornl.gov/fed/sofe05.

Summary of Fusion Power Associates Symposium on Fusion and Energy Policy, Steve Dean, Fusion Power Associates, Gaithersburg, MD.

Fusion Power Associates held its annual meeting and symposium on October 11-12, 2005 in Washington, DC. The theme of the meeting was "Fusion and Energy Policy." The talks at the symposium are summarized here. Presentations are posted at: http://fire.pppl.gov/fpa_annual05.html

Dr. Robert Marlay, Director, Science and Technology Policy, at the U.S. Department of Energy described current energy policy perspectives at the Department. He described recent events and near-term energy outlook, Administration responses and near-term actions, longer-term energy outlook and framework for research and development.

Sir Chris Llewellyn-Smith, Director of the UK's Culham Laboratory and Chairman of the EU's Consultative Committee on Fusion, described fusion in the context of the world energy scene. He said that if the chance of achieving viable fusion power is judged to be "reasonable," then fusion should be developed "as fast as possible." He said that what is deemed to be a "reasonable chance" depends on such factors as security of future access to fossil fuels, the degree of concern about the continued use of fossil fuels, the potential of other alternatives to fossil fuels, and the cost of fusion development.

Roberto Andreani, Associate Leader for Technology for the European Fusion Development Activity (EFDA) described the European fusion development strategy. He said the European fusion program is an energy-oriented program, whose main objective is to develop a competitive power-producing fusion reactor, exploiting all the potential characteristics of fusion: benign environmental impact, fuel abundance, reactor control and safety.

Masahiro Seki, Director General of the Fusion Energy Research Directorate, Naka Fusion Institute, Japan Atomic Energy Research Agency discussed Fusion Energy Development in Japan. He said that fusion development has two major components: fusion plasma research and fusion engineering research. He said that the recent agreement between Europe and Japan on the siting of ITER was based on a 50% contribution from Europe and 10% from each of the other parties (Japan, China, Korea, Russia and U.S.) with an additional 8% each from Europe and Japan towards "broader approach" activities in

Japan. The latter possibilities include materials testing and demo design, simulation and remote ITER operations center, and satellite tokamak. He said that by the end of 2005 it was expected to finalize the selection of the "broader approach" activities. He said the JT-60, the major Japanese tokamak facility, would resume operation shortly with a research program focused on long-time sustainment of high performance plasmas.

Bruce Warner, Deputy Associate Director for NIF Programs, Lawrence Livermore National Laboratory, described the status of construction and preparation for operations for the National Ignition Facility (NIF). He said that NIF, a 192 beam laser, was designed to deliver 1.8 megajoules in a 500 terawatt pulse, focused to a spot about 300 microns in diameter. He said the NIF construction was over 80% complete as of July 2005. Warner also discussed status of planning for operation of NIF. He said, "Our plan for 2009-2010 concentrates on systems integration and executing a credible ignition campaign." He said, "We have developed new high performance target designs" for the ignition campaign. "Improvements in ignition point designs have reduced the required laser energy estimates from 1.8 MJ to about 1 MJ. We have demonstrated target fabrication at the component level," he said.

Ned Sauthoff, head of the U.S. ITER office at Princeton Plasma Physics Laboratory, discussed the status of U.S. planning for participation in ITER. He said the U.S. had been given a provisional allocation of the systems and components it would provide to ITER. Sauthoff said the U.S. had placed contracts in FY2004 with industrial suppliers to demonstrate the production of the required superconducting strand, that testing of that strand was currently underway and that it was intended to produce larger volume prototypes in FY2006 if the budget permits. Procurement contracts for the ITER strand would be made in FY2007 if the ITER organization has approved the procurement package by that time, he said. Similar activities to reduce risk in the ultimate procurement packages were underway for the other U.S. designated allocations, he said.

Ray Fonck, University of Wisconsin and chair of the newly formed U.S. Burning Plasma Organization (USBPO), described the activity. He said, "The mission of the Organization is to advance the scientific understanding of burning plasmas and ensure the greatest benefit from a burning plasma experiment by coordinating relevant U.S. fusion research with broad community participation."

John Sethian, U.S. Naval Research Laboratory, presented a talk on Progress on High Average Power Lasers (HAPL) and Introducing the Fusion Test Facility, on behalf of himself and Steve Obenschain. Sethian indicated that two types of lasers were being developed: Krypton Fluoride gas lasers and Diode-Pumped Solid State (DPSSL) lasers. "Both have the potential to meet the requirements for target physics, rep-rate, cost and durability," he said. He said that the needed technologies were being developed and demonstrated on large, but sub-scale, facilities and that the technologies must scale to megajoule size systems.

B. Grant Logan, Lawrence Berkeley National Laboratory, presented the status of the heavy ion fusion program. He said "large advances" had been made over the past year in beam science common to high energy density physics (HEDP) and heavy ion fusion. He said the central question to both HEDP and fusion is "How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion?" "Creating warm dense matter and fusion ignition conditions longitudinal as well as transverse beam compression," he said. During the past year the program has adopted a new approach that involves neutralizing the beam space charge both in longitudinal drift compression as well as in the final focus. This technique has also enabled a new modular driver development path to inertial fusion energy, he said.

Craig Olson, Sandia National Laboratories, presented progress in Z-Pinch Inertial Fusion Energy (Z-IFE). Olson said that Z-pinches offer the promise of a cost-effective, energy-rich source of X-rays for inertial fusion energy. He noted that the ZR facility at Sandia, to be operational in 2007, would be within a factor of 2-3 in current and 4-9 in energy of that required for a high-yield fusion driver.

Jill Dahlburg, U.S. Naval Research Laboratory, summarized a recent panel report of the U.S. Department of Energy Fusion Energy Sciences Advisory Committee (FESAC), which she chaired. She said, "The three major toroidal fusion research facilities in the U.S. have diverse and complementary characteristics, which were developed on the basis of evolving U.S. innovation in fusion energy sciences. Taken together, these three facilities provide the U.S. with a very effective presence in the world program of fusion research. Their success has enabled the U.S. to have substantial impact on the direction of progress of the field, including leadership in understanding fundamental transport processes in magnetically confined plasmas, and continuing optimization of the magnetic configuration for confinement of high pressure plasmas."

Martin Peng, Oak Ridge National Laboratory, summarized the status of world spherical torus research. There are 22 concept explorations and proof of principle spherical torus experiments in the world, he reported. He said that world spherical torus research has a tradition of strong collaboration. He noted that there had been annual international workshops since 1994, formal bilateral collaborations since 1997, and IAEA technical meetings since 1999. Peng said that spherical torus experiments were contributing to the physics basis for ITER, the possible construction of a component test facility (CTF) and eventually to the design of a fusion demonstration power plant. He said that a "fast track CTF" could be operating in 2026, consistent with the fast track proposal made in the UK.

Glen Wurden, Los Alamos National Laboratory, summarized recent progress on magnetic confinement innovative concepts (ICC) program. He said the program was focused on finding "better" solutions to the magnetic confinement problem. He said its focus on small-scale experiments also provided the "premier method" for training the next generation of plasma researchers (over 100 students per year). He said that the U.S. ICC program was running at $20.8 M per year, distributed as follows: tokamak innovations and physics ($3.9 M); stellarators ($3.4 M); self-organized concepts, such as spheromaks and field-reversed concepts ($6 M); high pressure and high field concepts ($4 M); and others, such as levitated dipole ($3.5 M). Wurden said that ICC results were constrained by the breadth of fielded diagnostics and manpower available to each experiment. He said that all could use more theory and modeling support. He noted that none of the experiments approached the $5 M per year level recommended by the DOE Fusion Energy Sciences Advisory Committee.

Neil Morley, UCLA, presented a summary of some of the U.S. fusion nuclear technologies program and opportunities for ITER utilization, on behalf of himself and Mohamed Abdou. The technologies include blanket and first wall, plasma interactive and plasma-facing components, vacuum vessel and shield, tritium processing systems, instrumentation and control systems, remote maintenance components, and heat transfer and power conversion systems.

John Sheffield, Joint Institute for Energy and Environment, University of Tennessee, described the world energy situation. He said that projected world energy demand in gigatonnes of oil energy equivalent per year (Gtoe/year) were expected to grow from current usage of about 10 to about 20 in 2050 and to about 35 in 2100, though there were projections both lower and higher than this middle ground case. He said that currently coal and oil each provided a little over 3 Gtoe/y and natural gas provide a little over 2. Estimates of “recoverable reserves” were 643 Gtoe of coal, 148 of oil, and 146 of gas. He said that nuclear reactors were presently consuming about 0.6 Gtoe/y and that there was about 130 Gtoe of uranium reserves if used in conventional fission reactors. Thus the world energy problem is not one of supply in the near-term, he concluded.

“So what is the problem?” Sheffield asked. He noted that although there are enormous untapped energy resources, they are not uniformly distributed. He said that all energy use caused pollution, some more than others and that nuclear weapons proliferation is a concern for nuclear sources. Financing is an issue, he said. Thus, energy raises substantial geopolitical concerns, he said. In his opinion, fusion energy will be part of the solution. Increased efficiency in energy use is also part of the solution, he said.

DIII-D Research for Burning Plasmas in ITER and Beyond, E.J. Strait and T.S. Taylor, General Atomics, San Diego, California.

Introduction

The research program of the DIII-D tokamak at General Atomics is aimed at providing the scientific basis for optimization of the tokamak approach to fusion energy production [1]. The International Thermonuclear Experimental Reactor (ITER), for which a site was recently selected, will be a crucial next step in development of fusion energy. ITER will be the first “burning plasma” device, in which much of the heating of the fuel is provided by the fusion reaction itself. The DIII-D device is very similar in configuration to ITER but at about one-quarter the size (Fig. 1), making it a “scale model” in which scientific, engineering, and control issues for ITER can be addressed before the larger machine begins operation.

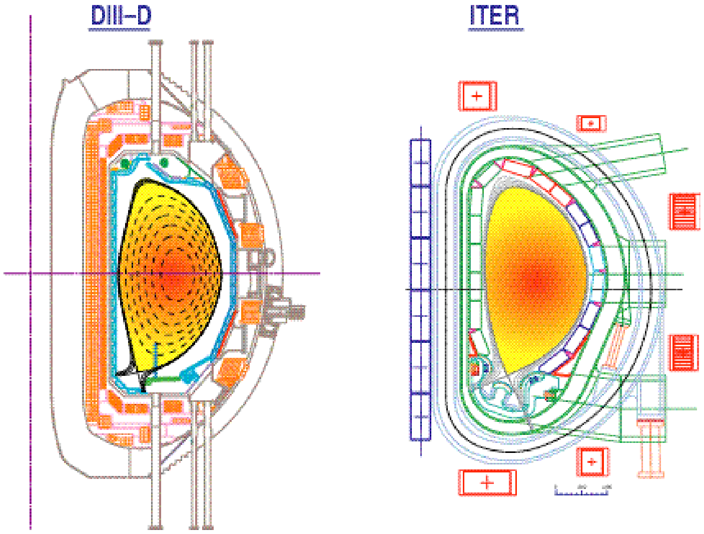

Figure 1. Cross-sections of DIII-D (major/minor radius = 1.7/0.6 m) and ITER (major/minor radius = 6.2/2.0 m), showing similar shapes and divertor geometries.

At the temperatures of greater than 100 million degrees that are required for controlled nuclear fusion, the fuel takes the form of an ionized gas, or plasma. A tokamak confines a toroidal ring of plasma by means of strong magnetic fields, generated by external coils and by electric current flowing in the plasma itself. The fusion power produced is roughly proportional to the square of the plasma pressure. Thus, a major challenge in the development of fusion energy has been to maximize the pressure of the confined plasma, while maintaining stable confinement. A second challenge is that of steady-state operation. Electric current in the plasma generates a crucial component of the tokamak's confining magnetic field. Normally, the plasma current is driven inductively, with the plasma acting as the secondary circuit of a transformer. However, this method limits the tokamak to pulsed operation, with a pulse duration determined by the maximum current in the primary winding. Steady-state operation requires noninductive means of sustaining the plasma current.

DIII-D research has focused on control of the plasma and its internal structure, as well as control of instabilities that can occur as the plasma pressure is raised, using a wide range of control tools. Recent results give confidence that the fusion performance goals can be reached in ITER's planned baseline operating scenario. In addition, DIII-D research points the way to advanced, steady-state operating scenarios, with the potential of improving ITER's performance beyond its initial mission. Upgrades now in progress will enhance DIII-D's capability to address these key issues.

Burning Plasma Scenarios

A. Baseline Scenario

DIII-D results show that the desired fusion performance can be reached and sustained in ITER. A measure of the plasma's ability to reach self-heated "burning plasma" conditions, in terms that can be easily extrapolated from one experiment to another, is given by the parameter $G = \beta_N H_{89}/q_{95}^2$. Here β_N is a measure of the plasma pressure relative to conventional stability limits; H_{89} represents the plasma's energy confinement, or thermal isolation from its surroundings, relative to an empirical scaling law; and $1/q_{95}$ represents the magnitude of the plasma current and its magnetic field, relative to the main toroidal magnetic field provided by external magnet coils. Recent results show that the quality of the energy confinement (H) does not degrade as the plasma pressure (β_N) is raised [2], with favorable implications for operation at high values of G in ITER. DIII-D experiments (Fig. 2) have exceeded the value of G required for ITER [3]; These discharges at $G \approx 0.6$ project to a fusion gain Q (fusion power/input power) of about 40, significantly larger than the ITER baseline specification of Q=10.

It is important that the desired operating condition is not just achieved transiently, but can be sustained for a long time. One of the longest relevant time scales for a fusion plasma is τ_R , the time required for the internal distribution of plasma current to relax to a stationary value (on the order of 1 s in DIII-D, but more than 100 s in ITER). The value of G required for ITER has been reached and exceeded in DIII-D for durations up to 10 τ_R (Fig. 2), indicating that true stationary operation was achieved. These "advanced inductive" discharges with $G \approx 0.6$ project to durations of >30 minutes in ITER.

B. Hybrid Scenario

A recently developed operating scenario [4] forms a hybrid between the planned baseline scenario for ITER and the steady-state modes of operation to be discussed in the next section. Here the presence of a benign, small-amplitude instability in the plasma core prevents the plasma current from fully relaxing to the normal, centrally peaked distribution. This actually improves the fusion performance so that the burning plasma regime can be reached with lower plasma current, allowing significantly longer pulses with inductively driven current. The increased neutron fluence made possible by this operating mode would be favorable for a nuclear materials testing program. Hybrid discharges in DIII-D (Fig. 2) have also achieved the ITER target range of G for durations longer than the current relaxation time τ_R . These hybrid discharges project to a fusion gain Q=9 for durations of more than one hour in ITER.

Among the key issues for reliable, stationary operation of ITER in the baseline and hybrid scenarios are edge-localized modes, fast ion-driven instabilities, neoclassical tearing modes, and disruptions. As described below, DIII-D research has successfully addressed these issues of plasma stability.

