# American Nuclear Society
# Fusion Energy Division
# December 2006 Newsletter

**Letter from the Chair**, Jeff Latkowski, Lawrence Livermore National Laboratory, Livermore (LLNL), CA.

First, I would like to personally thank Dr. Said Abdel-Khalik, the outgoing chair of the Fusion Energy Division (FED), for his service during his term. Said now serves not only as the past chair, but he has assumed the role of FED's liaison to the ANS Public Policy Committee.

I am pleased to report that the state of our division is quite strong. Division membership has exceeded 750 for three years in a row, and the student membership has grown to more than 200. These numbers reflect the strength and growth in the fusion community. ITER has ramped up dramatically in recent months with many team members moving from Naka and Garching to the Joint Work site in Cadarache, France. Current plans call for delivery of a new baseline design in the late spring of next year. In the U.S., NIF has demonstrated its full system performance on a single beam basis and is expected to have 25% of the beams operational by January 2007. Truly, it is a very exciting time in the fusion community!

Recently, Dr. Susana Reyes left the United States for a new position with the ITER safety team. In order to give her utmost attention to this exciting opportunity, Susana elected to resign her role as the FED Vice Chair/Chair-Elect. We will certainly miss Susana and we wish her the best with this new adventure. Fortunately, Dr. Roger Stoller has graciously agreed to step into the Vice Chair role. Roger, the Program Manager of Oak Ridge National Laboratory's Fusion Materials Program, has been a member of the Executive Committee for the past few years. Please join me in welcoming Roger to this new role within the FED.

On a very sad note, I must report that Dr. William Hogan, a longtime friend of FED, passed away in October. Bill held pretty much every position within FED, including serving as FED's representative on the ANS Public Policy Committee for the past several years. Bill was an LLNL employee for 37 years, and he was instrumental in developing the concept of inertial fusion for energy applications. Bill was a prolific author and organized many fusion conferences. He served on the editorial board of *Fusion Science and Technology* and as the associate editor of the IAEA journal, *Nuclear Fusion.* Bill was awarded the outstanding achievement award by FED in 1996. Although Bill retired from LLNL in 2001, he continued to consult for the lab and other fusion laboratories. Bill and the enthusiasm he brought will be missed by friends and colleagues alike.

We concluded a successful 17$^{th}$ Topical Meeting on the Technology of Fusion Energy (TOFE). I would like to thank Dr. Craig Olson (General Chair), Dr. Gary Rochau (Program Chair) and the rest of the 17$^{th}$ TOFE team for putting on an excellent meeting. ANS FED provided financial support ($500 per student) enabling six students to attend this meeting.

Finally, the FED Executive Committee recently approved a host for the 18$^{th}$ TOFE meeting. The 18$^{th}$ TOFE will be a stand-alone meeting held in the fall of 2008 in the San

Francisco Bay Area and will be a collaboration between the Northern California Section of the ANS and the Fusion Energy Program at Lawrence Livermore National Laboratory. The General Chair will be yours truly, and Dr. Wayne Meier will serve as the Program Chair. We look forward to seeing many of you in two years.

**Slate of Candidates for 2007/2008 FED Executive Committee**, Said Abdel-Khalik, Georgia Institute of Technology, Atlanta, GA.

All FED members will receive a ballot early in 2007 for the election of FED officers and Executive Committee members. We all will benefit from a good turnout, so please take the time to fill out and return your ballot per the instructions supplied with the ballot. The outcome of the election will be announced before the June 2007 ANS annual meeting in Boston. The FED is always looking for members who would like to become active in the operation of the division. If you are interested, please contact Jeff Latkowski (who will be chairing the nominating committee for next year's candidates) or any other member of the Executive Committee.

We have an excellent slate of candidates for the upcoming FED election and their willingness to contribute their time and effort to FED is much appreciated. The current Vice Chair/Chair-Elect, Roger Stoller (Oak Ridge National Laboratory), who replaced Susana Reyes following her resignation, will automatically become Chair for 2007-2008. We are fortunate that Professor Farrokh Najmabadi (UCSD) has agreed to run for election as Vice Chair/Chair Elect. Also, Lee Cadwallader from Idaho National Laboratory has graciously agreed to run for another term as Secretary/Treasurer. We also have a strong list of candidates for the three Executive Committee positions to be filled in this election. The Nominations Committee wishes to thank all candidates, and continuing members of the FED Executive Committee for their contributions to the success and vitality of our division.

The list of candidates (in alphabetical order) for the 2007 election consists of:

- Vice Chair/Chair-Elect: Farrokh Najmabadi (UCSD)
- Secretary/Treasurer (two-year term): Lee Cadwallader (INL)
- Executive Committee (3 members to be elected):
  - Pattrick Calderoni (Idaho National Laboratory – Idaho Falls)
  - Sam Durbin (Sandia National Laboratories - Albuquerque)
  - Mohamed Sawan (University of Wisconsin - Madison)
  - John Sethian (Naval Research Laboratory – Washington, DC).

**17th ANS Topical Meeting on the Technology of Fusion Energy**, Craig Olson, Sandia National Laboratories, Albuquerque, NM.

The 17th Topical Meeting on the Technology of Fusion Energy (TOFE) was held November 13-15, 2006 at the Albuquerque Convention Center in Albuquerque, NM. The General Chairman was Dr. Craig Olson from Sandia National Laboratories (SNL) and the Vice Chairman was Prof. Ichiro Yamamoto from Nagoya University. Mr. Gary Rochau from SNL was the Technical Program Chair and Prof. Akihiro Shimizu from Kyushu University was the Assistant Technical Program Chair. Meeting sponsors included the Fusion Energy Division (FED) of the American Nuclear Society (ANS), the U.S. Department of Energy, Sandia National Laboratories, and the Atomic Energy Society of Japan. Additional financial support for this meeting was provided by the SNL Nuclear and Risk Technologies Center, the SNL Pulsed Power Sciences Center, and the Fusion Engineering Division of the Atomic Energy Society of Japan.

The total number of papers for this meeting was 240. Since this was an embedded meeting, and since the ANS does not keep separate registration records for TOFE attendees, it is difficult to establish the exact number of TOFE attendees. Based on attendance at the opening TOFE plenary session, we estimate that the total number of TOFE attendees was about 250 or more. The number of student attendees was approximately 45. The papers were arranged into one opening plenary session, 23 oral sessions, and one large poster session. The number of invited plenary talks was 7, the number of invited oral talks was 42, the number of contributed oral talks was 99, and the number of posters was 92. After peer review, most papers will be published in the ANS journal, *Fusion Science and Technology*.

The opening plenary session included overview talks on Magnetic Fusion Energy (MFE) and Inertial Fusion Energy (IFE). Dr. David Campbell (ITER) summarized the status of the International ITER program, and noted that first plasma in ITER is expected to be in about 2016, with full DT burning plasma experiments several years later. Dr. Ned Sauthoff (ORNL) summarized the status of the U.S. ITER program, noting the specific ITER components that the U.S. will provide. Dr. Ed Moses (LLNL) summarized the status of the National Ignition Facility (NIF), which already has a small number of its 192 laser beams operational, and noted that ignition experiments on NIF will begin in 2010. Dr. Farrokh Najmabadi (UCSD) gave an overview of the ARIES-CS Compact Stellarator Power Plant study, as an introduction to two special ARIES-CS sessions held later in the meeting. Prof. Yamamoto (Nagoya University) gave an overview of recent Japanese activities and plans in fusion technology. Dr. John Sethian (NRL) gave an overview of the laser IFE program (the High Average Power Laser [HAPL] program) and the recently proposed Fusion Test Facility. Dr. Craig Olson summarized progress on the Z-Pinch IFE (Z-IFE) program.

The second day of the meeting was organized into three parallel oral sessions with presentations on ARIES-CS power plant studies; high heat flux components; tritium handling and processing; in-vessel components; IFE target fabrication, injection, and tracking; hydrogen production, socioeconomics and other fusion ideas; power plant studies; and computational tools and validation experiments. A large and lively poster session was held in the afternoon and included presentations on all aspects of fusion energy technology. The third day of the meeting was organized into three (and sometimes four) parallel oral sessions on in-vessel components and magnets; IFE drivers; engineering of experimental devices; alternate non-electric applications; material and component test facilities; nuclear analysis and experiments; ARIES-CS plant studies; IFE chamber dynamics and clearing; blanket testing and safety and environment; diagnostics; and tritium handling and processing. Substantial progress is being made in all aspects of MFE and IFE, and the intermingling of the MFE and IFE communities was enhanced by the mix of MFE and IFE presentations in each session. The growth of IFE was clearly evident at this TOFE, which had 29 papers on the HAPL program, and 23 papers on the Z-IFE program.

