American Nuclear Society
Fusion Energy Division
December 2002 Newsletter

Letter from Chair: Wayne Meier, Lawrence Livermore National Laboratory, Livermore, CA.

The past six months have been a very active period for the fusion community, and it is clear that the nuclear aspects of fusion will be receiving more attention in coming years. In July, several hundred fusion scientists and engineers met in Snowmass, Colorado to discuss and compare options for a burning plasma experiment for MFE and next step experiments for IFE. Official top-level findings have been reported widely and can be found on the summer study web site: http://web.gat.com/snowmass/. (Also see the article by Ned Sauthoff in this newsletter). The Snowmass study also laid out the facilities in addition to the burning plasma experiment, whichwill be needed to develop fusion power. Of key interest to the members of the FED is the International Fusion Materials Irradiation Facility (IFMIF), an accelerator based 14 MeV facility for radiation damage testing, and a Component Test Facility to do nuclear component testing and development. As the fusion program moves toward demonstration of fusion power, the importance of nuclear science and technology will surely increase in importance.

After Snowmass, the FESAC burning plasma subpanel carefully considered the findings of the summer study and made recommendations to proceed with a burning plasma experiment (see article by Stewart Prager in this newsletter). In essence, there is broad consensus by the MFE community that a burning plasma experiment should be built as soon as possible. A key recommendation was that the U.S. should seek to rejoin ITER (in case anyone forgot, T is for Thermonuclear), while continuing work on the FIRE option (http://fire.pppl.gov/). In September, Dr. Ray Orbach, Director of the Office of Science, asked FESAC to address the question of whether a 35-year timeline to electric power demonstration (by MFE and/or IFE) is a credible goal. Preliminary findings will be reported by December 2002, and a final report is due in March or April 2003. Development of low activation materials, breeding blanket qualification, tritium supply, and other nuclear-related issues will be important considerations in this planning.

As far as division activities, we are currently focused on the 15th Topical Meeting on Technology of Fusion Energy (TOFE) that will be completed by the time this newsletter hits the press. Currently, we have a program with ~150 papers covering the usual range of topics. My thanks to the organizers and program chairs for their hard work. Your comments on our biennial TOFE would be useful input to the FED Executive Committee.

Current membership stands at 673 with 20 new members added since the June meeting. If there are issues or activities you would like the FED leadership to consider, please contact me @ meier5@llnl.gov or any other member of the FED executive committee.

FED Slate of Candidates: James Stubbins, University of Illinois at Urbana-Champaign, Urbana, Illinois

The slate of candidates for the upcoming Fusion Energy Division (FED) of the American Nuclear Society is now complete. All FED members will receive a ballot early next year. It is important that each member vote in these elections, so please take the time to mark and return your ballot. The outcome of the elections will be announced before the June 2003 ANS Annual Meeting in San Diego. The FED is always looking for members who would like to become more active in the operations of the Division. Please contact Wayne Meier, current FED Chair, if you are interested.

The slate of candidates is given below. The current Vice Chair/Chair-Elect, René Raffray of University of California-San Diego, will become FED Chair at the end of the FED Executive Committee meeting in June 2003. We have three spots to fill on the Executive Committee in addition to the spots for Vice Chair/Chair-Elect and Secretary/Treasurer. The candidates for the 2003 FED elections are:

Vice Chair:	Jake Blanchard (UW-Madison)
Secretary/Treasurer:	Jeff Latkowski (LLNL)
Executive Committee: (listed in alphabetical order; three spots available)	Said I. Abdel-Khalik (Georgia Tech) Henry Chu (GA) Charles (Chip) Martin (DNFSB) Ken Schultz (GA) Phil Sharp (INEEL) Dennis Youchison (SNL)

15th ANS Topical Meeting on Technology of Fusion Energy: Roger Stoller, Oak Ridge National Laboratory, Oak Ridge, Tennessee

The 15th ANS Topical Meeting on the Technology of Fusion Energy (TOFE) was held as an embedded topical meeting during the 2002 Winter ANS Meeting in Washington, DC from November 18-21. The General Chairman of the meeting was Dr. Roger E. Stoller from the Oak Ridge National Laboratory (ORNL), with Professor Akira Kohyama from Kyoto University and Dr. John D. Sethian of the Naval Research Laboratory (NRL) serving as Vice-General Chairmen. Dr. Lance L. Snead from ORNL was the Chairman of the Technical Program Committee, assisted by Dr. Masahiro Seki from JAERI and Dr. Dai-Kai Sze from UCSD as Vice-Chairmen. Financial support for the meeting was provided by the Atomic Energy Society of Japan, INEEL, General Atomics, LLNL, NRL, ORNL (UT-Batelle), PNNL, SNL, Kyoto University, and the U.S. DOE. The organizers as well as the other participants would like to express their thanks to these individuals in particular for making it possible to hold the enjoyable symposium banquet at Union Station, and for underwriting the student poster awards.

Because this was an embedded topical, there was no separate record of TOFE registrations distinct from the ANS meeting. This makes it difficult to determine the exact attendance, but 45 oral and 101 poster presentations were scheduled in nine oral and two poster session. There were a few no-shows, but about 135 presentations were made. The oral sessions included one that was scheduled to present key data and results from the bilateral collaboration on fusion reactor materials between the U.S. DOE and Japanese universities (formerly MONBUSHO): the JUPITER program. Additional data from the JUPITER program was presented in several posters. The excellent attendance and participation in TOFE can in part be attributed to the U.S.-Japan collaborations and the efforts to attract broader representation from the materials research community. There was also a substantial contribution from researchers involved in inertial confinement fusion.

Highlights of the meeting included a keynote address by Dr. Patrick Looney, Assistant Director for Physical Sciences and Engineering from the U.S. President's Office of Science and Technology Policy. He represented the President's Science Advisor, Dr. Jack Marburger, who was prevented from attending by a last-minute schedule change. Patrick provided a summary of the current administration's views on fusion research and development. In particular, he discussed those issues related to the upcoming decision on whether or not the U.S. would rejoin the ITER project.

