



**American Nuclear Society
Fusion Energy Division
June 2014 Newsletter**

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Letter from the Chair, Minami Yoda, Georgia Institute of Technology, Atlanta, GA.

On behalf of the Division, it is my pleasure to welcome the newly elected officers of the Division: Susana Reyes (LLNL), who will be succeeding me as Chair, Arnie Lumsdaine (ORNL) as Vice-Chair, and Paul Humrickhouse (INL) as Secretary/Treasurer. I'd also like to welcome the new members of the FED Executive Committee: Blair Bromley (AECL), Craig Taylor (LANL), and Neill Taylor (CCFE). With Drs. Bromley and (N.) Taylor joining Satoshi Konishi, we are now up to three international ExCo members.

Many thanks to Secretary/Treasurer Steve Combs (ORNL), who has done the real work of the Division for the last two years, and our outgoing Committee members Yutai Katoh, Arnie Lumsdaine (both ORNL), and Rene Raffray (ITER), for their service over the last three years. I will miss working with all of you.

In a very pleasant surprise, the FY2014 Omnibus Appropriations Act approved by Congress allocated more money than expected for fusion, including \$22 million for Alcator C-Mod operations. Clearly, there is still enthusiasm for fusion on the Hill. There are, however, serious concerns about ITER: the Act caps US cash contributions to ITER until the recommendations of the most recent International Organization Management Assessment are implemented.

The Act also requires Fusion Energy Sciences (FES) to submit a ten-year strategic plan within a year to the House and Senate Appropriations Committees. Dr. Mark Koepke, chair of the FES Advisory Committee, has therefore assembled a Strategic Planning (SP) Panel, which includes Dr. Reyes and myself. The Panel is charged with assessing priorities for the domestic fusion program (excluding US contributions to ITER of \$150 million based on the President's FY15 request) based on four budget scenarios: the President's FY15 request (\$266 million); current funding levels (\$305 million); current funding levels + cost-of-living increases; and current funding levels + modest (2%) growth. The panel will start drafting this report, which is due October 1, in early September. Given the importance of this ten-year strategic plan, the absence of facilities experts on the panel because of conflict of interest issues, and the reorganization of FES budget categories into Burning Plasma Science (Foundations, Long Pulse, ITER) and Discovery Plasma Science, I hope that Division members will be actively involved in the strategic planning process. Further information on the SP Panel can be found on the USBPO (<https://www.burningplasma.org/>) and FIRE (<http://fire.pppl.gov/>) websites.

The recent ANS Student Conference held at Pennsylvania State University had a panel on Fusion Technologies, which is I believe a first. Many thanks to Trey Gebhardt and Leigh Winfrey (Virginia Tech) for organizing this panel, and panelists Ronald Gilgenbach (U. Michigan), Rob Goldston, Rajesh Maingi (both PPPL) and Susana Reyes (LLNL). Finally, I look forward to seeing you and hearing about the latest developments in fusion at the 21st Topical Meeting on the Technology of Fusion Energy (TOFE21), which will be embedded in the American Nuclear Society Winter Meeting on November 9-13, 2014 in Anaheim, California.

List of Officers and Executive Committee Members, Lee Cadwallader, Idaho National Laboratory, Idaho Falls, ID.

The FED election was held in the spring of 2014, with voting being closed by mid-April. Our FED Chair, Dr. Minami Yoda (GIT), completes her term of office at the end of the ANS summer meeting and Dr. Susana Reyes (LLNL) becomes FED Chair. Dr. Arnold Lumsdaine (ORNL) was elected to the position of Vice-Chair/Chair-Elect. Mr. Stephen Combs (ORNL) completes his term as Secretary/Treasurer and Dr. Paul Humrickhouse (INL) was elected to that office. The persons elected to three-year terms on the FED executive committee are: Dr. Neill Taylor (CCFE), Dr. Blair Bromley (AECL), and Dr. Craig Taylor (LANL). We thank the outgoing committee members Dr. Yutai Katoh (ORNL), Dr. Arnold Lumsdaine (ORNL), and Dr. Rene Raffray (ITER) for their service and look forward to working with the newly elected members.

FED Officers:

Susana Reyes (LLNL)	Chair (14-16)
Arnold Lumsdaine (ORNL)	Vice Chair/Chair-elect (14-16)
Paul Humrickhouse (INL)	Secretary/Treasurer (14-16)

Executive Committee:

Jean Paul Allain (UIUC)	(13-16)
Blair Bromley (AECL)	(14-17)
Satoshi Konishi (U. Kyoto)	(12-15)
Kevin Kramer (LLNL)	(13-16)
Jacob Leachman (WSU)	(12-15)
Juergen Rapp (ORNL)	(12-15)
Craig Taylor (LANL)	(14-17)
Neill Taylor (CCFE)	(14-17)
Kelsey Tresemer (PPPL)	(13-16)

Past Chair:

Minami Yoda (GIT)	(14-16)
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FED Standing Committee Chairs:

Nominating: Minami Yoda (GIT) - Chair
Honors and Awards: Nermin Uckan (ORNL) - Chair
Program Committee: Arnold Lumsdaine (ORNL) - Chair

FED Representatives on National Committees:

ANS Publications: Nermin Uckan (ORNL)
ANS Public Policy: Minami Yoda (GIT)
ANS Program Committee:
Lance Snead (ORNL), Lee Cadwallader (INL), Minami Yoda (GIT)

Editors:

Newsletter: Laila El-Guebaly (UW)

Fusion Science and Technology Journal: Nermin Uckan (ORNL)

Liaisons to other organizations and ANS divisions:

ANS Board: Andrew Klein (OSU)

MS&T: Lance Snead (ORNL)

IEEE: Mark Tillack (UCSD)

RPS: Paul Wilson (UW)

YMG: Ahmad Ibrahim (ORNL)

Webmasters:

FED Website: Mark Tillack (UCSD)

UW Website: Dennis Bruggink (UW)

Treasurer's Report, Stephen Combs, Oak Ridge National Laboratory, Oak Ridge, TN.

As of March 31, 2014, our division had a balance of \$56,152. Our initial balance at the beginning of 2014 was \$56,523. Our income for the first three months of 2013 was \$429 in member allocation, and this suggests a total allocation for the year of \$1716. The other source of income this year is proceeds from the 2014 TOFE that is estimated as ~\$4500. Thus, the total estimated income for 2014 is ~\$6216. The standard expenses for the first three months of 2013 were \$500 for support of the 2014 ANS student conference in University Park, Pennsylvania (hosted by Pennsylvania State University student section) and \$300 to assist student travel to the two national ANS meetings (June in Reno and November in Anaheim). Additional planned standard expenses for 2014 include \$500 for the ANS NEED scholarship fund, \$600 for conference phone lines during the two executive committee meetings (June in Reno and November in Anaheim— costs could be less), and \$500 for miscellaneous expenses (which is rarely used in full). We also have significant costs planned to support the 2014 TOFE, including \$1500 for awards (two professional and one student) and \$3000 for student travel assistantships. Thus, our total expenses planned for 2014 are \$6900, giving FED a projected balance of \$55,839 at the end of the year or a deficit for the year of \$684. The actual income and expenses for 2014 will vary somewhat from the estimates, and a surplus is possible.

Update on the 21st Topical Meeting on the Technology of Fusion Energy (TOFE), Brian D. Wirth, University of Tennessee, