Fusion Energy Division
American Nuclear Society
December 2001 Newsletter

Letter from the Chair, James Stubbins, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign

At the beginning, I would like to extend my thanks to Kathy McCarthy, Past Chair, and last year's Executive Committee and Officers for the fine job they did in moving the Fusion Energy Division forward. I would also like to welcome aboard the new additions to the Division Officers and Executive Committee. We should especially welcome Wayne Meier, LLNL, who is now Vice-Chair/Chair Elect, and René Raffray, UCSD, who is Secretary/Treasurer. The FED is among the smaller ANS Professional Divisions. Nevertheless, the membership in the FED increased last year from 646 to 687 members, which is back to the 1997 membership level. By comparison, the overall ANS membership has dropped by 15% from its 1997 level. The FED is also in fine financial shape as a result of the success, and accompanying proceeds, of the 14th Topical Meeting on the Technology of Fusion Energy in Park City, Utah in October 2000. These results are due to the efforts of the previous FED leadership, and an inspiration for us to follow in the coming year.

FESAC Activities

The Fusion Energy Science Advisory Committee met at the beginning of August at Princeton and will meet again at the end of February 2002 in Washington DC. FED has an ex-officio position on FESAC. As typical, the FESAC activities have been fast paced in the past year. This year's budget will permit the expansion of the compact stellerator program and will also support a Fusion Summer Study at Snowmass, Colorado in mid-summer 2002. These were the major items of discussion at the August 2001 FESAC meeting. FESAC supported these directions, which are aimed at keeping the US in the lead in the stellerator area and competitive in the tokamak field. The Snowmass Study (see http://lithos.gat.com/snowmass/) is the next step in a process that is evolving from a detailed FESAC report regarding the US direction toward a Burning Plasma effort The report, available on the web at: http://www.ofes.science.doe.gov/More_HTML/FESAC/BurningPlasma.pdf, represents a major reexamination of the US position regarding toroidal confinement, and near-term fusion energy options. This effort was necessitated, in part, by the major new focus on energy resources by the new administration, as detailed in the National Energy Policy (see http://www.whitehouse.gov/energy/). The timing is also crucial with respect to the evolution of ITER which has completed the Engineering Design Activities (EDA) stage in July 2001 and will shortly transition to the ITER Legal Entity (see Aymar's article in this newsletter). Along with this, the Canadian Province of Ontario has proposed a site for ITER at Clarington, Ontario near Toronto. A delegation from Canada presented their proposal to the FESAC for information. The Clarington site, while attractive in its own right, would be more appealing should the US elect to rejoin the ITER effort. Siting proposals from Japan and Europe are expected shortly. The Burning Plasma Report concentrates on three alternatives of which ITER is one. The other two are IGNITOR and FIRE, all of which will be competitively assessed at Snowmass. The Inertial Fusion Energy (IFE) community will also participate in the Snowmass meeting. Plans are being made to discuss the full range of IFE options (various targets, drivers and chambers) with a focus on near-term plans. Proponents of various driver options (KrF and DPSSL lasers, heavy ion accelerators, z-pinch, and fast ignition drivers) will present requirements, status, key issues and R&D plans. Associated research on target physics, target fabrication and injection technology, chamber technology and plans for integrated facilities such as the Integrated Research Experiments (IREs) will be key part of the meeting. One of the main objectives is to gain community input on near term-plans for development of the various IFE options. Dr. Anne Davies, Associate Director for the Office of Fusion Energy Sciences, has requested endorsement for the Snowmass Summer Study. The ANS FED Executive Committee voted unanimously to endorse the meeting.

Fusion Technology Conferences

The plans for the 15th Topical Meeting on the Technology of Fusion Energy (TOFE) are shaping up. The 15th TOFE will be held as an embedded topical meeting at the ANS Winter Meeting in Washington DC, November 17th through 21st 2002. More information regarding this meeting is found later in the newsletter in an article from Dr. Roger Stoller, ORNL, General Chair.

Other upcoming meetings of interest to FED members are listed below:

19th IEEE/NPSS Symposium on Fusion Energy – SOFE (Rescheduled)
January 22-25, 2002, Atlantic City, NJ, USA
http://www.pppl.gov/sofe01/
mabrown@pppl.gov

6th International Symposium on Fusion Nuclear Technology - ISFNT-6
April 7-12, 2002, San Diego, CA, USA
http://isfnt6.ucsd.edu
chennessy@vlt.ucsd.edu

ANS Annual Meeting
June 9-13, 2002, Hollywood, Florida, USA
http://www.ans.org/

14th International Conference on High-Power Particle Beams and
5th International Conference on Dense Z-Pinches
June 23-28, 2002, Albuquerque, New Mexico, USA
http://www.sandia.gov/BeamsDZP

Snowmass Fusion Summer Study
July 8-19, 2002, Snowmass Village, CO, USA
http://lithos.gat.com/snowmass/

22nd Symposium on Fusion Technology - SOFT
September 8-13, 2002, Helsinki, Finland
http://www.vtt.fi/val/soft2002/

IAEA Fusion Energy Conference
October 2002, Lyon, France
u.schneider@iaea.org

15th ANS Topical Meeting on the Technology of Fusion Energy
November 17-21, 2002, Washington, D.C., USA
http://fed.ans.org/

ANS FED News

Several issues are active within the ANS and FED. There continues to be a debate about the frequency of ANS meetings with an even split between one versus two per year. Professional Divisions have been polled regarding their preferences regarding the frequency of ANS national meetings. While there is an even split between one versus two meetings per year, many Divisions have indicated that they can support sessions at only one meeting per year. For FED, and other divisions, this issue has financial impacts due to the financial incentives for supporting the meetings. Divisions smaller than 800 members, like FED, are "rewarded" if they run at least three sessions, equivalent to 15 papers, at each meeting in a given year. These incentives would not be allotted to Divisions that participate heavily in only one meeting per year. As a follow-on, this incentive applies to the FED 15th TOFE meeting next year. We have endeavored to field at least three sessions in the ANS Annual Meeting, June 9-13, 2002 in Hollywood, FL in order to capitalize on the financial incentives from the 15th TOFE in November 2002. At least one session at the ANS Annual Meeting is being arranged in collaboration with the newest ANS Professional Technical Group, the Aerospace Nuclear Science and Technology Technical Group. We ask your support of this effort.