Dr. Y. Shimomura from the ITER joint working site in Naka, Japan made an excellent presentation on the current status and schedule of ITER work. A presentation entitled "ITER at Cardarache: An Example of Licensing a Fusion Facility," by Dr. G. Marbach of the French CEA was presented by Dr. N. Taylor from the UKAEA. As the title implies, this talk summarized the French approach to licensing ITER and provided a good overview of the issues involved for the ultimate host country. Dr. A. Kohyama discussed the perceived importance of fusion making a relatively early (< 40 years) contribution to electrical generation in order to maintain public support and interest, and referred to public information activities being carried out in Japan. The desire for an early contribution by fusion was the driving force for novel work at the University of Wisconsin-Madison. The use of D-^{3}He fusion as a proton source for preparing medical (positron-emitting) isotopes was described in an oral presentation by Dr. G. Kulcinski, and in two posters. Time and space prevents more discussion of the many other authors and presenters who are worthy of mention. Interested parties are encouraged to obtain the proceedings of the symposium. After peer review, complete papers will be published in a special edition of Fusion Science and Technology, which can be pre-ordered from ANS.

The meeting organizers and the editor of Fusion Science and Technology recognized several students for their research presented in the poster sessions. There was a tie for the Best Poster Award. The following two students received a $500 cash award from the TOFE, and a page-charge waiver from the Fusion Science and Technology journal if the paper is submitted within one year: S. G. Durbin, Georgia Tech, "Turbulent Liquid Sheets for Protecting IFE Reactor First Walls," and B. B. Cipiti, University of Wisconsin-Madison, "Cathode Embedded D-He3 Fusion Reactions in Inertial Electrostatic Confinement."

The following nine students received Honorable Mention and were awarded a Cross pen set. In addition, the first two authors also received a page-charge waiver from the Fusion Science and Technology journal for a paper submitted within one year:

R. Sugano, Kyoto University
J. W. Weidner, University of Wisconsin-Madison
A. Abou-Sena, University of California, Los Angeles
C. Dubonnel, University of California, Berkeley
S. Kondo, Kyoto University
X. Y. Luo, University of California, Los Angeles
P. Meekunnasombat, University of Wisconsin
M. Nieto, University of Illinois
K. H. Park, Kyoto University

Finally, the organizers would like to thank Renetta Godfrey and Kimberly (aka Missy) Neal for all their administrative support of the symposium, both onsite and during the planning of the meeting. The contribution of the student volunteers who helped with session logistics is also appreciated.

ANS-FED Awards Presented at 15th TOFE: Gerald Kulcinski, Fusion Technology Institute, University of Wisconsin-Madison

The Honors and Awards Committee of the Fusion Energy Division (FED) of the American Nuclear Society (ANS) is pleased to announce the recipients of the FED Awards for 2002. The *Outstanding Achievement Award* was presented to Professor Farrokh Najmabadi at the University of California, San Diego, California. The Outstanding *Technical Accomplishment Award* was presented to Dr. Gianfranco Federici at the ITER Garching Joint Work Site in Germany.

The *Outstanding Achievement Award* is the most prestigious award of the FED and is presented to an ANS member in recognition of exemplary individual achievement requiring professional excellence and leadership of high caliber in the Fusion Science and Engineering area. The award to Professor Farrokh Najmabadi was made in recognition of his leadership of the ARIES Advanced Fusion Concepts Design Team.

The *Outstanding Technical Accomplishment Award* is presented in recognition of an exemplary technical accomplishment requiring professional excellence of a high caliber in the area of Fusion Science and Engineering. The award to Dr. Federici was made in recognition of his outstanding accomplishments in the area of theoretical and computational research on plasma-wall materials interactions that led to the design of the ITER divertor.

News from Fusion Science and Technology Journal: Nermin Uckan, Editor

It was a great 2002 year for the Fusion Science and Technology (FS&T) journal, and 2003 year will be even better. A total of 140 manuscripts (plus 210 conference papers) were received during the period of October 1, 2001-September 30, 2002 as compared to the 55 manuscripts from the previous 12 months. FS&T published an excellent selection of contributed papers and several special issues in 2002. Two of these special issues were the July 2002 issue on East Asia Fusion Research Activities with papers from Japan, China, and Korea and the September/November 2002 double issue on JT-60 with set of papers summarizing the history and results from one of the world's major tokamak fusion experiments. Other 2002 special issues included the 5th Carolus Magnus Summer Euro-School on Plasma and Fusion Energy Physics (Transactions, Jan 2002, 50 lectures), selected papers from 14th ICF Target Fabrication Meeting (May 2002) and 6th International Conference on Tritium Science and Technology (Proceedings, May 2002, 160 papers).

The following special issues will appear in 2003: selected papers from 2nd IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers, Proceedings of 15th Topical Meeting on Technology of Fusion Energy, NCSX, ASDEX-U, ARIES-IFE papers, and Open Systems 2002 Conference Proceedings (Transactions).

The following special issues are planned for 2004: EU Fusion Research Activities, DIII-D, NIF, FTU, JET, selected papers from 15th ICF Target Fabrication Meeting, and 6th Carolus Magnus Summer Euro-School on Plasma and Fusion Energy Physics (Transactions).

Finally, a long-waited development - electronic access to FS&T. As of June 2002, ANS member subscribers have an online access to current journal issues. Libraries and non-member subscribers will enjoy the same access starting in 2003. In 2003, member and non-member subscribers will be able to access the back issues of the journal from 1998-current. ANS indicates that additional journal years (1997-1992) will be added over the next 18 months.

Looking forward to your continued feedback and active participation in the journal as authors, as reviewers, and as readers.

The 2002 Snowmass Fusion Summer Study: Ned Sauthoff, Snowmass co-chair DOE Princeton Plasma Physics Laboratory, Princeton, NJ

The 2002 Fusion Summer Study (July 8-19, 2002) carried out a critical technical assessment of major next steps in the fusion energy sciences program in both Magnetic Fusion Energy (MFE) and Inertial Fusion Energy (IFE). The conclusions of this study were based on eight months of analysis and two weeks of intense discussion by over 250 US and 30 non-US fusion physicists and engineers.

The following summary is extracted or paraphrased from the Executive Summary posted at http://web.gat.com/snowmass/exec-summary.pdf.

Magnetic Fusion Energy

In the MFE program, the world is now at a major decision point which is to go forward with exploration of a burning plasma, opening up the possibility of discoveries in a plasma dominated by self-heating from fusion reactions and filling this crucial and now missing element in the MFE program.

