American Nuclear Society
Fusion Energy Division
June 2003 Newsletter

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

It has been an interesting six months for fusion researchers. The US announced it was entering negotiations to once again become partners in the ITER project (see Sauthoff/Baker article). The President of the United States discussed the importance of developing fusion **energy** and noted that fusion could serve as a primary energy source for a hydrogen economy (see Schultz article). The Director of the Office of Science asked the Fusion Energy Sciences Advisory Committee (FESAC) for a plan to demonstrate fusion power production within 35 years (see Goldston article). Despite all this seemingly good news, the President's FY04 budget leaves a lot to be desired. The FY04 budget eliminates funding for fusion chamber technology, an area of research that many members of the ANS FED are involved in. Many fusion community leaders strongly opposed these actions and are working with Congress to get the FY04 budget increased to cover the shortfalls.

On the Division level, there are several items to report. The 15th Topical Meeting on the Technology of Fusion Energy (TOFE) was quite successful for FED. Peer review of over 100 papers has been completed, and accepted papers will be published in a special issue of the Fusion Science and Technology journal. FED is now moving forward with plans to hold the next TOFE in Madison, Wisconsin (hosted by the University of Wisconsin Fusion Technology Institute) in September 2004. The 15th TOFE provided FED with significant income. Our financial situation is very good, which will allow us to continue support of FED awards and student activities. The ANS Professional Divisions Committee completed a preliminary evaluation of FED against recently established "Vitality Measures." I'm happy to report that we scored well in nearly all categories. The few areas where recommended actions at the Division level were noted will be discussed at our semi-annual Executive Committee (EC) meeting at the ANS Summer Meeting in San Diego.

At the conclusion of the June meeting, we will be welcoming new officers and EC members. René Raffray (UC San Diego) will become Chair, Jake Blanchard (U. Wisconsin) moves into the Co-chair role; and Jeff Latkowski (Lawrence Livermore National Lab) will be the new Secretary/Treasurer. The three new members to the EC are Said Abdel-Khalik (Georgia Tech), Ken Schultz (General Atomics) and Phil Sharpe (Idaho National Lab). As my term ends, I'd like to thank the EC members and the many others who serve the FED in various capacities for their hard work and helpful attitudes.

Officers and Executive Committee List, James Stubbins, University of Illinois at Urbana-Champaign, Urbana, IL.

On behalf of the entire Fusion Energy Division, I would like to welcome the new officers and Executive Committee members of the Division. They join a excellent group of individuals who have already been serving the FED as Executive Committee members. Special congratulations go to René, Jake and Jeff who are the Division major officers for the coming year for FED. I would also like to make special note of the FED members who are now and have been serving on the many standing committees that keep the Division vital and well functioning. Congratulations to all -- we are all looking forward to another active and productive year for FED under excellent leadership.

Chair:	René Raffray (UCSD)	(03-04)	raffray@fusion.ucsd.edu
VC/Chair-Elect:	James Blanchard (UW)	(03-04)	blanchard@engr.wisc.edu
Secy./Treas.:	Jeffery Latkowski (LLNL)	(03-05)	latkowski@llnl.gov
Exec. Committee:	Said Abdel-Khalik (GT)	(03-06)	said.abdelkhalik@me.gatech.edu
	Susana Reyes (LLNL)	(02-05)	reyessuarez1@llnl.gov
	Akio Sagara (Japan)	(01-04)	sagara@LHD.nifs.ac.jp
	Ken Schultz (GA)	(03-06)	ken.schultz@gat.com
	Phil Sharpe (INEEL)	(03-06)	SHARJP@inel.gov
	Lance Snead (ORNL)	(02-05)	sneadll@ornl.gov
	Roger Stoller (ORNL)	(01-04)	stollerre@ornl.gov
	Neill Taylor (England)	(01-04)	neill.taylor@ukaea.org.uk
	Paul Wilson (UW)	(02-05)	wilsonp@engr.wisc.edu

FED Standing Committee Chairs:		
	Nominating	Wayne Meier (LLNL) - Chair
	Honors and Awards	Gerald Kulcinski (UW) - Chair
FED Special Committee Chairs:		
	Membership	Ken Schultz (GA)
FED Representatives on National Committees:		
	ANS Publications	Ken Schultz (GA)
	ANS Public Policy	Bill Hogan (LLNL)
	ANS Public Information	Julie Van Fleet (Van Fleet & Associates)
Editors:	Newsletter	Laila El-Guebaly (UW) Dennis Bruggink (UW)
	Fusion Science & Technology Journal	Nermin Uckan (ORNL)
Liaisons to other ANS divisions and organizations:		
	ANS Board	Gary Gates (Omaha Public Power District)
	AAD	Jim Anderson (DOE)
	MS&T	Ken Schultz (GA)
	IEEE	George Miley (UIUC)
FED web masters:		Mark Tillack (UCSD) Dennis Bruggink (UW)

Treasurer's Report, Jake Blanchard, University of Wisconsin, Madison, WI.

As of December 2002, our division had a balance of $15,185. Income in 2002 included $620 from membership dues and $9,060 from the November 2002 ANS Fusion Topical Meeting. Expenses in 2002 included $614 for conducting business meetings during the ANS National Meetings, $1,500 to support student travel to the TOFE Meeting, $2,130 for awards, and a $300 contribution to the NEED Scholarship.

Our income for 2003 is projected to be $600 and projected expenses of $1850, which include $250 for conducting business meetings during the ANS National Meetings, $200 to support student travel to meetings, $500 for awards, a $300 contribution to the NEED Scholarship, and $600 for other expenses. Hence, we project a balance at the end of 2003 of $13,935.

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

Electronic access to FS&T is now available online. Tables of contents and abstracts of papers can be accessed at http://www.ans.org/pubs/. If you are a subscriber, you can also access the full text articles! As of June 2002, ANS member subscribers have been enjoying an online access to FS&T from 1999-to-current journal issues. Libraries and non-member subscribers started the same access in January 2003. ANS indicates that, depending on the reader and subscriber interests, additional journal years (1998-1992) will be added over the next year or so.

For the time period from May 1, 2002 to April 30, 2003, FS&T has received a total of 94 manuscripts. Not included in this total are the ~100 papers submitted to the ANS 15th Topical Meeting on the Technology of Fusion Energy (TOFE) and the over 70 papers submitted to the Open 2002 Systems Conference. FS&T published an excellent selection of contributed papers and several special issues in 2002/2003. Also, an impressive set of special issues is coming up in 2004. Don't miss any of these issues.

