# Fusion Energy Division
# American Nuclear Society
# December 2000 Newsletter

The December 2000 newsletter of the American Nuclear Society (ANS) Fusion Energy Division (FED) has been archived on the ANS-FED web site: http://fed.ans.org/. Please share this newsletter with your colleagues. If you are changing you E-mail address or believe you are outside the fusion community, please inform the editor (elguebaly@engr.wisc.edu) and accept our apology for the inconvenience. The topics for this issue include:



**Message from the Chair**, Kathryn McCarthy, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

In my first message to you as Chair, there are four major areas I'll cover: FY-01 budgets, upcoming conferences, FESAC activities, and ANS national activities.

## Budgets

The FY-01 budget is finally signed, and while it is not a great year for the fusion budget, at least the budget remains relatively flat. DOE-OFES was provided $255 million, the same as the House had recommended previously. This is much better than the original Senate budget of only $227 million (the Administration request was $247 million). The language indicated that "Funds for this program should be allocated in accordance with the Fusion Energy Sciences Advisory Committee's (FESAC) report on Balance and Priorities. The Committee is pleased that the FESAC review process seems to be positioning the U.S. program to take advantage of the much larger international fusion research effort with the resources available and also positions the program to accelerate the development of fusion energy." While there was an effort to bring the fusion budget up to the $300 million level, once again, it was not successful. DOE-OFES is now in the process of allocating the funds, and it is up to us researchers to show congress that we produce great things and are deserving of increased budgets.

## Fusion Technology Conferences

Although the Energy and Water bill this year includes restrictions on travel, the restrictions were lessened somewhat relative to FY-00, and should alleviate some of the pressure felt by laboratory travelers. The 14th Topical on Fusion Energy (TOFE) was recently held in Park City, Utah, and was a very successful meeting (see the article in this newsletter for details). The TOFE is typically held every two years, and FED has begun discussions on the best time and place to hold the 15th TOFE. At the last Executive Committee meeting (held in Park City during the 14th TOFE), a lively discussion was held on whether the next Topical meeting should be embedded in the ANS Annual Meeting or not. Executive Committee members have been tasked with information gathering to help the FED make the appropriate decision.

Also coming up in 2002 is the 6th International Symposium on Fusion Nuclear Technology (ISFNT-6). This meeting will be held April 7-12, 2002, at the Hyatt Islandia on San Diego's Mission Bay. This Symposium is recognized as a major event for the international exchange of technical information on all aspects related to fusion nuclear technologies and for the promotion of international collaboration. All conference papers are peer reviewed, and will be published in a special volume of Fusion Engineering and Design. Authors are requested to submit tentative titles for contributed papers by January 7, 2001, and abstracts are due August 7, 2001. Full papers are due on January 7, 2002. For further information, contact Claudia Hennessy, chennessy@vlt.ucsd.edu. The Conference web site is http://cer.ucsd.edu/isfnt.html.

## FESAC Update

FESAC recently completed a charge from James Decker, Acting Director of DOE-SC, to review the draft Integrated Program Plan for Fusion Energy Sciences. FESAC met in July, commented on the draft plan, and heard public comments. FESAC was split into four groups (public attendees were invited to participate in the groups), and based on the input that had been received, made changes to the draft. A subgroup was formed to support completion of the plan. A revised version of the final report of the Integrated Program Planning Activity (IPPA) that was submitted to the Office of Fusion Energy Sciences on behalf of the IPPA Steering Committee and IPPA Working Group is available for review and comment on the VLT web site at http://vlt.ucsd.edu/. This report incorporates all the specific changes recommended as a result of the FESAC review.

US DOE Office of Science Director Mildred Dresselhaus, in an October 6 letter to FESAC chair Richard Hazeltine, asks the committee "to address the scientific issues of burning plasma physics" and to provide a report by July 21, 2001. The FESAC will formally receive this charge at its November 14-15 meeting in Bethesda, Maryland. Dresselhaus notes, "For many years, the U.S. magnetic fusion community has recognized that burning plasma physics is the next frontier of fusion research," and that "in the last two decades, the program has made several attempts, both international and domestic, to move forward on the design and construction of a tokamak experimental device in which the science of burning plasmas could be explored." She notes, "For various reasons, all these attempts failed." Dresselhaus says, "the community needs to come to consensus on two aspects of burning plasma physics as follows:

1. What scientific issues should be addressed by a burning plasma physics experiment and its major supporting elements? What are the different levels of self-heating that are needed to contribute to our understanding of these issues?
2. Which scientific issues are generic to toroidal magnetic confinement and which ones are concept-specific? What are the relative advantages of using various magnetic confinement concepts in studying burning plasma physics? She indicates that, "As a part of your considerations, please address how the Next Step Options program should be used to assist the community in its preparations for an assessment in 2004, as recommended in the Priorities and Balance report.

## ANS National News

ANS national is working hard to update its image, and to better serve its members. I recently attended a Strategic Planning Retreat, the goals and objectives being:

(1) To review the Strategic Plan and reaffirm the direction that the Society should take to enable it to continue as "international leaders in the development, dissemination and application of nuclear science and technology to benefit humanity.
(2) To review, and where necessary, update the goals and objectives for the Society, so that it can move in this direction.
(3) To develop effective methods for implementing the Strategic Plan, through Society committees, Society members and the staff.

The meeting was facilitated by Mr. Ed Barlow, (from Creating the Future, Inc.), who provided some interesting information on change and how to survive it (and thrive in it!). The dialogue during the meeting was very honest, and addressed some real problems in the Society. Emphasis was on public outreach activities including providing information to science teachers, reacting to erroneous information in the press, and how to make the national meetings better. The national meetings have been reorganized to include Technical Tracks. As of this writing, over 900 people are registered for the ANS Winter meeting this year (November 12-16 in Washington DC), making it one of the largest in the last fifteen years. ANS has also worked hard to improve the web site — check it out at http://www.ans.org/ ; you can even renew your membership online now.