The Snowmass participants reaffirmed that fusion energy shows great promise to contribute to securing the energy future of humanity. The science that underlies this quest is at the frontier of the physics of complex systems and provides the basis for understanding the behavior of high-temperature plasmas.

The participants of the 2002 Fusion Summer Study developed major conclusions regarding the opportunities for exploration and discovery in the field of magnetically confined burning plasmas. Below are summarized the principal conclusions:

A. The study of burning plasmas, in which self-heating from fusion reactions dominates plasma behavior, is at the frontier of magnetic fusion energy science. The next major step in magnetic fusion research should be a burning plasma program, which is essential to the science focus and energy goal of fusion research.

B. The three experiments proposed to achieve burning plasma operation range from compact, high field, copper magnet devices to a reactor-scale superconducting-magnet device. These approaches address a spectrum of both physics and fusion technology, and vary widely in overall mission, schedule, and cost.

C. IGNITOR, FIRE, and ITER would enable studies of the physics of burning plasma, advance fusion technology, and contribute to the development of fusion energy. The contributions of the three approaches would differ considerably.
   1- IGNITOR offers an opportunity for the early study of burning plasmas aiming at ignition for about one current redistribution period.
   2- FIRE offers an opportunity for the study of burning plasma physics in conventional and advanced tokamak configurations under quasi-stationary conditions (several current redistribution time periods) and would contribute to plasma technology.
   3- ITER offers an opportunity for the study of burning plasma physics in conventional and advanced tokamak configurations for long durations (many current redistribution time periods) with steady state as the ultimate goal, and would contribute to the development and integration of plasma and fusion technology.

D. There are no outstanding engineering-feasibility issues to prevent the successful design and fabrication of any of the three options. However, the three approaches are at different levels of design and R&D.
   There is confidence that ITER and FIRE will achieve burning plasma performance in H-mode based on an extensive experimental database. IGNITOR

would achieve similar performance if it either obtains Hñmode confinement or an enhancement over the standard tokamak Lñmode. However, the likelihood of achieving these enhancements remains an unresolved issue between the assessors and the IGNITOR team.

E. The development path to realize fusion power as a practical energy source includes four major scientific elements:
   1- Fundamental understanding of the underlying science and technology, and optimization of magnetic configurations
   2- Plasma physics research in a burning plasma experiment
   3- High performance, steady-state operation
   4- Development of low-activation materials and fusion technologies.

F. A strong base science and technology program is needed to advance essential fusion science and technology and to participate effectively in, and to benefit from, the burning plasma effort. In particular, the development path for innovative confinement configurations would benefit from research on a tokamak-based burning plasma experiment.

Inertial Fusion Energy

In the IFE program, the decision to construct a burning plasma experiment has already been made. The National Nuclear Security Administration (NNSA) is currently building the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory. The NIF, and other facilities worldwide are expected to provide the needed data on inertial fusion burning plasmas. The IFE questions examined at the Fusion Summer Study revolve about the pace of development of the additional sciences and technologies needed for power production.

As noted earlier, the programmatic issues facing inertial and magnetic fusion are quite different. The burning plasma experiments for inertial fusion, namely the NIF in the United States and the Laser MegaJoule (LMJ) device in France are already under construction. Currently plasma ignition on NIF is expected around FY2010 depending on future funding decisions about the pace of funding for diagnostics and cryogenic capabilities. Existing facilities in the United States (e.g., Omega, Z, and Nike) and other facilities worldwide are providing information leading to burning plasma experiments at the NIF and at the LMJ. The domestic facilities have been built, or are being built, under the auspices of the NNSA, primarily for defense purposes.

Although the NIF will provide the needed data on burning IFE plasmas, it does not have the capability to operate at high repetition rates or to manage the fusion power that high repetition rates produce. Moreover, the NIF has neither the efficiency nor the durability needed for commercial power production. Substantial scientific and technical issues must be studied and resolved in parallel to enable high repetition rates, good efficiency, and adequate lifetime. The modularity of IFE drivers and the separability of power plant components make it possible to study these issues and issues associated with supporting subsystems in scaled facilities. The IFE community refers to these facilities as ìintegrated research facilitiesî or IREs. They are the next major steps in inertial fusion. They are expected to be substantially less expensive than either the magnetic burning plasma experiment or the NIF. While the NIF can demonstrate the creation of fusion energy in single shots, the IREs will provide the foundation of science and technology needed for the subsequent demonstration of net fusion power, and the delivery of net fusion electricity to the grid.

Assessment of the plans and status at this workshop led to three important conclusions:

1- The various driver programs (lasers, heavy ion accelerators, and Z-pinches) are advancing at different rates because of funding differences and their relative maturity. The most advanced programs are unlikely to be in position to propose an integrated research experiment for several years.
2- The inertial fusion community (both proponents and critics of the individual approaches) believes that the Phase I research plans are sound and that they address the correct technical issues.
3- Phase I funding rates are the programmatic issue. Resolution of this issue will require coordination of the inertial and magnetic programs.

Despite the significant near-term issues relating to funding, there has been important progress since the last Snowmass Summer Study. The Snowmass participants concluded with a summary of this progress and a summary of some of the important remaining issues:

1- Laser systems have made impressive progress in efficiency, pulse rate, and lifetime. Efficiency and lifetime remain important issues for KrF lasers. Cost of major components and beam quality are important issues for solid state lasers.
2- The heavy ion fusion program has made excellent progress in basic beam science. Several new science experiments have recently begun operations. Fielding integrated experiments (for example the IBX) at moderate beam energy and current and focusing intense beams in the chamber environment remain the important technical issues.
3- There has been impressive progress in z-pinch targets and good progress in conceptual power plant designs. Producing economical recyclable transmission lines at low cost remains the most important issue.
4- Recent calculations indicate that fluid instabilities in the targets may be controlled by appropriate choice of pulse shape. Both directly driven and indirectly driven targets appear to be feasible.
5- Chamber technology and target fabrication and injection are being placed on a sound scientific basis. For example, experiments on dry-wall damage limits are underway. Scaled hydraulics experiments have identified nozzle designs that can create all liquid jet configurations required for thick liquid chambers, and a target injection experiment is under construction. For heavy-ion fusion there is now a chamber design where the final focus magnets and chamber structures have predicted lifetimes exceeding 30 years.
6- There is broad international interest in fast ignition. If fast ignition is successful, it will produce higher energy gains than conventional targets. So far the target experiments have been encouraging, particularly the recent Japanese results. Fast ignition power production is at a rudimentary level for all drivers. An integrated research plan is required.