The following special issues have been/will be published for 2003:

- Open Systems 2002 Conference, July 1-4, 2002, Korea - FS&T Transactions, January 2003 (70 papers, not included in the FS&T paper count).
- Selected papers from IAEA Meeting on Physics and Technology of Inertial Fusion Energy Targets, June 17-19, 2002, San Diego, California (31 papers) - FS&T regular issue, May 2003.
- Selected papers from ANS 15th TOFE, November 17-21, 2002, Washington, D.C. - FS&T July and September 2003 (98, not included in the FS&T paper count).
- ASDEX-U (EU, MFE Experiment) - FS&T regular issue, November or December 2003 (13 papers).

The following special issues are being planned for 2004:

- 6th Carolus Magnus Summer Euro-School on Plasma and Fusion Energy Physics - FS&T Transactions.
- Magnetic Fusion Reactor (EU, JA, US) - FS&T regular issue (organized by Drs. Shimomura and Andreani, FS&T Associate Editors).
- ARIES-IFE Reactor Study - FS&T regular issue (7 papers).
- DIII-D (US, MFE Experiment) - FS&T regular issue.

- FT-U (EU, MFE Experiment) - FS&T regular issue (12 papers).
- NCSX (US Compact Stellarator Experiment) - FS&T regular issue (12 papers).
- NIF (US, IFE Experiment) - FS&T regular issue.
- TEXTOR (EU, MFE Experiment) - FS&T regular issue (17 papers).

The FESAC Fusion Development Plan, Robert J. Goldston, Princeton Plasma Physics Laboratory, Princeton, NJ.

Dr. Raymond Orbach, Director of the DOE Office of Science, charged the Fusion Energy Sciences Advisory Committee (FESAC) to "develop a plan with the end goal of the start of operation of a demonstration fusion power plant in approximately 35 years. The plan should recognize the capabilities of all fusion facilities around the world, and include both magnetic fusion energy (MFE) and inertial fusion energy (IFE)." Consistent with this, President Bush stated "The results of ITER will advance the effort to produce clean, safe, renewable, and commercially-available fusion energy by the middle of this century. Commercialization of fusion has the potential to dramatically improve America's energy security while significantly reducing air pollution and emissions of greenhouse gases."

A FESAC sub-panel composed of scientists and engineers working in the areas of MFE, IFE, and fusion technology prepared a plan for the deployment of a fusion demonstration power plant within 35 years, leading to commercial application of fusion energy by mid-century. The plan was derived from the necessary features of a demonstration fusion power plant and from the time scale defined by President Bush. It identified critical milestones, key decision points, needed major facilities, and required budgets.

A set of overlapping scientific and technological challenges was found to determine the development path for both magnetic and inertial fusion energy. These challenges define a sequenced set of decisions for the construction of major facilities:

- *Configuration Optimization,* in which a range of potentially attractive configurations is tested and optimized for both MFE and IFE;
- *Burning Plasma,* in which a plasma is brought simultaneously to conditions of high temperature, density and confinement, so that the fusion process can be self-sustaining;
- *Materials Testing,* in which materials are qualified for use in the energetic neutron environment associated with fusion energy;
- *Component Testing,* in which near full-scale fusion power technologies such as chamber components are qualified in a realistic fusion environment;
- *Demonstration*, in which fusion is demonstrated to be an environmentally and economically attractive energy source.

Scientific and Technology Development Programs in theory and simulation, basic plasma science, concept exploration and proof of principle experimentation, materials development and plasma, fusion chamber and power technologies form the foundation for this research.

The overlapping scientific and technological challenges will be met during four development periods, whose decision-driven goals and approximate time periods are:

Present – 2008: *Acquire Science and Technology Data to Support MFE and IFE Burning Plasma Experiments and to Decide on Key New MFE and IFE Domestic Facilities; Design the International Fusion Materials Irradiation Facility*

Specific Objectives:

- Begin construction of ITER, and develop science and technology to support and utilize this facility. If ITER does not move forward to construction, then complete the design and begin construction of the domestic FIRE experiment.
- Complete NIF and ZR (Z Refurbishment) (funded by NNSA).
- Study attractive MFE configurations and advanced operation regimes in preparation for new MFE Performance Extension (PE) facilities required to advance configurations to Demo.
- Develop configuration options for MFE Component Test Facility (CTF).
- Participate in design of International Fusion Materials Irradiation Facility (IFMIF).
- Test fusion technologies in non-fusion facilities in preparation for early testing in ITER, including first blanket modules, and to support configuration optimization.
- Develop critical science and technologies that can meet IFE requirements for efficiency, rep-rate and durability, including drivers, final power feed to target, target fabrication, target injection and tracking, chambers and target design/target physics.
- Explore fast ignition for IFE (funded largely by NNSA).
- Conduct energy-scaled direct-drive cryogenic implosions and high intensity planar experiments (funded by NNSA).
- Conduct z-pinch indirect-drive target implosions (funded by NNSA).
- Provide up-to-date conceptual designs for MFE and IFE power plants.
- Validate key theoretical and computational models of plasma behavior.

2008 Decisions: Assuming successful accomplishment of goals, the cost-basis scenario assumes that by this time decisions are taken to construct:

- International Fusion Materials Irradiation Facility
- First New MFE Performance Extension Facility
- First IFE Integrated Research Experiment Facility

2009 – 2019: *Study Burning Plasmas, Optimize MFE and IFE Fusion Configurations, Test Materials and Develop Key Technologies in order to Select between MFE and IFE for Demo*

Specific Objectives:

- Demonstrate burning plasma performance in NIF and ITER (or FIRE).
- Obtain plasma and fusion technology data for MFE CTF design, including initial data from ITER test blanket modules.
- Obtain sufficient yield and physics data for IFE Engineering Test Facility (ETF) decision.
- Optimize MFE and IFE configurations for CTF/ETF and Demo.

- Demonstrate efficient long-life operation of IFE and MFE systems, including liquid walls.
- Demonstrate power plant technologies, some for qualification in CTF/ETF.
- Begin operation of IFMIF and produce initial materials data for CTF/ETF and Demo.
- Validate integrated predictive computational models of MFE and IFE systems.