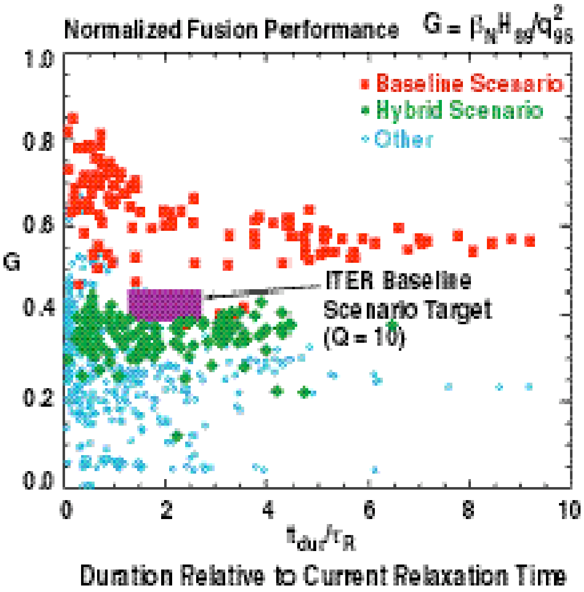

Figure 2. Fusion performance parameter G = $\beta_N H_{89}/q_{95}^2$ plotted versus duration normalized to the current relaxation time. The red squares are ITER baseline scenario discharges and the green diamonds are hybrid scenario discharges. The blue circles are other types.

C. Edge-Localized Mode (ELM) Control

All of the operating scenarios envisioned for ITER include an “edge transport barrier,” a localized region of reduced thermal conductivity at the edge of the plasma that can more than double the energy confinement (the H_{89} factor in G). However, the strong pressure gradient at the edge that is associated with this barrier can lead to instabilities known as ELMs. These ELMs cause the periodic ejection of bursts of hot plasma, with a peak intensity that in ITER could cause erosion of the material components facing the plasma. A good theoretical understanding of ELMs has been developed, based on intermediate-wavelength magnetohydrodynamic instabilities driven by the edge pressure gradient and the localized “bootstrap current” generated by that pressure gradient [5]. Numerical codes now accurately predict the onset of the instabilities as well as their observed [6] wavelength and edge-localized structure (Fig. 3).

Under certain rather restricted conditions, “quiescent” operating regimes have also been found where ELMs do not occur [7]. If these regimes can be extended to ITER-like conditions, the ELM issue may be avoided. Otherwise, a recent promising development is the control of ELMs by the use of external coils to introduce a small chaotic component into the magnetic field at the plasma edge [8]. This can increase the energy loss rate at the edge enough to keep the plasma pressure just below the threshold level required for triggering ELMs, distributing the heat flux more uniformly in time and space and thus reducing the peak heat flux to the wall (Fig. 4). This technique has successfully suppressed large-amplitude ELMs even in the high temperature, low collision rate conditions expected for ITER (Fig. 5).

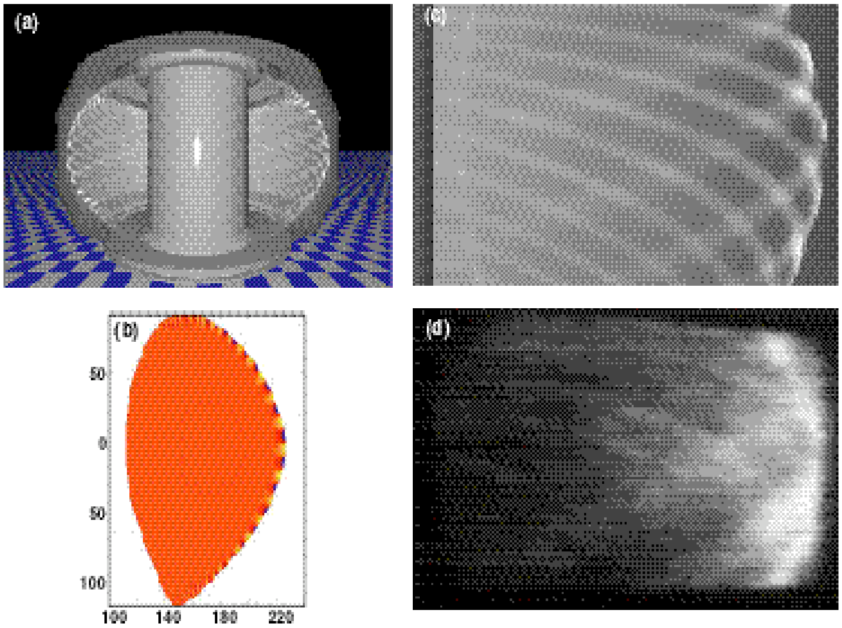

Figure 3. Predicted structure of the ELM in a DIII-D plasma in (a) 3-D and (b) cross-section views, showing the edge localization and moderately short wavelength. There is good agreement between (c) the predicted structure shown in an expanded view, and (d) the image from a camera with the same view of an experimental discharge.