ANS is making a real effort to reach out to its members; if you have suggestions for how ANS can improve, please send them to me (KM3@inel.gov) and I'll make sure they get to the appropriate person. I believe there are things that FED can do to support ANS national that would benefit both national and FED. One idea is to co-sponsor a session on waste issues, possibly with either the Decontamination, Decommissioning, and Reutilization Division or the Fuel Cycle and Waste Management Division. Is anyone interested in heading up this effort?

I recently received a phone call from Sharron Kerrick--she's the liaison to ANS national for the FED. She called to verify that the FED home page was appropriately linked to the ANS national home page (it is), and to find out what fusion-specific educational materials we would like included in the ANS web site. Now the ball is in our court to get this information to ANS — as a start, I recommend providing links to this information on the FED web site; that will give ANS national time to review the material and decide how to best include it in the ANS web site.

If anyone has any suggestions or ideas, please let me know — let's take advantage of this opportunity to better integrate with ANS national, and increase the benefit for FED and ANS!

**FED Slate of Candidates,** Clement Wong, General Atomics, San Diego, California

We are offering an excellent slate of candidates for election to 2001 FED offices. It is gratifying this diverse group of qualified people is committing time from their busy schedules to work on behalf of our members to provide advice and guidance to FED. We are now asking you to examine these candidates, select the new group of leaders to represent us, and vote.

Vice Chair/Chair Elect:
- Mohamed Bourham, North Carolina State University
- Wayne Meier, Lawrence Livermore National Laboratory

Secretary/Treasurer:
- Rene Raffray, University of California, San Diego

Executive Committee Candidates:
- Hesham Khater, University of Wisconsin, Madison
- Akio Sagara, National Institute for Fusion Science, Japan
- Roger Stoller, Oak Ridge National Laboratory
- Neill Taylor, Culham Science Centre, England

**14th Topical Meeting on Technology of Fusion Energy**, Glen Longhurst, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

The 14th Topical Meeting on the Technology of Fusion Energy was held October 15-19, 2000 at the Park City Marriott Hotel, Park City, Utah. Meeting sponsors included the

Idaho and NORCAL sections and the Fusion Energy Division of the American Nuclear Society, and the Fusion Engineering Division of the Atomic Energy Society of Japan. Corporate sponsors included Bechtel BWXT Idaho LLC (the INEEL operating contractor) and General Atomics. Participants numbered 139 coming from Belgium (1), Canada (2), Italy (3), Japan (39), Kazakhstan (1), Spain (3), the U. K. (1), and the U.S.(89). Of these, 17 were students. A total of 162 papers were presented 14 in plenary sessions, 71 in oral sessions, and 77 as posters. Details of program structure and abstracts may be viewed at the meeting web site: http://ev2.inel.gov/ParkCity/abstracts/topic_list.html. Judging by the feedback given to the organizers, the meeting was highly successful.

Each day of the meeting began with a plenary session. On Monday, October 16, the plenary session provided participants with an overview of activities in fusion in major programs around the world. Prof. Nobuyuki Inoue (Institute of Advanced Energy, Kyoto University) described the Japanese Fusion Program and ITER. Dr. Charles Baker (Virtual Laboratory for Technology, University of California, San Diego) spoke of U.S. directions in fusion technology, and Prof. Satoru Tanaka (Department of Quantum Engineering and Systems Science, University of Tokyo) reviewed the status of fusion technology issues in Japan.

Tuesday's plenary session focused on innovative concept developments. Dr. Peter Peterson (General Atomics) presented recent findings in DIII-D relative to advanced tokamak modes and discussed their implications for fusion energy. He was followed by Dr. Kenkichi Ushigusa (JT-60, Japan Atomic Energy Research Institute) who spoke of progress in steady-state high performance plasmas and related technologies in the JT-60U tokamak, and then by Dr. Craig L. Olson (Sandia National Laboratories) who reviewed recent results related to the Z Machine and their implications for fusion energy. Tuesday's final plenary speaker was Prof. Osamu Kaneko (National Institute for Fusion Energy) who presented recent results from the Large Helical Device and their implications for fusion energy.

The plenary session on Wednesday centered on next step options and system studies. The first speaker, Dr.Bill Hogan (Lawrence Livermore National Laboratory) described progress on the National Ignition Facility and provided comments on the Laser MegaJoule now under construction. He was followed by Dr. Farrokh Najmabadi (University of California, San Diego) who addressed the impact of advanced technologies on fusion power plant characteristics as manifested in the ARIES-AT study. Dr. Dale Meade (Princeton Plasma Physics Laboratory) then described the Fusion Ignition Research Experiment (FIRE) and ways it would move us toward the goal of fusion energy. Dr. Mark Tillack (University of California, San Diego) concluded Wednesday's plenary session with a discussion of the ARIES inertial fusion chamber assessment.

On Thursday, the final day of the meeting, the plenary session was concerned with Safety, Waste Management, and Licensing. Dr. Murray Stewart (Canadian Bid, ITER Canada) made a multimedia presentation describing advantages of Canada as the host for ITER. Dr. David Petti (Idaho National Engineering and Environmental Laboratory) described present and future directions in U.S. Fusion safety and environmental activities. He was followed by Dr. Neill Taylor (EURATOM/UKAEA Fusion Association) who gave an overview of international waste management activities in fusion.

On each day, following the plenary session, parallel oral sessions were held. These were grouped into several technology areas, most distributed over multiple sessions, including

Advanced Design
Alternate and Advanced Concepts
Chamber Technology
Flibe Issues
Non-Electric Applications
Plasma Technology
Safety and Environment

Most oral sessions featured one or two invited speakers and contributed papers to make a total of five presentations per session.

Poster sessions were held on Monday and Tuesday afternoons. Nominally 40 poster papers were presented in each of those sessions.

On Monday evening, October 15th, participants were hosted at an excellent reception sponsored by the Fusion Engineering Division of the Atomic Energy Society of Japan. Guests and some conferees made an excursion into the backwoods of the American West on Tuesday afternoon, riding on the Heber Valley Railroad. Others spent casual moments strolling the quaint streets of Park City or shopping at the nearby factory outlet malls.