Intermediate Decisions: Assuming successful accomplishment of goals, the cost-basis scenario assumes a decision to construct two additional configuration optimization facilities, which may be either MFE or IFE.

  - MFE Performance Extension Facility
  - IFE Integrated Research Experiment

2019 Decision: Assuming successful accomplishment of goals, the cost-basis scenario assumes a selection between MFE and IFE for the first generation of attractive fusion systems.

  - Construction of MFE Component Test Facility (CTF)

    or
  - Construction of IFE Engineering Test Facility (ETF)

2020 – 2029: *Qualify Materials and Technologies in Fusion Environment*

Specific Objectives:

- Operate ITER with steady-state burning plasmas providing both physics and technology data.
- Qualify materials on IFMIF with interactive component testing in CTF or ETF, for implementation in Demo.
- Construct CTF or ETF; develop and qualify fusion technologies for Demo.
- On the basis of ITER and CTF/ETF develop licensing procedures for Demo.
- Use integrated computational models to optimize Demo design.

2029 Decision:

Construction of U.S. Demonstration Fusion Power Plant

2030 – 2035: *Construct Demo*

Specific Objective: Operation of an attractive demonstration fusion power plant.
The facilities and key decisions for this planned are shown in the figure below:

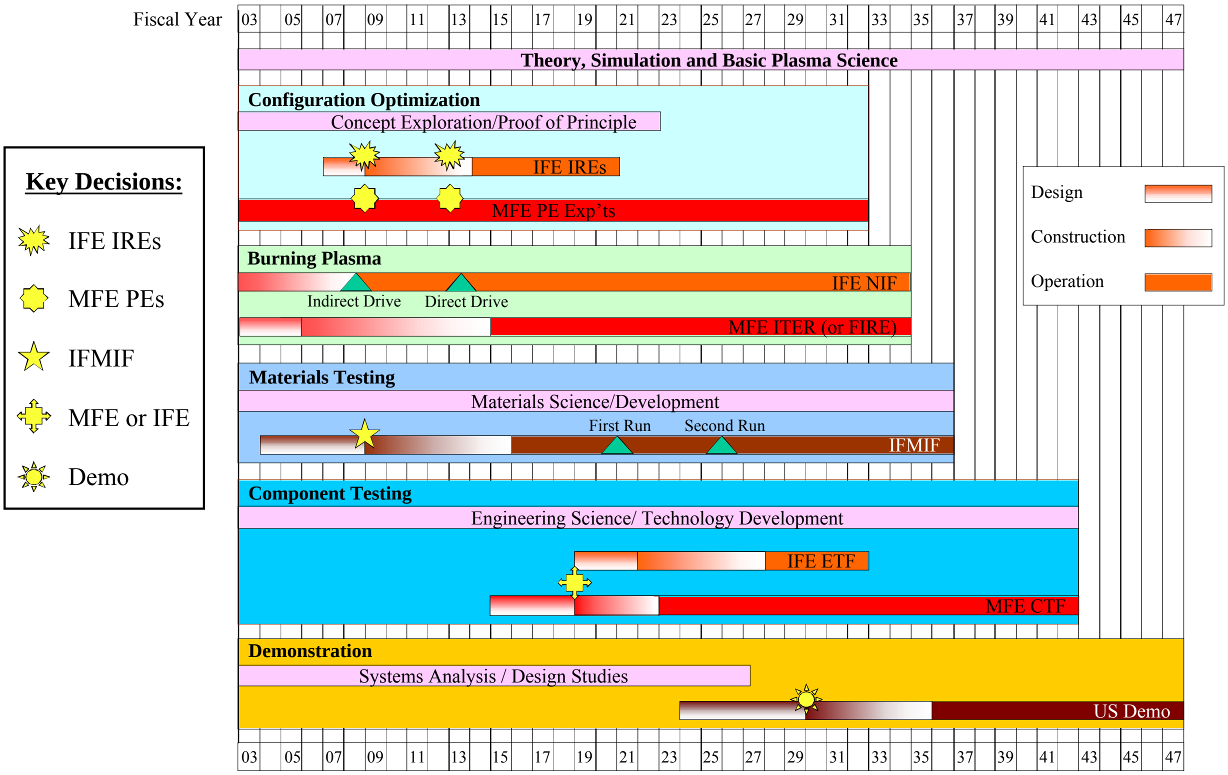

Figure 1. The fusion development plan.

A key conclusion of the plan is that to develop fusion energy on the requested timescale, it is imperative to have a strong balanced program that develops fusion science and technology in parallel, for both IFE and MFE.

The FESAC Development plan report is available at:
http://fire.pppl.gov/fesac_dev_path_wksp.htm

ONGOING FUSION RESEARCH:

The Role of Fusion in the Hydrogen Economy, Ken Schultz, General Atomics, San Diego, CA, USA

Hydrogen has captured the imagination of the technical community, with visions of improved energy security, reduced global warming, improved energy efficiency and reduced air pollution as potential benefits. A significant "Hydrogen Economy" is predicted that will reduce petroleum imports, and reduce pollution and greenhouse gas emissions. Such a hydrogen economy will need significant new sources of hydrogen.

Fusion can play an important role in the Hydrogen Economy by providing a major source of hydrogen. In his *"Hydrogen Fuel Initiative"* speech on 6 February 2003, President

Bush stated: "We are also going to work to produce electricity and hydrogen through a process called fusion. ... The energy produced will be safe and clean and abundant. … Imagine a world in which our cars are driven by hydrogen and our homes are heated by electricity from a fusion power plant." In his 5 March 2003 speech to the National Hydrogen Association, Energy Secretary Spencer Abraham said: "If successful, fusion could well be the most cost effective, long-term source of hydrogen we will ever find."

Hydrogen could potentially be produced from water using fusion energy. Significant effort was devoted to study these possibilities in the 1970-80s. It is instructive to review these earlier studies today as interest in production of hydrogen is revived and as we in the fusion community consider the large responsibility we have been given to be the basic energy source to fuel the Hydrogen Economy.

The FAME Study

Earlier studies were reviewed and evaluated in the late 1980s by the Fusion Applications and Market Evaluation (FAME) study [1]. The goal of FAME was to investigate potential applications of fusion energy beyond electricity production, and to look for ways to capitalize on unique fusion characteristics. The FAME study concluded that there were a number of useful products that fusion could make that had reasonable market potential, and a credible pathway to serve those markets. Hydrogen was one of the more attractive potential products of fusion. A potentially huge market exists; more that twice as big as the market for electricity, and fusion appears well suited for the production of hydrogen. The conclusions of the FAME study are reviewed in the sections below.

