American Nuclear Society
Fusion Energy Division
June 2006 Newsletter

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

I am pleased to report that the state of our Fusion Energy Division is strong; our membership has been steadily increasing and our financial balance sheet is in good order. I would like to take this opportunity to welcome our incoming Chair, Dr. Jeff Latkowski (Lawrence Livermore National Laboratory), who will assume the Chairmanship at the conclusion of the June annual meeting in Reno. I would also like to welcome all the newly elected members of the Executive Committee (see election results below), for their willingness to serve on behalf of the Division members.

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

FESAC

As Chair of the ANS Fusion Energy Division, I am honored to serve as an Ex-Officio member of FESAC. During my tenure on the Committee, FESAC has met twice (July 19, 2005, and February 28 to March 1, 2006); a third meeting is scheduled for June 1st, 2006. Among the matters discussed at the first two meetings are: (1) Report by the Facilities Panel (chaired by Dr. Jill Dahlberg of NRL) assessing the mission and the need for the three major U.S. toroidal fusion facilities (C-MOD, DIII-D, and NSTX); (2) Report by Dr. Ray Fonck (University of Wisconsin) on behalf of the U.S. Burning Plasma Organization, a fusion research community-based effort to advance burning plasma science and optimize benefits from participation in ITER; (3) Report by Dr. Jerry Navratil (Columbia University) on the program's progress toward achieving Program Assessment Rating Tool (PART) measures; (4) Presentations by Dr. Ned Sauthoff (Director, U.S. ITER Project Office) and Dr. Warren Morton (OFES) on the status of the ITER project; (5) Report of the Committee of Visitors (chaired by Dr. Kathryn McCarthy of INL) on Tokamak Research and Enabling Technologies; and (6) Presentation by Dr. Allen Hauer (ICF Program Manager) on the status of the National Ignition Facility Project. Meeting minutes and copies of the presentations for all FESAC meetings can be found at
http://www.ofes.fusion.doe.gov/More_HTML/FESAC_Charges_Reports.html

17th TOFE

Consistent with our practice of alternating between "standalone" and "embedded" Topical meetings, the 17th Topical Meeting on the Technology of Fusion Energy (TOFE) will be held on November 13-15, 2006 in Albuquerque, NM as an embedded meeting within the ANS Winter meeting. Dr. Craig Olson is the General Chair and Dr. Gary Rochau is the Technical Program Chair (see detailed report in this newsletter). We look forward to another highly successful TOFE meeting.

ANS

Several actions have been taken by the ANS Professional Divisions Committee (PDC) during the previous year. Most notable among these is the approval of the formation of a

"Young Members Group" which is aimed at providing a vehicle for young professionals to become involved in activities that enrich their professional lives and to continue their involvement in the society after their period of student membership. The proposal was subsequently approved by the ANS Board of Directors. A petition was submitted to the PDC to form a Technical Group on Nuclear Production of Hydrogen; the effort is led by Dr. Ken Schultz of General Atomics (FED member). Other activities include the development of "Standard Bylaws" for the various Professional Divisions, along with procedures for the founding of new Technical Groups and Working Groups.

List of Officers and Executive Committee Members, Jake Blanchard, University of Wisconsin-Madison, Madison, WI.

We are pleased to welcome the new Officers and Executive Committee members of the Fusion Energy Division. Vice-Chair Jeff Latkowski (LLNL) becomes our new Chair and Susana Reyes (LLNL) has been elected as the new Vice-Chair/Chair-Elect. Lee Cadwallader (INL) will stay on to serve his second year as Secretary/Treasurer. The newly elected Executive Committee members are Mark Anderson (University of Wisconsin), Brad Nelson (ORNL) and Brian Wirth (UC-Berkeley). These new members join a strong group of individuals who will continue to serve the FED as Executive Committee members.

We would like to thank the Executive Committee members whose terms have just ended, namely Akio Sagara (NIFS), Phil Sharpe (INL) and Ken Schultz (GA). Above all, we would like to express our appreciation to Said Abdel-Khalik (Georgia Tech) for his service this past year as FED Chair. He will now become the Nominating Committee Chair. The Executive Committee members for 2006/2007 are:

FED Officers:

Jeff Latkowski (LLNL)	(06-07)	latkowski@llnl.gov	Chair
Susana Reyes (LLNL)	(06-07	reyes20@llnl.gov	Vice Chair
Lee Cadwallader (INL)	(05-07)	lee.cadwallader@inl.gov	Sec./Treas.

Executive Committee Members:

Mark Anderson (UW)	(06-09)	manderson@engr.wisc.edu
Gianfranco Federici (IPP)	(04-07)	federig@ipp.mpg.de
Neil Morley (UCLA)	(05-08)	morley@fusion.ucla.edu
Farrokh Najmabadi (UCSD)	(04-07)	najmabadi@fusion.ucsd.edu
Brad Nelson (ORNL)	(06-09)	nelsonbe@ornl.gov
Roger Stoller (ORNL)	(04-07)	stollerre@ornl.gov
Paul Wilson (UW)	(05-08)	wilsonp@engr.wisc.edu
Brian Wirth (UC-Berkeley)	(06-09)	bdwirth@nuc.berkeley.edu
Minami Yoda (GIT)	(05-08)	minami.yoda@me.gatech.edu

Past Chair:

Said Abdel-Khalik	(06-07)	said.abdelkhalik@me.gatech.edu

FED Standing Committee Chairs:

Nominating: Said Abdel-Khalik (Georgia Tech) - Chair
Honors and Awards: Farrokh Najmabadi (UCSD) - Chair
Program Committee: Jake Blanchard (UW) - Chair

FED Representatives on National Committees:

ANS Publications: Ken Schultz (GA)
ANS Public Policy: Bill Hogan (LLNL)

Editors:

Newsletter: Laila El-Guebaly (UW), Dennis Bruggink (UW)
Fusion Science and Technology Journal: Nermin Uckan (ORNL)

Liaisons to other organizations and ANS divisions:

ANS Board: Gary Gates (Omaha Public Power District)
MS&T: Ken Schultz (GA)
IEEE: George Miley (UIUC)
RPS: Ham Hunter (ORNL)

Webmasters:

Mark Tillack (UCSD) – FED website
Dennis Bruggink (UW) – UW website

Treasurer's Report, Lee Cadwallader, Idaho National Laboratory, Idaho Falls, ID.

As of the end of December 2005, our division had a balance of $19,437. Our income in 2005 was $767 in membership dues and $8,999 from the September 2004 16th ANS Topical Meeting on the Technology of Fusion Energy (TOFE). Expenses in 2005 included $537 costs in conducting division meetings at the ANS national meetings, a $500 contribution to the 2006 ANS student conference that took place at Rennselaer Polytechnic Institute on March 30-April 1, 2006, and a $500 contribution to the Landis Challenge in June 2005.