The FESAC Recommendations for a Strategy for Burning Plasmas:

Stewart Prager, The University of Wisconsin, Madison, WI

As described above, one aim of the Snowmass Fusion Summer Study was to perform a uniform technical assessment of the three options for a magnetically confined burning plasma experiment (IGNITOR, FIRE, and ITER). The study did not aim to evaluate the best path forward to a burning plasma experiment. For this task, the Fusion Energy Sciences Advisory Committee was charged by the Department of Energy to "recommend a strategy for burning plasma experiments." A FESAC Panel was convened for this purpose. The Panel consisted of 47 members of the fusion energy sciences community. In large part, the recommendations of the panel are based on the extensive scientific assessment of the three options by the Snowmass Study. The Panel met August 6 ñ 8, and its report entitled "A Burning Plasma Program Strategy to Advance Fusion Energy" was accepted by FESAC at its meeting on September 11, 2002.

The Panel has produced a strategy to enable the U.S. to proceed with this crucial next step in fusion energy science. The strategy was constructed with awareness that the burning plasma program is only one major component in a comprehensive development plan for fusion energy. A strong core science and technology program focused on fundamental understanding, confinement configuration optimization, and the development of plasma and fusion technologies is essential to the realization of fusion energy. The core program will also be essential to the successful guidance and exploitation of the burning plasma program, providing the necessary knowledge base and scientific work force.

The Panel recommendations are guided by the design options and considerations presented above and by two primary findings:

1- ITER and FIRE are each attractive options for the study of burning plasma science. Each could serve as the primary burning plasma facility, although they lead to different fusion energy development paths.

2- Because additional steps are needed for the approval of construction of ITER or FIRE, a strategy that allows for the possibility of either burning plasma option is appropriate.

With this background, the Panel puts forth the following major strategy recommendations:

Since ITER is at an advanced stage, has the most comprehensive science and technology program, and is supported internationally, we should now seek to join the ITER negotiations with the aim of becoming a partner in the undertaking, with technical, programmatic and timing considerations as follows:

- The desired role is that the U.S. participates as a partner in the full range of activities, including full participation in the governance of the project and the program. We anticipate that this level of effort will likely require additional funding of approximately $100M/yr.

- The minimum acceptable role for the U.S. is at a level of effort that would allow the U.S. to propose and implement science experiments, to make contributions to the activities during the construction phase of the device, and to have access to experimental and engineering data equal to that of all partners.

- The U.S. performs a cost analysis of U.S. participation and reviews the overall cost of the ITER project.

- The Department of Energy concludes, by July, 2004, that ITER is highly likely to proceed to construction and terms have been negotiated that are acceptable to the U.S. Demonstrations of likelihood could include submission to the partner governments of an agreement on cost-sharing, selection of the site, and a plan for the ITER Legal Entity.

Since FIRE is at an advanced pre-conceptual design stage, and offers a broad scientific program, we should proceed to a physics validation review, as planned, and be prepared to initiate a conceptual design by the time of the U.S. decision on participation in ITER construction.

If ITER negotiations succeed and the project moves forward under terms acceptable to the U.S., then the U.S. should participate. The FIRE activity should then be terminated.

If ITER does not move forward, then FIRE should be advanced as a U.S.-based burning plasma experiment with strong encouragement of international participation.

If IGNITOR is constructed in Italy, then the U.S. should collaborate in the program by research participation and contributions of related equipment, as it does with other major international facilities.

A strong core science and technology program is essential to the success of the burning plasma effort, as well as the overall development of fusion energy. Hence, this core program should be increased in parallel with the burning plasma initiative.

A burning plasma science program should be initiated by the OFES with additional funding in FY 04 sufficient to support this strategy.

The full report is available at
www.ofes.fusion.doe.gov/More_HTML/FESAC_Charges_Reports.html

ONGOING FUSION RESEARCH:

Progress in Inertial-Electrostatic Confinement Fusion: John F Santarius, Gerald L Kulcinski, and Robert P Ashley, University of Wisconsin, Madison, Wisconsin

A small, but active, worldwide research effort exists on inertial-electrostatic confinement (IEC) fusion. The potential for even small (< 0.5 m^3) IEC devices to produce high-energy (multi-MeV) neutrons and protons or electromagnetic radiation at levels useful for medical, environmental, and industrial applications motivates the research [1,2]. Active gridded IEC fusion research groups exist in the U.S. at the University of Illinois, the University of Wisconsin-Madison, Los Alamos National Laboratory, Marshall Space Flight Center, and Greatbatch, Ltd. In Japan, gridded IEC research takes place at Kyoto University, Kansai University, Tokyo Institute of Technology, Kyushu University, and Hitachi, Ltd. The University of Sydney conducts Australian IEC research. This article will primarily discuss U.S. IEC research, but will briefly cover the Japanese and Australian programs. Five U.S.-Japan IEC Workshops have been held at intervals of approximately one year. The two most recent were held at Kyoto University in March 2002 and at the University of Wisconsin in October 2002.

In gridded IEC fusion, which originated in the 1950's [3-5] and is the main subject of this article, a voltage difference on concentric, nearly transparent grids focuses charged particles radially in either spherical or cylindrical geometry. Ions accelerate down the electrostatic potential hill and convergence at the origin creates a high-density fusion core. Present IEC experiments routinely operate steady-state, but pulsed operation is also used. IEC fusion possesses the key advantage that high voltages (50-200 kV), therefore, high ion energies can be achieved with relative ease. This facilitates advanced-fuel fusion, using pure deuterium or mixed deuterium/helium-3 fuel, for example with reactions $D(d,n)^3He$, $D(d,p)T$, and $^3He(d,p)^4He$. In the ideal IEC operating mode, multiple passes of ions through the core enhance the effective ion current and the core density, increasing the fusion reaction rate. At the relatively high pressures (2-10 mtorr) of most present IEC experiments, however, the bulk of the neutron and proton production stems from fusion reactions of streaming ions or charge-exchange neutrals with background gas and fusion of ions impacting ions embedded in the grid wires. Typical neutron and proton production rates are 10^7-10^8 s^{-1}. Table 1 gives approximate operating regimes for present U.S. devices.