A. Direct Use of Radiation

Possibilities include utilizing the radiation or the energetic particle plasma exhaust, or, in inertial confinement, the target debris. Direct process utilization of neutrons may seem simple, but there is a basic difficulty coupling the neutron energy into the reacting medium. Some energy will be deposited in the structure, and much will go to simply heating up the medium, not causing the desired reactions. If a gas is being reacted, only a small fraction of the neutron energy is likely to be available.

1. Radiolysis

Radiolysis is the use of the neutron or secondary gamma ray energy to directly sever chemical bonds, breaking H_2O into H_2 and O, for example. The most energy efficient processes use less than 30% of the deposited energy. The reject energy must therefore be utilized in a co-process or for co-generation. To do so, it must be recovered at high temperature, which implies gaseous cooling media and very low capture fractions for the neutron energy. One of the more interesting radiolytic reactions is the decomposition of carbon dioxide to carbon monoxide. This could be one step of a closed two step water splitting cycle:

$$(2CO_2 + \text{Energy} \rightarrow 2CO + O_2, \quad CO + H_2O \rightarrow CO_2 + H_2)$$

If the reject energy is used for generating additional hydrogen by normal low temperature electrolysis, an upper limit on the estimated overall efficiency would be about 40%.

Radiolysis might thus find a role as a topping cycle to electricity production. A potential problem is the production of radioactive carbon, ^{14}C.

2. Thermal Spike Chemistry

Thermal spike chemistry is the use of very energetic knock-on atoms to create microscopic regions of very high temperature to produce chemical dissociation, which cool off so quickly that reverse reactions cannot occur. While this is a novel and unique application of fusion, calculations show that less than 5% of the neutron energy captured by the reacting medium is channeled into chemical reactions.

B. Use of Fusion Heat

For D-T fusion, 80% of the fusion energy is carried by high energy neutrons. These neutrons are highly penetrating and may be used to generate very high temperature heat in a non-structural refractory ceramic that is thermally insulated from the structural components. Temperatures ≥1000ºC should be achievable, which could be used to produce electricity for electrolysis or for thermochemical water-splitting.

1. Electrolysis

Hydrogen can be produced by electrolysis of water using electricity generated by fusion. By using the potential of fusion to produce high temperature heat, and using that heat in a high temperature electrolysis process, high hydrogen production efficiency can be achieved. Brookhaven National Laboratory proposed a tokamak fusion reactor of the STARFIRE design to generate high temperature steam (~1400°C) for electrolysis to hydrogen and oxygen in a high-temperature electrolysis (HTE) unit. This combination of STARFIRE and HTE was called HYFIRE [2]. An efficiency of ~50% appears possible with 1400ºC HTE units and 40% power cycle efficiency. Work has begun recently at INEEL on HTE using solid oxide membranes developed for fuel cells that may be applicable to fusion production of hydrogen.

2. Thermochemical Water-Splitting

Thermochemical water-splitting is the conversion of water into hydrogen and oxygen by a series of thermally driven chemical reactions. Energy, as heat, is input via endothermic high-temperature chemical reactions. Heat is rejected via exothermic low temperature reactions. All the reactants, other than water, are regenerated and recycled. The Sulfur-Iodine cycle is a prime example of a thermochemical cycle [3]. It consists of three chemical reactions, which sum to the dissociation of water:

$2H_2O + I_2 + SO_2 \rightarrow 2HI + H_2SO_4$ (~120°C)
$H_2SO_4 \rightarrow SO_2 + H_2O + 1/2\ O_2$ (>800°C)
$2HI \rightarrow I_2 + H_2$ (~350°C)

Two studies were done investigating the application of thermochemical water-splitting to fusion energy, one at General Atomics [4] and one at Lawrence Livermore National Laboratory [5]. Both used the Sulfur-Iodine cycle. The results showed a process efficiency of 43%, and an estimated cost of hydrogen of \$1.70 to \$2.00 per kg.

3. Heat Exchangers
To effectively couple the very high temperatures fusion blankets can produce to either HTE or a thermochemical cycle requires use of innovative heat transport loop and heat exchanger designs. The extreme temperatures and aggressive process fluids require use of ceramic components. Tritium permeation from the breeding blanket into the process stream must be avoided, as cleanup of the hydrogen product stream would be prohibitively expensive. Use of two coolant streams, one at moderate temperature to cool the tritium breeding zone and the other at high temperature to cool the process heat zone appears essential.

Economic Projections

The economics of hydrogen production are challenging. Virtually all of the 11 million tons per year of hydrogen that are produced and consumed annually in the USA is produced by steam reformation of methane. At the current cost of natural gas of about \$4.00/MBtu, the cost of the hydrogen is about \$1.10 per kg. The price of natural gas will rise but is expected to be in the \$5–6/MBtu range during the next 20 years or more. This translates into a cost of hydrogen by steam reformation of about \$1.40/kg of hydrogen [6]. Assuming the capital recovery factor for a 10% interest rate and a 40 year lifetime, a fusion plant could produce hydrogen by water-splitting at this \$1.40/kg cost if the fusion plant costs less than about \$450/kW(t). This appears to be a believable cost goal for fusion.

Conclusions

There exists a large market for hydrogen that will grow significantly before fusion will be available. Several processes exist by which fusion energy could be used to produce large quantities of hydrogen. Direct utilization of fusion products (radiolysis) appears to be limited to fractional topping cycles that would add considerable complexity to the fusion blanket design. The most promising approaches are use of high temperature heat in a thermal process such as high temperature electrolysis or thermochemical water splitting. Fusion can potentially provide very high temperatures, which are needed for high efficiency. However, fusion introduces additional concerns, including the need to produce tritium in the blanket, which will limit the fraction of heat that could be delivered at high temperature and will require strict permeation limits. The cost target for fusion to compete is a not unreasonable goal. With development, fusion could help fill the future needs for hydrogen for the Hydrogen Economy.