Our income for 2006 is projected to be $760 from member dues. There will be a TOFE meeting during the year but no income will be received until 2007. Our projected expenses for 2006 are $6,100. The expenses include $2,000 for awards and plaques, $600 for conducting division meetings at ANS National Meetings, $2,500 to support student travel to the 17th TOFE in November 2006, a $500 contribution to the ANS Nuclear Engineering Education for the Disadvantaged (NEED) Scholarship fund, and $500 for other miscellaneous expenses. Our projected balance at the end of 2006 is $14,097.

17th TOFE to be held in Albuquerque, NM on November 13-15, 2006,

Craig Olson and Gary Rochau, Sandia National Laboratories, Albuquerque, NM.

The 17th ANS Topical Meeting on the Technology of Fusion Energy (TOFE) will be held on November 13-15, 2006 in Albuquerque, NM, as an embedded meeting during the 2006 Winter ANS Meeting in Albuquerque, NM on November 12-16, 2006. Albuquerque is home to Sandia National Laboratories, the Air Force Research Laboratory, and the University of New Mexico. In addition, Los Alamos National Laboratory, the Very Large Array, and White Sands Missile Range are within easy travel distance. Albuquerque has numerous museums (National Atomic Museum, Natural History Museum, Albuquerque Museum, Maxwell Museum of Anthropology, …), fiestas (the International Balloon Fiesta in October is the largest hot air balloon event in the world), the Sandia Peak Tram (the longest tram in the world - that connects to Sandia peak at 10,500 feet), Old Town, theatres, fine dining, music, sports, and extensive southwest culture. In addition, Santa Fe, Taos, and numerous Indian pueblos are within a short drive from Albuquerque.

The scope of the TOFE meeting is to provide a forum for the discussion of new results in fusion technology as it relates to present fusion research and to future fusion energy applications. This is a particularly exciting time for fusion technology due to the development of ITER and NIF, and many other fusion facilities worldwide.

Organizing Committee

General Chair	Craig Olson (SNL)
Vice Chair	Ichiro Yamamoto (Nagoya University)
Technical Program Chair	Gary Rochau (SNL)
Assistant Technical Program Chair	Akihiro Shimizu (Kyusyu University)
Finance Chair	Sally Ek (SNL)
Publication Chair	Virginia Vigil (SNL)
Student Awards	Ben Cipiti (SNL)
Special Events and Guest Program	Terrie Hof (SNL)
Publicity and Webmaster	David York (SNL)

TOFE Website

The TOFE website is at http://TOFE17.sandia.gov/. Please visit this website periodically, as it will be updated often.

Abstracts and Papers

You are invited to submit one-half page abstracts (http://tofe17.sandia.gov/Abstract.html) on work that is new and significant in all areas of fusion technology. Please see the TOFE website for a complete list of topics. Full papers will be due at the meeting. Papers that are accepted by the peer review process will be published in the Fusion Science and Technology journal. Abstracts are due by July 7, 2006.

Technical Program

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

Banquet

The TOFE banquet will be held Tuesday, November 14, 2006. The ANS-FED awards will be announced at the banquet.

Awards

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

Registration

You may register for the TOFE meeting through either the TOFE website or the ANS website. Registration at the ANS Winter Meeting includes admittance to all TOFE technical sessions. Registration will not open until after the ANS Annual Meeting this June (check the ANS website at http://www.ans.org/). A separate fee will be required for tickets to the TOFE banquet.

Key Deadlines

Abstracts due	July 7, 2006
Notification to authors	August 1, 2006
Nominations for ANS-FED Awards	September 1, 2006
Early registration deadline	October 10, 2006
Plenary/Oral PowerPoint (or PDF) presentations uploaded to Web	November 10, 2006
Hotel reservation deadline	See ANS Winter Meeting
Full papers due at meeting	November 13, 2006

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

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

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

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

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

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

The deadline for nominations is September 1, 2006. The awards will be presented at the ANS 17th Topical Meeting on the Technology of Fusion Energy, TOFE-2006, to be held in Albuquerque, NM.

Nominations can be made by anyone at anytime to the Honors and Awards Committee Chair of the FED. The nomination package should include:

1) The nomination letter including a description of the exemplary achievements and the recommended citation to appear on the award plaque.
2) Additional letters supporting the nomination (a minimum of three and a maximum of five, including the nominator letter).
3) Nominee's CV and publication list.

Please send the complete nomination package (electronic submission is accepted and encouraged) to

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

Request for Expressions of Interest for 18th TOFE Meeting, Jeff Latkowski, Lawrence Livermore National Laboratory, Livermore, CA and Said Abdel-Khalik, Georgia Institute of Technology, Atlanta, GA.

The 18th ANS Topical Meeting on the Technology of Fusion Energy (TOFE) will be held in the fall of 2008. By tradition, it will be a stand-alone meeting. At this time, the Fusion Energy Division (FED) is seeking expressions of interest from ANS local sections and/or fusion groups interested in hosting the meeting. We would like to select the meeting venue in time for it to be announced at the 17th TOFE meeting in Albuquerque, New Mexico (November 13-15, 2006). If you are interested in hosting the meeting, please contact Dr. Jeff Latkowski, our incoming FED Chair (latkowski@llnl.gov or 925-423-9378). We would appreciate receiving expressions of interest no later than September 1, 2006 so that the FED Executive Committee can take action prior to the 17th TOFE. The lessons learned from organizing past TOFE meetings are available upon request.

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

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

EPS Award

The Plasma Physics Division of the European Physical Society (EPS) has awarded the 2006 Hannes Alfvén Prize to Dr. **Paul-Henri Rebut** for his:

- Seminal contributions to progress in magnetic confinement fusion, including his pioneering work in plasma theory, and his contributions to the development of various early magnetic confinement configurations.
- Innovations in tokamak design, first with the construction of TFR, subsequently with the design and construction of JET, which remains after 25 years the world's leading magnetic fusion device, and culminating in the EDA Outline Design of ITER.
- Vision, leadership, and technical accomplishments in planning and carrying out the first deuterium-tritium experiment in a magnetically confined plasma, which broke new ground in fusion physics and produced multimegawatt fusion power in a controlled way.

Global Energy International Prize

Robert Aymar, Evgenii Velikhov and **Masaji Yoshikawa** are the recipients of the 2006 Global Energy International Prize. The prize is "a unique award intended to assist international cooperation in solving the most important current problems in the field of power generation." The three recipients are honored "for the development of scientific and engineering foundation for building the International Thermonuclear Reactor (ITER) project."