At the conference banquet, held Wednesday evening, several awards were presented. Dr. Jerry Kulcisnski, on behalf of the Fusion Energy Division, presented three FED awards (see the Award's article in this newsletter). Also, Susana Reyes, a graduate student from the University of Madrid working on safety issues at Lawrence Livermore National Laboratory, was presented a plaque for the best student paper at the conference by Dr. Jeff Latkowski of the meeting organizing committee. Her title was "Accident Consequences Analysis of the SOMBRERO Inertial Fusion Energy Power Plant Design." Entertainment for the evening was provided by the "Cowfolks", a quartet of musicians who enthralled the audience with cowboy songs and poetry.

The organizing committee for the meeting was:

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| General Chair | Glen Longhurst (INEEL) |
| Vice General Chair | Satoru Tanaka (Tokyo University) |
| Technical Program Committee Chair | Dave Petti (INEEL) |
| Assistant Technical Program Chairs | Wayne Meier (LLNL) |
| | Yasushi Seki (JAERI) |
| Finance | Steve Herring (INEEL) |
| Registration & Publicity | Phil Sharpe (INEEL) |

| | |
|---|---|
| | John Commander (Consultant) |
| Publication | Lee Cadwallader (INEEL) |
| | Sandra Brereton (LLNL) |
| Arrangements | Marie Warnick (INEEL) |
| Student Programs | Jeff Latkowski (LLNL) |
| Technical Liaison | Brad Merrill (INEEL) |
| Foreign Liaison | Kathy McCarthy (INEEL) |
| Guest Program | Darla Miller (INEEL) |
| | Cindie Jensen (INEEL) |

Additional support was provided by the Chemical Engineering Department and Nuclear Engineering Program at the University of Utah who furnished students to assist with registration and presentations. Proceedings of the meeting will be published in Fusion Technology, hopefully in the March 2001 edition.

**ANS-FED Awards Presented at 14th 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 2000. The Outstanding Achievement Award was presented to Dr. Michael Willliams of Princeton Plasma Physics Laboratory. The Outstanding Technical Accomplishment Award was presented to Dr. David Petti of the Idaho National Engineering and Environmental Laboratory. The Student Award was presented to Luis Chacón de la Rosa who recently received his doctorate from the University of Illinois at Urbana-Champaign and is presently employed at the Los Alamos National Laboratory. The FED Awards were presented at the 14$^{th}$ Topical meeting on the Technology of Fusion Energy held in Park City, Utah, October 15-19, 2000.

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 Dr. Williams was made in recognition of his long-standing research and leadership in the PDX, TFTR, and NSTX projects. Dr. Williams led the engineering effort on the NSTX project, which was constructed on cost and ahead of schedule, and its performance has exceeded the original specifications in several areas.

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. Petti was made in recognition of his outstanding accomplishments in the area of safety and standards for the International Thermonuclear Experimental Reactor (ITER). Dave led the U.S. effort on the safety analysis of the ITER facility and he has had a major influence on the safety standards for nuclear systems in the United States.

The purpose of the Student Award is to recognize significant research accomplishment by a student in the area of Fusion Science and Engineering. Selection was based on a letter of nomination and journal quality paper resulting from the student's research. Dr. Luis Chacón de la Rosa was nominated by Professor George Miley of the University of Illinois. His paper was entitled "Fokker-Planck Modeling of Spherical Inertial Electrostatic Virtual-Cathode Fusion Systems" and is scheduled to be published in the Physics of Plasmas Journal.

**Uckan Appointed "Editor-Designate" of Fusion Technology Journal**, Ken Schultz, General Atomics, San Diego, California.

Professor George Miley of the University of Illinois has served as the Editor of the ANS journal *Fusion Technology* (and its predecessor *Nuclear Technology/Fusion*) since their inception in January 1981. During this time *Fusion Technology* has become the premier journal for the publication of research papers on fusion engineering and fusion technology. As was announced in this newsletter a year ago, George has decided to retire from the Editorship in June 2001.

The Technical Journals Committee of the ANS conducted a careful search for a successor to lead *Fusion Technology* into the 21st Century. They advertised the position, got numerous inquiries, and received applications from 9 fully qualified individuals. After a thorough interview process, the Technical Journals Committee recommended Dr. Nermin Uckan of Oak Ridge National Laboratory be appointed the new Editor, and on June 20 the ANS President Jim Lake appointed Nermin "Editor-Designate." Nermin will complete the transition during the next few months, taking over all new papers while George completes his efforts on papers previously submitted. Nermin will begin her first 3-year term as Editor in June 2001.

Nermin is very well qualified for the position. She received her B.S. (1968) and M.S. (1969) in Electrical Engineering from the Technical University of Istanbul, Turkey. At the University of Michigan, Ann Arbor, as a NATO scholar, she received a M.S. (1973) in Nuclear Engineering, M.S. in Computer Information and Control Engineering, A.M. (1973) in Mathematics, and Ph.D. (1975) in Nuclear Engineering. She is a Fellow of the ANS and received the FED Outstanding Lifetime Achievement Award for her contributions to fusion science and engineering (1994)

Nermin is the Program Leader/Section Head for Advanced Studies/Next Step at ORNL and Adjunct Professor of Nuclear Engineering at the University of Tennessee-Knoxville (UTK). This year marks her 25th year in ORNL's Fusion Energy Division (FED) and 25th year as a member of ANS. During these years she has held numerous positions: Program Management for the International Thermonuclear Experimental Reactor (ITER) Design Activity at ORNL, ANS/FED Executive Committee Chair, ANS-Fusion Topical Technical Program Chair, and various other ANS committee memberships.

She has a broad background and experience in the physics and engineering of magnetic fusion energy and has worked on plasma transport, plasma performance, plasma waves and current drive, burning plasma physics, plasma engineering, physics-safety interface, magnetic configurations, and various fusion power plant studies.