D. Fast Ion-Driven Instabilities

In a tokamak, much of the heating of the plasma comes from energetic ions. In a burning plasma such as ITER, high-energy helium ions (alpha particles) produced by the fusion reaction are trapped by the magnetic field, allowing the plasma to become self-heating, while in DIII-D beams of energetic deuterium atoms are injected into the plasma, where they are ionized and captured by the magnetic field. These superthermal ions can excite high-frequency waves in the plasma, and the resonant interaction with the waves can lead to loss of the fast ions before they transfer their heat to the plasma. Theory predicts the possibility of a “sea” of short-wavelength instabilities driven by the alpha particles in a burning plasma. Recent measurements using new diagnostics that probe the center of the plasma with interferometry and scattering of electromagnetic waves have revealed a similar spectrum of short-wavelength instabilities [9]. The frequency (Fig. 6) and mode structure agree well with theoretical predictions; future research will investigate the conditions under which these instabilities appear, the interactions between multiple modes, and their impact on confinement of the fast ions.

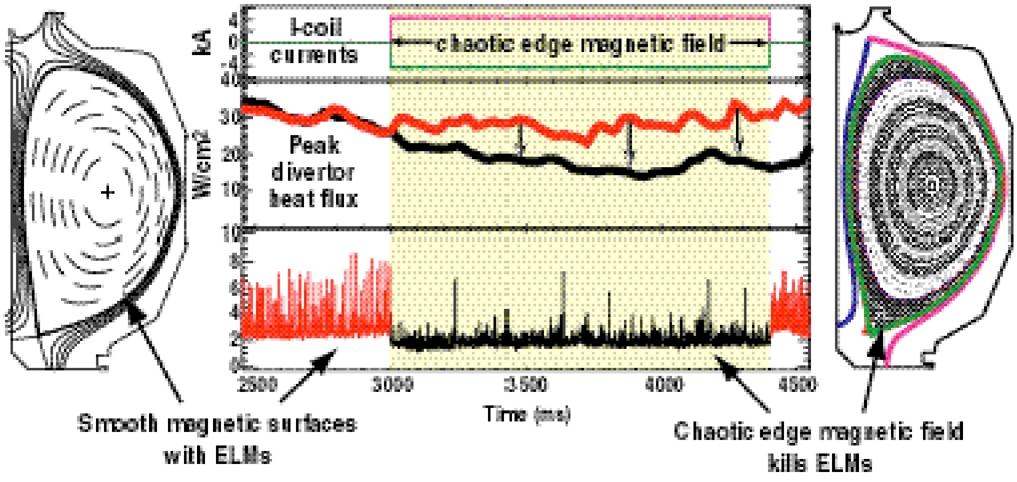

Figure 4. Calculated magnetic contours show smooth magnetic surfaces in normal operation (left), and regions of chaotic magnetic field when the ELM control coils are energized (right). In the middle panel, the time evolution of two such discharges shows rapidly repeated ELM instabilities in normal operation (red), but very few ELMs and reduced peak heat flux to the divertor at the bottom of the tokamak when the control coils are energized.

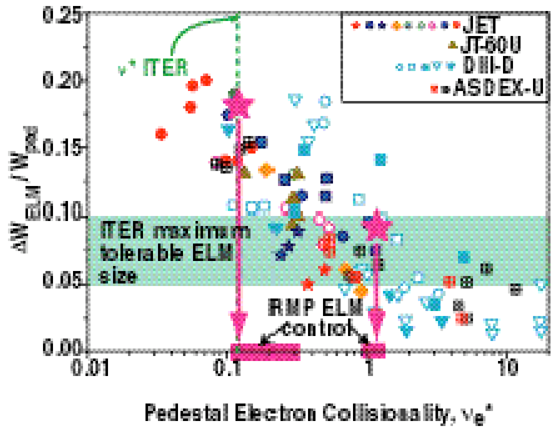

Figure 5. Fractional ELM energy loss plotted versus the normalized electron collision rate in the edge plasma. Resonant magnetic perturbations reduce the energy loss to near-zero levels (stars) in both high collisionality and ITER-relevant low-collisionality discharges in DIII-D.

E. Neoclassical Tearing Mode Stabilization

As the plasma pressure increases (the β_N factor in G), it can lead to tearing of the magnetic surfaces that confine the plasma, at certain specific weak points in the magnetic field structure. The resulting “magnetic islands” create a localized short-circuit for heat conduction and increase the rate of energy loss. Once an island is formed, its growth is enhanced by the localized loss of the “bootstrap current” that is normally driven by the pressure gradient. DIII-D results, leveraged by joint experiments with other tokamaks worldwide, indicate that ITER may be unstable to these tearing modes, but that they can be stabilized by using a high-power microwave beam to drive a localized current in the plasma, replacing the missing bootstrap current [10]. The placement of the current drive beam must be extremely precise, within about 1 cm of the center of the island (Fig. 7), in order to be effective. DIII-D experiments have demonstrated the ability of control systems to detect the presence of a magnetic island, place the current drive at the center of the island, and maintain the current drive at the known weak spot even after the island has disappeared.