The FED has been actively seeking potential candidates for ANS Fellow nomination. The FED has about 24 active ANS Fellows and, by virtue of the breadth of research activities in the fusion field, should have several more potential ANS Fellow candidates. The FED will seek the help of current Fellows in identifying and supporting possible candidates.

The ANS has focused on an increased international participation in Society activities. The FED has two international Executive Committee members, while most other Divisions have none. Based on the international activities and interconnectivity of fusion programs, the FED should be well placed to increase the level of international participation.

As we move forward this year, the FED leadership would to solicit issues and suggestions from the members. If you have anything that you would like for us to consider, please contact me directly. My E-mail address is jstubbin@uiuc.edu

FED Slate of Candidates, Kathryn McCarthy, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

We have a full slate of candidates for the upcoming elections for the Fusion Energy Division (FED) of the American Nuclear Society. All FED members will receive a ballot that should be filled out and returned per the instructions supplied with the ballot. Please take the time to return your ballot--this is your chance to be heard! If you'd like to get more involved in FED, please contact Jim Stubbins, the current chair. FED is active in student support and technical meeting sponsorship, and is a great way to get to know the fusion community. If you think that running for a position in FED is something that you'd like to do, don't hesitate to contact Jim Stubbins--he will be heading the nominating committee for next year's candidates.

The list of candidates for the 2002 FED elections includes:

Vice-Chair:	Mohamed Bourham (NCSU) Rene Raffray (UCSD)
Secretary/Treasurer:	Jake Blanchard (UW) Lee Cadwallader (INEEL)
Executive Committee:	Ahmed Hassanein (ANL) Susana Reyes (LLNL) David Senor (PNNL) Lance Snead (ORNL) Phil Sharpe (INEEL) Paul Wilson (UW)

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

The 15th ANS Topical Meeting on the Technology of Fusion Energy (TOFE) is being planned as an embedded topical meeting during the 2002 Winter ANS meeting in Washington, DC. The dates for the meeting are 17-21 November 2002. The General Chairman of the meeting will be Dr. Roger E. Stoller from the Oak Ridge National Laboratory. Professor Akira Kohyama from Kyoto University and Dr. John D. Sethian of the Naval Research Laboratory have agreed to serve as Vice-General Chairmen. The Chairman of the Technical Program Committee will be Dr. Lance L. Snead from the Oak Ridge National Laboratory, with Dr. Masahiro Seki from JAERI and Dr. Dai-Kai Sze from UCSD serving as his Vice-Chairmen. The Atomic Energy Society of Japan has kindly offered to co-sponsor the meeting. Consistent with past meetings, the organizers of the TOFE-15 anticipate accepting papers covering a broad range of fusion technology topics. In addition, they hope to have special sessions that will focus on the similarities and differences between the IFE and MFE environments, and dealing with the interface between the fusion design and the basic fusion materials research communities.

FED Awards: Call for Nominations, Gerald Kulcinski, Fusion Technology Institute, University of Wisconsin-Madison

Enclosed you will find announcements for 3 awards to be given at the 15th Fusion Topical Meeting in Washington, DC, November 17-21, 2002. These awards are:

* 2002 Outstanding Technical Accomplishments Award

* 2002 Outstanding Achievement Award
* 2002 FED Student Award for Fusion Science and Engineering

Nomination deadline is July 30, 2002.

Please make this announcement known to your colleagues and students. Thank you for your cooperation and I am looking forward to your submissions.

Mail nominations to: Dean Gerald L. Kulcinski
Chair FED Honors and Awards Committee
University of Wisconsin-Madison
College of Engineering
1500 Engineering Drive, #443
Madison WI 53706-1687

2002 Outstanding Technical Accomplishment Award
Fusion Science and Engineering

Purpose

* 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.
* So others will understand that the Fusion Energy Division of the American Nuclear Society encourages such technical accomplishment and recognizes its importance to fusion.
* Award to recognize technical accomplishment and professional excellence by a member of the American Nuclear Society.

Criteria

* Emphasis is on individual accomplishment through a specific technical accomplishment. Therefore, the award is usually given to an individual, however, there could be a partnership.
* Emphasis is on a single technical contribution to fusion science and engineering however that contribution is made.
* Contribution to be measured as recognized by others in the field.

Procedure

* Nominations can be made by anyone at anytime to the Honors and Awards Committee Chair of the Fusion Energy Division of the American Nuclear Society.
* On an annual basis, a call will be made for candidates and the Committee will evaluate the information, gather additional information if necessary, and may actively search for additional nominations.
* A decision is made whether an award will be given to any nominee in a specific year.
* The recommended accomplishment is presented to Fusion Energy Division Executive Committee for approval and to the ANS Honors and Awards Committee for concurrence.

Award

* An object of ornamental or useful type with intrinsic value.
* A certificate designating the presentation of the award.
* Presented at any American Nuclear Society Annual Meeting or Division Topical Meeting.

2002 Outstanding Achievement Award
Fusion Science and Engineering

Purpose

* 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.
* So others will understand that the Fusion Energy Division of the American Nuclear Society encourages such achievement and recognizes its importance to fusion.
* Award to recognize achievement, leadership, and professional excellence by a member of the American Nuclear Society.

Criteria

* Emphasis is on a history of achievements in advancing the technological development of fusion.
* Emphasis is on a continued series of contributions to fusion science and engineering however those contributions are made.
* Contributions to be measured as recognized by others in the field.