Nermin's present research is in plasma engineering, burning plasmas, fusion power plant studies, and fusion energy development. She has published more than 200 technical papers/reports on these topics, as well as her widely used compendium of measures of plasma performance and physics design rules and requirements for tokamak experiments and power plants. Recently, she has served as the Co-Editor of the ITER Physics Basis document that was published by the IAEA [*Nuclear Fusion*, vol. **39** (12) 2137-2664 (1999)].

Please welcome Nermin to the job of editing *Fusion Technology*. Help her as she works to keep *Fusion Technology* strong by submitting your papers to this important journal and by providing timely, critical reviews of papers when she asks. Together, we can keep *Fusion Technology* strong and vibrant in the 21st Century.

## Ongoing Fusion Research:

**Fusion Energy with KrF Lasers**, John Sethian*, Plasma Physics Division, Naval Research Laboratory, Washington DC

The Naval Research Laboratory (NRL) is playing a major role in the development of Inertial Fusion Energy (IFE) using direct drive implosion of a pellet with a krypton fluoride (KrF) laser. The laser would symmetrically and directly illuminate a cryogenically cooled deuterium-tritium (DT) pellet that has been injected into a chamber. The target is compressed and heated to undergo thermonuclear burn, and the released energy is captured by the chamber and converted into electricity. A conceptual design of a laser fusion power plant is shown in Fig. 1. It consists of an array of identical laser beam lines, a chamber, a target factory, a target injector, a set of final optics, and the electrical generator.

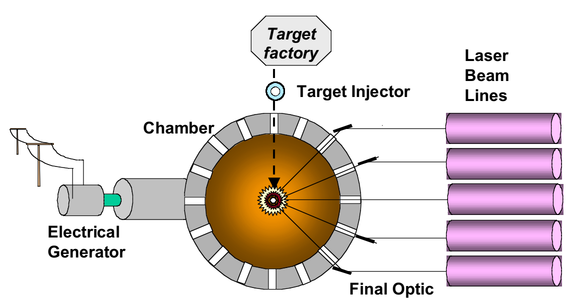


Fig. 1 Conceptual Design of a Laser IFE Power Plant

This is a very attractive approach for IFE. Recent advances in target designs have shown that it should be possible to achieve the high gains required for a fusion power plant. KrF lasers have demonstrated that they have the illumination uniformity needed to achieve these high gains. A KrF laser is scalable to power plant size systems, the pellets are relatively simple to fabricate, and power plant studies have shown this can be an economically attractive approach [1] with reasonable laser costs and efficiencies. Moreover, the modular and separable nature of laser IFE significantly reduces its development costs.

NRL's role in laser fusion energy is two fold: to develop target designs that can produce sufficient gain for a fusion power plant, and to develop a repetitively pulsed efficient KrF laser driver. This article concentrates on these contributions. The other components for laser fusion energy are being developed by the University of Wisconsin, the University of California San Diego, Los Alamos National Laboratory, Livermore National Laboratory, General Atomics, and Schafer Corporation. These components are being developed in concert with one another to ensure laser fusion energy is being developed as a coherent integrated system.

In laser fusion, the outside of the pellet is illuminated with such intensity that material is blown off, or ablated. The resulting rocket effect drives the pellet inward and collapses it. The density of the DT fuel increases sufficiently that the central core can ignite, causing a thermonuclear burn to propagate outward. Achieving this in the laboratory has been challenging as the pellet tends to undergo deleterious hydrodynamic (Raleigh-Taylor) instabilities as it is compressed. At NRL, we are evaluating designs that heat the ablator, to reduce the instability growth but keep the fuel cold (i.e. dense), to maximize the gain [2]. Here, the gain is defined as the ratio of laser energy out divided by laser energy in. When one factors in the other elements of a laser fusion system, the gain needs to be above 100 for laser fusion energy to be viable. In one of the NRL target designs, shown in Fig. 2, the ablator is a low density CH foam shell that is filled with DT. The foam is encapsulated with a thin (1 μm) CH layer that has been overcoated with a 0.03 μm layer of gold or other high Z-material. The fuel itself is a layer of pure DT inside the DT/foam shell.

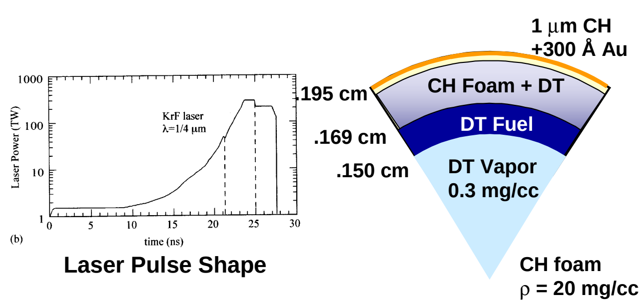


Fig. 2 One example of an NRL High Gain Target Design. The Gain is 127 at a laser Energy of 1.3 MJ

The target is irradiated by a shaped laser pulse that consists of a long duration (15 nsec) low intensity foot, followed by a relatively short duration (5.5 nsec) high intensity main pulse. The foot heats the high-z coating so it emits x-ray radiation near 250 eV, i.e. just below the K-edge of the carbon in the foam. This radiation penetrates into the low-opacity ablator and heats it. After the pulse starts to rise, the ablator is further heated by carbon radiation coming from the outer layer of the target. As most of the radiation is stopped in the ablator, the inner layer of DT fuel remains cold. We also "zoom" the laser twice during the drive, i.e. decrease the laser focal spot size to match the target as it is compressed. Zooming is straightforward for KrF lasers, and reduces the energy needed to drive the target. Our calculations show this design has a 1-D gain of 125 [3], which should be sufficient for a fusion energy power plant. Recently NRL has computed that high gains can also be achieved with targets that have no gold coating. The final choice will be influenced by target fabrication/injection and other power plant considerations. All of these designs are being evaluated with planar experiments on the Nike KrF laser [4] and with 2-D and 3-D models.