References:

[1] R.F. Bourque and K.R. Schultz, “Fusion Applications and Market Evaluation (FAME) Study,” General Atomics Report, GA-A18658 (February 1988).
[2] J.A. Fillo and J.R. Powell, eds., Proceedings of Brookhaven National Laboratory’s Fusion Synfuel Workshop, BNL-51188 (August 1979).
[3] G.E. Besenbruch, et al., “Hydrogen Production by the GA Sulfur-Iodine Process. A Progress Report,” Proceedings of the 3rd World Hydrogen Energy Conference, Tokyo, Japan, **1**, 243 (23–26 June 1980).

[4] I. Maya et al., “Utility Fusion Synfuel Study, Phase III of a Study of Chemical Production Utilizing Fusion Energy,” GA Technologies Report, GA-A16813 (July 1983).
[5] R.W. Werner, ed., “Synfuels from Fusion Using the Tandem Mirror Reactor and a Thermochemical Cycle to Produce Hydrogen,” Lawrence Livermore National Laboratory, UCID-19609 (November 1982).
[6] C.E. Gregoire Padro and V. Putsche, “Summary of the Economics of Hydrogen Technologies,” NREL/TP-570-27079 (September 1999).

Current Fusion Safety Research at INEEL,

Dave Petti, Bob Anderl, Lee Cadwallader, Theron Marshall, Kathy McCarthy, Brad Merrill, Rich Moore, Bob Pawelko, Stan Schuetz, Phil Sharpe, and Galen Smolik, Fusion Safety Program, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID.

The Fusion Safety Program (FSP) at the INEEL (http://www.inel.gov/fusion-safety/) has performed experimental research on a wide variety of safety-related phenomena, including oxidation-driven activation product mobilization, tritium uptake and migration in materials, tokamak dust characterization, and chemical reactivity of plasma facing components (PFCs). The FSP has also developed state-of-the-art analytical computer codes and data sets for safety analysis of candidate fusion designs. This article gives an overview of our present experimental research and safety analysis pursuits to serve the fusion research community.

Safety and Tritium Applied Research Laboratory

The Safety and Tritium Applied Research (STAR) facility at the INEEL is nearing completion and promises to fulfill several research needs of the international fusion community [1]. Sponsored by DOE’s Office of Fusion Energy Science and INEEL, the STAR National User Facility allows researchers throughout the world to direct and participate in cutting edge research on plasma-material interactions, molten salts, fusion safety studies, and other programs requiring experimentation with small to moderate levels of radioactive tritium (< 1.6 grams). Established facility infrastructure includes fume hood ventilation, glovebox atmosphere treatment systems, and lab support services. Present activities at STAR include installation of tritium handling systems (assay and cleanup), tritium monitoring systems for room air and stack effluent, and computer network services. Sandia National Laboratories’ Tritium Plasma Experiment [2] has been moved to STAR and will soon be re-assembled, forming a national collaboration between INEEL, SNL, and others on tritium behavior in PFCs. STAR is also used to perform R&D as part of the Japan-US JUPITER-II international collaboration. STAR has the potential to host many more collaborations. Full operational capability of STAR is scheduled for Spring 2004.

Fusion Dust Research

The FSP is investigating the role of dust in the safety and operation of fusion energy systems [3]. By the very nature of its operation, a fusion device generates aerosol particulate, broken flakes, globules, chunks, and other debris that may ultimately affect its safety and operational performance; understanding how dust is generated and transported within a fusion device is of special interest. Initially, dust has been collected and characterized from several US experiments (NSTX, DIII-D, Alcator C-Mod, TFTR, and NOVA). International collaborations have been established with colleagues in Europe (Tore Supra and ASDEX-Upgrade) and Japan (LHD and JT-60U). The FSP has also performed experiments that simulate dust production in tokamaks, providing a first look at the dust generation effects from the mixture of materials likely to be used in future large fusion experiments (e.g., ITER). Other experiments are being planned to study dust mobilization in a toroidal chamber with heated structures and penetrations arranged to represent a fusion device. In addition to these experiments, we are developing comprehensive models to simulate dust production and transport in fusion systems. The models have been used to estimate particulate concentrations in inertial fusion reactor chambers; the results influence chamber design parameters. Effectiveness of dust monitoring and removal systems can be gauged with these modeling tools.

Fusion Liquids Experiments

In recent years, the FSP has expanded research into materials behavior and safety issues associated with advanced coolant and breeder technologies. We are participants in the Japan-US JUPITER-II collaboration to study the behavior of molten salts, in particular the binary (Li and Be) fluoride salt FLiBe [4]. Along with building valuable experience in handling this material, such as bulk generation, closed-system molten state transfer and purification, experiments are underway to determine basic material properties, such as FLiBe and LiSn vapor pressure. Oxidation-reduction reactions using various control agents are being studied to better understand and minimize corrosion mechanisms in fusion reactor systems using FLiBe. Solubility and hydrogen permeation are also being investigated [5]. The FSP investigates advanced materials with attractive features for fusion device applications, and provides feedback to design teams regarding material behavior under accident conditions.

Fusion Safety Codes and Design Support

The analytical portion of the FSP focuses on the development of computer codes and the application of these computer codes to provide safety insights and recommendations for fusion machine designs, candidate fusion materials, and accident progression during hypothesized off-normal events. The principal computer code used for our safety analyses is MELCOR Version 1.8.5, which has been updated by the FSP to include several fusion-specific modifications [6]. MELCOR tracks the flow of a two-phase fluid, as well as any radioactive aerosols that may exist in either fluid phase, and predicts structural component temperatures during accident conditions. While MELCOR is our primary safety analysis code, we also have the analysis capabilities for thermal-hydraulics (ATHENA), component temperatures during decay heating (CHEMCON), magnet circuits and arcs (MSCAP and MAGARC), tritium permeation (TMAP4), and radiological dose consequences (MACCS2).

Safety modeling of fusion machine operating data and lab experiments of physical phenomena allow us to validate our computer codes and give added assurance that our predictions of accident consequences for future fusion reactors are accurate. To this end, the FSP has been involved with code validation experiments of the CEA Experimental Vacuum Ingress Testing Apparatus (EVITA) and the JAERI Ingress of Coolant Experiment (ICE) by applying the ATHENA and MELCOR codes [7,8]. Both of these experiments feature steam injection into a vacuum environment containing superheated or cryogenic surfaces. The FSP is also participating in the safety analysis [9] of liquid metal first wall designs. The analytical section of the FSP is also contributing to the fusion community's understanding of fusion material properties by developing detailed models of the chemical reactivity of lithium [10] and the mobilization and transport behavior of molten salts such as FLiBe and FLiNaK.