FPA Awards

The Fusion Power Associates (FPA) Board of Directors has presented its 2006 Distinguished Career Award to Dr. **N. Anne Davies**, recently retired head of the U.S. fusion program. In selecting her, the Board recognized her many years of dedicated leadership of the U.S. fusion program. In presenting the award, FPA president Steve Dean said, "Ever since your arrival in the fusion office in 1974, you have shown an extraordinary ability to assess and balance the many conflicting opinions and priorities of the fusion community. Your service as Chief of the Tokamak Systems Branch during the critical decade of the 1970s, and then as Director of the Toroidal Confinement Systems Division during the 1980s, demonstrated your management skills. Since assuming leadership of the program as a whole in 1989, you have guided the U.S. fusion community through a series of budget and policy crises, and eventually to the point where the U.S. is once more moving forward toward the construction of a new major fusion test facility, ITER."

The FPA Board of Directors has selected **Gerald Navratil** (Columbia University) and **Ned Sauthoff** (Princeton Plasma Physics Laboratory) as recipients of the FPA 2006 Leadership Awards for outstanding leadership qualities in accelerating the development of fusion. In selecting, The Board recognizes Dr. **Navratil**'s role in founding and continuing to guide the University Fusion Association (UFA), in organizing the fusion Snowmass meetings and the series of UFA-sponsored burning plasma workshops, in advocating burning plasma physics within the framework of the National Academies, and in defending a broad-based domestic fusion research program. In selecting Dr. **Sauthoff**, the Board recognizes both his many outstanding scientific contributions to fusion research and his community leadership, his many scientific contributions to tokamak research, his role in guiding energy and education policy within the Institute of Electrical and Electronic Engineers (IEEE), and especially his role in leading preparations for U.S. participation in the ITER project.

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

During the past twelve months (May 1, 2005-April 30, 2006), FS&T received 391 manuscripts and 48 lecture notes, and has been busy with publication and scheduling of several special issues and an excellent selection of contributed papers. The 2005 (second half)/2006 (first half) issues included the following special issues:

July/Aug. 2005	Proceedings of the 7th International Conference on Tritium Science and Technology (Baden-Baden, Germany)
October 2005	DIII-D Tokamak (General Atomics, CA)
February 2006	JFT-2M Tokamak (JAEA, Japan)
February 2006	Transactions/Proceedings - 7th Carolus Magnus Summer School
April 2006	Fast Ignition (U.S., JA, EU)
May 2006	Selected papers from 16th Target Fab. Specialist's Meeting (Scottsdale, Arizona)

The following issues are already scheduled for the remaining of 2006:

July 2006	Regular issue plus several papers from W60/IEA Burning Plasma Workshop (Tarragona, Spain) and Fusion Related Plasma Surface Interactions (PSIF) Meeting (Oak Ridge)
Aug. & Oct. 2006	Selected papers from 15th IEA International Stellarator Workshop (Madrid, Spain) – Parts 1 and 2

Future (2007-2008) special issues will include: Alcator C-Mod Tokamak (MIT), JET Tokamak (EU), MFE Diagnostics (EU, JA, RF, U.S.), 17th TOFE (Albuquerque, NM), IFMIF (EU, JA, U.S.), DEMO (EU, JA), NIF (LLNL), and more.

Don't miss any of these issues by signing-up for individual ANS member subscription or through your libraries. Electronic access to FS&T is available from 1997-to-current. Additional journal back issues will continue to be added (depending on demand). Recent (2002 and later) camera-ready special issues are also available online. 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/.

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:

Validation of Direct-Drive Ignition Target Design on OMEGA, Thomas C. Sangster and John M. Soures, University of Rochester, Laboratory for Laser Energetics, Rochester, NY.

Abstract

Under the right conditions, the fusion energy released by imploding a spherical capsule filled with a relatively thin layer of DT ice is predicted to be greater than the energy of

the laser pulses used to drive the implosion. The gain of the target implosion is defined to be unity when the energy released from the DT fusion is the same as the energy of the laser light on the target. High target gains are therefore required to produce net energy because of the relatively low energy efficiency of large laser systems. Directly illuminating the capsule is the most efficient way to couple the laser energy into the capsule and is expected to produce gains in excess of 30 on megajoule-class lasers such as the National Ignition Facility (NIF), which is under construction in Livermore, CA. High-gain, direct-drive target designs are being validated with scaled experiments on the symmetric 60-beam, 30-kJ OMEGA laser at the Laboratory for Laser Energetics (LLE). These experiments utilize power- and energy-scaled cryogenic targets similar to those being developed for the NIF. This article will detail the hydrodynamic scaling of the target and explain the criteria that will be used to establish ignition scaling.

Introduction

In direct-drive inertial confinement fusion (ICF) [1], a spherical capsule containing a relatively thin, uniform layer of frozen thermonuclear fuel (DT) is imploded by symmetrically illuminating the capsule surface with high-power laser beams. The laser energy ablates mass from the capsule and accelerates the fuel shell inward via the rocket effect [2]. The frozen fuel layer is compressed to several hundred times liquid density as it implodes and the central, gas-filled cavity heats rapidly. If the temperature and areal density of this central "hot spot" reaches approximately 10–12 keV and 300–400 mg/cm^2, respectively, a thermonuclear burn wave initiates because of the rapid deposition of energy from the DT □'s and propagates through the high-density fuel surrounding the hot spot. This process can also be initiated using x-ray or indirect drive. With x-ray drive, the capsule is mounted in the center of a cylindrical high-*Z* (e.g., gold) can called a hohlraum [2]. The laser beams illuminate the wall of the can (instead of the capsule surface) filling it with a uniform x-ray radiation field. The radiation field is then absorbed by the capsule, ablating mass and accelerating the fuel shell inward. The capsule physics during the implosion process is independent of the drive type. Figure 1 conceptually illustrates the difference between indirect and direct drive.

The National Ignition Facility (NIF) [3], a 192-beam, 1.8-MJ, UV laser under construction at Lawrence Livermore National Laboratory, was designed to study and use igniting plasmas for stockpile stewardship. A series of experiments on the 60-beam, 30-kJ, UV OMEGA laser [4] at the University of Rochester's Laboratory for Laser Energetics is under way to validate the capsule physics leading to ignition. These experiments utilize a target that is energetically scaled from the ignition designs for the NIF (the energy scales as the cube of the capsule radius, the power as the square of the radius, and the implosion time as the radius). The basic target design and energy scaling are illustrated in Fig. 2. The targets are thin spherical shells of plastic filled with approximately 1000 atm of DT. When cooled to the DT triple point, a layer of frozen fuel is formed on the inside of the CH shell and the gas cavity contains a dense DT vapor.