Procedure

* Nominations can be made by anyone at anytime to the Honors and Awards Committee Chair of the Fusion Energy Division of the American Nuclear Society.
* On an annual basis, a call will be made for candidates and the Committee will evaluate the information, gather additional information if necessary, and may actively search for additional nominations.
* A decision is made whether an award will be given to any nominee in a specific year.
* Nominees' achievements not receiving an award will be re-evaluated for the next three years.

Award

* An object of ornamental or useful type with intrinsic value.
* A certificate designating the presentation of the award.
* Presented at any American Nuclear Society Annual Meeting or Division Topical Meeting.

2002 Fusion Energy Division Student Award
Fusion Science and Engineering

The Honors and Awards Committee of the Fusion Energy Division (FED) of the American Nuclear Society (ANS) is soliciting student papers for the 2002 FED Student Award for Fusion

Science and Engineering. This student award will be presented at the 15th Topical Meeting on Technology of Fusion Energy from November 17-21, 2002 in Washington, DC. The award consists of a Certificate of Accomplishment and a cash award. Travel support is also provided if the student attends the meeting to present the paper and receive the award. In addition, the student will be given the opportunity to publish his(her) full length paper in Fusion Technology without a page charge. Eligibility and nomination requirements are summarized below.

Eligibility:

* Nominee must be a student sometime between September 2001 and July 2002.
* Nomination is made by a faculty member familiar with the accomplishment.
* Submit seven (7) copies of a complete research paper of journal publication caliber, plus nomination requirements listed below.

Requirements:

* Name and address of nominee
* Education (degrees with institutions, dates and field; present status, etc.)
* Nomination letter by a faculty member that includes comments on student's contributions to fusion science and engineering that would be recognized as significant by educators, scientists, and engineers; the creativity, novelty, and current and future importance of the accomplishment.

The award's purpose is to recognize a significant research accomplishment, of journal publication caliber, by a student in the fusion science and engineering area, and to encourage student involvement in future fusion energy programs.

Second International Conference on Inertial Fusion Sciences and Applications (IFSA2001) and the 2001 ANS/FED Teller Awards, Bill Hogan, Lawrence Livermore National Laboratory, Livermore, California

The 2nd International Conference on Inertial Fusion Sciences and Applications (IFSA2001) was held 9-14 September 2001 at the Kyoto International Conference Hall in Kyoto, Japan. The IFSA conferences are held every two years and feature all the sciences and technologies associated with inertial fusion. They contain many sessions on basic high energy density sciences such as high temperature and pressure equation of state measurements, short pulse laser interactions with matter, and laboratory astrophysics. They also include IFE target physics and technology sessions on IFE power plants, drivers and target fabrication. It's a real cross section of the international Inertial Confinement Fusion (ICF) community.

The Institute of Laser Engineering (ILE) at Osaka University was the host organization for IFSA2001 although the planning organization included representatives from all over the world. There were 390 participants at IFSA2001, including 62 who were exhibition members or IFE Symposium participants (see below). Nine societies (including the American Nuclear Society) and 21 other organizations either endorsed IFSA2001 or directly contributed funds. A technical tour was offered to visit the ILE laser laboratories in nearby Osaka. ILE has the Gekko XII solid state laser facility and many papers at the conference presented results of target physics work done there in the last two years. During the conference, ILE held a press conference to announce the opening of their Petawatt laser facility at ILE. They have converted one beamline of Gekko XII into a 0.5 ps pulsed laser at 500 J giving 1 PW of power to use in experiments examining the feasibility of the fast ignition concept for IFE. They plan to do experiments over the next several years (some in collaboration with American colleagues) to examine hot spot formation in targets that have been compressed with the remaining beams of Gekko XII.

You will note that the conference was held during the week that contained the tragic events in New York City on September 11. Several participants learned that they had friends or relatives in New York City at the time of the event. The Japanese Hosts and the international colleagues were extremely solicitous of the feelings and safety of their American colleagues but we all decided the conference must proceed. The Japanese provided extra security at the conference and placed monitors in the hallways so that participants could follow the news. We learned that most of the countries represented at the conference had lost citizens. Because air travel was stopped to the United States, many travelers had to extend their trip a day or two before they were allowed to return.

There was also an IFSA2001 Symposium during the conference. Put on by the Japanese IFE Forum, it discussed industrial participation in IFE and other uses of ICF technology. The conference also included an industrial exhibition. In addition, the IAEA held a Technical Committee Meeting on High Average Power Drivers for IFE jointly with IFSA2001. Papers were presented on diode pumped solid state lasers, KrF lasers, and heavy ion accelerators. The IAEA sponsored TCM was run as special sessions of IFSA2001, reviewed by the IFSA Technical Program Committee so that the arrangement was beneficial to both organizations and one extra meeting on the calendar was avoided.

The 328 IFSA technical participants, including those in the TCM sessions, submitted 423 papers. All papers at IFSA conferences are peer reviewed, both at time of abstract and final paper submission. The Session Chairs have the responsibility to have papers reviewed and have authors make revisions if necessary. The IFSA2001 Proceedings will be published by Elsevier Press in March 2002.

The distribution of participants and papers among the 19 countries participating is as follows:

Country	**Participants**	**Papers**
Australia	2	5
Austria	1	0
Canada	2	3
Czech Rep.	3	6
France	32	47
Georgia	2	3
Germany	16	29
India	2	14
Israel	5	1
Italy	3	10
Japan	149 (+62*)	126

Korea	3	4
Nepal	1	1
P.R. China	13	28
Russia	24	49
Spain	3	8
U. K.	3	8
U.S.A.	63	79
Yugoslavia	1	2
Totals	**328 (+62*)**	**423 (210 submitted)**

* 62 persons participated in the exhibition or the IFE Forum but did not participate in the IFSA2001 technical sessions.