The TOFE banquet was held the evening of the second day. The Organizing Committee, the Technical Program Committee, and the Session Chairs were all thanked for their many contributions to TOFE. Dr. Jeff Latkowski (LLNL), ANS-FED Chair, made several announcements regarding the FED. Dr. Farrokh Najmabadi (UCSD), the Chairman of the FED Honors and Awards Committee, announced this year's award recipient Prof. Said Abdel-Khalik (GT) (see the Awards article in this newsletter). Dr. Jeff Latkowski read a memorial tribute in honor of Dr. Bill Hogan, a fusion energy pioneer from LLNL and a former head of the ANS-FED, who recently passed away. According to Dr. Ben Cipiti (SNL), the Chair for the Student Awards, the student papers could not be obtained from the ANS and reviewed until after the TOFE meeting - the winners will be announced by e-mail within a few weeks. Lastly, Dr. Jeff Latkowski announced that the 18$^{th}$ TOFE will be held in the San Francisco bay area in 2008, with Dr. Jeff Latkowski as the General Chair and Dr. Wayne Meier (LLNL) as the Technical Program Chair.

The Organizing Committee would like to thank Mary Keenan and Ellen Leitschuh from the ANS, for their extensive help in making this 17$^{th}$ TOFE possible. The Organizing Committee also thanks Dr. Nermin Uckan (editor, FS&T) for her help regarding TOFE publications. Finally, the Organizing Committee is especially thanked for making this TOFE a success:

| | |
|---|---|
| General Chair: | Craig Olson (SNL) |
| Vice Chair: | Ichiro Yamamoto (Nagoya University) |
| Technical Program Chair: | Gary Rochau (SNL) |
| Assistant Technical Program Chair: | Akihiro Shimizu (Kyushu University) |
| Abstracts Chair: | Terrie Hof (SNL) |
| Publications Chair: | Samuel Durbin (SNL) |
| Student Awards: | Ben Cipiti (SNL) |
| Publicity and WebMaster: | David York (SNL). |

## 2006 Fusion Award Recipients, Laila El-Guebaly, University of Wisconsin-Madison, Madison, WI.

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

The ANS-FED officers and executive committee members congratulate the honored recipients of the 2006 fusion awards on this well-deserved recognition and our kudos to all of them.

### ANS-FED Awards

**Said Abdel-Khalik** has been awarded the 2006 Outstanding Achievement Award of the ANS's Fusion Energy Division. The Award cites Said's "exemplary achievements in research and education in fusion science and engineering." The award was presented in November 2006 at the 17$^{th}$ TOFE meeting in Albuquerque.

**Steve Zinkle** has been selected to receive the American Nuclear Society's 2005 Outstanding Achievement Award from the ANS's Materials Science and Technology Division. The award cites Steve's "sustained contributions to the understanding of metals and ceramics materials behavior for fusion and advanced fission reactor applications." The award was presented at the ANS Novvember 2006 winter meeting in Albuquerque.

### APS Awards

The American Physical Society - Division of Plasma Physics has awarded the following prizes at the APS-DPP meeting in Philadelphia, Oct 28-Nov 3, 2006:

> **Chandrasekhar Joshi (**University of California, Los Angeles) received the James Clerk Maxwell Prize for his insight and leadership in applying plasma concepts to high energy electron and positron acceleration, and for his creative exploration of related aspects of plasma physics.
>
> **Ryosuke Kodama** (Osaka University), **Peter Norrys** (Rutherford Appleton Laboratory), **Max Tabak** (Lawrence Livermore National Laboratory), **Kazuo Tanaka** (Osaka University), and **Scott Wilks** (Lawrence Livermore National Laboratory) received the Excellence in Plasma Physics Research award for developing the Fast Ignition inertial fusion concept and for demonstrating key aspects of it in a series of experiments that have catalyzed the worldwide effort on the concept.
>
> **Cameron Geddes (**Lawrence Berkeley National Laboratory) received the Marshall N. Rosenbluth Outstanding Doctoral Thesis Award for experimental and computational studies of channel guided laser wakefield accelerators.

## Columbia University

**John Chu** received an honorary doctorate from Columbia University. **Chu**, who was a pioneer in MHD large-scale computation for fusion equilibrium and stability, was recognized at the university's 2006 commencement ceremony.

## DOE Awards

**David Crandall** and **Michael Roberts** were among 15 U.S. Department of Energy (DOE) executives chosen to be designated as "Meritorious Executives" within the U.S. government. The award is a "Presidential Rank Award" evaluated by boards of private citizens and approved by the President. The recipients are chosen for their "exceptional long-term accomplishments" within the Federal Service.

## FPA Awards

**Yutai Katoh** has been selected by Fusion Power Associates Board of Directors as the recipient of its 2006 Excellence in Fusion Engineering Award. **Katoh** was recognized for his many outstanding scientific contributions, including his leadership role in the development of new, attractive silicon carbide composites for potential use in future fusion power plants.

## IAEA Nuclear Fusion Awards

The inaugural Nuclear Fusion Award was presented recently at the 21$^{st}$ IAEA Fusion Energy Conference in Chengdu, China, for a paper that demonstrates how one of the primary physics goals of ITER might be more safely realized. The lead author **T.C. Luce**, along with contributing authors, including Oak Ridge National Laboratory's M.R. Wade and M. Murakami; General Atomics' J.R. Ferron, A.W. Hyatt, A.G. Kellman, R.J. La Haye, P.A. Politzer, and J.T. Scoville; J.E. Kinsey of Lehigh University; and C.J. Lasnier of Lawrence Livermore National Laboratory, were awarded the prestigious prize for their paper "Stationary High-Performance Discharges in the DIII-D Tokamak" published in Nuclear Fusion 43 (5), pp. 321 - 329. The paper outlines a tokamak scenario that can maintain high fusion performance at reduced plasma current (compared with the conventional tokamak operational scenario), thereby lessening the potential for structural damage in the event of a major disruption. Projections in the paper show that realization of this scenario in ITER could lead to fusion performance at or above an energy gain of 10 for longer duration with reduced risk.

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

During the October 1, 2005 – September 30, 2006 period, we received 346 manuscripts. Of the 346 papers, 153 were from North America, 97 were from Asia, 94 were from Europe (including Russia), and 2 were from other countries. We also received 48 papers/lecture notes from the 7$^{th}$ Carolus Magnus Summer School (CMSS05), published in FS&T Transactions (Feb-06). The CMSS05 papers are not included in our paper counts.

FS&T issues for the next 12 months are assigned and/or committed.

The following special/dedicated issues have been published during the reported period:

- DIII-D Tokamak (GA, San Diego) – FS&T regular issue, Oct-05 (35 papers)
- JFT-2M Tokamak (JAEA-Naka, Japan) – FS&T regular issue, Feb-06 (10 papers)
- 7th Carolus Magnus Summer School – FS&T Transactions, Feb-06 (48 lectures)
- Fast Ignition (US, EU, JA) – FS&T regular issue, Apr-06 (20 papers)
- Selected papers from 16th IFE Target Fab. – FS&T camera ready, May-06 (49 papers)
- Papers from 15th IEA Stellarator (Part 1) – FS&T regular issue, Aug-06 (26 papers).

The following special/dedicated issues are being published or planned for the remainder of 2006 and 2007-2008:

- Papers from 15th IEA Stellarator (Part 2) – FS&T regular issues, Oct-06 (17 papers)
- Papers from 15th IEA Stellarator (Part 3) – FS&T regular issues, Jan-07 (15 papers)
- NCSX Stellarator – FS&T regular issue, Feb-07 (7 papers)
- Open Systems 2006 – FS&T Transactions, Feb-07 (papers due)
- Alcator C-Mod Tokamak (MIT) – FS&T regular issue, Apr-07 (14 papers)
- Selected papers from 17th IFE Target Fab. – FS&T camera ready, May-07 (50+ papers)
- MFE Diagnostics (EU, JA, RF, US) – FS&T regular issue (13 papers, to be scheduled)
- TOFE-06 Proceedings – FS&T camera-ready (200+ papers, to be scheduled)
- ECH/ECE Physics and Technology – FS&T regular issues (54 papers, to be scheduled).

The following special/dedicated issues are in the planning stages:

- ARIES Compact Stellarator Power Plant Study – FS&T regular issue (papers due 2007)
- JET Tokamak (Culham, England) – FS&T regular issue (papers due 2007)
- Tritium 2007 – FS&T Proceedings (under discussions for 2008)
- 16th IEA Stellarator (2007) – FS&T regular issues (under discussion for 2008)
- DEMO Studies (EU, JA) – FS&T regular issue (in planning/preparation)
- IFMIF (EU, JA, US) – FS&T regular issue (in planning/preparation)
- Test Blankets (EU, JA, RF, US) – FS&T regular issue (in planning/preparation)
- NIF (LLNL) – FS&T regular issue (in planning – on hold?)
- KSTAR (Korea) – FS&T regular issue (under discussion for 2008/09)
- W7-X (Germany) – FS&T regular issue (under discussion for late 2008/09).

Over the past 6 years, the journal has grown and manuscript submissions have increased steadily. Summary of paper statistics during this and previous periods are summarized in the following tables:

| FS&T Manuscript Submission by Region 10/01 through 09/30 | | | | | |
|---|---|---|---|---|---|
| Year | Total Ms Received | North America | Asia | Europe | Others |
| 2005/06 | 346 | 153 | 97 | 94 | 2 |
| 2004/05 | 363 | 156 | 89 | 114 | 4 |
| 2003/04 | 296 | 158 | 68 | 68 | 2 |
| 2002/03 | 232 | 99 | 51 | 35 | 47* |
| 2001/02 | 140 | 53 | 55 | 30 | 2 |
| 2000/01 | 55 | 25 | 14 | 13 | 3 |
| * For 2002/03: Rejected/withdrawn papers from TOFE02 are included under other regions, not sorted out in the ANS/FS&T database. | | | | | |

| FS&T Manuscripts in Progress 10/01 through 09/30 | | | | |
|---|---|---|---|---|
| Year | Total Ms Received | Accepted/ Scheduled | Rejected/ Withdrawn | Review/ Revision |
| 2005/06 | 346 | 138 | 43 | 165 |
| 2004/05 | 363 | 299 | 64 | 0 |
| 2003/04 | 296 | 249 | 47 | 0 |
| 2002/03 | 232 | 153 | 79 | 0 |
| 2001/02 | 140 | 116 | 24 | 0 |
| 2000/01 | 55 | 34 | 21 | 0 |

FS&T is now offering color printing for the special issues and will soon be offering online color figures for regular/special issues. April 2007 issue will serve as a test for future application of color figures online for all three ANS journals.

Please check your library subscription. Electronic access to FS&T is available from 1997-to-current. Additional journal back issues will continue to be added (depending on demand). Tables of contents and abstracts of papers can be accessed at http://www.ans.org/pubs/journals/fst. Individual and library subscribers can access the full text articles at http://epubs.ans.org/.

On a personal note, I am saddened to report that one of our editorial advisory board members, Dr. William J. Hogan, a pioneer and leader in the field of inertial fusion energy, passed away on 19 October 2006 at the age of 66. FS&T and his friends and colleagues around the world will sorely miss his hard work, friendship, and enthusiasm.

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

## Ongoing Fusion Research:

**ARIES-CS Compact Stellarator**, A. René Raffray, University of California, San Diego, La Jolla, CA.

ARIES is a multi-institution national program led by UCSD (with Prof. F. Najmabadi as program leader). Its mission is to perform advanced integrated studies of long-term fusion energy concepts to identify key R&D directions and to provide visions for the fusion program. The ARIES Team (see Fig. 1) is completing a three-phase study of a compact stellarator power plant, ARIES-CS, to explore attractive compact stellarator configurations and to define key R&D areas [1].

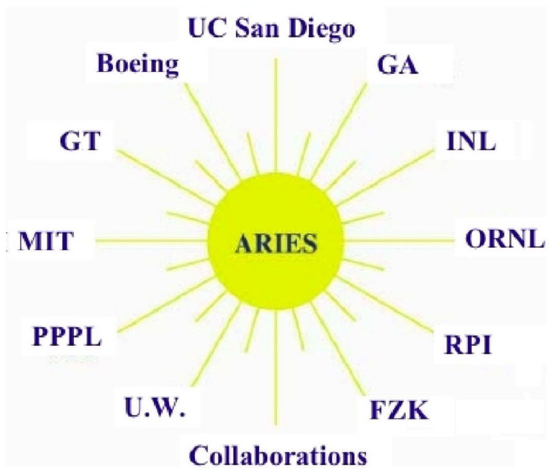


Fig. 1. Multi-institution ARIES team.

In a stellarator, most of the confining field is produced by the external coils (the poloidal field is generated by the external coils as well as the bootstrap current). Stellarators have many attractive features as a power plant because there is no large driven external current; they are an inherently steady state device (with low recirculating power), stable against external kink and axisymmetric modes, and resilient to plasma disruptions. Earlier stellarator power plant studies resulted in large devices because of the constraints imposed by the minimum distance between the plasma and the coils and of the relatively large aspect ratios. A major thrust of the ARIES-CS study was aimed at reducing the device size by:

1) Developing configurations with reduced plasma (or coil) aspect ratio while maintaining the “good” stellarator properties; and/or
2) Reducing the required minimum coil-plasma distance through nuclear optimization.

The early phases of the study focused on exploration of physics and engineering options, leading to a choice of preferred configuration and design parameters for the detailed and integrated power plant study performed during the final phase of the study. Several quasi-axisymmetric configurations were explored, including NCSX-like 3-field period and MHH2-like 2-field period configurations, and physics results indicated the possibility of low plasma aspect ratio (~4.5) [2].

## Power Plant Configuration

Both physics and engineering constraints were used in the system and cost optimization of the configuration and machine parameters [3]. Key engineering considerations include the size of the power core, access for maintenance, penetration requirements, and the minimum distance between the plasma and coil that affects shielding and breeding.

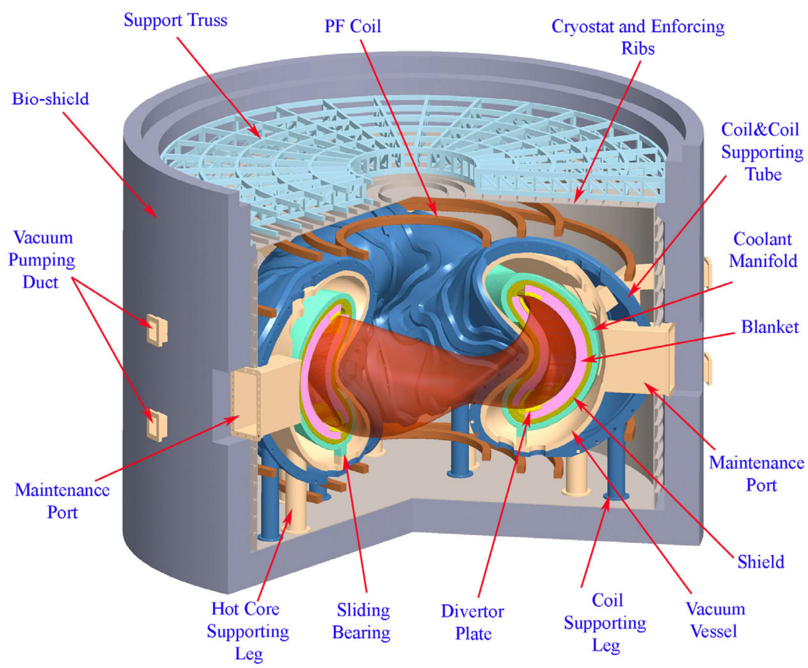


Fig. 2. ARIES-CS machine layout.