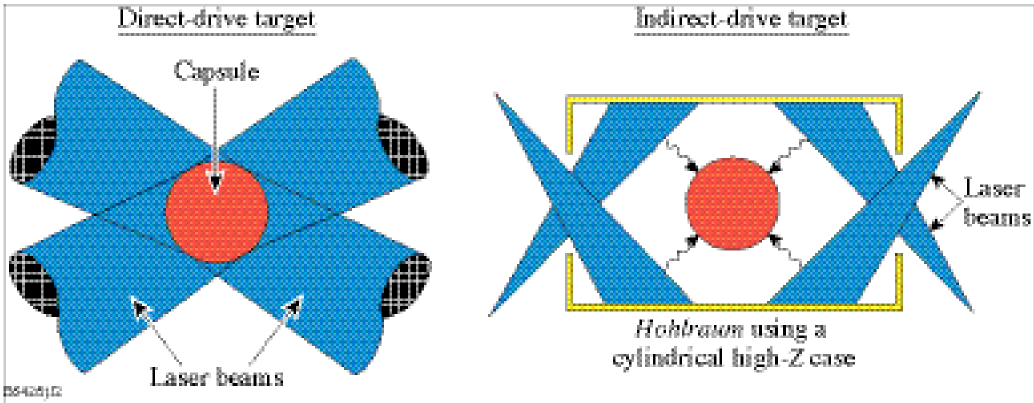

Figure 1. Schematic representation of the direct-drive and indirect-drive concept for imploding a capsule filled with thermonuclear fuel using high-power laser beams.

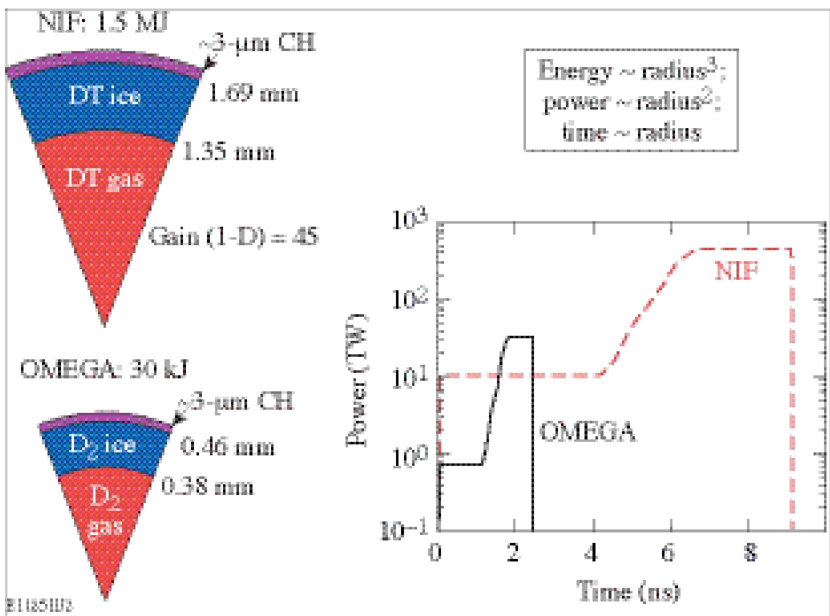

Figure 2. The baseline direct-drive ignition design for the NIF is nearly 3 mm in diameter and has an ice layer thickness of 340 μm. The energy-scaled, ignition-equivalent design for the OMEGA laser is just under 1 mm in diameter with an ice layer thickness of 80 μm.

Experiments

The current ignition-scaled experiments on OMEGA use D_2 fuel [5–9]. The implosion dynamics are independent of the fuel choice and the D_2 fuel is considerably easier to handle. At LLE, targets are permeation filled with 1000 atm of D_2 and cooled to near the triple point (18.7 K) in the Fill/Transfer Station (the process takes about four days). The capsules are then loaded into moving cryostat transfer carts. These carts contain all the necessary systems to create and manipulate an ice layer inside the plastic capsules. The capsules are located at the center of a 1-in. layering sphere with four viewing ports, a keyhole for the target access, and a small port for an infrared (IR) laser to deliver up to 150 mW of 3.16-μm light to the inside surface of the layering sphere (effectively, the layering sphere is an integrating sphere for the IR light). The IR power is preferentially coupled into the D_2 molecules and low-pressure (hundred's of millitorr) helium is used to conduct heat from the capsule to the layering sphere (maintained at ~16 K). The settings for the exchange-gas pressure, the temperature of the layering sphere, and the IR laser power control the layering rate of the ice and the ultimate smoothness of the inner surface (in other words, these settings control the shape and local gradients of the isothermal "surface" around the capsule). The goal is to achieve a very smooth inner surface to minimize perturbations that grow because of the Rayleigh–Taylor [2] (RT) instability during the deceleration of the fuel shell as the pressure in the hot spot reaches tens of gigabar. Perturbation growth of the colder fuel into the hot spot can prevent the temperature from reaching the threshold for burn initiation.

Shadowgraphy is used to characterize the ice layer quality [9]. A shadowgraph of a 860-μm diameter capsule with an 80-μm D_2 ice layer is shown in Fig. 3(a). The primary bright band is a reflection of the incident (optical) plane wave from the inner surface of the ice; the secondary bright bands arise from higher order reflections from both the inner and outer surface of the ice layer. The ice layer quality is determined by unfolding the primary bright band around the center of the image and Fourier analyzing the inner "surface" [Fig. 3(b)]. A power spectrum is then extracted from the Fourier analysis with meaningful amplitudes out to approximately mode 100 (the resolution limit for the imaging system). The power spectrum of this shadowgraph is given in Fig. 3(c). The ignition requirement is 1.0-μm^2 rms over all modes. For this particular view, the rms is comfortably below the ignition requirement. By rotating the capsule, however, 48 independent shadowgraphs are taken and a 3-D representation of the inner ice surface is created [Fig. 3(d)]. This 3-D surface is then Fourier analyzed to create a final ice roughness (but limited to the lower ℓ and m modes). The final rms for this capsule was 2.1 μm rms following the full analysis. Further work is under way to improve the uniformity of the IR illumination in the layering sphere and minimize the thermal imprint of the target mounting structures onto the ice. As can be seen in Fig. 3(a), the capsule is mounted to a C-style frame using spider silks. The silks and the C-frame also absorb the IR laser light and the resulting thermal gradients in the helium exchange gas can cause low mode structure within the ice.

A laser pulse similar to the one shown in Fig. 2 is used for these capsule implosions. The laser system is designed to minimize the imprinting of laser beam nonuniformities onto the surface of the capsule. These nonuniformities feed through to the inner ice surface during the implosion, becoming additional perturbation seeds for RT growth late in time. The shape of the drive pulse is designed to keep the pressure of the ice at the inner surface as low as possible prior to the arrival of the main compression wave. The compression wave is launched by the high-intensity part of the drive pulse.