Table 1- Operating Regimes for Present U.S. Gridded IEC Devices.

	Fuel	Upper Voltage (kV)	Typical Current (mA)	Typical Pressure (mtorr)
University of Illinois	D-D	80	10-100	1-10
Los Alamos National Laboratory	D-D	75	50	~10
Marshall Space Flight Center	D-D	80	30-50	5-10
University of Wisconsin-Madison	D-D D-^{3}He	180	30-60	0.5-3

The Fusion Studies Laboratory at the University of Illinois, which is led by Prof. George H. Miley, operates three IEC devices: two spherical and one cylindrical, using D-D fuel [6]. Experimental investigations focus on core convergence, multiple potential wells, pulsed operation, grid geometry, "star-mode" operation (ions and electrons flowing in spokes through the grid openings), and radio-frequency (RF) ion sources. Applications being studied conceptually include neutron calibration sources, space propulsion, direct energy conversion using D-^{3}He proton collimation by magnetic fields, neutral beam injection for IEC fueling, an IEC-driven sub-critical fission reactor, plus using D-D neutrons, D-T neutrons, and bremsstrahlung radiation to interrogate luggage and shipping cartons. Modeling tools include a Monte Carlo particle code (MCP) for cylindrical IEC devices and a Fokker-Planck code to explore core convergence.

The Fusion Technology Institute at the University of Wisconsin-Madison, led by Prof. Gerald L. Kulcinski, performs IEC experiments using D-D or D-^{3}He fuel, with the key objective of operating at high voltage and using D-^{3}He protons (~14.7 MeV) to produce radioisotopes for nuclear medicine. The initial focus centers on short half-life isotopes (2-20 minutes; ^{11}C, ^{13}N, and ^{15}O) for positron emission tomography (PET) scans. Present experiments use spherical grids in a cylindrical aluminum chamber. A photo of the plasma core appears in Figure 1. A water-cooled, stainless-steel, spherical chamber has just begun operation. Modeling is accomplished using MIEC, a 1-D Mathematica™ code that follows atomic physics effects for several generations of ion and electron current. A helicon ion source, under construction, will be used to explore low-pressure, converged-core operation.

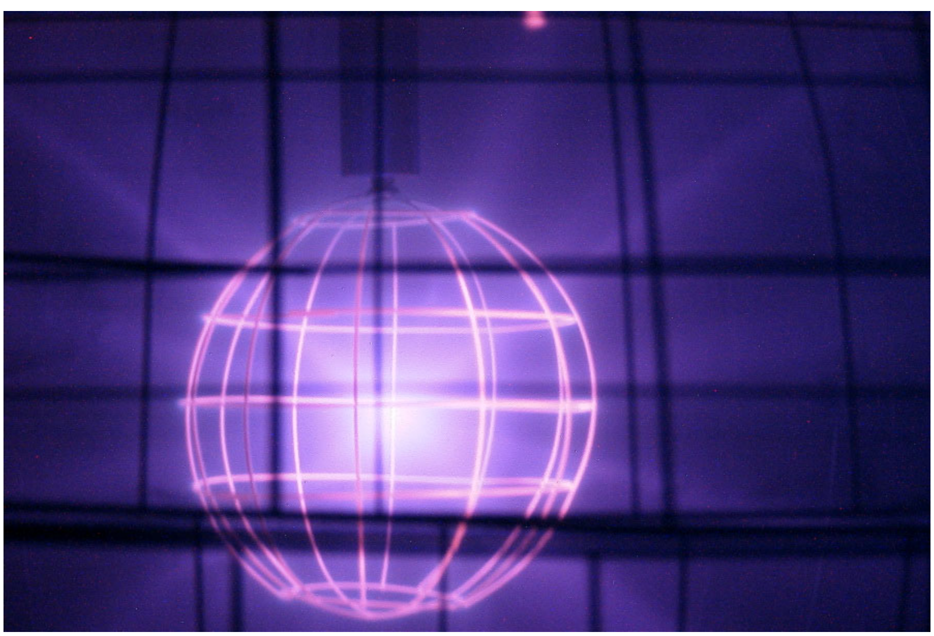

Figure 1. Plasma Core of the UW IEC Experiment.

The Los Alamos National Laboratory effort, led by Dr. Richard A. Nebel, explores a unique mode of IEC operation, the periodically oscillating plasma sphere (POPS) [7]. In the POPS mode, properly tuned radio-frequency waves would cause a Maxwellian plasma to oscillate radially, increasing the density in the core while maintaining a Maxwellian distribution. The present LANL effort explores instabilities for converging electrons in a gridded IEC device at very low pressure (10^{-5}-10^{-6} torr). Earlier LANL experiments explored converging ion flow in gridded IEC devices operating at pressures of 1-10 mtorr.

The Marshall Space Flight Center IEC research program, led by Dr. Ivana Hrbud, has begun operation of a spherical IEC device that will investigate the potential of IEC fusion space propulsion. Another U.S. IEC experiment, at Greatbatch, Ltd., has just begun operation in a very large chamber (radius~1 m), and will explore direct electrostatic conversion in IEC devices.

In Japan, Prof. K. Yoshikawa of Kyoto University coordinates a large effort on IEC neutron sources for landmine detection. The research groups mentioned earlier all play a role; their leaders include Profs. E. Hotta, H. Matsuura, M. Ohnishi, and T. Tadokoro. The University of Sydney, Australia, led by Prof. J. Khachan, also participates in this research. Typical operation of the IEC experiments occurs at pressures of 2-10 mtorr in deuterium plasmas.

Alternative IEC concepts exist that aim to overcome the disadvantage of finite grid transparency, which leads to excessive grid heating at high power densities. These utilize either Penning-trap geometry [8] or magnetically trapped electrons as a virtual cathode [9].