F. Disruption Mitigation

If the control system should fail, a neoclassical tearing mode or other large-scale instability can cause a plasma disruption, in which the entire thermal and magnetic energy of the plasma is suddenly lost. This can lead to possible erosion or damage of the plasma-facing components. Experiments pioneered at DIII-D have developed a “disruption mitigation” scheme to shut down the plasma safely and quickly before an impending disruption. Injection of a high-pressure jet of a noble gas such as neon or argon leads to strong electromagnetic radiation by the impurity as it encounters the plasma, removing the plasma energy quickly but more slowly and more uniformly than in a disruption. Such gas jet-induced shutdowns remove nearly 100% of the plasma energy as electromagnetic radiation [11] (Fig. 8), while in an unmitigated disruption 50% or more of the energy may be transferred through localized contact of the hot plasma with the wall. The heat load on the floor of the DIII-D vacuum vessel during a gas jet shutdown is measured to be a factor of 3 to 100 times less than in a normal, instability-driven disruption. Electric currents flowing from the plasma to the wall, and the generation of high-energy “runaway” electrons, both of which can also cause damage to plasma-facing components in a disruption, are greatly reduced or eliminated in a gas jet shutdown.

Steady-State Scenarios

A. Noninductive Operation

In true steady-state operation, the plasma current must be sustained by noninductive means. Most important is the self-generated “bootstrap current,” which increases with plasma pressure. A large fraction of bootstrap current is desirable to minimize the recirculating power required for other supplemental means of current drive such as energetic neutral particle beams or electromagnetic waves. DIII-D experiments (Fig. 9) have reached the value of G required for ITER with bootstrap current fractions up to 60%, sufficient for ITER steady-state scenarios [3]. The measured radial profile of current density for such a discharge (Fig. 10), in which the high fusion parameter was sustained for 0.8 second, shows that the remaining inductive current is essentially zero across the entire profile, demonstrating fully noninductive operation. In addition, recent results [12] also indicate that values of G significantly larger than the value required for the ITER steady-state scenario can be reached with bootstrap current fractions up to 60% (Fig. 9). If future experiments show that such plasmas can be sustained for long durations, this result would be favorable for development of a compact steady-state fusion plasma.

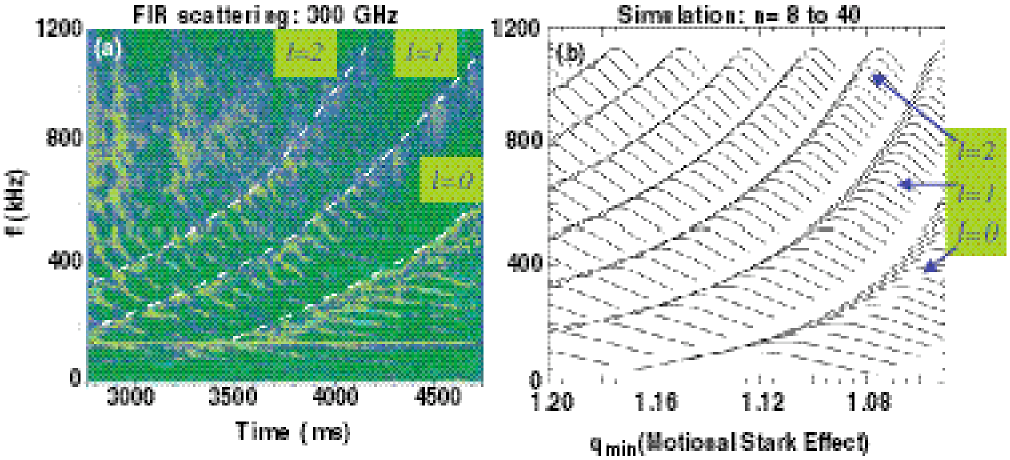

Figure 6. (a) Spectrogram (amplitude contours versus frequency and time) of density fluctuations in the central plasma, measured by far infrared scattering, shows bands associated with different wavelength modes as the plasma evolves. (b) Theoretical calculations reproduce both the bands and the finer structure within each band.

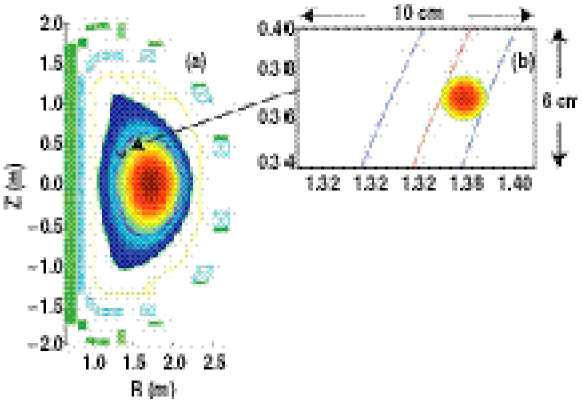

Figure 7. (a) Cross-section of DIII-D showing a plasma with a magnetic island (black curves). (b) Expanded view showing the microwave beam (about 2.5 cm in diameter) aligned to within about 1 cm of the center of the magnetic island. These computer reconstructions are derived from experimentally measured data.