Fusion Operating Experience Analysis

Fusion facilities require a safety assessment to obtain permission to operate. Probabilistic safety assessment (PSA) is the preferred safety approach [11]. To complete a PSA, a set of component failure rates is necessary for quantification. To meet this need, the FSP and other researchers in the International Energy Agency's Cooperative Agreement on the Environmental, Safety and Economic Aspects of Fusion Power (IEA/ESE-FP) are collecting and analyzing fusion component operating experiences [12]. As fusion experiments "stair-step" toward a demonstration power plant, the dataset from existing experiments will extrapolate to the next step. Recent data work has focused on vacuum components from the DIII-D tokamak [13]. Future work in this area will continue to examine DIII-D data, including personnel safety equipment [14] and equipment pertinent to next-step experiments. Through the IEA/ESE-FP, these results will be compared to similar work in progress for JET.

Personnel Safety Issues

Another aspect of FSP safety research is personnel safety. Fusion personnel shall be protected from routine hazards commensurate with that of comparable industrial facilities [11]. Research has been performed on the energy sources that fusion personnel are exposed to during facility operations. This research has expanded to include safety walkthroughs of fusion research labs and participation in the US-Japan Safety Monitoring Program. Recent work has focused on chemical safety issues for the public and facility personnel [15]. Future work will continue to support personnel safety assessment in magnetic field exposure, radiofrequency energy exposure, and other pertinent issues.

References:

[1] R. A. Anderl et al., "The Safety and Tritium Applied Research Facility," Fusion Science and Technology, **41,** 568 (2002).

[2] R. A. Causey et al., "Status and Future of the Tritium Plasma Experiment," Fusion Technology, **28,** 1144 (1995).

[3] J. P. Sharpe et al., "A review of dust in fusion devices: Implications for safety and operational performance," Fusion Engineering and Design, **63-64,** 153 (2002).

[4] D. A. Petti et al, "JUPITER-II Flibe tritium/chemistry and safety experimental program," Fusion Science and Technology, **41,** 807 (2002).

[5] S. Fukada et al., “Flibe-D_2 Permeation Experiment and Analysis,” presented at the 15th Topical Meeting on the Technology of Fusion Energy (TOFE), Washington DC, November 17-21, 2002, to be published in Fusion Science and Technology.
[6] B. J. Merrill, R. L. Moore, S. T. Polkinghorne, and D. A. Petti, “Modifications to the MELCOR Code for Application in Fusion Accident Analyses,” Fusion Engineering and Design, **51-52,** 555 (2000).
[7] R. L. Moore and B. J. Merrill, “Comparison of ATHENA/RELAP Results Against ICE Experimental Data,” Fusion Engineering and Design, **63-64,** 411 (2002).
[8] T. D. Marshall, M. T. Porfiri, L. Topilski, and B. J. Merrill, “Fusion Safety Codes: International Modeling with MELCOR and ATHENA-INTRA,” Fusion Engineering and Design, **63-64,** 243 (2002).
[9] B. J. Merrill, D.K. Sze, H. Y. Khater, and E. A. Mogahed, “Safety Implications of CLiFF Liquid Metal First Walls,” Fusion Engineering and Design, **63-64,** 285 (2002).
[10] B. J. Merrill, “A Lithium-Air Reaction Model for the MELCOR Code for Analyzing Lithium Fires in Fusion Reactors,” Fusion Engineering and Design, **54,** 485 (2001).
[11] Safety of Magnetic Fusion Facilities: Requirements, DOE-STD-6002-96, US Department of Energy (1996).
[12] T. Pinna and L. C. Cadwallader, “Component failure rate data base for fusion applications,” Fusion Engineering and Design, **51-52**, 579 (2000).
[13] L. C. Cadwallader and P. I. Petersen, “Confinement Reliability Estimates for Vacuum System Components,” presented at the 15th TOFE, Washington DC, November 17-21, 2002, to be published in Fusion Science and Technology.
[14] L. C. Cadwallader and P. I. Petersen, “Reliability Estimates for Oxygen Monitors,” submitted to the 20th IEEE/NPSS Symposium on Fusion Engineering, to be held in San Diego, California, October 14-17, 2003.
[15] L. C. Cadwallader, “Chemical Hazards and Safety Issues in Fusion Safety Design,” presented at the 15th TOFE, Washington DC, November 17-21, 2002, to be published in Fusion Science and Technology.

Experimental Benchmarks for Data and Model Validation in Integral Material Neutronics, H. T. Hunter, Oak Ridge National Laboratory, Oak Ridge, TN.

Purpose and Background

Neutron transport computations have been a larger focus of new designs that integrate many materials within the exterior regions of the vacuum vessel in magnetically confined plasmas that produce a DT fusion neutron. From the 1970’s, US and non-US scientists have been interested in defining an engineering breakeven design that allows for heat and fusion kinetics properties. The designs must be able to withstand bombardment of 14.1 MeV neutrons from each fusion reaction. Typical nuclear fission experimental spectrums have a very small high-energy flux at 14 MeV, resulting in very poor statistical assessments of the cross sections at these higher energies. Further, many magnetic, cryogenic, blanket, and other vacuum components must reside nearest to the plasma boundaries to enhance the efficiency of the operations. This further creates a integral maze of materials that have ducts and multiple material interfaces affecting the neutron flux. High temperature materials that normally are not used in other fission measurements are prevalent in the structure, vacuum vessel, and surrounding walls and blankets and have very little cross section information available.

Access to the physics and operations instruments and components attached to the plasma wall and surrounding the vacuum vessel is essential. Activation of materials within these regions will emit secondary gamma radiation influencing the dose rates as a function of time after shutdown. A typical exponential decline of dose rates with time will determine a 'waiting period' before personnel can access their equipment. Operations depending on this access will be delayed and may be a limiting factor on the cycle of work done with the plasma device.

Experiments

In order to better understand the flux of neutrons passing through or activating the materials surrounding the plasma, it is important to have experiments use sources at the energy of the fusion neutrons and the materials surrounding the plasma wall interfaces. Experiments should involve multiple mean free paths of these materials, as well as geometries that model specific portions of the plasma wall, blanket, and magnet regions receiving the dose of neutrons coming from the plasma.