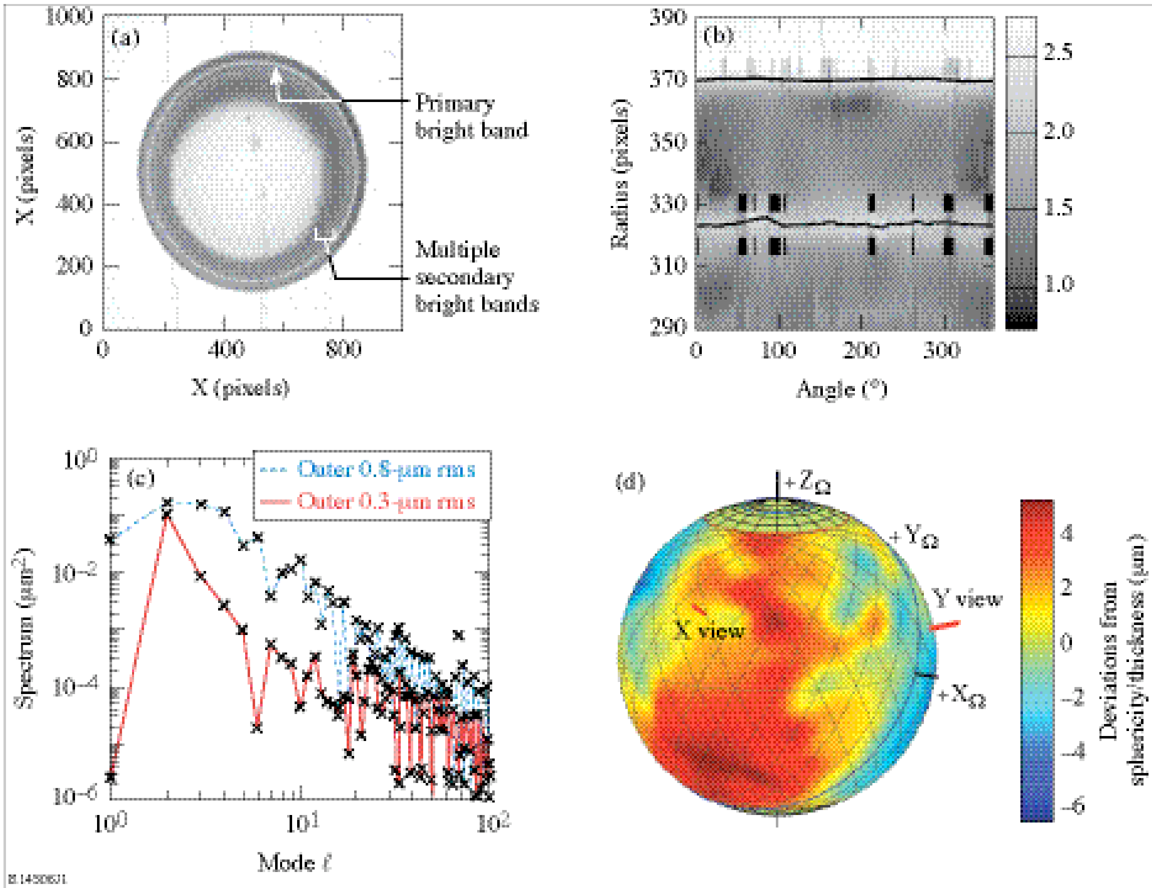

Figure 3. A shadowgraph of an OMEGA cryogenic target (a) shows the primary bright band that is used to determine the roughness of the inner ice surface. The primary bright band is unwound around the center of the target (b) and the "surface" is Fourier analyzed to determine the modal amplitude contributions to the power spectrum (c). By rotating the target, multiple shadowgraphs are acquired and a 3-D representation of the ice is generated (d). The final ice roughness (and the decision to melt and re-layer) is determined from this 3-D representation.

Results

There are two primary metrics for target performance in these experiments: the primary neutron yield and the areal density of the fuel shell during the neutron burn. Neutron emission begins once the temperature of the hot spot reaches about a kilovolt. The emission lasts for typically 100–150 ps, during which time the areal density of the fuel shell increases by about a factor of 2. Secondary proton emission is used to infer the burn-averaged areal density. Secondary protons are created in a two step process. The initial D+D fusion has two branches: one leading to a 2.45-MeV neutron and a 0.8-MeV ^{3}He and the other leading to a 3.02-MeV *p* and a 1.01-MeV *T*. If the recoiling ^{3}He fuses with a background D, the resulting proton can have an energy between 12.5 and 17.4 MeV. The produced spectrum is kinematically constrained by the two-body nature of the reaction. By measuring the energy loss of these protons as they pass through the dense outer fuel, it is therefore possible to infer the areal density of the fuel shell. Details of this measurement can be found in Ref. [10]. Neutron yields are typically measured using current mode detectors or Cu activation (for DT). Further details of these measurements can be found in [11].

Figure 4 shows the areal density measured from the d*E*/d*x* of the secondary protons plotted against the areal density calculated from a 1-D hydrodynamics code (*LILAC*). The 1-D code does not account for perturbation growth or multidimensional effects such as mass flow and laser illumination uniformity; the code predictions represent the idealized target performance (the burn of the fuel is calculated based on the time-dependent, 1-D temperature and density profiles). The influence of factors such as the ice roughness and laser uniformity degrade the experimental performance with respect to the 1-D code predictions. Therefore, the ratio of a measured quantity (such as yield) and the 1-D prediction is a useful benchmark for target performance. For stable implosions (i.e., higher implosion velocities), the influence of the perturbations is minimized and the areal density inferred from the secondary proton energy loss agrees well with the 1-D prediction (40–50 mg/cm^2). However, these stable implosions do not lead to ignition conditions when scaled to the larger capsule size on the NIF. The very unstable implosions, driven by a pulse similar to the one shown in Fig. 2, lead to much higher experimental areal densities (close to 100 mg/cm^2), but these measurements do not agree with the 1-D predictions. This discrepancy is not understood and experiments are under way to investigate a number of possible explanations. For example, if the equation-of-state of the solid D_2 or plastic in the shell is not correct, the timing of the shocks launched by the scaled-ignition pulse shape would be incorrect (the heating of the hot spot is primarily due to the convergence of two shocks at the center of the capsule). Preheating of the fuel by radiation or electrons would also limit the peak density achieved as the hotter fuel would compress less for the same kinetic energy in the shell.

A uniformity parameter is used to scale target performance from OMEGA to NIF [12]. This parameter, σ-bar, is calculated at the end of the shell acceleration (when the laser turns off) and takes into account all of the known perturbation sources that lead to degradation in target performance. These sources include the inner ice roughness, the roughness of the outer surface of the plastic capsule, and laser-imprinted perturbations from both single-beam nonuniformities (speckle) and beam-to-beam energy (or power) variations (beam balance). σ-bar can be calculated for both OMEGA and NIF implosions. On the basis of these calculations, there is a threshold value for the NIF at which the capsule will ignite (in other words, if the value of σ-bar is below a certain value, the capsule should ignite and burn). The primary assumption for scaling performance from OMEGA to the NIF is that under equivalent uniformity conditions, implosions on OMEGA and the NIF will perform identically. Equivalent uniformity conditions depend on the modal power spectrum of the uniformities and the size of the capsule (the mode of a particular perturbation at a point in time can be imagined as the scale of the perturbation divided by the perimeter of the fuel shell). Therefore, equivalent uniformity does not imply similar values of σ-bar.