KrF driver development is carried out on the new Electra laser. Like Nike, Electra will use double pass laser amplification with double-sided electron beam pumping of the laser gas. The difference from Nike is that Electra will operate at 5 Hz and use technologies that can meet the fusion energy requirements for efficiency, durability, and cost. Electra will have an optical aperture of 30 cm and an output of 700 J. This is about 1-2% of the energy of a power plant size laser beam line. However, the technologies we develop on Electra will be scalable to IFE sized systems. The main laser components that need to be developed are: a durable, efficient, and cost effective pulsed power system; a durable electron beam emitter; a long life, transparent pressure foil structure to isolate the laser cell from the electron beam diode (the "hibachi"); a recirculator to cool and quiet the laser gas between shots; and long life optical windows. Technologies that can meet these requirements have been identified [5]. Electra will be built by integrating each component as it is developed. To date, we have built a first generation pulsed power system to allow development of the laser technologies [6] and electron beam studies have begun. A photo of the Electra Laser Facility is shown in Fig. 3.

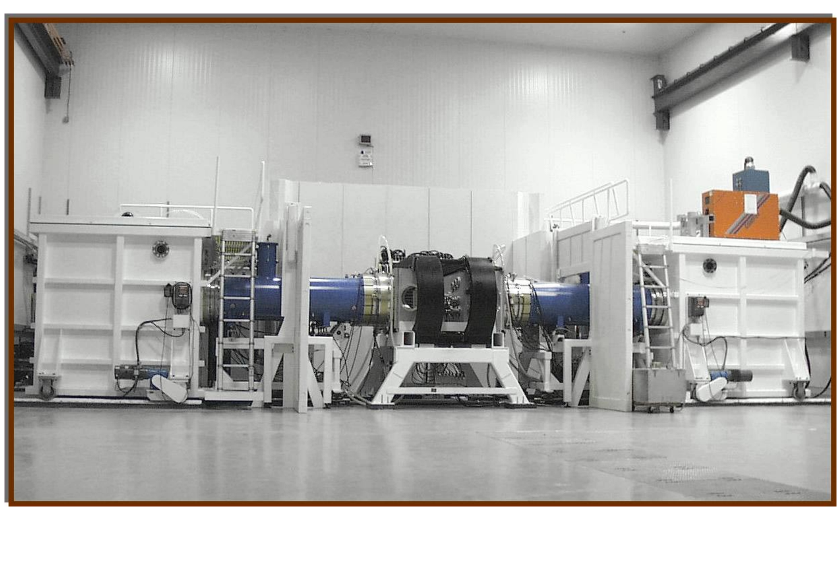

Fig. 3 The Electra Laser Facility

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[4] S.P. Obenschain et al, Physics of Plasmas, **3**, 2098 (1996).
[5] J.D. Sethian, et al Proc 17$^{th}$ IEEE Symp on Fusion Eng, IEEE 0-7803-4226-7/98, p 593.
[6] J. D. Sethian, et al, Digest of Technical Papers, Twelfth IEEE Pulsed Power Conference, Monterey, CA, June 27-30, 1999, p 351.

* In collaboration with M. Myers, M. Friedman, R. Lehmberg, J. Giuliani, D. Colombant, A.N. Mostovych, S.P. Obenschain, C.J. Pawley, A.J. Schmitt, V. Serlin, Plasma Physics Division, Naval Research Laboratory, J. H. Gardner, Laboratory for Computational Studies, Naval Research Laboratory, Y.A. Aglitskiy and Y. Chan, Science Applications International Corporation, McLean, VA, S. Swanekamp; Jaycor, Inc Alexandria, VA, M. Klapisch; Artep, Inc, Columbia, MD, F. Hegler Commonwealth Technology, Alexandria, VA.

**FIRE- A Next Step Option for Magnetic Fusion**, Dale Meade, Princeton University, Plasma Physics Laboratory, Princeton, NJ

The Next Step Option (NSO) activity is managed through the Virtual Laboratory for Technology (VLT) and involves a national team of universities, national laboratories, and industry including: Advanced Energy Systems, ANL, Boeing, General Atomics, Georgia Tech, INEEL, LLNL, MIT, ORNL, PPPL, Sandia, Stone and Webster, University of Illinois, and University of Wisconsin. The NSO is currently focused on FIRE, a design study to assess near term opportunities utilizing a compact high-field tokamak for producing and studying fusion-dominated plasmas in the laboratory (http://fire.pppl.gov). The study is currently at the pre-conceptual level with the goal of being ready to begin a conceptual design at the end of FY-2001. The mission of FIRE is to attain, explore, understand, and optimize alpha-dominated plasmas to provide knowledge for the design of attractive magnetic fusion energy systems. This mission requires fusion plasmas dominated by alpha heating ($Q \geq 5$) that are sustained for a duration comparable to the characteristic plasma time scales (≥ 20 tau_E and ~ 1.5 tau_skin where tau_E is the energy confinement time and tau_skin is the time for the plasma current profile to redistribute at fixed current). An overall goal is to define the minimum cost (size) device to achieve this mission with a cost target in the $1B range.

The physics activities have focused on attaining burning plasma conditions initially with elmy H-modes while maintaining the flexibility of adding other advanced modes such as reversed shear and pellet enhanced performance modes. The general parameters chosen for this study are: major radius = 2 m, minor radius = 0.525 m, strongly shaped plasma cross-section with elongation = 1.8, triangularity = 0.4, double null divertors, magnetic field on axis of 10 T (12 T), plasma current of 6.44 MA (7.7 MA) with a flat top time of

18 s (12 s) where the ( ) indicate parameters for the higher field mode of operation. Projections of performance based on existing large tokamaks indicate that FIRE can access burning plasma conditions (http://fire.pppl.gov/IAEA_Paper2_093000.pdf. There are uncertainties in projecting the performance of a burning plasma, and one of the main reasons for building a major Next Step experiment would be to resolve these uncertainties, thereby providing a basis for confidently predicting the performance of an engineering test reactor. A goal of this design study is to identify the minimum size (cost) device that would be needed to resolve these uncertainties. Studies are continuing with the goal of quantifying sensitivities in plasma performance using recent experimental data, evolving theoretical models, and incremental design point variations. In addition, studies will begin to address the capability of FIRE to address advanced tokamak (AT) modes.