In summary, U.S. IEC research programs explore neutron and proton production for detecting clandestine materials and generating radioisotopes, with longer range goals of electricity production and space propulsion. The Japanese and Australian IEC efforts primarily focus on neutron production for landmine detection. All groups use D-D fuel at voltages up to 80 kV for neutron production. The University of Wisconsin also uses voltages up to 180 kV to produce D-^{3}He protons. The Los Alamos National Laboratory effort explores the periodically oscillating plasma sphere mode of IEC operation. Researchers have made considerable improvement in IEC parameters during the past few years, and experiments presently hover at the edge of economic attractiveness.

References:

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INTERNATIONAL ACTIVITIES:

The New CIEL Plasma Facing Components in Tore Supra: a Major Step towards Steady-State, High Power Operation: Didier van Houtte, Equipe Tore Supra, CEA/DSM/DRFC, France

The main magnetic fusion research activities at the French-Euratom Association take place in the "Department of Controlled Fusion Research" at the CEA Cadarache site in Provence. The flagship of the programme is the Tore Supra tokamak shown in Figure 1. Owing to its high field strength (4T) provided by superconducting toroidal field coils, cooled by superfluid helium at 1.8 K, its main role is the investigation of high power, steady-state operation. From 1988 to 1999, a significant part of the programme was devoted to the study of physics and technology of a hot core plasma in steady-state conditions. Optimisation and sustainment of the plasma current and pressure distributions over long periods are achieved in Tore Supra by means of strong radio-frequency (RF) power at frequencies absorbed by the plasma: "lower hybrid resonance" at 3.7 GHz (6 MW), "ion cyclotron resonance" at 42-63 MHz (9 MW), and "electron cyclotron resonance" at 118 GHz (2 MW). The power coupled to the plasma must be extracted continuously which means tackling the problem of plasma facing surfaces subject to a permanent attack by particles and power. For continuous power exhaust, it is necessary to simultaneously control the convective power deposition on the components facing the plasma and the flow of radiated power to all the internal components in direct line of sight of the plasma.

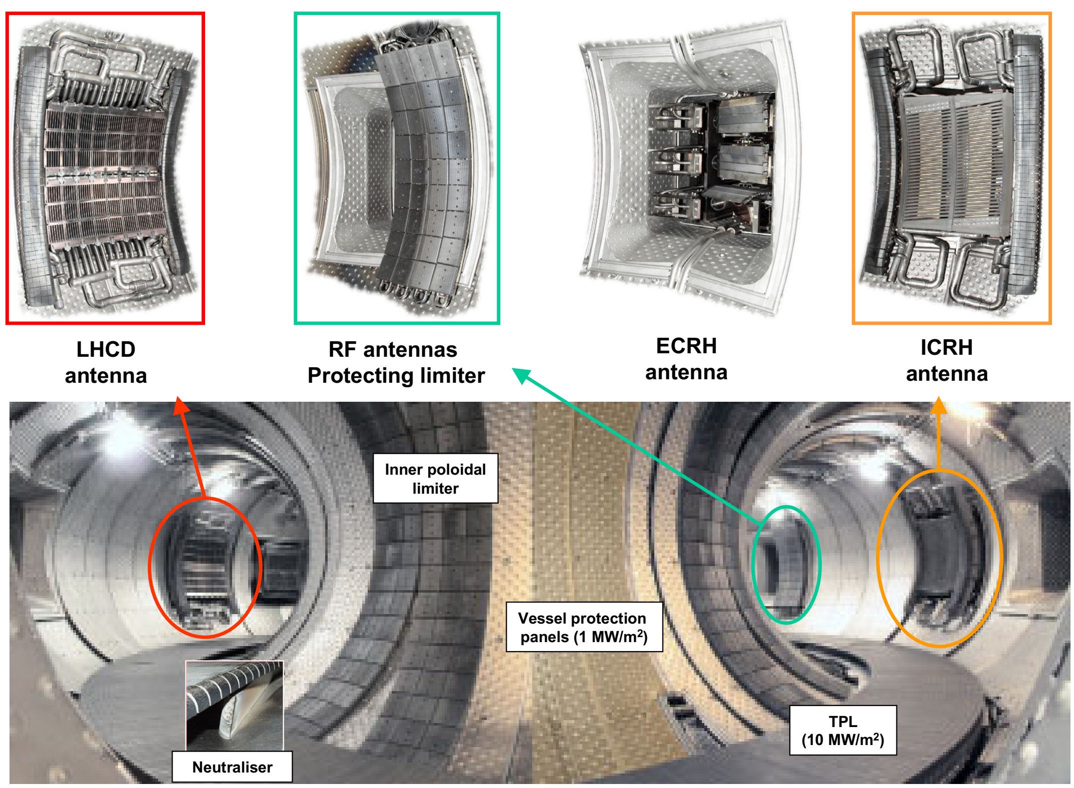

Figure 1. Interior of Tore Supra vacuum vessel in the new CIEL configuration.

Studies of long duration plasma discharges between 1988 and 1999 showed that the power exhaust capacity of the first generation of actively cooled plasma facing components was marginal for attaining steady-state operation. Therefore, all the internal components in Tore Supra were upgraded, within the framework of the CIEL (acronym in French for "Internal Components And Limiter") project, with the objective of giving Tore Supra the capacity to control, in steady state, the injected power (up to 15 MW of convected power with a maximum flux of 10 MW/m^2, and 10 MW of radiated power with a flux of 1 MW/m^2, continuously). The design, done in 1992 was aimed at simplifying the manufacturing processes and a series of mockups were realised and tested before the elements could be ordered in 1997.

The main component of the CIEL project is a Toroidal Pump Limiter (TPL) which has the form of a flat ring with 5 m diameter and 0.5 m width. In order to extract the particles escaping the plasma, 12 throat-shaped "neutralisers" are located at one of the edges of the ring under the limiter. Each neutralizer is connected to a turbo-molecular pump. The TPL consists of 576 "fingers" ("aiguilles" in French), cladded with carbon fibre tiles bonded to a copper structure that is actively cooled by pressurised water (30 bars) at high temperature (150 ^oC). The TPL is located at one centimeter away from the plasma surface. The fabrication of these "fingers" was particularly complex, especially the bonding of the carbon composite fibre to the water-cooled copper base. It incorporates a proprietary process patented by our supplier, the Plansee Austrian company. The process is based on engraving tiny cavities into the carbon tiles using laser and subsequently impregnating the surface with liquid copper. The solidified 2 mm layer of copper is then welded using an electron beam to the hardened copper-alloy base (copper-chromium-zirconium).