A number of maintenance schemes and blanket concepts were evaluated. Our preferred option in a 3-field period configuration is a dual-coolant (He+Pb-17Li) ferritic-steel modular blanket concept coupled with a Brayton power cycle (with a resulting efficiency of 42%) and a port-based maintenance scheme utilizing articulated booms [4]. The vacuum vessel is internal to the coils and for blanket maintenance, no disassembling and re-welding of the VV is required and modular coils are kept at cryogenic temperatures. The overall coil system, consisting of the inter-coil structure, coil cases and winding packs, is enclosed in a common cryostat. The coils are wound into grooves at the inside of a strong supporting toroidal tube for each field period, which are then bolted together to provide a ring structure to accommodate the electromagnetic forces. A schematic of the ARIES-CS machine layout for a 3-field period configuration is shown in Fig. 2 and a cross-section showing details of the power core components is shown in Fig. 3. The machine parameters are summarized in Table I. These are based on system optimization at the limit of many constraints to assess how "compact" a stellarator can be, but with the understanding that it might be better that some of these parameters can be relaxed (e.g. major radius) to provide more margins on space and material stress/temperature limits.

Table I. ARIES-CS parameters

| | |
|---|---|
| Average major radius | 7.75 m |
| Average minor radius | 1.7 m |
| Aspect ratio | 4.5 |
| Minimum coil-plasma distance | 1.3 m |
| $\beta$ | 5.0% |
| Number of coils | 18 |
| On-axis magnetic field | 5.7 T |
| Maximum magnetic field at coil | 15.1 T |
| Fusion power/electrical power | 2.4/1 GW |
| Average/maximum neutron wall load | 2.6/5.3 $MW/m^2$ |
| Alpha loss | 5% |

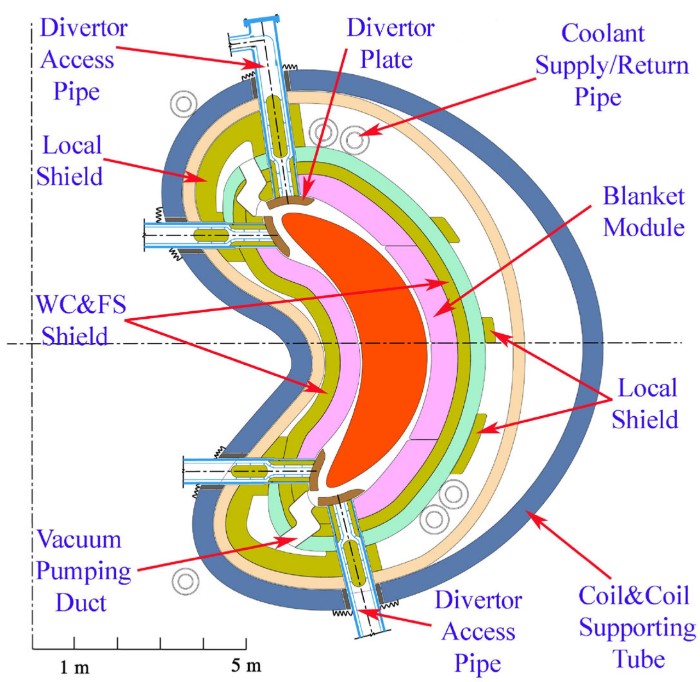


Fig. 3. ARIES-CS cross-section at the 0° toroidal location.

## Engineering Summary

The engineering effort has yielded some interesting and some new evolutions in power core design, including [4,5]:

- Novel blanket/shield approach utilizing highly efficient tungsten carbide shielding to minimize plasma to coil minimum distance by ~20-25% and reduce machine size, while providing the required shielding and breeding (overall tritium breeding ratio = 1.1).
- First ever 3-D modeling of complex stellarator geometry for nuclear assessment using CAD/MCNP coupling approach.
- Minimization of thermal stresses as guiding principles in design, including separation of the hot core components from the colder vacuum vessel (allowing for differential expansion through slide bearings).
- Design of coil structure over one field-period with variable thickness based on local stress/displacement; when combined with a rapid prototypic fabrication technique this can result in significant cost reduction.
- Development of He-cooled W-alloy T-tube unit able to accommodate at least 10 $MW/m^2$ and applicable to both stellarator and tokamak divertors. However, R&D is required on W-alloy material and fabrication development.
- Possibility of in-situ alignment of divertor, if required.
- Significant reduction in stellarator radwaste stream.
- Decay heat removal in ARIES-CS achievable by VV in natural convection mode.
- Accommodation of pressurization events without failure of all ARIES-CS confinement boundaries.
- Accommodation of alpha loss (~5%) heat flux using divertor-like modules; however, R&D is required to find an engineering solution to the He implantation issue (perhaps with a porous nano-structured W armor).

For more information, please visit our website at: http://aries.ucsd.edu/ARIES

**References**:

(All presented at the 17$^{th}$ ANS TOFE, Albuquerque, NM, November 2006.)

[1] F. Najmabadi and the ARIES Team, "Overview of ARIES-CS Compact Stellarator Power Plant Study."

[2] L. P. Ku and the ARIES Team, "Configuration Optimization and Physics Basis of ARIES-CS."

[3] J.F. Lyon, L.P. Ku, L. El-Guebaly, L. Bromberg and the ARIES Team, "Optimization of the ARIES-CS Compact Stellarator Power Plant Parameters."

[4] A.R. Raffray, L. El-Guebaly, T. Ihli, S. Malang, X. Wang and the ARIES-CS Team, "Engineering Design and Analysis of the ARIES-CS Power Plant."

[5] L. El-Guebaly, R. Raffray, S. Malang. J. Lyon, et al., "Overview of ARIES-CS In-vessel Components: Integration of Nuclear, Economic, and Safety Constraints in Compact Stellarator Design."

## The Laser-Based Fusion Test Facility: on the Road Towards Practical Fusion Energy, Stephen Obenschain, John Sethian and Andrew Schmitt, Plasma Physics Division, U.S. Naval Research Laboratory, Washington DC.

An alternate and complementary path to magnetic fusion energy is inertial fusion in which small pellets of frozen deuterium-tritium are imploded to high velocities (100's of km/s) to obtain fusion burn. Most laboratory work in inertial fusion has involved large laser systems that can provide at most one or two laser-target interaction experiments per hour. A laser fusion power plant would need to operate at 5 to 10 Hz, requiring over 15,000 times higher repetition rate. There would be similar increases in other important parameters such as the average neutron and charged particle flux on the reaction chamber walls. Laser fusion power plants are thought to need several megajoule laser energies in order to obtain sufficient energy gain and power from the pellet implosions to economically supply power to the grid. However, there would be tremendous advantages in the cost and speed of development if one could build substantially smaller high repetition facilities prior to the full scale power plants. Recent progress in target designs along with progress in laser technology could allow high-repetition ignition facilities that would fill this fast-track development role. For example, gains above 50 are predicted for directly driven implosions using a krypton fluoride (KrF) laser driver with energy of 500 kJ. (For reference, this is about one third the design energy of the National Ignition Facility (NIF) under construction at Lawrence Livermore National Laboratory). These advances have prompted consideration of a laser based Fusion Test Facility (FTF) to develop and demonstrate the unique science and technology needed for a laser fusion energy power plant. The baseline design incorporates a 500 kJ KrF laser in a direct-drive configuration [1]. With a 5 Hz 500 kJ laser, a pellet gain of 50 would provide 125 MW of fusion power. The resulting neutron flux would be sufficient to test the durability of large components needed for a power plant, as well as demonstrating crucial technologies such as breeding tritium fuel for the fusion reaction. This knowledge base would pave the way for evaluating the economic feasibility and building follow-on full size power plants.

### 3-Stage Plan to Energy

The proposed FTF is part of a three stage plan to develop laser fusion energy. In each of these stages the essential elements are developed and implemented as systems in progressively more capable IFE oriented facilities. In Stage I, the basic science and technology for the FTF would be developed in parallel with existing efforts to develop and demonstrate single shot ignition on facilities like the NIF. The Stage I effort would culminate in demonstration of a full size beamline needed for the FTF, as well as other critical technologies such as prototype target fabrication and injection systems. Stage II would be the construction and utilization of the FTF. The FTF should provide the technological basis for full size prototype power plants in Stage III. Stage III would involve building prototype power plants that could be connected to the grid. We envision that the FTF could operate before 2020, so the entire three stage development program could, in principle, be accomplished well before 2040.