The basic device concept has Oxygen-Free-High-Conductivity (OFHC)/BeCu toroidal field coils and OFHC Cu poloidal coils that are pre-cooled to 77 °K prior to the pulse. The FY-2001 engineering studies have addressed all engineering subsystems and have provided basic parameters and configuration requirements for all subsystems. The magnet and structure design activity has been taken to sufficient depth to show that the coil design can meet the project requirements with margin, exceeding the original flat top requirement by almost a factor of two. The plasma facing materials chosen are tungsten divertor plates and Be first wall tiles to minimize tritium retention issues. A plasma facing component design effort has provided a concept that meets the power and particle handling requirements for burn times of 20 s at fusion power levels of 150 MW and Q ≥ 5. A cost estimate for constructing FIRE at a Green Field site has been developed at the engineering component level based on detailed cost estimates for the magnet systems and algorithm-based estimates for the other systems. These algorithms have been calibrated to TFTR and JET construction and updated based on BPX, TPX, and ITER costing methodologies. The results indicate a cost (FY-1999$) of $323 M (including 30% contingency) for the tokamak load assembly with an additional $870 M (including 19% contingency) for auxiliary systems, power supplies, buildings, and project management. If FIRE were built at an existing site, the cost would be in the $1B range.

Engineering activities for FY-2001 include: detailed analyses of disruption effects on internal components, peer reviews of key areas in physics, engineering, and costing, a review of ways to improve performance and/or reduce the costs (configuration, materials, manufacturing), and identification of engineering R&D needs. In addition, a study of potential new design points that would accommodate a wider range of physics uncertainties has begun. As part of this study, a bucked and wedged OFHC toroidal coil will be evaluated. This study is a specific example of a design optimization that has the potential to improve performance while permitting costs to be maintained or possibly reduced. Details on the FIRE engineering activities can be found at the FIRE web site (http://fire.pppl.gov/FIRE_PAC_EngRpt.pdf) as a book-marked pdf document. A CD is available upon request (pheitzen@pppl.gov).

There will be discussions on Burning Plasma Physics and/or NSO/FIRE activities at the following meetings:

FESAC November 14-15, 2000, Bethesda, MD
VLT Program Advisory Committee meeting, December 4-5, 2000, UCLA
UFA sponsored Burning Plasma Physics Workshop, December 11-13, 2000, Austin, Texas
NSO Program Advisory Committee meeting January 17-18, 2001, MIT

FIRE has undertaken an active outreach initiative to seek the communities views on the issues to be addressed by a near term next step in magnetic fusion. If you are interested in setting up a discussion on FIRE and burning plasma issues, please contact Dale Meade (dmeade@pppl.gov).

## International Activities:

**Fusion Activities in the International Energy Agency (IEA),** Michael Roberts*, Office of Fusion Energy Sciences, US Department of Energy

International collaboration has been one of the key hallmarks of fusion research since its inception in the late 1950s. Fusion programs around the world have found it valuable to work together, pooling technical and often financial resources as well as providing access to experimental facilities and computational activities for mutual benefit in advancing fusion knowledge. One basic form of this collaboration is the bilateral arrangement between two programs, formally agreed by the governmental authorities sponsoring the fusion programs. Bilateral arrangements exist between most, but not all, of the major fusion programs. Another form of collaboration is participation in multilateral work under the auspices of an international agency. Two agencies provide these auspices for fusion work, the IEA and the International Atomic Energy Agency (IAEA). {The International Thermonuclear Experimental Reactor (ITER) Agreement is a stand-alone agreement with IAEA auspices.} While this article deals with fusion in the IEA, an important point is the growing fusion connection between the two agencies; this connection strengthens the work under both agencies and minimizes unintended overlaps, particularly in technical meetings, which both hold. For more on this point, see the second article in the May ITER Newsletter at http://www.iaea.org/worldatom/Periodicals/Iter/itermay2000.pdf.

The IEA, based in Paris, is an autonomous agency, linked with the Organization for Economic Cooperation and Development (OECD), whose objectives range from handling near-term oil supply issues to promoting rational energy policies, as well as encouragement of research, in a global context through co-operative relations with both Member and Non-Member Countries. The IEA has a Governing Board and a Secretariat and operates through three Standing Groups (on Emergency Questions of oil supply preparedness, on the Oil Market, and on Long Term Cooperation associated with energy security and environmental protection) and two Special Committees (on Non-Member Countries and on Energy Research and Technology (CERT)). The CERT sponsors four subordinate groups: the End-Use Working Party (WP), the Renewable Energy WP, the Fossil Fuels WP and the Fusion Power Coordinating Committee (FPCC). Over its 26-

year history, IEA has provided a vital means for fusion programs to work together through the FPCC on joint efforts using facilities, funds, information, and personnel collaboratively. In the 1980s, the IEA Large Coil Task enabled the US, European Union (EU) and Japan to design, build and operate this important superconducting coil test facility in Oak Ridge providing a basis for the later ITER coil design. In the physics area, collaborations that were started on several tokamak experiments in the late 1970s and early 1980s are still continuing productively.

These efforts are enabled through Implementing Agreements that provide the legal basis for joint efforts, covering all necessary aspects of working together, notably provisions dealing with intellectual property rights, planning, resources, etc. While IEA Member Countries are from North America and Western Europe with Japan, Australia and New Zealand, recent policies have actively opened participation to Non-Member Countries. The IEA now has bilateral agreements with Russia, China and India enabling their participation in IEA activities. Korea and Brazil also participate in various IEA agreements. Please see http://www.iea.org for more information.