Many fusion neutron experiments have been performed within the US and non-US communities since the 1960's in order to better assess the variables involved within the experiment and the model that incorporates the test materials and/or geometries being tested. Cross sections that are inherent to any model of the transport and capture of neutrons must be accurately known within the energy ranges the materials are subjected. Many different types of light and heavy materials have been employed in the experiments, as well as geometries and the computational models that are used to approximate the fusion facility.

Data Preservation and Compilation

Preservation of older experimental work as well as compiling all relevant sources of information is a necessary first step if 'new' work areas are to be accurately assessed. Lost data and missing information plague efforts at combining the skills and resources in long-term research. To mitigate this problem, an international effort was begun in 1992 called SINBAD (Shielding Integral Benchmark Archive and Database) that continues today. SINBAD's mission is to produce a well organized electronic collection of fusion neutronics experiments that have undergone scrutiny for the following information:

1. Complete accurate source definition, including the energy-angle of emissions, timing and power levels of the accelerator-target region, fluctuations and errors involved in the calibration of the source.

2. Geometric organization of materials and their compositions. Included with this information may be tables and graphics depicting the experimental configuration, and error evaluations in the material dimensions, placement, and compositions.

3. Data results and errors from the detectors and unfolding or postprocessing methodology. The inclusion of the detection efficiency and resolution is included.

4. Modeling and computational verification of results may be available and is extremely useful in understanding the experimental and computational weaknesses.

Fusion Experiments

To help assess the needs of the fusion community, a compilation of SINBAD experimental benchmarks is listed below:

SINBAD FUSION, Neutronics Benchmark Experiments.

SINBAD-FNS-OXYGEN.
FNS/JAERI Time-of-Flight Experiment on Liquid Oxygen Slab With 14 MeV D-T Neutrons (1989).

SINBAD-TUD-FE (TUD Iron Slab Experiment).

SINBAD-OKTAVIAN/AL.
Leakage Neutron and Gamma Spectra from Aluminium Sphere Pile With 14 MeV Neutrons (December 1988).

SINBAD-OKTAVIAN/FE.
Osaka Iron Sphere Benchmark Experiment (OKTAVIAN) (1983).

SINBAD-OKTAVIAN/NI.
Osaka Nickel Sphere Benchmark Experiment (OKTAVIAN) (1983).

SINBAD-TUD-FNG-BS.
TUD Measurement of Neutron and Photon Spectra in an ITER Bulk Shield Mock-up (1996).

SINBAD-FNS-C-CYLIND.
Integral Experiment on a 60 cm-thick Graphite Cylindrical Assembly (FNS/JAERI clean benchmark) (1984).

SINBAD-OKTAVIAN/SI.
Leakage Neutron and Gamma Spectra from 40 and 60 cm diameter Silicon Sphere Pile With 14 MeV Neutrons (March 1987)

SINBAD-FNS-V.
Neutron spectra and dosimetry, gamma-ray spectra and heating from a 25.4 cm cube of Vanadium irradiated with a D-T neutron source (FNS/JAERI clean benchmark) (1996).

SINBAD-IPPE-V.
IPPE neutron transmission benchmark experiment with 14 MeV neutrons through vanadium shells.

SINBAD-FNG-SS.

SS Bulk Shield Benchmark Experiment at FNG/ENEA, FENDL Benchmark for IAEA/NDS, 1989.

SINBAD-FNG-BLKT.
FNG Neutronics Bulk SS Shield Experiment (1995).

SINBAD-ILL-FE.
University of Illinois Iron Sphere Benchmark (1975).

SINBAD-SB5-FUS.
ORNL 14-MeV Neutron Stainless-Steel/Borated Polyethylene Slab Experiment (1979).

Additional experiments are added as possible. There are new computational evaluations for the LLNL pulsed sphere measurements conducted on more than 25 materials at various mean free path thicknesses. These results will be published and are presented in part at the San Diego ANS Summer meeting by J. Bucholz. These types of re-evaluations have uncovered what appear to be anomalies and attempts to resolve the measurement details 20+ years later.

Computational Evaluations

Use of newer computational tools has yielded better accuracies for more equivocal models to the experimental arrangements. The importance of gathering and publishing the completed experimental details so others may use and benefit from them is not to be underestimated.

It is estimated that a computational expert will spend up to 2 weeks gathering specific data for each computation. This information often will not include other's computational efforts and bugs or errors found within the dataset. Accuracy within the computational effort is compromised due to lost information. SINBAD seeks to alleviate this with its mission as a living database of experimental measurements for fusion neutronics. Any updates to SINBAD benchmark information have been incorporated and re-released to those users of fusion benchmarks.

Two sources of the SINBAD benchmark databases are the OECD NEA Databank at http://www.nea.fr/html/databank/welcome.html and the ORNL RSICC at http://www-rsicc.ornl.gov/BENCHMARKS.html for release to the public.

The effort invested in SINBAD is voluntary from both these organizations and others that have contributed their work. SINBAD is truly an international effort, involving 22 organizations around the world.

Formats

The chosen format for SINBAD distribution has a two-fold motivation. To gain a wide audience for its use, an HTML format was chosen. Hyperlinks to the abstract, experimental information, and computational information are included in a main searchable table for materials, facilities, and general listings of the experiment. Graphics are linked into the HTML documents to better describe a geometry, source, or result, and these normally use a TIF or JPG type format, both widely recognized by HTML browsers on the Internet. Overall there are more than 50 fission, fusion, and accelerator benchmarks that follow the same format as described above.

Reference:
[1] H. Hunter et al., "**SINBAD Benchmark Mission and Recent Activities**," ANS RPSD Topical Meeting, Santa Fe, NM (April 2002).

INTERNATIONAL ACTIVITIES:

Status of US Efforts Supporting ITER Negotiations, Ned Sauthoff (PPPL) and Charles Baker (UCSD), US ITER Planning Office

In a press release from the White House on January 30, 2003, President Bush said "I am pleased that the United States will join ITER, an ambitious international research project to harness the promise of fusion energy." Secretary of Energy Abraham said that "ITER will help answer tough questions about fusion power. It will advance both the science and technology of fusion by opening the way to a vast array of critical experiments. And it will produce industrial levels of fusion power for long durations."