## Objectives of the Fusion Test Facility

The primary usefulness of the FTF in advancing the feasibility of fusion energy would be four-fold:

1. Develop the key components of a laser fusion system and demonstrate they can work together with the precision, repetition rate, and durability required for a power plant.
2. Provide a platform to evaluate and optimize the fusion energy pellet physics: while the facility would be initially optimized for advanced direct drive, other potentially high-performance concepts such as Fast Ignition might also be explored.
3. Provide a facility to test and evaluate materials and components for a fusion power plant.
4. Provide operational experience and develop techniques applicable to follow-on full-scale power plants.

## The Physics Underpinnings for the Fusion Test Facility

Direct-drive was the first approach proposed for laser fusion because of its simplicity and efficiency. It remains the simplest, and now offers a path both to ignition at modest energy for development facilities like the FTF, and the high-gains (>100x) required for economical power production. Two laser drivers show promise for the laser fusion energy application; frequency-tripled diode pumped solid state lasers, and the krypton fluoride laser. It was well known that the deeper ultraviolet UV wavelength with the KrF laser provides advantages in the interaction physics. However, it was only recently realized that this advantage is accentuated at energies near that required for ignition, and the deeper UV allows ignition and moderate gain at about half the energy previously thought to be needed. High-resolution 2-D simulations of a pellet implosion (see Fig. 1) using a 490 kJ KrF driver have given gains above 50x even after accounting for gain degradation from hydrodynamic instability seeded by shell surface imperfections.

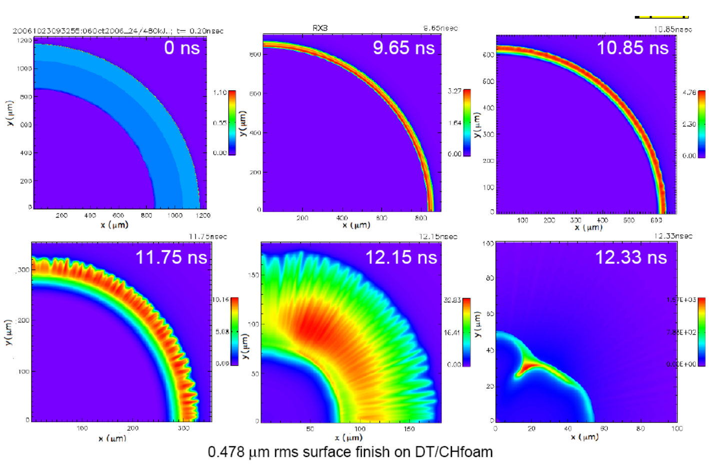


Fig. 1. High resolution 2-dimesional simulation of a pellet implosion with a 490 kJ KrF driver. The design is resistant to the effects of hydrodynamic instability and gave a yield of 27 MJ despite growth of instability seeded by outer surface imperfections.

## The Technological Underpinnings for the Fusion Test Facility

The FTF would build on the laser and target technology of existing single shot systems, but there needs to be far higher levels of durability and the targets need to be mass produced and less expensive. The Naval Research Laboratory (NRL) Electra system has been developing the basic technologies needed for durable high energy, high repetition rate KrF laser systems. Highlights of progress to date include multithousand shot continuous runs at 1-5 Hz, with laser energies of 300-700 Joules. The overall laser efficiency as a fusion drive is predicted to be at least 7%, sufficient for the long term power plant application. General Atomics has recently demonstrated construction of pellet shells consisting of low density foam that meet all the pellet specifications, and that used techniques consistent with mass production. These shells, when filled with DT, form the pellet's ablation layer and need to be precise and smooth to achieve a symmetric pellet implosion. Under the auspices of NNSA's High Average Power Laser Program [2] there have been similar advances in development of concepts for the chamber wall, the final optic, and the target injection, tracking and beam alignment.

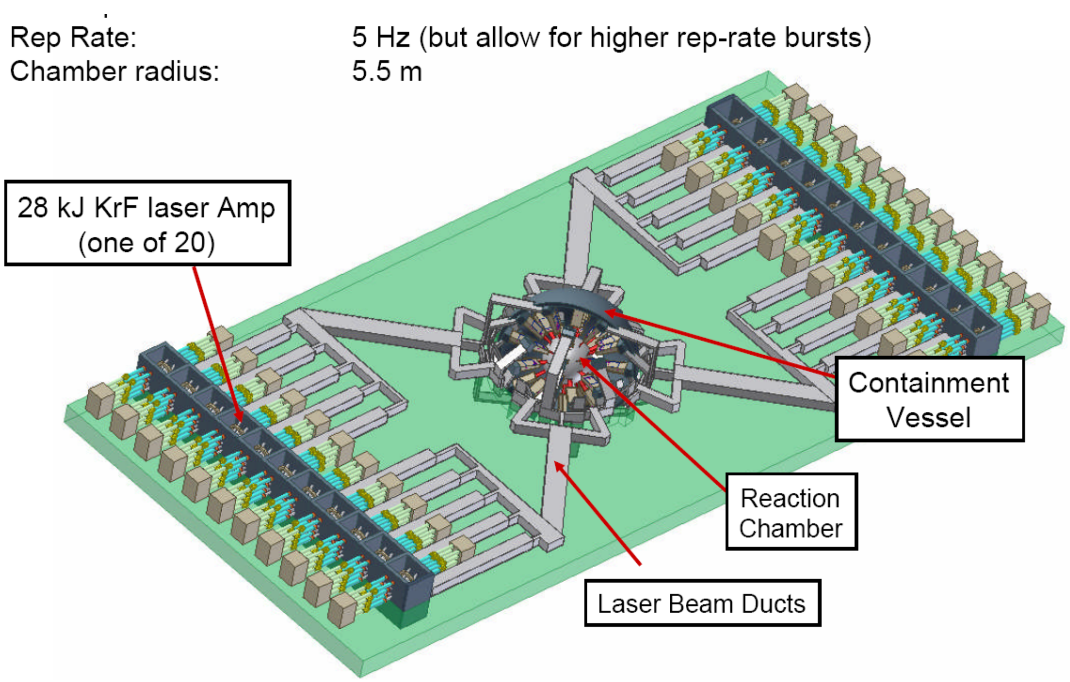


Fig. 2. Conceptual configuration for a KrF based fusion test facility.

## The Fusion Test Facility Configuration

A conceptual design for a Fusion Test Facility has been developed using a KrF driver. This involves modest extrapolations from demonstrated technologies. As shown in Fig. 2, twenty 28 kJ final amplifier modules produce 500 kJ of laser light on target (after losses) distributed in 1800, 2 ns long, angularly multiplexed beams. The beams can be arranged in clusters for uniform target illumination. Note also there are two spare amplifiers shown in Fig. 2. These can be used for spares, for backlighters, or even for more advanced target concepts such as fast ignition. In the baseline design, there are 45 clusters arranged in 6 rings centered on the target. Only 2% of the solid angle is taken up by the optics, so there would be plenty of room between the clustered beams to place components and materials for testing in a high-flux neutron environment. Since the neutrons emanate from a point source, one could conduct accelerated testing by placing the object closer to the target.

The FTF would develop and demonstrate many of the essential technologies needed for full scale power plants. This includes a durable reaction chamber, routine high reaction target fabrication and injection, and breeding of the tritium fuel from neutrons interacting with a chamber blanket.

**References:**


[1] S.P. Obenschain, D.G. Colombant, A.J. Schmitt, J.D. Sethian, and M.W. McGeogh, "Pathway to a lower cost high repetition rate ignition facility," Phys. Plasmas 13, 056320 (2006).

[2] The High Average Power Laser Program, http://www-ferp.ucsd.edu/HAPL


## Plan for U.S. Participation in the ITER Test Blanket Module Program,


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Test Blanket Modules (TBMs) inserted in ITER represent a principal strategy by which ITER will provide experimental data on the potential of fusion as an energy source. TBMs are essential to answering two critical questions about D-T fusion:

- *Can tritium be produced in the blanket at a rate sufficient to supply tritium to fuel the plasma?*
- *Can heat be extracted from the blanket, simultaneously with tritium breeding, at temperatures high enough for efficient electricity generation?*

Breeding blankets are complex, heterogeneous, highly integrated systems with diverse, competing constraints: multiple materials and material interfaces; and complex fabrication with many welds and joints. No fusion blanket has ever been build or tested, and their satisfactory integrated functioning is by no means assured. This is why successful TBM experiments in ITER represent an essential step on the path to DEMO in all the ITER Parties' fusion development plans, including the U.S.