The two winners of the ANS/FED Teller Medal for 2001 were M. Rosen of LLNL and S. Atzeni of the University of Rome "La Sapienza". The awards were presented at the IFSA2001 banquet. Dr. Rosen was recognized for major contributions to the development of laboratory soft x-ray lasers and to the design and analysis of complex high energy density and ICF target physics experiments. Prof. Atzeni, who did much of the research for this award while he was at the Frascati laboratories of ENEA, was honored for his leading contributions to understanding and teaching the high energy density physics related to ICF.

The ANS/FED Edward Teller Medal Endowment Fund now has $24,259 and the ANS has pledged to consider a cash award to accompany the Medals in future years (beginning with the 2003 awards). The contributors to the fund through June 30, 2001 are as follows:

Benefactors:

Fannie & John Hertz Foundation	$10,000

Principal sponsors:

General Atomics	$2500
Hoya Corporation USA	$2000
Schott Glass Technologies	$2000

Sponsors:

IFSA'99 Conference	$1259
AC Martin Partners, Inc.	$1000
Corning, Inc.	$1000
Hogan Manufacturing, Inc.	$1000
Meyer Tool & Mfg., Inc.	$1000
Zygo Corp.	$1000
Lawrence Livermore National Laboratory	$1000

Contributors:

Fusion Energy Division/ANS	$500

The next IFSA conference will be held 7-12 September 2003 on the West Coast of the United States. American Co-Chairs Mike Campbell and Erik Storm accepted responsibility to host IFSA2003 and will form a local organizing committee that includes all ICF organizations in the United States.

Ongoing Fusion Research:

Design of the National Compact Stellarator Experiment (NCSX), Hutch Neilson, Princeton Plasma Physics Laboratory, Princeton, New Jersey.

A new stellarator project, the National Compact Stellarator Experiment (NCSX), recently passed key physics reviews and is currently in conceptual design. The national design team is led by Princeton Plasma Physics Laboratory, in partnership with Oak Ridge National Laboratory. The NCSX will be the lead experiment in a U.S. program to develop the physics of compact stellarators, an innovative magnetic plasma confinement concept for fusion. The NCSX builds upon the advances in stellarators and tokamaks and combines their best features. It takes advantage of the tokamak's excellent confinement, ability to stabilize and manipulate turbulent transport, and lower aspect ratio (compared to classical stellarators) to reduce development costs and system size. It uses the stellarator's externally generated helical field and three-dimensional shaping flexibility to passively stabilize the magnetohydrodynamic modes (particularly the external kink and neoclassical tearing modes) that limit the pressure and pulse length in tokamak plasmas. These compact stellarator features have the potential to provide low aspect ratio plasma that can be steady-state and disruption-free without external current drive or feedback systems.

The NCSX mission is to develop physics understanding needed to evaluate the attractiveness of the compact stellarator as a concept for fusion energy and to advance the understanding of three-dimensional plasma physics in toroidal geometry. The design is based on the quasi-axisymmetric stellarator (QAS) concept, in which the plasma has a three-dimensional shape, but approximate toroidal symmetry in the magnetic field magnitude in magnetic coordinates. The QAS provides good fast-ion confinement and low neoclassical transport losses, allows undamped flows to stabilize turbulence, and allows self-generated bootstrap currents to generate some of the rotational transform. It is best suited for merging tokamak and stellarator physics at aspect ratios ≤ 4.4 approaching those of tokamaks rather than those of typical stellarators, which are in the 6-12 range.

The reference QAS plasma configuration of NCSX (Fig. 1) has three periods, an aspect ratio $R/\langle a \rangle = 4.4$, and strong axisymmetric and three-dimensional components of shaping. It is optimized using advanced theoretical and computational design tools to provide good physics properties: low effective helical ripple, good magnetic surfaces, and marginal stability to ballooning, external kink, vertical, and Mercier modes at $\beta = 4\%$. The rotational transform (0.4 – 0.65) is generated by a combination of external coils (75%) and bootstrap current (25%). The plasma as designed has good magnetic surfaces all the way to the edge except for a small island chain at a rational surface, which is removed by boundary perturbations that are small enough not to affect the transport and stability properties.

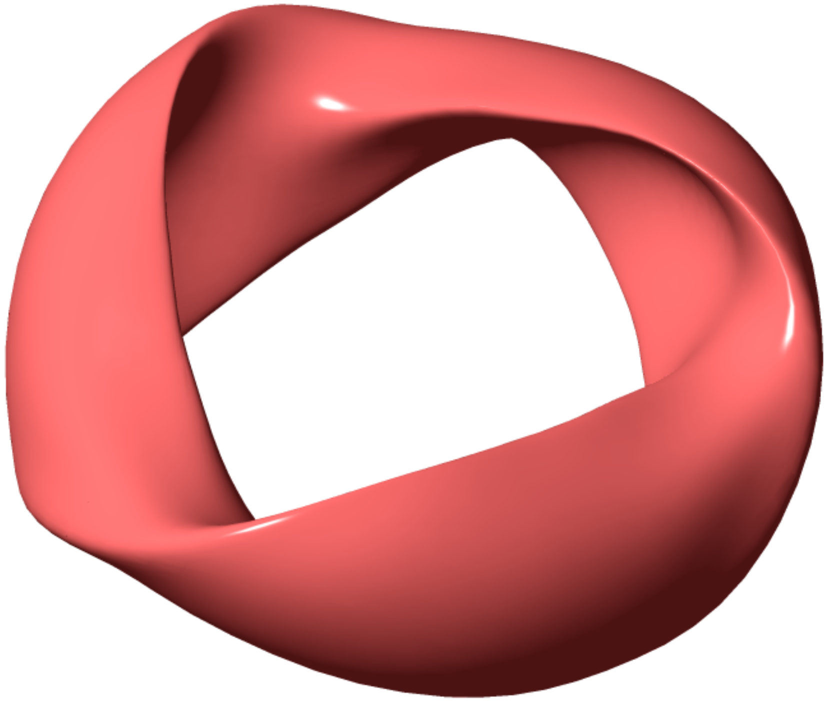

Fig. 1 NCSX reference plasma configuration

The NCSX magnet set consists of the eighteen modular coils (of three different shapes) shown in Fig. 2, eighteen toroidal field coils, five pairs of poloidal field coils, and helical field trim coils. The coils produce equilibria with the physics properties of the reference plasma, drive Ohmic current, and provide flexibility, for example the ability to vary the rotational transform, the shear, and the stability beta limit, while maintaining good quasi-symmetry. Good physics properties are available over wide variations in beta, plasma current, and profile shapes. The design provides a stable evolution path from an initial vacuum state to the high-beta target state. Residual islands are eliminated by making small resonant perturbations in the coil geometry. The trim coils provide a capability for reducing islands over the range of equilibria needed for startup and flexibility. As a further measure, the configuration is designed with “reversed shear” so that neoclassical effects should reduce the widths of any islands.