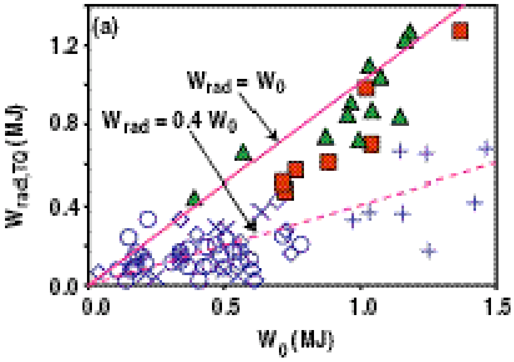

Figure 8. Radiated energy during a rapid thermal quench plotted versus plasma energy before the quench, for gas jet-initiated shutdowns (filled squares and triangles) and several types of disruptions (open symbols and crosses). The solid diagonal line indicates the limit where 100% of the energy is radiated away.

B. Resistive Wall Mode Control

Since the bootstrap current is driven by the pressure gradient, which is zero at the center of the plasma, the current density in noninductive plasmas is typically largest at mid-radius (Fig. 10) in contrast to the centrally-peaked profile of the baseline and hybrid scenarios. Plasmas with a broad or hollow current density profile tend to have a lower pressure limit to fast-growing “kink” instabilities, unless there is a nearby conducting wall. Eddy currents induced in a perfectly conducting wall would stabilize the kink mode up to much higher pressure, but a real, resistive wall simply slows down the growth of the kink. DIII-D experiments have confirmed theoretical predictions that complete stabilization can be achieved through rapid rotation of the plasma with respect to the wall, or direct feedback control of the unstable kink. Using sets of control coils both outside and inside the vacuum vessel wall (Fig. 11), DIII-D has demonstrated feedback control of the resistive wall mode in cases where rotation alone was not sufficient [13] (Fig. 12). Future experiments will make use of high bandwidth amplifiers to achieve the full potential of the faster-acting internal coils. The results of these experiments will help to decide whether internal control coils should be added to the ITER design.

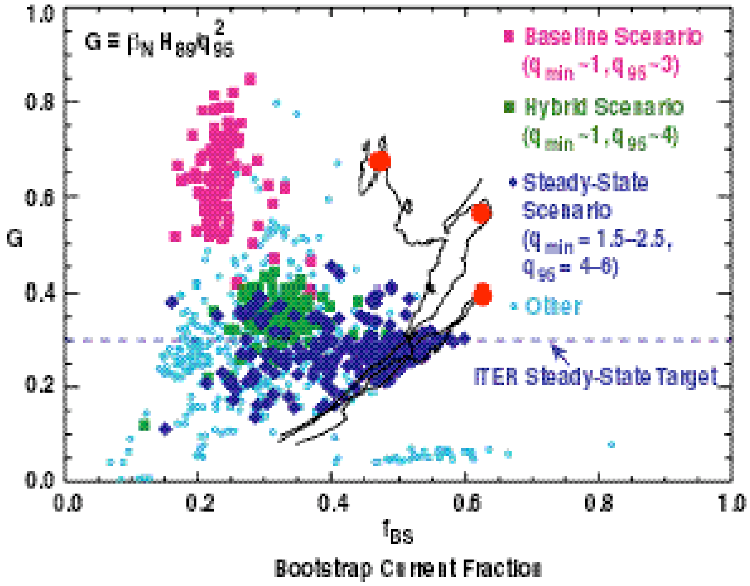

Figure 9. Fusion performance parameter $G \equiv \beta_N H_{89}/q_{95}^2$ plotted versus f_{bs}, the fraction of the total plasma current provided by self-generated bootstrap current. The red squares are ITER baseline scenario discharges, the green squares are hybrid scenario discharges, and the solid blue diamonds are steady-state scenario discharges. The three red circles are representative of recent experiments in which an internal thermal barrier improved the fusion parameter G while maintaining a large bootstrap current fraction.

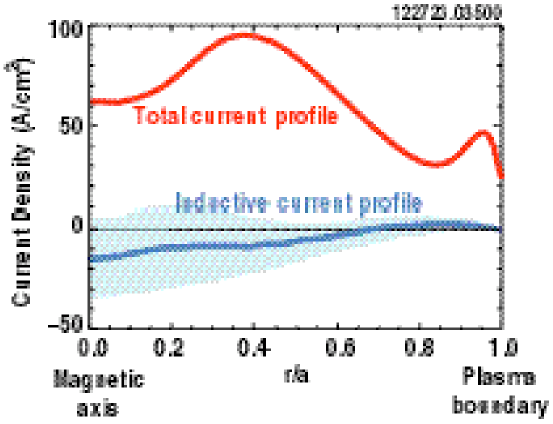

Figure 10. Measured radial profiles of total current and inductive current density show an achievement of fully noninductive DIII-D operation with normalized fusion performance value (G = $\beta_N H_{89}/q_{95}^2$) of 0.3 and bootstrap current fraction of 60%, consistent with requirements for ITER steady-state scenario.

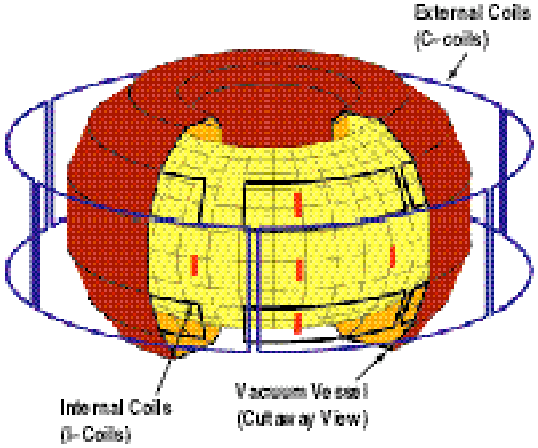

Figure 11. Cutaway view shows internal control coils used for resistive wall mode control (and also for the ELM control experiments of Figs. 4-5), as well as the older external control coils.