### Coordination of TBM Testing in ITER

More than a decade ago, during the early stages of the ITER project, the ITER Parties decided to keep the management of the TBM program independent of that for the ITER design and construction. Therefore, an ITER Test Blanket Working Group (TBWG), consisting of senior representatives from the International Team and the Parties, has been responsible for the coordination of the blanket module test program and its interface with the ITER device. Over the last two years, TBWG, with strong U.S. participation and intellectual leadership, has made significant progress in defining a credible and practical ITER TBM Testing Program making use of the three equatorial ports reserved for TBM testing. Currently, TBWG, ITER management, and government level representatives of the Parties are exploring scenarios for test space allocation, ITER machine and TBM interface requirements, international collaboration, information sharing, intellectual property rights, and other issues.

## Preparation of a Draft U.S. TBM Plan

The current planning calls for the first TBMs to be delivered to ITER for installation before the first phase of ITER plasma operation, *i.e.* prior to the beginning of the H-H plasma phase. This "Day One" testing in the H-H (non-nuclear) phase is valuable for several reasons, including: determination of ITER plasma control parameters in the presence of ferritic-steel-containing modules, qualification of TBM remote handling and port integration procedures, and demonstration of the operation and control of TBM systems; all three of which are needed for qualification and licensing of ITER for D-T (nuclear) operation. In order to prepare for the U.S. participation, a preliminary technical plan and cost estimate for a U.S. ITER Test Blanket Module (TBM) Program has been under development for the past year [1], in response to a request from the Office of Fusion Energy Sciences in the U.S. Department of Energy (DOE). This technical plan and cost estimate were evolved by a team that included scientists and engineers from Plasma Chamber, Materials, Safety, Tritium, and Plasma-Facing Components elements of the U.S. fusion program, complemented by input from DOE project costing and scheduling professionals.

Two blanket concepts with substantially different features, performance, and feasibility issues – the Dual-Coolant Lead-Lithium (DCLL) and the Helium-Cooled Ceramic Breeder (HCCB) – have been proposed for testing in ITER by the U.S. The DCLL is chosen as an innovative concept that provides a "pathway" to higher outlet temperature (~700$^{o}$C) and higher efficiency while using current generation reduced-activation ferritic steel (RAFS) as the structural material and SiC flow channel inserts as the non-structural, electrical and thermal insulator (see Fig. 1A). The HCCB is chosen as the most likely candidate for near term tritium breeding blankets, e.g. in an extended performance phase of ITER, while providing high grade heat for electricity production (see Fig. 1B).

A U.S. strategy for ITER TBMs is proposed where a series of TBMs are tested during the first 10 years of ITER operation (2016–2026), each with a different technical mission and unique set of diagnostics designed to maximally exploit the ITER testing environment. For the DCLL, an independent TBM will occupy vertical half of an ITER test port (484 – 1660 mm, the standard size TBM as proposed by ITER), with supporting ancillary equipment including helium and PbLi coolant loops, tritium processing systems, and diagnostic support systems (see Fig. 2). DCLL tests in ITER during the first 10 years will operate with PbLi outlet temperature at or below the compatibility limit with RAFS (~470$^{o}$C). At these PbLi temperatures, the key features of the DCLL blanket can still be tested and studied, without the need for immediate development of higher temperature piping material. The U.S. strategy for the HCCB concept is to test a series of smaller sub-modules with size 1/3 of horizontal half-port, each with its own first wall structure, but sharing a common half-port manifold/support structure and ancillary equipment with international partners.

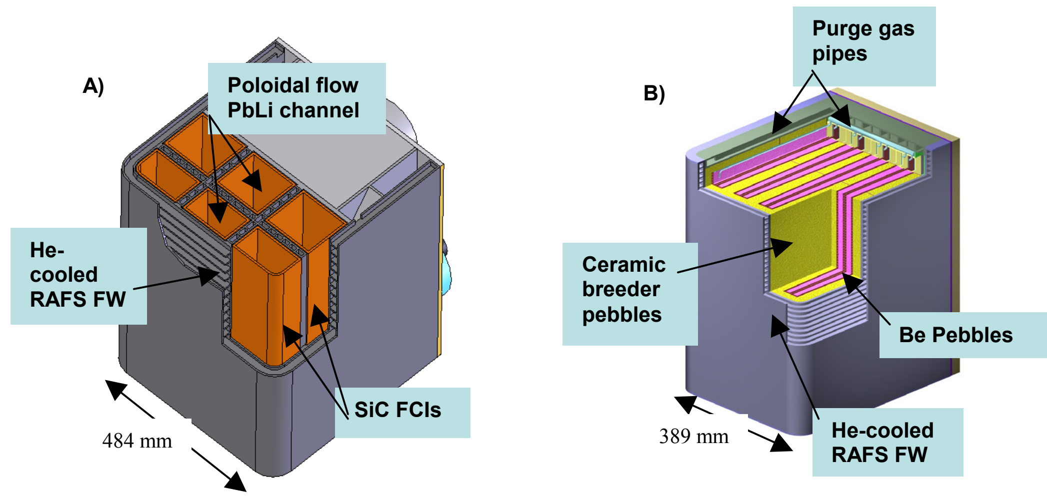
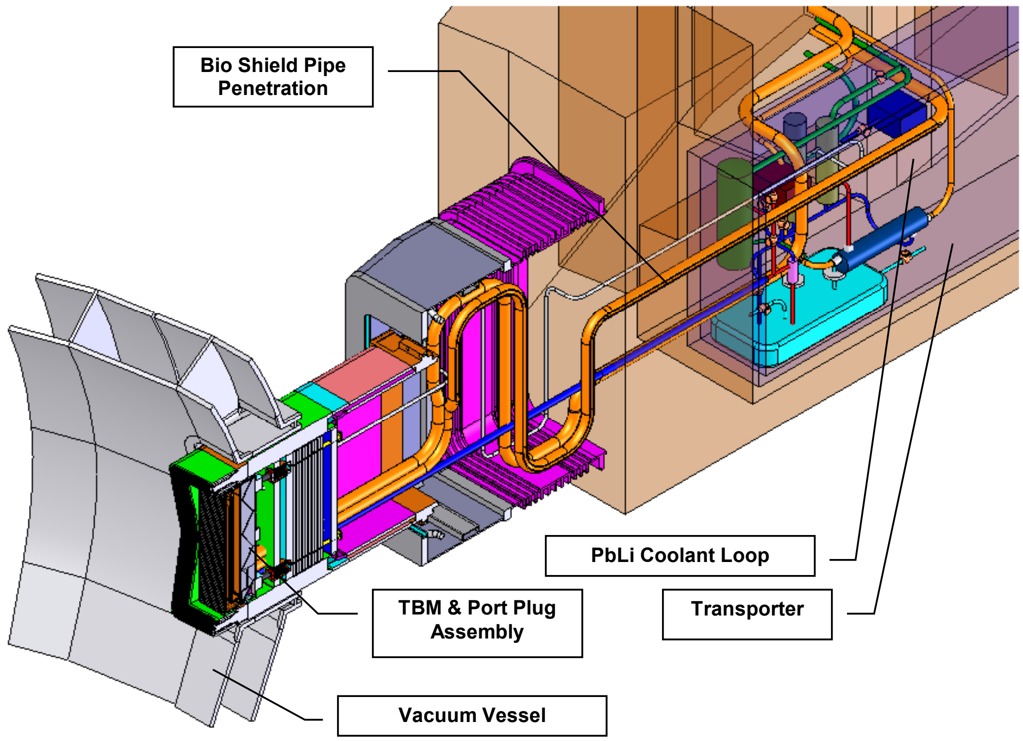



Fig. 1. Cutaway views of conceptual U.S. (A) DCLL (size 484 x 1660 mm) and (B) HCCB (size 389 x 710 mm) test blanket modules showing key features.