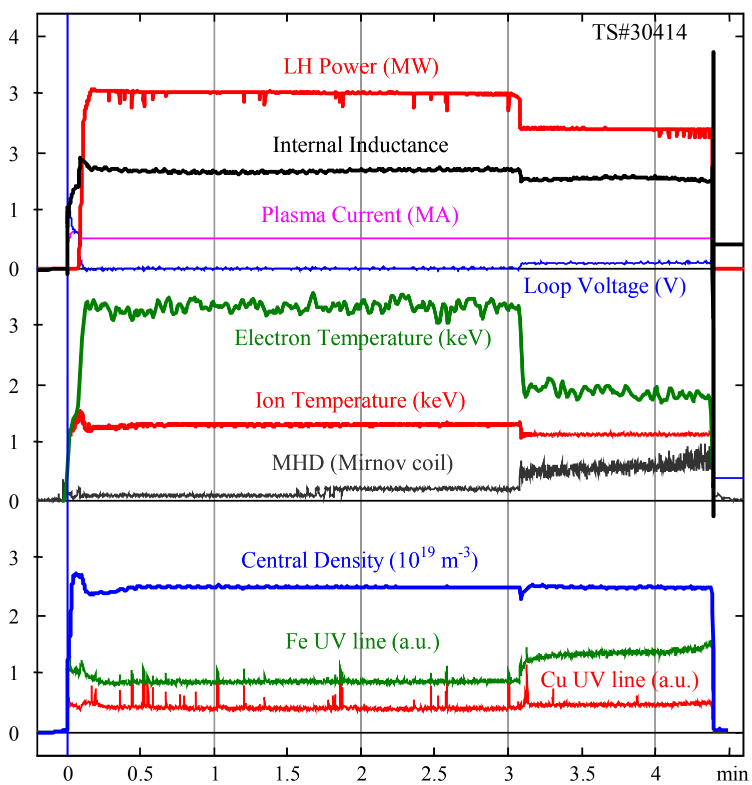

Figure 2. Time evolution of plasma parameters.

Tore Supra was successfully restarted in the full CIEL configuration for the experimental 2002 campaign oriented towards long steady-state discharges. The ultimate goal is to couple 1 GJ of energy to the plasma. To achieve this performance, the main route was a low density, low plasma current scenario (GJ-A) with purely lower hybrid current drive. So far, a steady state 265 s discharge has been obtained (Figure 2), allowing an injected and extracted energy of 0.74 GJ that largely overpasses our 1996 previous record (280 MJ - 120 s). In most of these long –duration discharges, zero loop voltage has been maintained and discharges with negative loop voltage have even been obtained. It should be mentioned that the plasma density has been very efficiently controlled for duration longer than 4 minutes at a higher level of lower hybrid power. This is a consequence of operating a complete actively cooled machine coupled with an efficient pumping system. The capability to run long pulse plasma discharges on a regular basis opens the way to explore new scientific areas in ITER relevant conditions, such as the aging of the plasma facing components under thermal cycling and high heat and particle fluxes, or hydrogen trapping, wall saturation and limiter erosion as shown in Figure 3.

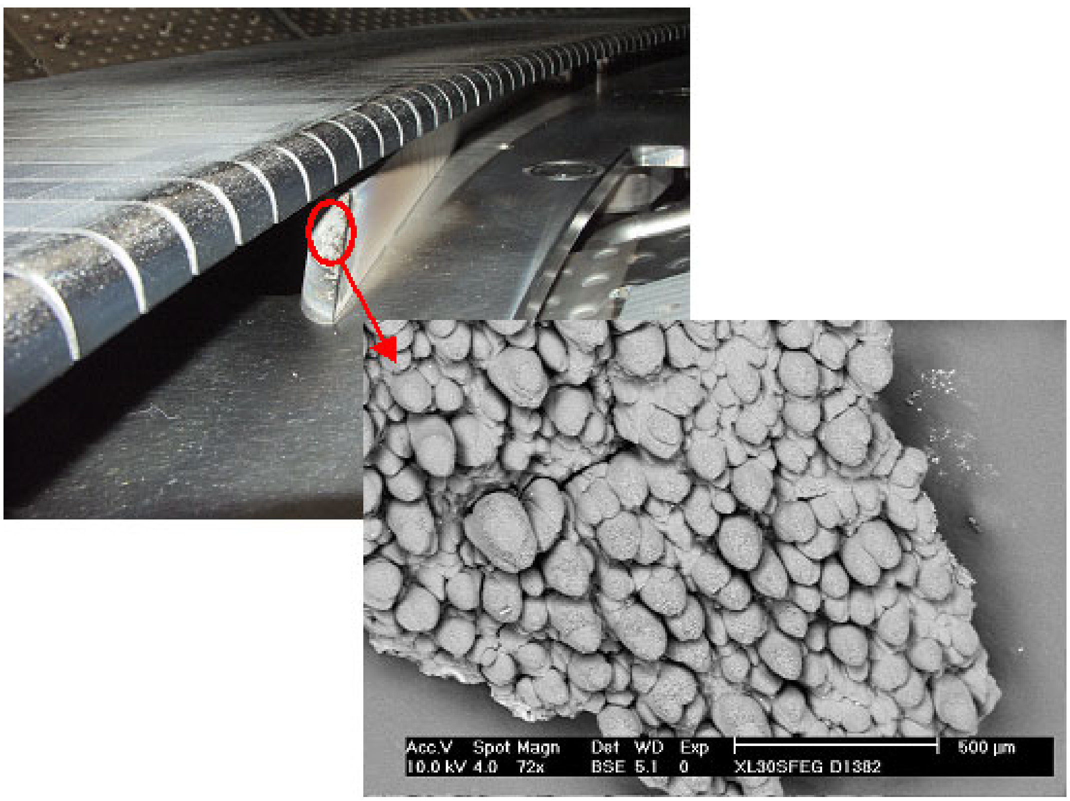

Figure 3. TPL neutraliser modified surface after several long pulse discharges.

A higher current and higher density scenario (GJ-B) was also developed with combined lower hybrid current drive and ion cyclotron heating allowing 0.42 GJ of injected and extracted energy. Figure 4 presents the new domain of performance achieved during the 2002 campaign indicating discharges in the GJ-A and GJ-B scenarios, as well as in the previous experimental campaigns.