There are eight active Implementing Agreements under FPCC auspices. Three are related to tokamak physics and technology, contributing to the overall tokamak database. These are the Large Tokamak Agreement (involving JET, JT-60 and US large tokamak science), the Poloidal Divertor Agreement (divertor–related tokamak science and technology centered on the ASDEX Upgrade facility), and the TEXTOR Agreement (technology related tokamak activities with the TEXTOR facility). There are two other concept agreements, the Stellarator and the Reversed Field Pinch Agreements, enabling collaborative work amongst the various stellarators and the various RFP devices, respectively. There are also three technology-oriented agreements. These are the Fusion Materials Agreement under which irradiation experiments have been jointly conducted, materials specimens and research results have been exchanged, and joint work has been conducted on the conceptual design of a materials testing facility, although no commitment has been made to construct such a facility. The Fusion Nuclear Technology Agreement facilitates joint work in all aspects of fusion chamber science and technologies associated with the production of tritium, the shielding of radiation-sensitive components, and the extraction of fusion energy for useful purposes. The Environment, Safety and Economics (ESE) Agreement provides a means for experts in each of these three areas to collaborate. While initial ESE work has been aimed at the environmental and safety issues primarily, interest is now commonly high for joint work in the economics area, including collaboration on designs of possible future fusion facilities, to provide insights in environmental, societal and public acceptability and economics questions that the Office of Fusion Energy Science (OFES) expects to use here in guiding US fusion science and technology activities.

An Executive Committee composed of members from each of the Contracting Parties, as the participants are called formally, manages each Implementing Agreement. The Department of Energy is the Contracting Party for the US side. Typically, the European Atomic Energy Community (EURATOM) is the Contracting Party for the European Union side and the Japan Atomic Energy Research Institute (JAERI) and the Ministry of

Education, Science, Culture and Sports (Monbusho) have been the Contracting Parties for Japan. The Ministry of Atomic Energy is the Contracting Party for Russia. The State Science and Technology Commission is China's Contracting Party.

Each Executive Committee meets regularly to plan and carry out annual programs of joint work. This plan often includes both committed activities, in which each participant provides a certain contribution to the work, typically in-kind, but occasionally in funds as well, and technical workshops. All fusion technical people are welcome to the workshops.

The FPCC supervises the fusion work in the IEA. The FPCC meetings are attended by senior representatives of the fusion programs from the US, EU, EU Fusion Program Member States, Japan, and Russia as well as Canada. Representatives from the IAEA and the Nuclear Energy Agency, another OECD body whose nuclear fission work includes materials studies of some interest to the fusion community, also participate. The FPCC agenda covers four areas: 1) IEA sponsorship issues such as the mandate and work program for the FPCC; 2) ITER and IAEA activities in the sense of information transfer; 3) Reviewing the work of the eight Implementing Agreements; and 4) New Initiatives. In recent years, the US has raised a number of topics under New Initiatives, including a focus on Remote Participation, via electronic means, in experiments at a distance. This work is becoming a natural element in collaboration without needing a specific ad-hoc group as was the case for some years. A second topic is possible interest in collaborative work in Inertial Fusion Energy (IFE) topics. Because of concerns over the connection to military applications, IFE as a topic for joint work under IEA auspices seems unlikely; joint activities are more likely to proceed for now under bilateral auspices where individual concerns can be more easily taken into consideration in developing work programs.

While the balance of science and energy motivations of the US and the other fusion programs differ, the underlying scientific and often technological efforts have many elements in common. Consequently, the IEA fusion Implementing Agreements are continuing to provide an important mechanism for the US to work closely with colleagues abroad on a whole host of technical topics of high value to the US fusion community and to the US program mission.

* Dr. Roberts was recently elected to a three-year term as Chair of the FPCC.

**Potential Well Measurements by the Laser-Induced Fluorescence Method in an Inertial-Electrostatic Confinement Fusion Device**, Kiyoshi Yoshikawa, Institute of Advanced Energy, Kyoto University, Japan

Inertial-Electrostatic Confinement Fusion (IECF) was first proposed in the 1950's aiming at future fusion power plants; it is basically a beam-beam colliding fusion device with an extremely compact and simple configuration. Working with Farnsworth at ITT laboratories in the US, Hirsch obtained in 1967 record neutron outputs of approximately

$10^8$ n/s and $10^{10}$ n/s for D-D and D-T, respectively, from a gridded IECF device driven by six ion guns(1).

After a long pause in the research, a new concept came out at the University of Illinois (UIUC) early in the 1990's, primarily involving use of a single wire-cathode grid and discovery of a new discharge mode without complicated ion guns. This resulted in a potentially promising compact neutron source for versatile industrial applications, as shown in Fig. 1. Since then, IECF research based on this concept has been carried out widely at various institutions in the world, leading to the currently highest steady-state neutron yields of $5\times10^7$ neutrons/s for D-D and $7\times10^6$ protons/s for D-$^3$He at the University of Wisconsin(2), as well as the much higher neutron production of $7\times10^8$ n/s during the peak of each pulse operated in the large-current pulse mode (17 Amps, 100 µs, 10 Hz) at UIUC(3).

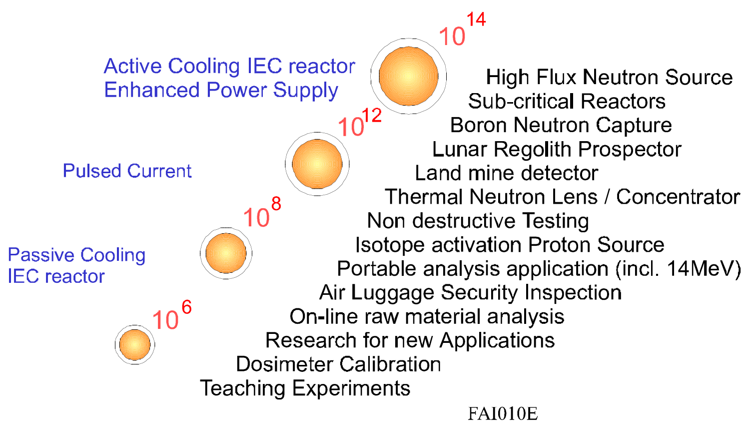


Fig. 1 Applications of IECF devices as neutron and proton sources.