## International Collaboration

The worldwide blanket programs have historically been highly collaborative. In developing the proposed U.S. plan, it was recognized that the level of assumed international collaboration is a larger driver of overall program costs than uncertainty in other areas. To address this reality, several program scenarios were evaluated, whose primary distinction is the degree of assumed international collaboration and cost sharing with other Parties. The U.S. costs average between \$5M to \$10M per year over the next 10 years for all the R&D, design, engineering, fabrication and testing needed for the U.S. H-H Phase TBMs and their supporting systems. The exact amount depends on the level of international collaboration and degree of integration among the ITER Parties. A significant fraction of the manpower, facilities, codes and other important resources already exist in the base program. Large ticket items include the development of a qualified fabrication technology for RAFS TBM structures; testing of partially-integrated TBM mockups and prototypes; and the engineering design and fabrication costs of first prototypes, TBMs, and TBM support systems, including helium and PbLi coolant loops.




HCCB (size 389 x 710 mm) test blanket modules showing key features.

Fig. 2. Perspective view of DCLL TBM and supporting systems in an ITER equatorial port and port cell area.

## U.S. TBM Plan Reviewed in Oak Ridge National Laboratory

An intensive two-day external review of the proposed U.S. Plan was conducted in August 2006 at ORNL by technical and project experts invited by the DOE. The review was well attended by the U.S. fusion technology community and the U.S. ITER Project Office. The review committee found that the "TBM effort is essential for the overall development of fusion in the U.S.," and strongly recommended that the effort continue. The cost estimate and plan were found to be "complete and credible" and "ready to be implemented". Reviewers strongly recommended the U.S. move forward with establishing collaborations to take advantage of technical and cost sharing opportunities, and push for settlement of port allocation and qualification rules to help reduce uncertainties in the proposed U.S. plan.

## The Path Forward for U.S. ITER TBM

The draft U.S. TBM Program Plan Report [1] and review make the case that utilization of ITER for fusion nuclear technology experiments and testing is essential for the U.S. to build knowledge, experience, and competence in fusion nuclear and tritium technologies that are so vital to the feasibility, practicality, and safe operation of D-T fusion devices. Without TBM and ignoring power extraction and tritium self-sufficiency, the U.S. fusion strategy for the mid- to long-term will have an obvious hole – invalidating any claim to meet an energy goal. For these reasons, TBM is already included in the Energy Policy Act Plan on the proposed U.S. participation and scientific program in ITER, submitted to

Congress earlier this year. The U.S. DOE is currently considering the plan options and the results of the TBM review as part of the process for determining the type and scope of the U.S. program for Test Blanket Module experiments in ITER.

**References**:

[1] M.A. Abdou et al., "US ITER Test Blanket Module (TBM) Program. Volume 1: Technical Plan and Cost Estimate Summary," UCLA Report UCLA-FNT-216 (2006).

## International Activities:

**ITER Progress,** Ned Sauthoff, U.S. ITER Project Office, Oak Ridge National Laboratory, Oak Ridge, TN.

Following the April 2006 selection of the ITER Principal Deputy Director General Norbert Holtkamp and the initialing of the ITER Joint Implementing Agreement in May 2006, the ITER team has been moving toward real construction. The ITER Director General (DG) solicited from the parties' candidates for the positions of Deputy Director General (DDG) and completed these selections; the DDGs are now either in Cadarache or soon to arrive there. The ITER team is now moving toward recruiting staff, advancing the design, and preparing for the signing of the ITER Agreement.

The DG has issued several postings of "Urgent Positions" to which the ITER parties have supplied candidates; in many cases, the candidates have been interviewed and the position awarded in the form of a secondment since the ITER Organization does not yet exist as a legal entity capable of offering employment. Pending positions for which the U.S. intends to offer candidates are posted on http://www.usiter.org/.

R&D and design work continue to be performed by the parties. The ITER DG and PDDG have announced a design review process to be conducted under their auspices starting in November 2006 with the goal being the establishment of a new baseline in Summer 2007. Working Groups have been formed in areas of near-term urgency; these groups will collect and assess so-called "issue cards" that identify issues or opportunities. In the U.S., the U.S. ITER Project Office, the Burning Plasma Organization, and the Virtual Laboratory for Technology are all working to prepare and submit issue cards. For further information, contact Brad Nelson at ORNL.

The ITER parties expect to jointly sign the ITER Joint Implementing Agreement on November 21, 2006. This action will build on the initialing that occurred in May 2006 and will set into motion the ratification activities required in several parties before the ITER Agreement comes into force. The parties are exploring a provisional application of the Agreement following the signing and preceding ratification to enable the ITER Organization to form as a legal entity prior to ratification.

The ITER Central Team has just launched the ITER Newsline, a new online publication aimed to inform the fusion community on the current status of the ITER project. To be published bi-weekly, it will contain a status update, announcements, staff changes, what happens on the ITER site, news on the Domestic Agencies, a calendar, a Directors' corner, etc. The ITER Newsline can be found at: http://www.iter.org/newsline/issues/current/ITERnewsline.htm. A link is also present on the ITER homepage http://www.iter.org/. If you would like to automatically receive a PDF copy of the ITER Newsline in your email box every two weeks, please send a request to mark.westra@iter.org. Comments, suggestions and corrections are also welcome.

## Highlights of the 8th IAEA Technical Meeting on Fusion Power Plant Safety

A. Malaquias, G. Mank, M. El-Shanawany, International Atomic Energy Agency (IAEA), Vienna, Austria.

### Background

Over the last two decades, advances in fusion research and technology have boosted awareness of the potential of fusion to be a lasting and clean source of energy. The decision to construct ITER represents a landmark in the path to underpin the plasma burning approach. Attention is now focused at assessing balance between advances in the technology and safety requirements aiming at demonstrating safe operation and satisfying the licensing requests for ITER. However, the current work is just the beginning of a more challenging process: the establishment of the safety basis for the licensing of a DEMO fusion power plant.

The IAEA is planning to continue the series of Technical Meetings (TMs) on Fusion Safety as recommended by the International Fusion Research Council. This series of Technical Meetings started in 1980 and is held approximately every 4 years. The objective of the 8th meeting was to examine in an integrated manner all safety aspects of the first prototype power plant, expected to become operational by the middle of the century, that will lead to the first generation of economically viable power plants with attractive safety and environmental features.

Lessons learned from ITER are expected to be useful for the safety assessment of the DEMO. Moreover, some of the safety approaches and requirements currently being developed for a DEMO plant could be tested within the ITER project. The same is true in principle for the inertial fusion devices under construction, sharing many safety issues with magnetic confinement fusion. However, the participation of the inertial fusion community in the 8th meeting was modest and more effort should be put in place to enhance their participation in the future.

### The 8th Technical Meeting

The 8th IAEA Technical Meeting on Fusion Power Plant Safety was held at the IAEA headquarters in Vienna from 10 to 13 July, 2006. Thirty-seven participants from 12 countries, European Union, IAEA and ITER contributed to the discussions. There were 28 presentations including four invited speakers on the topics of the meeting. The International Advisory Committee under chairman B.N. Kolbasov (Russian Federation) was responsible for evaluating the submitted papers and organizing the meeting program. A brief summary of the topics discussed is given below.

## Fusion Specific Operational Safety Approach

The U.S. fusion program has long recognized that the safety and environmental potential of fusion can be attained by prudent materials selection, appropriate design choices, and integration of safety requirements into the design of the facility. The availability of fusion plants was also discussed. The present tokamak's availability (experimental time) is affected mainly by the unreliability of components. The availability in most of the machines is about 75%. The determination of the availability target for ITER and assessment of the main factors contributing to its unavailability were recommended. An update of ongoing work exploring characteristics, quantities, and behavior of dust in fusion facilities was presented. Particular emphasis was placed on the concerns about dust in ITER, whereas extrapolation to a fusion power plant would be premature with the present level of understanding.

## Fusion Reactor Licensing Basis, Requirements and Computational Codes

Several studies were presented covering mostly the ITER licensing case from the site preparation phase to the present status of implementation in Cadarache as substantiated in the "Dossier d'Options de Sûreté" (DOS). In France, ITER is considered a research facility in the class of "laboratories and fuel plants." Its consideration by regulatory bodies would provide a possible route for licensing fusion power plants. In this perspective, the speakers stressed the need for continuous communication between scientific and regulatory safety communities, public education, and debate.

The safety assessment is based on the two approaches (namely conservative and best estimates) to demonstrate adequate safety margins in the design. The need for an international fusion safety structure to address the fusion-specific safety issues was also discussed. The meeting debated the idea of engaging the IAEA as the possible implementing agent because of its extensive history and experience in nuclear fission safety which shares some similar aspects with fusion safety.