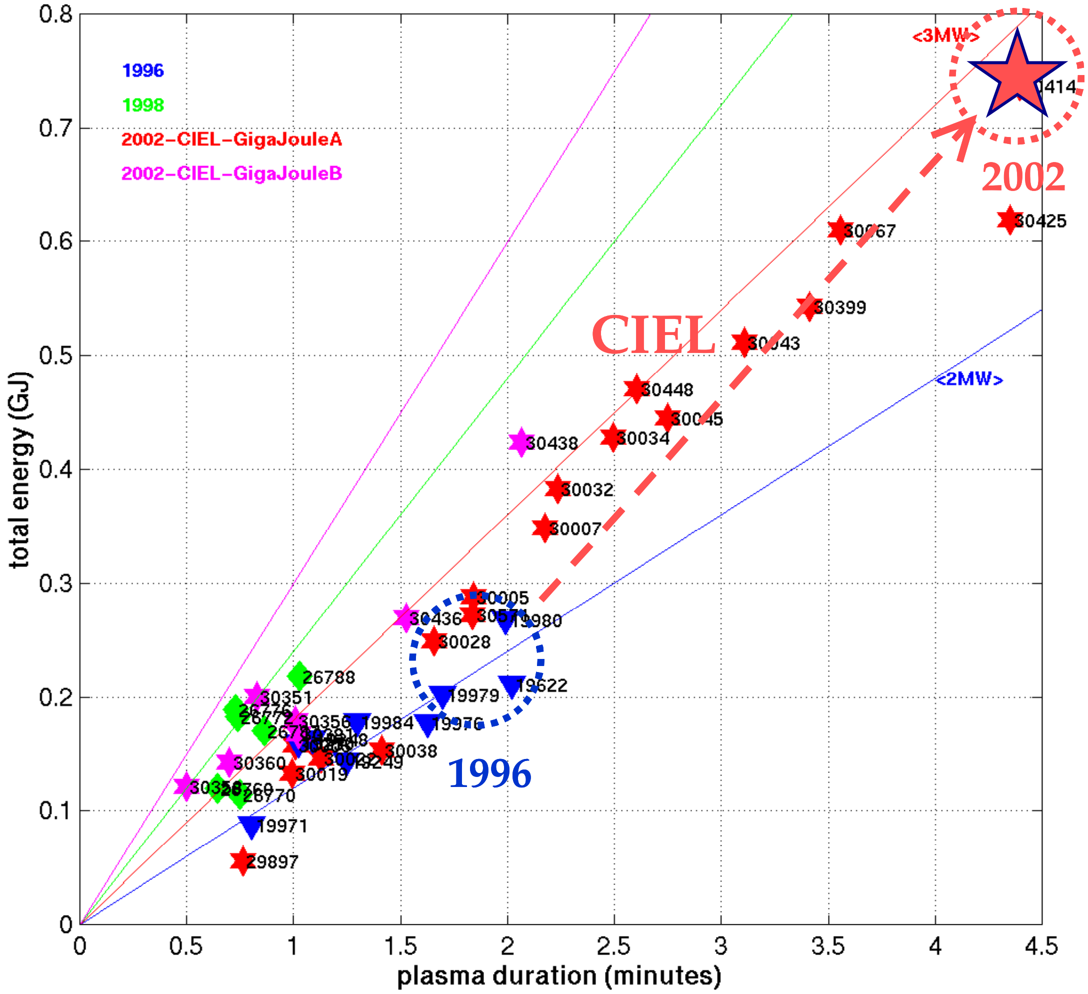

Figure 4. Total energy injected-extracted versus plasma duration showing the new domain reached after CIEL implementation during the Tore Supra 2002 campaign.

The main limitation encountered is the performance of the additional heating systems, which in general do not provide sustained steady state full power operation. This resulted in an “early” termination of the discharge when the maximum available magnetic flux of the poloidal transformer is consumed. This stresses the importance of upgrading the Tore Supra lower hybrid system, which is planned in the near future as part of the CIMES project (acronym in French for "Composants pour l’Injection de Matière et d’Energie en Stationnaire”). For more information, visit the Tore Supra web site at: http://www-drfc.cea.fr/cea/ts/ts.htm.

Highlights of the Second IAEA Technical Meeting on Physics and Technology of IFE Targets and Chambers: Dan Goodin and Ron Petzoldt, General Atomics, San Diego, CA

The Second IAEA Technical Meeting (IAEA-TM) on Physics and Technology of Inertial Fusion Energy Targets and Chambers was held at General Atomics in San Diego, California from 17-19 June 2002. (The first meeting was held in Madrid, Spain, 7-9 June 2000.) There were 68 participants from 9 countries.

The meeting provided an excellent opportunity to report on recent technical progress, discuss key issues, and identify means to resolve these issues. The meeting helped advance the understanding of targets and chambers for all proposed inertial fusion energy power plant designs including laser direct drive, heavy ion indirect drive, Z-Pinch and fast ignition. Papers related to technology, experiments, facilities, modeling, analysis, and design were presented on the following topics:

1. Target design and physics, including fast ignition
2. Chamber physics and technologies
3. Target fabrication, injection, and tritium handling
4. Accident analysis and safety assessment

The target design and physics work is directed primarily at reducing instabilities in established targets and early design considerations for fast ignition and Z-pinch targets.

IFE chamber R&D is now emphasizing small-scale experiments to investigate fundamental aspects of chamber designs and to provide data to complement and benchmark models being developed for material response and chamber dynamics. Work also continues on issues related to integrating chambers, drivers and targets for IFE power plants.

Target fabrication R&D emphasized glass, foam, and polyimide capsule production, fast freeze and fluidized bed target layering, low-density material fabrication for use in hohlraums, fast ignition target fabrication with cones, and target cost modeling.

Target injection work emphasized drag force and protection of targets in chamber, and an experimental target injection and tracking system under construction.

Safety work emphasized minimizing tritium inventories, accident analysis, and management of radioactive equipment.

For detailed information, including abstracts and electronic copies of most presentations, please see http://web.gat.com/conferences/iaea-tm/main.html.

Selected papers from this meeting will be included in a special issue of Fusion Science and Technology scheduled for publication in May 2003.