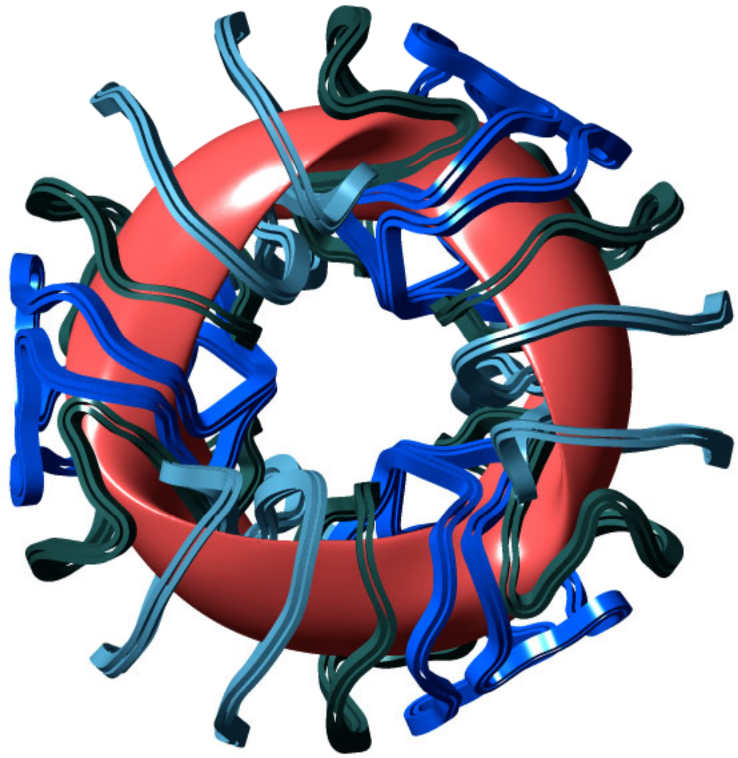

Fig. 2 NCSX modular coils and plasma. Not shown are toroidal field, poloidal field, and trim coils.

The NCSX will have a major radius of 1.4 m and a magnetic field (B) range of 1.2-1.7 T with a flattop time of ≥ 0.2 s in the nominal configuration and 2 T at reduced rotational transform. Transport predictions based on these machine parameters indicate that plasmas with $\beta = 4\%$, $\nu_i^* = 0.25$, B = 1.2 T, and average density 6×10^{19} m^{-3} can be realized with 6 MW of neutral beam injected power. This requires a global confinement time 2.9 times the ISS95 scaling, somewhat higher than the best achieved on LHD and W7-AS, or 0.9 times the ITER-97P tokamak H-mode scaling.

The machine will accommodate up to 12 MW of auxiliary heating, 6 MW of tangential neutral beam injection (NBI) and 6 MW of radiofrequency (rf) heating. The NBI will be provided by the four existing PBX-M neutral beamlines, and high-field-side wave launchers can be installed for mode conversion rf heating. Initially, the machine will be equipped with 3 MW of 0.3-s pulse-length NBI heating. The power and pulse length (up to 1 s) can be increased later, depending on the needs of the program. About 80 ports of various sizes provide good diagnostic access, including good views of the plasma's six symmetry planes, where measurement interpretation is easiest. The plasma-facing components are being designed to control neutral sources for good plasma performance, to absorb plasma energy losses, and to protect the vacuum vessel walls.

The plasma will be surrounded by an inconel vacuum vessel with an internal structure that can support molded carbon fiber composite (CFC) panels that are bakable to 350ºC. Surrounding the vessel are the magnets, which will be made of flexible copper conductor wound on structural winding forms. A cryostat will enclose the stellarator core (Fig. 3) to allow the magnets to be pre-cooled to cryogenic temperatures. The NCSX will be installed in the former PBX/PLT test cell at the Princeton Plasma Physics Laboratory. Many systems, such as the neutral beams, power supplies, and vacuum pumping system, are available from previous projects and will be reused. The total cost is expected to be about $65M.