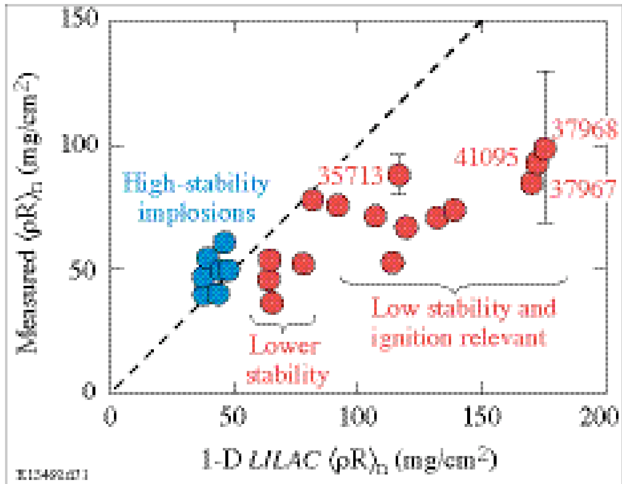

Figure 4. A plot of the correlation between the measured fuel areal density, $\langle\rho R\rangle_n$ (the nomenclature indicates that the value is the average areal density during the neutron burn) and the predicted areal density using the 1-D hydrocode *LILAC*. The agreement between the predicted and measured areal density is quite good for stable implosions (these do not scale to ignition conditions). As the stability of the implosion goes down (and the convergence goes up), the measured values deviate from the 1-D predictions. This deviation is due to a number of factors that include the ice roughness, uncertainties in the equation of state of the solid fuel, and laser nonuniformities seeding mass perturbations that grow exponentially (the RT instability) during the deceleration phase as the fuel density reaches its peak value.

Figure 5 shows the target performance relative to a 1-D simulation as a function of the parameter σ-bar for the baseline direct-drive ignition design for the NIF and the experiments being performed on OMEGA. The vertical dotted lines at the σ-bar values of 1.1 and 1.4 are equivalent uniformity on OMEGA and the NIF, respectively. The NIF value represents an implosion performance that is predicted to achieve 60% of the 1-D prediction (in other words, the performance is degraded by 40% relative to the 1-D ideal because of the ice and laser illumination imperfections). This would be comfortably above the expected ignition threshold [12]. Therefore, if the performance of an implosion on OMEGA is close to 40% of the 1D prediction, it is possible to claim that the target, under equivalent uniformity conditions, would have ignited on the NIF.

The best implosions on OMEGA to date with D_2 fuel have achieved 10–15% of the 1-D performance (where 40% would be ignition equivalence). This is primarily due to the inner ice roughness as well as uncertainties in the equation of state of the fuel and plastic shell and in the coupling and thermal transport of the laser energy. Figure 6 shows the predicted performance of these capsules as a function of the ice roughness (with no other sources of perturbation) using the 2-D hydrocode *DRACO* (the effects of the inner ice surface roughness can be approximated in a 2-D hydrosimulation). Clearly, the ice roughness will need to be close to 1-μm^2 rms (root-mean-square) before the target performance will approach ignition equivalence. Additional experiments are being performed to improve the physics (equation of state, shock propagation, radiation transport, etc.) in the hydrocodes.

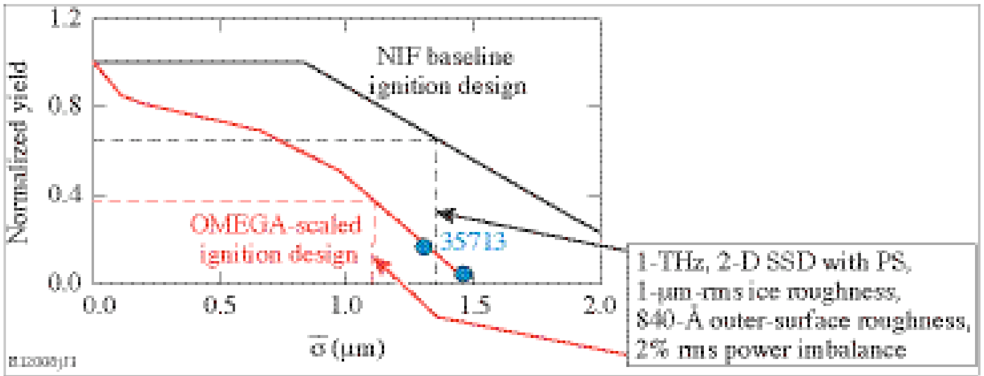

Figure 5. The calculated scaling parameter -bar is used establish ignition-relevant target performance for the OMEGA cryogenic fuel implosions. Under equivalent uniformity conditions represented by the vertical dashed lines, the target performance should be equivalent. The best implosion to date produced a neutron yield relative to the 1-D prediction of between 10% and 15%. A target implosion that produces a yield of approximately 40% would likely ignite under equivalent conditions on the NIF.

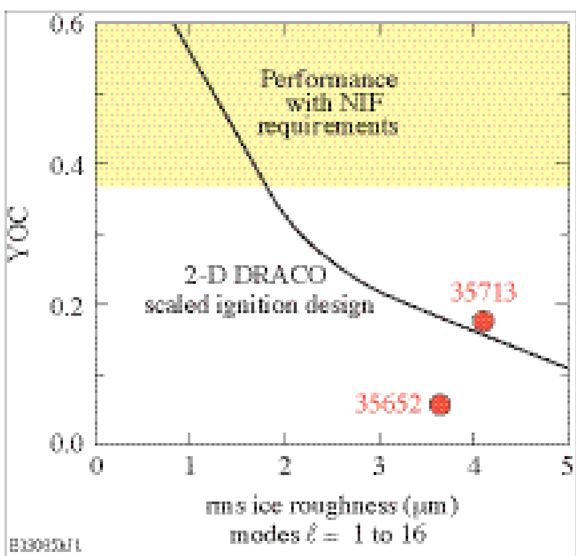

Figure 6.The 2-D hydrocode *DRACO* suggests that much of the performance degradation measured to date has been due to the roughness of the inner ice surface. The ice surface roughness for the best implosion to date was approximately 4-m rms, nearly four times the ignition specification for the NIF targets.