Future Work

Several major upgrades to the DIII-D facility are now in progress. Improvements to the pumping of gas from the “divertor” region at the edge of the plasma will give greater control of the plasma density, crucial for bootstrap current and other noninductive current drive. Additional gyrotrons will extend the microwave power and pulse length available for current drive and tearing mode control. The reorientation of a neutral beam line to apply torque to the plasma in the opposite direction from the others will give greater control over plasma rotation, a key influence on both energy confinement and stability. The reoriented beam line will also lead to a more uniform distribution of fast ion velocities, more closely resembling conditions in a burning plasma heated by alpha particles. These upgrades will improve the capability to understand the physics and improve the performance of high-pressure fusion plasmas.

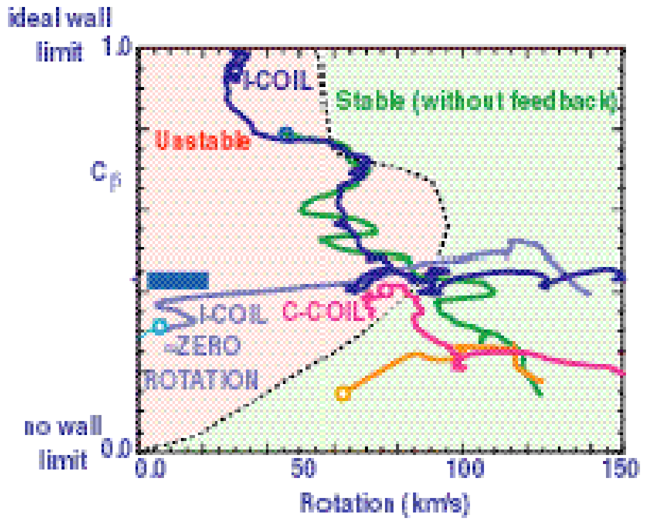

Figure 12. Trajectories of representative DIII-D discharges plotted against the stability parameter C_{β}, and the plasma rotation velocity. As plasma pressure increases, C_{β} varies from 0 (no wall needed for stability) to 1 (theoretical maximum pressure for wall stabilization). In the region to the right of the dashed line, the plasma rotation is predicted to be large enough to provide stability. Feedback control with the internal coils (I-coils) allows operation inside the low-rotation regime on the left, which would otherwise be unstable.

Summary

DIII-D experiments give confidence that the required fusion performance can be achieved and exceeded in ITER, which will make possible the first demonstration of a sustained, self-heated fusion plasma. DIII-D results also show the existence of improved regimes of operation, including the hybrid scenario with longer pulse duration at lower plasma current, and steady-state scenarios making use of noninductive plasma current. The feasibility of suppressing several key instabilities has been demonstrated, as well as a method to deal safely with the consequences if an instability is not avoided. Although much work remains in order to refine the control techniques and make the extrapolation to ITER more quantitative, these results are encouraging for the success of ITER in both baseline and advanced operational scenarios.

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ITER Progress, Ned Sauthoff, U.S. ITER Project Office, DOE Princeton Plasma Physics Laboratory, Princeton, NJ.

The major headline for the ITER project is “we have a site.” Since the December 2003 stalemate on site selection, the European Union and Japan engaged in a vigorous and determined negotiation, each party demonstrating its site’s capabilities and its commitment to hosting ITER. From the project participant’s perspective, it was great to see such strong recognition of the value of ITER, but it was frustrating to see the development of arrangements stalled. Nevertheless, on June 28 the European Union and Japan reached an agreement in which ITER will be sited in Cadarache, France, and Japan will play a strong role in the ITER project and in the broader fusion program.

With the site decided, the negotiations and associated discussions resumed, with an aim to resolve the barriers to a formal international agreement to enable the construction, operation, and decommissioning of ITER. During a September meeting in Cadarache and an October meeting in Chengdu, China, the Negotiators’ Standing Sub-Group (NSSG) addressed challenging organizational arrangements in areas ranging from management and staffing to procurement systems and intellectual property; the N-level meetings heard reports of the progress and provided direction to the NSSG. The target is the completion of the drafting of the Agreement and annexes and common understanding by early July 2006, followed by initialing, signing, and coming into force.

Technical work continues, completing R&D and design for the ITER systems. The International Team leads the joint preparatory activities, with parties performing tasks requested by the International Team. During construction, the formal work control vehicles will be a set of Procurement Agreements between the ITER organization and the parties specifying not only technical requirements and design, but also the QA, reporting, and other requirements as well as the “credit” or “value” to be earned by each performing party by delivering in-kind contributions. During the current ITER Transitional Arrangements, the R&D and design is advancing to enable prompt issuance of procurement agreements.

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