A number of safety analysis computer code validation results and the experimental data used were reviewed. These are the computer codes used to perform the safety analysis for fusion plants and ITER. The remaining gaps in the codes validation were also presented and the need for further code development was discussed. The presented results indicated that computer codes and models appear to be reasonably validated for carrying out fusion power plant designs and for the licensing of ITER. However, the quality of the safety analysis would benefit from further code and model development.

## Power Plant Safety

The inherent fusion favorable features have been used in the recent European fusion Power Plant Conceptual Study (PPCS), to provide major safety and environmental advantages. The study focused on five power plant models, which are illustrative of a wider spectrum of possibilities. Safety methodology implementation in the conceptual design phase of fusion power plants was discussed.

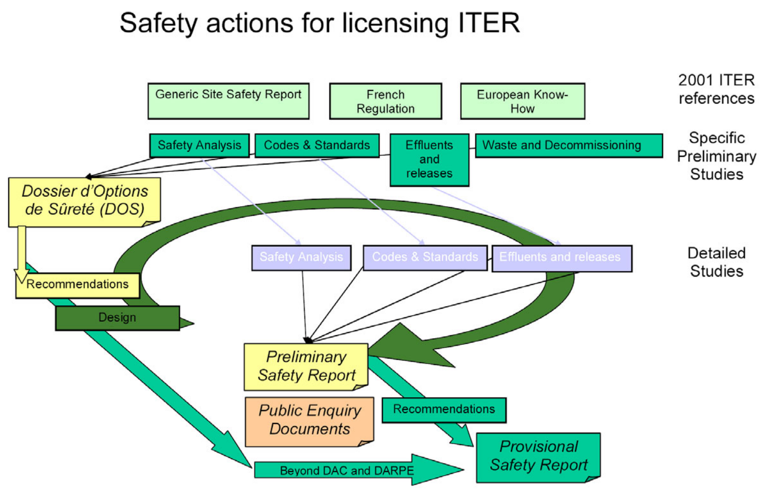



Fig. 1. Safety actions necessary for licensing ITER in France [courtesy G. Marbach].

It was argued that the experience gained with fission may be helpful and was questioned whether fusion really needs new safety standards or can adopt those from fission. The utilization of a fusion-driven sub-critical experimental breeder to produce fissile material for fission reactors as an option for fusion energy to satisfy expanding energy demand in China in the future was discussed. During the discussion concerns were raised about the safety aspects of this hybrid concept that are not in line with the safety and environmental advantages of fusion (e.g., the radiological hazard of transuranics, $\alpha$-emitters, and non-proliferation).

Ongoing safety and environmental studies within the U.S. inertial fusion energy (IFE) community are focusing on two emerging design concepts. These are the high average power laser (HAPL) program for development of a dry-wall laser-driven IFE power plant, and the Z-Pinch IFE program for the production of an economically-attractive power plant using high-yield Z-Pinch-driven targets.

## Test Blanket Modules

A breeding blanket is at present foreseen to produce tritium for the operation of a fusion power plant. Several test blanket module (TBM) concepts were presented to be tested in ITER. Safety analyses results have been presented for Chinese TBM with helium-cooled solid breeder (HCSB). The Helium Cooled Lithium-Lead (HCLL) breeding blanket concept is one of the two concepts currently being developed in the European Union (EU) for the DEMO fusion reactor. A He cooled molten lithium (HCML) blanket with ferritic steel structure is being developed in the Republic of Korea to participate in the test program for tritium breeding blanket studies in ITER.

An overview of a preliminary safety analysis performed for the U.S. proposed TBM to be tested in ITER was presented. This DEMO relevant dual coolant liquid lead-lithium (DCLL) TBM has been explored both in the U.S. and EU. In general, the reduced inventory of activation products and tritium associated with the TBM makes the impact of this system almost negligible to the overall safety risk of ITER. Nevertheless, the possibility to jeopardize ITER safety has been analyzed in connection with the consequences of specific accident sequences.

An experimental TBM, planned to be tested in ITER, is under development in the Russian Federation. The ceramic lithium orthosilicate will be used for tritium breeding. The tritium cycle system (TCS) will extract tritium, process gaseous mixtures containing tritium, and ensure radiation safety. The flow chart of the system demonstrates that the TCS will have the highest possible autonomy and independence of the ITER tritium plant under all the modes of the TBM operation.

### Accident Analysis

A failure rate database for fusion specific components was developed in Italy on the basis of data coming from operating experience gained in various fusion laboratories. The activity began in 2001 with the study of the Joint European Torus (JET) vacuum and active gas handling systems. Since then several other systems have been added to this database such as the Neutral Beam Injectors (NBI) and the Power Supply Systems (PSS). Formation of large holes in the ITER vacuum vessel and cryostat, combined with water and helium cooling pipe breaks, was re-analyzed using the latest MELCOR1.8.5.bdba and MELCOR1.8.5.dba versions. These versions relate to beyond design basis (best estimate) and design basis (conservative) accidents, respectively. Accident analysis with both versions was carried out for cross comparison.

### Tritium Safety and Inventories

Tritium safety was analyzed using the dynamic mathematical model (TRIMO). Such a tool is valuable for tritium inventory evaluation within each system of the ITER fuel cycle in various operational scenarios. Two new types of electrodes containing cerium oxide were developed in Japan for the ceramic electrolysis method that could be applied for the processing of high-level tritiated water and their performances were examined. Regarding tritium monitoring, a new measuring technique was presented that is based on utilization of X-rays induced by beta-rays emitting from tritium species. It was applied to three physical states of high-level tritium: gaseous, aqueous and solid tritium retained on/in various materials. The experiments have provided positive results.

### Decommissioning and Waste

An approach based on industrial experience of recycling of fusion irradiated material is being developed. Results have been presented on how a stringent impurity control simplifies recycling processes and reduces long-lived secondary waste. It was argued that a new strategy should be considered to reshape all aspects of handling the continual stream of radioactive materials during operation and after power plant decommissioning. With tighter environmental controls and the political difficulty of building new repositories worldwide, the disposal option may be replaced with more environmentally attractive scenarios, such as recycling and clearance. The development of commercial fusion plants includes the demonstration that the waste burden for future generations would be avoided. Recently, the IAEA, the U.S. Nuclear Regulatory Commission, and other institutions have revised clearance guidelines for nuclear applications. The implications of these new standards, particularly for slightly irradiated fusion materials, were considered.

## Lessons Learned

The topic of fusion power plant safety is an important issue that requires further work during the coming years. The following is a list of some of the lessons learned and the identified topics of safety research work that need to be examined in the future:

- The need for a fusion-specific approach to nuclear safety design guidelines.
- The importance of a sound strategy for confinement with an integrated "top down" framework and a "bottom up" assessment approach.
- The benefit of limiting source terms of hazardous materials and energies.
- The importance of design for maintenance in limiting the spread of contamination and releases into the environment during normal operation.
- The need for early implementation of a process to consider occupational safety during design.
- The limitation of impurities and selection of materials with respect to clearance levels for disposal of radioactive products.
- The need for rigor and quality control in safety analysis and the importance of qualifying the safety analysis computer codes by code verification and validation procedures.
- The need to provide accurate (credible) measurements/estimations of tritium inventory (in vessel, in water, in dust, in materials, in processing plant, etc.), activation levels in different areas inside and outside the reactor, Be and hazardous dust content at different areas, and radiation fluxes and fluencies at the occupational areas.

## Forthcoming IAEA Meetings on Related Subjects

The IAEA will hold a series of technical meetings in 2007, of which three are directly in line with fusion power plant design:

– 2$^{nd}$ IAEA TM on First Generation of Fusion Power Plant: Design and Technology, Vienna, Austria (20 – 22 June 2007).
– 5$^{th}$ IAEA TM on Steady State Operation of Magnetic Fusion Devices, Daejon, Rep. of Korea (14 – 18 May 2007).
– 4$^{th}$ IAEA TM on Physics and Technology of Inertial Fusion Energy Targets and Chambers, jointly with IFSA07, Kobe, Japan (10 – 14 September 2007).

For more information regarding the IAEA meetings please visit the Physics webpage at: http://www-naweb.iaea.org/napc/physics/ps/index.htm.