The inner ice surface roughness will also be improved with time. In particular, when DT fuel is introduced into the system later this year, β-layering [13] is expected to immediately improve the ice quality. The β-layering concept recognizes that the thermal heat generated by the β-decay of the tritium can be used to redistribute the ice on an isotherm (i.e., thicker ice heats preferentially and the sublimed fuel freezes on thinner, cooler regions). With the heat generated internally, imprinting of external thermal gradients associated with D_2 and IR layering will be minimized.

Acknowledgment

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INTERNATIONAL ACTIVITIES

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

Following the June 28, 2005 decision to site ITER in Cadarache, France, the ITER parties resumed their formal discussions of arrangements for the construction of ITER. In September in Cadarache, October in Chengdu, China, and December in Jeju, Korea, the parties discussed organization, management, staffing, and other topics that are the scope of the ITER Joint Implementing Agreement. At the close of the December meeting, the group had completed its technical discussions and the text of the Agreement was turned over to the lawyers who met in Barcelona in early 2006 to assure consistency of the text. The governmental considerations of the text are now on-going, expected to lead to initialing, signing, etc., perhaps by the end of 2006.

In December, the partners unanimously selected Kaname Ikeda, then the Japanese ambassador to Croatia, as the first ITER Director General Nominee ("nominee" because the ITER Organization is not yet in place). In April, the parties unanimously selected Dr. Norbert Holtkamp as the Principal Director General Nominee. With the most senior managers now in place, the ITER Preparatory Committee met in Goa, India, to discuss the Director General Nominee's (DGN) and Principal Deputy Director General Nominee's (PDDGN) proposed organizational structure and vision. Following some refinement of the proposal, the parties are now requested to nominate a candidate each for many of the positions of Deputy Director General and for other senior positions supporting the directorate. In addition, the DGN requested that the parties provide secondees or visiting researchers to fill "urgent positions" to fill key vacancies in the ITER International Team; since the International Team is not a legal entity, it will not be able to offer employment; more regular employment must await establishment of the ITER Organization. In addition, the ITER team is planning for a form of design review in the fall of 2006.

In parallel with the ITER project activities, parties like the U.S. are working to establish an effective "Burning Plasma Organization." Professor Raymond Fonck of the University of Wisconsin is now serving as the leader of the U.S. Burning Plasma Organization, seeking to build a community and a plan for U.S. research on burning plasma topics in both existing facilities and ITER.

Power Plant and DEMO Studies in Europe, David Maisonnier, EFDA CSU, Garching, Germany.

Background

From 1990 to 2000, a series of studies within the European fusion program examined the safety, environmental and economic potential of fusion power. These studies showed that:

- Fusion power has very promising potential to provide inherent safety and favorable environmental features, to address global climate change, and to gain public acceptance.
- The cost of fusion electricity is likely to be comparable with that from other environmentally responsible sources of electricity generation.

In the period since these earlier studies, there have been substantial advances in the understanding of fusion plasma physics and in the development of more favorable plasma operating regimes, and progress in the development of materials and technology. Accordingly, it was decided to undertake a comprehensive power plant conceptual design study to better guide the further evolution of the fusion development program.

The European Power Plant Conceptual Study

The European Power Plant Conceptual Study (PPCS) has been a study of conceptual designs for commercial fusion power plants. It focussed on five power plant models, named PPCS-A, -B, -AB, -C, and -D, which are illustrative of a wider spectrum of possibilities. They are all based on the tokamak concept and have approximately the same net electrical power output of 1500 MW_e. These designs span a range from relatively near-term, based on limited technology and plasma physics extrapolations, to an advanced conception. The five PPCS plant models differ substantially in terms of plasma physics, gross electrical output, and blanket and divertor technology from the previous models that formed the basis of earlier European studies. They also differ substantially among each other in their size, fusion power, and material compositions. These differences led to notable differences in economic performance and in the details of safety and environmental impact.

The main emphasis of the study is on system integration. Systems analyses were used to produce self-consistent plant parameter sets with approximately optimal economic characteristics for all models. For models A, B and AB that are based on “limited” extrapolations, significant efforts have been devoted to ensure the consistency of the developed concepts, requiring a better clarification of the physics basis, the development of adequate divertor concepts, and the proposal of a novel blanket segmentation. For the more advanced concepts (models C and D), a more favorable extrapolation of present physics scenarios has been assumed. Advanced blanket concepts that allow a higher thermodynamic efficiency for the power conversion system have also been considered. Together, these allow plants of smaller geometrical dimensions to be considered.

In PPCS-A, -B and -AB, the plasma scenario adopted is based on the H–mode regime, which is the reference regime for ITER - a well established regime for present day tokamaks. The plants are designed assuming monotonic q profile with q_{95}= 3, within the following limits for the global plasma performance: H_H <1.2, n/n_{GR} <1.2, $ß_N$ <3.5, and first stability region. The blankets are based, respectively, on the "water-cooled lithium-lead", the "helium-cooled pebble bed" and the "helium-cooled lithium-lead" concepts, developed in the European fusion program. All these concepts use low-activation ferritic-martensitic steel as the main structural material, which is currently being tested in the European fusion program. Associated with these blankets are water-cooled and helium-cooled divertors. The design of the helium-cooled divertor is a more advanced concept, though still using near-term materials.

PPCS-C and -D are based on successively more advanced concepts in plasma configuration and materials technology. The plasma physics goal was to identify a scenario requiring much less recirculating power for current drive (compared to models A, B and AB) and, at the same time, having realistic, but not excessive, nuclear loads on the first wall. Their technology stems, respectively, from a "dual-coolant" blanket concept (helium and lithium-lead coolants with steel structure and silicon carbide insulator) and a self-cooled lithium-lead blanket concept with silicon carbide structure. In PPCS-C the divertor is helium-cooled while in the most advanced concept, PPCS-D, the divertor is cooled with lithium-lead. The main features of the nuclear power cores of the PPCS models are summarized in Table 1.

Two key innovative developments made within the PPCS study are worthy of a special note. The frequency and the duration of the in-vessel maintenance operations are the prime determinants of the availability of a fusion power plant. ITER uses a segmentation of the blanket in several hundred modules and, in a power plant, this would result in an availability barely above 50%, which is unacceptable. An evolution of this scheme was developed and it shows the potential for an overall plant availability in excess of 75%. The other key innovative development is a conceptual design for a helium-cooled divertor, which permits the tolerance of heat loads of at least 10 MW/m^2. Preliminary tests have confirmed the validity of this concept. The main feasibility issue is the qualification of the tungsten alloy as a structural material.

In the PPCS models, the favorable, inherent features of fusion have been exploited to provide substantial safety and environmental advantages. The broad features of the safety and environmental conclusions of previous studies have been confirmed and demonstrated with increased confidence.