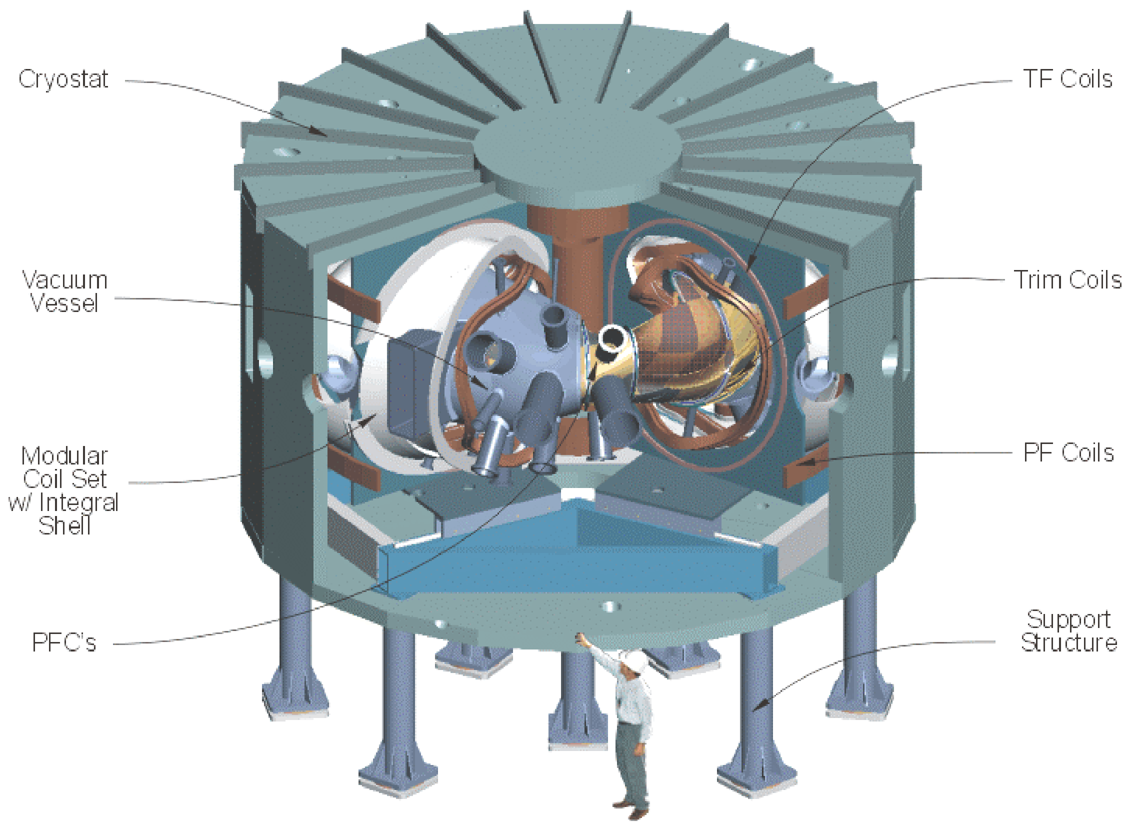

Fig. 3 NCSX stellarator core design.

In March, 2001, the NCSX passed a Department of Energy (DOE) physics validation review, which confirmed the QAS design approach as the appropriate choice for the lead U.S. compact stellarator experiment. The DOE approved the mission need for the new facility and the Fusion Energy Sciences Advisory Committee (FESAC) endorsed the proof-of-principle designation for the compact stellarator concept, citing its potential to resolve significant issues for fusion energy, to complement existing tokamak and stellarator research, and to advance the science of three-dimensional magnetized plasmas. The FESAC said that the potential gains "earn for the compact stellarator an important place in the portfolio of confinement concepts being pursued by the U.S. Fusion Energy

Sciences program." The NCSX project is now in conceptual design. Plans are to conduct a conceptual design review and begin detailed engineering design in 2002 and complete construction in 2006 or 2007. More information may be found at the NCSX web site http://www.pppl.gov/ncsx/.

Heavy Ion Beam Drivers for IFE, Craig Olson, Sandia National Laboratories, Albuquerque, New Mexico, and Simon Yu, Lawrence Berkeley National Laboratory, Berkeley, California

Heavy Ion Fusion (HIF) draws upon conventional accelerator technology and inertial confinement fusion (ICF) target development to produce an attractive power plant concept for Inertial Fusion Energy (IFE). An HIF system consists of (1) an accelerator driver, (2) a standoff region for drift compression and final focus/transport, (3) an IFE target, and (4) a power plant chamber. The separability of the HIF system into these four components is very advantageous, and allows for each component to be studied and developed individually. The accelerator driver draws on the inherent rep-ratability and reliability of conventional high-energy physics accelerators, with the new caveat that relatively high currents are required for HIF so collective effects (e.g., beam space charge fields and beam self-magnetic fields) become important. The U.S. HIF program is based on induction linear accelerator (linac) technology while the European HIF program uses conventional radio-frequency (RF) accelerator technology combined with a system of multiple storage rings to ultimately achieve the high currents required for HIF.

Development of the heavy ion induction linac driver for HIF is the charter of the Virtual National Laboratory for Heavy Ion Fusion (VNL-HIF). The driver parameters are determined by the target requirements. Current HIF IFE targets (distributed radiator designs and hybrid designs) typically have yields in the 400 MJ range, and require 3-6 MJ of 3-4 GeV Pb^+ ions in ion beams with either a circular spot (radius ~5 mm) or an elliptical spot (with minor/major axes from 1.0/1.8 mm up to 3.8/5.4 mm). The tradeoff in driver energy vs. spot size for a fixed yield is an important consideration for HIF. In each case, the driver must produce beams with sufficient beam quality so that after drift compression and final transport the beams can hit the required spot sizes. Beam quality includes characteristics such as transverse emittance, longitudinal energy spread, and beam uniformity. Emittance is a function of the transverse temperature of the beam, which is set initially by the ion source/injector. The emittance can grow in the accelerator due to, e.g., mismatches with the transport lattice, beam combining or splitting, or non-linearities in the transport quadrupoles. The emittance can also grow during drift compression and final transport. During transport in the accelerator and during drift compression, the beam is kept at relatively large average radius (~1-10 cm). During final transport in the power plant chamber, the beam is at peak current, shortest pulse length, and smallest radius (down to the required spot size at the target). Since final transport is also a function of the allowed chamber environment, choice of an optimum final transport method is an important issue for HIF.

Final transport methods can be grouped into two broad categories - ballistic transport and pinch transport. For ballistic transport, the beams are ballistically focused over a distance of several meters from a large radius (~3 - 10 cm) at the chamber entrance to a small radius (0.1 - 0.5 cm) at the target. The beams may be bare beams in vacuum (no neutralization), or beams neutralized in plasma or gas (partial charge and partial current neutralization). For pinch transport, the beams are focused to a small radius (≤ 0.5 cm) at the chamber wall, and then transported at the same small radius to the target. In all pinch transport, the beams are confined by an azimuthal magnetic field. With self-pinched transport, the beam is injected into a gas which results in good charge neutralization and partial current neutralization to produce the confining magnetic field. With channel transport ("assisted pinch"), a preformed current-carrying channel provides a field-frozen confining magnetic field before the beam is injected.

The chamber environment (wall type, wall radius, gas pressure, etc.) must be compatible with the transport method. Three categories of chamber concepts are presently being considered. Dry-wall chambers typically have a target-to-wall distance of ~ 6 meters, wetted-wall chambers have a target-to-wall distance of ~ 4-5 meters, and thick-liquid wall chambers have a target-to-wall distance of ~ 3 meters. A matrix of possibilities exists, as follows:

- Vacuum ballistic transport can, in principle, be used with a dry-wall chamber. Although this option is not presently being considered, it would require ~ 500 or more beams. For a wetted-wall chamber or thick-liquid wall chamber, the inherent minimum chamber gas pressure does not qualify for vacuum transport.
- Neutralized ballistic transport can be used with a thick-liquid wall chamber, and this is the present main-line approach. For this case, neutralization will be provided by plasma injected into the chamber near the chamber entrance, by gas ionization in the chamber, and by gas photo-ionized near the target by radiation caused by the pre-pulse beams on the target. Several simulation codes (LSP, IPROP, BICRZ, BPIC) have demonstrated this approach for HIF power plant parameters. For the wetted-wall case, neutralized ballistic transport is an option but, because of the longer transport distance, would require tighter constraints on chamber vacuum and beam emittance. For the dry-wall case, because of the longest transport distance, there is insufficient neutralization and this case is not being considered.
- Channel transport ("assisted pinch") can be used with all chamber concepts, and this is a backup approach. For this case, a background gas pressure of 1 - 10 Torr is used with a laser-initiated, two-step, z-discharge to create a current-carrying channel with a frozen current of ~ 50 kA. Several beams would be combined into a converging, conical, adiabatic z-discharge plasma lens, and then injected into the main channel. Two main channels would be used with two return-current channels. Channel transport of several 100's kA of 1 MeV protons over distances up to 5 meters was demonstrated in GAMBLE II experiments in the 1980's.
- Self-pinched transport can also be used with all chamber concepts, and this is also a backup approach. For this case, only a low-pressure background gas is needed (1-100 mTorr), and the number of beams would be in the range of 2 - 100. IPROP and LSP computer simulations have shown self-pinched transport for HIF parameters,

and the onset of self-pinched transport was demonstrated in scaled experiments on the GAMBLE II accelerator with 1 MeV protons in the 1990's.

These results are summarized, as part of the recent ARIES-IFE Study of HIF, in the following Table.

ARIES-IFE Study of HIF

Transport Mode / **Chamber Concept**	**Ballistic Transport** *chamber holes ~ 5 cm radius* *most studied*		**Pinch Transport** *chamber holes ~ 0.5 cm radius* *higher risk, higher payoff*	
	Vacuum-ballistic *vacuum*	**Neutralized-ballistic** *plasma generators*	**Preformed channel** **("assisted pinch")** *laser + z-discharge*	**Self-pinched** *only gas*
Dry-wall *~6 meters to wall*	**Not considered now: Requires ~500 or more beams**	**Not considered: insufficient neutral-ization for 6 meters**	ARIES-IFE (2001) **Option: uses 1-10 Torr** *2 beams*	ARIES-IFE (2001) **Option: uses 1-100 mTorr** **~2-100 beams**
Wetted-wall *~ 4-5 meters to wall*	HIBALL (1981) **Not considered: exceeds 0.1 mTorr, so in neutralized-ballistic category**	OSIRIS-HIB (1992) **Possible option: but tighter constraints on vacuum and beam emittance**	ARIES-IFE (2001) **Option: uses 1-10 Torr** *2 beams*	PROMETHEUS-H (1992) ARIES-IFE (2001) **Option: uses 1-100 mTorr** **~2-100 beams**
Thick-liquid wall *~ 3 meters to wall*	**Not considered: exceeds 0.1 mTorr, so in neutralized-ballistic category**	HYLIFE II (1992-now) **Main-line approach: uses pre-formed plasma and 1 mTorr for 3 meters** *~50-200 beams*	**Option: uses 1-10 Torr** *2 beams*	**Option: uses 1-100 mTorr** **~2-100 beams**

In past HIF power plant studies, vacuum ballistic transport was used with a wetted wall in HIBALL; neutralized ballistic transport was used with a wetted wall in OSIRIS-HIB; neutralized ballistic transport was used with a thick-liquid wall in HYLIFE II; self-pinched transport was used with a wetted wall in PROMETHEUS-H; and channel transport & self-pinched transport are currently being considered with dry and wetted walls in ARIES-IFE. For the U.S. HIF program, again, the present mainline approach is neutralized ballistic transport in a thick liquid wall chamber, and the backup approaches are channel transport and self-pinched transport.

For the U.S. HIF program, a series of scaled experiments is being implemented at LBNL to address the science issues associated with the development of the accelerator driver and the transport method. The scaled parameter is the generalized perveance K, which in the non-relativistic limit scales as the beam space charge potential divided by the ion kinetic energy. The absolute parameter is the line charge density λ (which is exactly equal to the beam space charge potential). The concept is to perform a series of experiments with driver-scale perveances of $K = 10^{-4} - 10^{-3}$, and to progressively increase λ from 10^{-4} μC/m (existing scaled experiments) up to 3 - 30 μC/m (driver-scale parameters). Keeping in mind that a single driver beam (1 of N) might be 1-4 kA of 4 GeV Pb^+, this series of experiments is as follows:

- SFFX (Scaled Final Focus Experiment): Already completed, this experiment (with K ~ 1-4x10^{-5} and λ ~ 2-8x10^{-4} μC/m) used a 160 keV Cs^+ beam with a current of 100 - 400 μA. With a heated filament providing a supply of electrons, charge neutralization fractions of 65-80% were achieved.
- NTX (Neutralized Transport Experiment): About to be set up, this experiment (with K ~ 10^{-3} and λ ~ 0.05 μC/m for 400 keV K^+ at 75 mA) is designed to study neutralized ballistic transport with preformed plasma and neutral gas.
- HCX (High Current Experiment): Now being set up, this experiment (with K ~ 10^{-3} and λ ~ 0.2 μC/m for 1.8 MeV K^+ at ~ 1 A) is designed to study electrostatic quadrupole transport and magnetic quadrupole transport at low energies.
- IBX (Integrated Beam Experiment): Just being proposed, this experiment (with K ~ 10^{-3}, final λ ~ 1-2 μC/m, and 10 -20 MeV K^+ likely) will be the first integrated HIF system consisting of an ion source/injector, low energy electrostatic quadrupole transport, higher energy magnetic quadrupole transport, velocity tilt, drift compression, bends, final focus, and final transport. A main theme of the IBX will be to study drift compression.

This series of experiments (plus some smaller-scale experiments to study, e.g., multiple beam effects) will form the basis of justification for an IRE (Integrated Research Experiment). The combination of the IRE and the results of target experiments on NIF will form the basis for proposing an ETF (Engineering Test Facility), which will be a rep-rated, moderate yield, final test facility before an IFE DEMO power plant. Note that the present series of experiments for the near future (NTX, HCX, IBX) are all specifically designed to study the important science issues that must be resolved to ultimately make HIF a viable IFE energy source.

International Activities:

ITER Status at the Start of Negotiations towards a Joint Implementation Agreement, Robert Aymar, ITER International Team Leader, Garching, Germany.

Following the end of the Engineering Design Activities (EDA) in July 2001, all the essential elements are now available to make a decision to construct ITER. The result of the EDA, documented in the ITER Final Design Report (1) in July 2001, provides a detailed, complete, and fully integrated engineering design of ITER which has been elaborated to the extent necessary to allow a realistic assessment of its feasibility, performance, and cost at a generic site. Essential physics and technology R&D has been carried out to underpin the design choices. This result was achieved over the nine years of the EDA at the expenditure (1989 values) of $660M (U.S., until 1999: $110M) on R&D, and nearly 1950 (U.S.: 350) professional person years of effort.

In parallel, the ITER Parties have explored the issues of how to establish the contractual arrangements between future international partners in ITER, and, in particular, the creation of an ITER Legal Entity at a particular site, and the establishment and formal acceptance of all commitments by host and participating countries during construction, exploitation, and decommissioning.

Quadripartite meetings on Negotiations on the Joint Implementation of ITER began in June 2001. The current participants are Euratom, Japan, and the Russian Federation, plus Canada, which contributed through Euratom to the EDA and has now made a government-backed site offer. As an original ITER Party, the U.S.A. may rejoin if it wishes, and other countries may also join subject to unanimous agreement by the negotiating Parties.

The tasks of the Negotiators include the following:

- Drafting the ITER Joint Implementation Agreement;
- Selecting the ITER construction site;
- Agreeing who will provide the various ITER components/systems and how the costs will be shared;
- Identifying the Director General for the ITER Legal Entity (ILE) and the organisation of its work.

The Negotiators are supported on technical aspects by Coordinated Technical Activities (CTA) to maintain the integrity of the project in preparation for joint construction and operation. A Project Board coordinates the activities of the Participant Team of each negotiating Party, plus an International Team located at the present ITER Joint Work Sites. A "Standing Sub-group" of the Negotiators can call on expertise in all other relevant areas necessary to draw up the Joint Implementation Agreement.

The work of the Participant and International Teams during the CTA will involve preparation for an efficient start of construction, including:

- Design adaptations to potential sites and their regulatory environment, and formal review and modification to ensure design completeness;
- Preparation of licensing applications by closer dialogue with potential host regulators;
- Exploitation of physics R&D to take advantage of latest experimental results, and of manufacturing R&D;
- Technical specification for procurements which need to be launched as soon as possible.

This phase will therefore move the project technically from the drawing boards of the EDA Joint Central Team and ITER Parties' Home Teams to a state of readiness for procurement by industry of the longest lead items, and for formal application for a construction license with the host country.

The time scale for the Negotiations foresees that the government of each Party interested in hosting ITER will offer a site in 2001, leading to a preferred site before the middle of 2002, and further development of design adaptations for the preferred site up to the end of the CTA at the end of 2002. The Joint Implementation Agreement should be initiated at the start of 2003. Formal signature (and/or ratification) will take place in 2003.

A key element is the preparation of a site choice and the consequent sharing of contributions, for which the potential participants in construction must evaluate at the highest level the advantages and disadvantages of the various possible outcomes for their scientific institutions, industry, and strategic planning. Such preparation will significantly shorten the time taken to reach a satisfactory compromise with the other participants. If the US is interested in participating in ITER construction, it should therefore rejoin the project soon.

There is an undisputed need for a burning plasma experiment at the centre of the fusion development strategy. As recognised many times in the past, a machine integrating the appropriate physics and technology is the right next step, and ITER fulfils this role. The objectives of the EDA have been fully met and the ITER design has been approved by the Parties. There is consensus that it will reach its objectives. The fusion programme is scientifically and technically ready to take the important ITER step.

Sharing costs and pooling expertise have allowed the EDA Parties jointly to undertake tasks that would have been beyond their individual financial and technical capacity. The Parties have developed a mature and wide-ranging capacity for successful focused international joint work. The success of the EDA demonstrates feasibility and underlines the desirability of jointly implementing ITER in a broad-based international collaborative frame: it supports the Parties' declared policy to pursue the development of fusion through international collaboration. The start of negotiations on an agreement for joint construction and operation is a very positive step in their commitment to the implementation of this policy.

Further details can be found on the ITER web site at http://www.iter.org

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(1) Technical basis for the ITER Final Design, EDA Documentation Series No 22, IAEA, Vienna, 2001