For further dramatic improvement of the fusion reaction rate, however, it is essential to clarify the mechanism of potential well formation, which is predicted to develop in the central plasma core of the cathode. Potential well formation due to space charge associated with spherically converging ion beams plays a key and essential role in the beam-beam colliding fusion, i.e., the major mechanism of the IECF devices. This has been the central issue for IECF researchers for the past 30 years. The first successful direct measurement of the double-well potential profile was made in an IECF device through the Laser-Induced Fluorescence (LIF) method at Kyoto University(4) in 1999 with an approximately 200 V dip at the center in a helium plasma core, as described below.

Many theoretical results have predicted strongly localized potential well formation, and many experiments were dedicated to clarifying this mechanism using, for example, electron beam reflection, spatially collimated neutrons or proton profile measurements, or an emissive probe, but none seems to be conclusive in convincing researchers that a well does form. Recently, theoretical results predicted a very promising new nonlinear regime for dramatically enhanced fusion reaction rates in a relatively large current (perveance) region. These results urgently call for diagnostics with a higher degree of temporal and spatial resolution for verification than has been achieved by the conventional methods.

In order to cope with this urgent issue, we have adopted optical diagnostics using the Stark effect, which is sensitive to local electric fields, to the IECF device with a hollow cathode as shown in Fig. 2. Also, to enhance the signal to noise (S/N) ratio as well as to analyze the radial potential profile, we introduced the LIF method. Consequently, we have measured a double-well potential profile with an approximately 200 V dip at the center for the first time in the helium plasma core of the Kyoto University IECF device (Fig. 3).

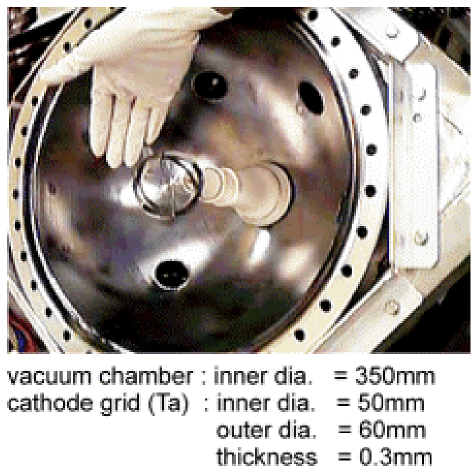


Fig. 2 A hollow cathode.

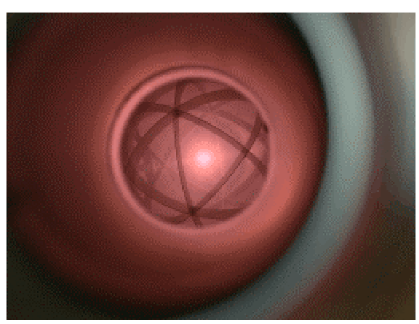

Fig. 3 An IEC plasma core at the center of the hollow cathode for scanning

The LIF system consists of a Nd:YAG laser, a dye laser to produce 504.2 nm light to cause the forbidden transition through Stark and quadrupole (QDP) transitions from $2^1S$ atoms to $3^1D$ states of HeI (Fig. 4). The LIF (667.8 nm) is then observed (Fig. 5) to provide peak spatial profiles that result in the profiles of degree of polarization, from which spatial electric field, thus potential, can be obtained. The operating conditions were chosen as: He pressure of 20-30 mTorr, cathode voltage of 7-11 kV, cathode current of 30-40 mA (regulated) to enhance the beam perveance.

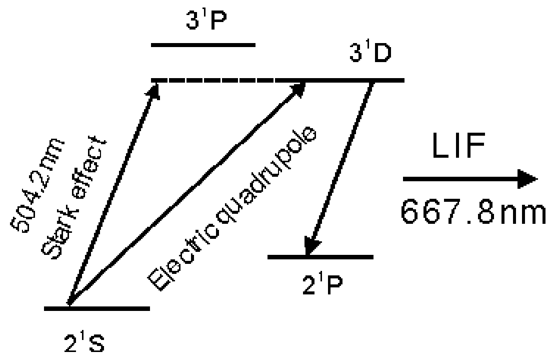


Fig. 4 Energy diagram for the LIF process of HeI

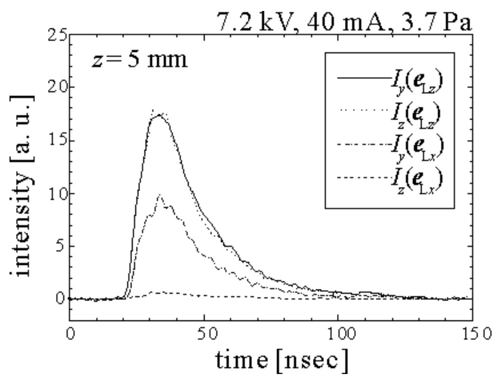


Fig. 5 Evolutions of LIF polarization components at $z$ = 5 mm

Considering the sign of the electric fields and symmetry, the potential profile along the horizontal $z$-axis is calculated by integrating the electric fields and is shown in Fig. 6 together with the representative QDP component $I_y(\boldsymbol{e}_{Lz})$. It is seen that the double well potential forms with an approximately 200 V dip in the potential profile. Also, it clearly shows peak correspondence with the QDP spatial intensity, since the peaks in the QDP profile are thought to be due to the convergence of electrons with higher energy, i.e., corresponding to the potential peaks.

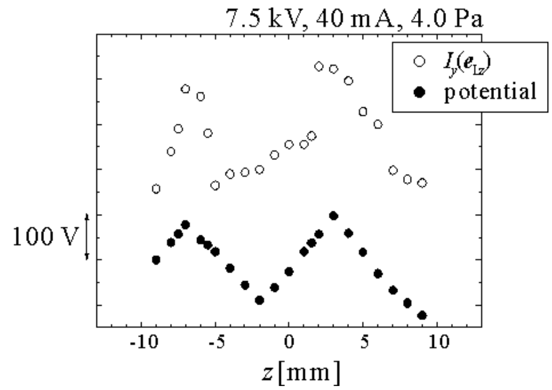


Fig. 6 Potential (black dots) and LIF QDP peak intensity (white dots) profiles along *z*-axis (horizontal).

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