DEMO issues

The PPCS study has also highlighted the need for specific design and R&D activities, in addition to those already underway within the European long term R&D program, as well as the need to clarify the concept of DEMO, a device that bridges the gap between ITER and the first-of-a-kind fusion power plant. A detailed assessment of the PPCS models with limited extrapolations indicated that the most important issue is the power exhaust. The maximum tolerable divertor heat flux imposed severe constraints on other aspects of the design, requiring relatively large major radius, very high plasma current, and very high level of current drive (see Table 2). This assessment highlighted a number of physics issues that must be addressed to establish the DEMO physics basis. Considering the latest achievements in existing machines, the physics basis will presumably assume a higher H factor than used in the PPCS (approximately 1.4 instead of 1.2) and, in addition, consider a "hybrid" scenario (a discharge where a small fraction of the current may still be driven inductively) as a back-up for the reference, steady-state scenario. In parallel, a number of technological issues are being addressed to establish the basic feature of the DEMO. They are primarily related to the blanket concept, maintenance scheme of the internal components, and magnet technology.

Table 1 - Nuclear power cores of the PPCS models

☐	**Model A**	**Model B**	**Model AB**	**Model C**	**Model D**
Blanket					
Structural material	Eurofer	Eurofer	Eurofer	Eurofer	SiC/SiC
Coolant	Water	Helium	Helium	LiPb/He	LiPb
Coolant temp. in/out (°C)	285 / 325	300 / 500	300 / 500	480 / 700 300 / 480	700 / 1100
Breeder	LiPb	Li_4SiO_4	LiPb	LiPb	LiPb
Overall TBR	1.06	1.12	1.13	1.15	1.12
Divertor					
Structural material	CuCrZr	W alloy	W alloy	W alloy	SiC/SiC
Armor	W	W	W	W	W
Coolant	Water	Helium	Helium	Helium	LiPb
Coolant temp. in/out (°C)	140 / 167	540 / 717	540 / 717	540 / 717	600 / 990

Table 2 - Key parameters of the PPCS models

PPCS Plant Parameter	**A**	**B**	**AB**	**C**	**D**
Unit Size (GW_e)	1.55	1.33	1.46	1.45	1.53
Fusion Power (GW)	5.00	3.60	4.29	3.41	2.53
Major Radius (m)	9.55	8.6	9.56	7.5	6.1
Net efficiency (fus. power / net electrical output)	0.31/0.33	0.36	0.34	0.42	0.60
Plasma Current (MA)	30.5	28.0	30.0	20.1	14.1
Bootstrap Fraction	0.45	0.43	0.43	0.63	0.76
P_{add} (MW, H&CD power injected into plasma)	246	270	257	112	71
Divertor Peak load (MWm^{-2})	15	10	10	10	5
Average neutron wall load (MWm^{-2})	2.2	2.0	1.8	2.2	2.4

Further reading

The full PPCS report is available at the EFDA website (http://www.efda.org/, Downloads, EFDA Reports).

Calendar of Upcoming Conferences on Fusion Technology

2006:

ANS Annual Meeting
June 4-8, 2006, Reno, NV, U.S.
http://www.ans.org/

29th European Conference on Laser Interaction with Matter – ECLIM-2006
June 11-16, 2006, Madrid, Spain
http://www.denim.upm.es/29eclim.html

16th International Symposium on Heavy Ion Inertial Fusion
July 9-14, 2006, Saint-Malo, France
http://hif06.lpgp.u-psud.fr/

24th Symposium on Fusion Technology – SOFT-2006
September 11-15, 2006, Warsaw, Poland

FPA Annual Meeting: Fusion: Pathways to the Future
September 27-28, 2006, Washington, DC, U.S.
http://fusionpower.org/

11th International Workshop on Plasma-Facing Materials and Components for Fusion Applications (PFMC-11)
October 10-12, 2006, Garching, Germany
http://www.ipp.mpg.de/pfmc-11

21st IAEA Fusion Energy Conference
October 16 – 21, 2006, Chengdu, China
http://www-pub.iaea.org/MTCD/Meetings/Announcements.asp?ConfID=149

48th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
October 30 - November 3, 2006, Philadelphia, PA, U.S.

ANS Winter Meeting
November 12-16, 2006, Albuquerque, NM, U.S.
http://www.ans.org/

ANS 17th Topical Meeting on the Technology of Fusion Energy – TOFE-2006
November 13-16, 2006, Albuquerque, NM, U.S.
http://TOFE17.sandia.gov/

2007:

13th International Conference on Emerging Nuclear Energy Systems (ICENES-2007)
June 3-8, 2007, Istanbul, Turkey
http://www.icenes2007.org/

ANS Annual Meeting
June 24-28, 2007, Boston, MA, U.S.
http://www.ans.org/

EUROMAT 2007, Materials for Fusion Applications
September 10-13, 2007, Nuremberg, Germany
http://www.euromat2007.fems.org/

5th International Conference on Inertial Fusion Sciences and Applications – IFSA-2007
September 2007, Japan

22nd Symposium on Fusion Engineering – SOFE-2007
Fall 2007, Albuquerque, NM, U.S.

8th International Symposium on Fusion Nuclear Technology - ISFNT-8
October 1-7, 2007, Heidelberg, Germany

ANS Winter Meeting
November 11-15, 2007, Washington, DC, U.S.
http://www.ans.org/

49th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 12-16, 2007, Orlando, FL, U.S.

13th International Conference on Fusion Reactor Materials - ICFRM-13
Fall 2007, Nice, France

2008:

ANS Annual Meeting
June 8-12, 2008, Anaheim, CA
http://www.ans.org/

17th International Symposium on Heavy Ion Inertial Fusion

ANS Winter Meeting
November 9-13, 2008, Reno, NV, U.S.
http://www.ans.org/

ANS 18th Topical Meeting on the Technology of Fusion Energy – TOFE-2008

50th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 17-21, 2008, Dallas, TX, U.S.

25th Symposium on Fusion Technology - SOFT-2008

2009:

ANS Annual Meeting
June 14-18, 2009, Atlanta, GA, U.S.
http://www.ans.org/

23rd Symposium on Fusion Engineering – SOFE-2009

ANS Winter Meeting
November 8-12, 2009, Washington, DC, U.S.
http://www.ans.org/

51st American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 2-6, 2009, Atlanta, GA, U.S.

2010:

ANS Annual Meeting
June 13-17, 2010, San Diego, CA, U.S.
http://www.ans.org/

18th International Symposium on Heavy Ion Inertial Fusion

26th Symposium on Fusion Engineering – SOFT-2010

ANS Winter Meeting
November 14-18, 2010, New Orleans, LA, U.S.
http://www.ans.org/

ANS 19th Topical Meeting on the Technology of Fusion Energy – TOFE-2010

52nd American Physical Society - Division of Plasma Physics (APS-DPP) meeting