On February 18-19, 2003, the United States formally joined the Eighth Negotiators Meeting in St. Petersburg, Russian Federation. A series of these meetings has been underway since November 2002 involving the European Union and the Governments of Canada, Japan and the Russian Federation. The Government of the People's Republic of China also recently joined the negotiations. It has also been reported that South Korea is interested in joining ITER and this is under consideration. At the February meeting, the head of the US delegation, Dr. Michael Roberts (US DOE), indicated that the US wishes to make a significant contribution that is comparable to other non-host parties.

Several US people will participate in the 8th Negotiators' Standing Sub-Group Meeting and related meetings in Garching, Germany from May 15-22, 2003. This meeting will deal with a variety of issues including possible procurement systems, management systems, general approach to allocation of tasks among the parties, decommissioning issues, financial regulations, intellectual property rights, and further steps in drafting an agreement. The overall goal is to have a draft agreement by the end of 2003 for submission for consideration by the governments of the parties.

Dr. Anne Davies, Associate Director for Fusion Energy Sciences for DOE, announced on March 4, 2003, in an open letter to the fusion energy sciences community, the formation of a US ITER Planning Office headed by Ned Sauthoff with Charles Baker as his deputy. The function of the planning office is to support DOE in the negotiation process by forming a multi-institutional working team. Ned was also asked to form a national Burning Plasma Program Advisory Committee (BPPAC).

The BPPAC has been formed under the chairmanship of Stewart Prager (University of Wisconsin); other members include Mohamed Abdou (UCLA), Rejean Boivin (GA), Harold Forsen (NAE), Jeffrey Freidberg (MIT), Richard Hawryluk (PPPL), Bick Hooper (LLNL), Stan Milora (ORNL), Gerald Navratil (Col. U), George Tynan (UCSD), and James Van Dam (U of Texas). The BPPAC has provided an initial assessment of the programmatic interest to the US of the 85 ITER work packages and an initial set of selection criteria and their relative weighting for possible US contributions to ITER.

Based on an assessment by the US ITER Planning Office and advice from the BPPAC, an initial set of potential US tasks have been selected for further study to determine the cost to the US if the US were to provide those systems. Teams of national laboratory and university experts, supported by selected industrial contractors, have been selected to evaluate the cost information from the international ITER Team (in terms of ITER value or credit), comparable US costs for the same scope of work, appropriate levels of contingency in the US, as well as necessary supporting design and R&D not part of the ITER work package. The work packages and team leaders currently under study include the following: diagnostics (Johnson and Young - PPPL), magnets (Minervini - MIT), plasma-facing components (Ulrickson - SNL), ECH (Temkin - MIT), ICH (Swain - ORNL and Hosea - PPPL), and fueling (Gouge - ORNL). Studies of additional areas will likely be undertaken in the coming months. A final report on these studies will be completed in June.

Recently, the University Fusion Association hosted an ITER Forum at the University of Maryland. Approximately 120 people attended from a broad cross section of the fusion research community. Everyone had an opportunity to participate in discussions concerning the potential roles of US institutions in the ITER construction and operation phases, and possible criteria for selecting US tasks and their relative weights. Further forums of this type are anticipated in the future.

Please send any comments or requests for further information to Ned Sauthoff (sauthoff@pppl.gov) or Charles Baker (cbaker@vlt.ucsd.edu).

Calendar of Upcoming Conferences on Fusion Technology

2003:

ANS Annual Meeting
June 2-5, 2003, San Diego, California, USA
http://www.ans.org/

3rd International Conference on Inertial Fusion Sciences and Applications – IFSA-2003
September 8-12, 2003, Monterey, California, USA
hogan5@llnl.gov

20th IEEE/NPSS Symposium on Fusion Energy - SOFE-2003
October 14-17, 2003, San Diego, California, USA
http://d3dnff.gat.com/SOFE03
kidney@fusion.gat.com

American Physical Society - Division of Plasma Physics (APS-DPP) meeting
October 27-31, 2003, Albuquerque, New Mexico, USA
http://w3fusion.ph.utexas.edu/aps/index.html

ANS Winter Meeting
November 16-20, 2003, New Orleans, Louisiana, USA
http://www.ans.org/

FPA Annual Meeting and Symposium: Forum on the Future of Fusion
November 19-21, 2003, Washington, D.C., USA
http://fusionpower.org
fpa@compuserve.com

11th International Conference on Fusion Reactor Materials - ICFRM-11
December 7-12, 2003, Kyoto, Japan
Icfrm@iae.kyoto-u.ac.jp
http://icfrm.iae.kyoto-u.ac.jp/

2004:

ANS Annual Meeting
June 14-17, 2004, Pittsburg, Pennsylvania, USA
http://www.ans.org/

16th ANS Topical Meeting on Technology of Fusion Energy - TOFE
Tentative date: September 14-17, 2004, Madison, WI, USA
elguebaly@engr.wisc.edu

22nd Symposium on Fusion Technology - SOFT
September 20-24, 2004, Venice, Italy
gnesotto@igi.pd.cnr.it

7th International Tritium Conference
September 12-17, 2004, Baden-Baden, Germany

20th IAEA Fusion Energy Conference
November 1-6, 2004, Vilamoura, Portugal
http://www.cfn.ist.utl.pt/
fserra@cfn.ist.utl.pt

ANS Winter Meeting
November 15-18, 2004, Washington, D.C., USA
http://www.ans.org/

American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 15-19, 2004, Savannah, GA, USA
http://w3fusion.ph.utexas.edu/aps/index.html

2005:

7th International Symposium on Fusion Nuclear Technology - ISFNT-7
May 22-27, 2005, Tokyo, Japan
http://isfnt.naka.jaeri.go.jp/
isfnt7@fusion.naka.jaeri.go.jp

ANS Annual Meeting
June 5-9, 2005, San Diego, California, USA
http://www.ans.org/

American Physical Society - Division of Plasma Physics (APS-DPP) meeting
October 24-28, 2005, Denver, Colorado, USA
http://w3fusion.ph.utexas.edu/aps/index.html

ANS Winter Meeting
November 14-17, 2005, Washington, D.C., USA
http://www.ans.org/

2006:

ANS Annual Meeting
June 5-8, 2006, Reno, Nevada, USA
http://www.ans.org/

ANS Winter Meeting
November 13-16, 2006, Albuquerque, New Mexico, USA
http://www.ans.org/

The content of this newsletter represents the views of the authors and the ANS-FED Board and does not constitute an official position of any US governmental department or international agency.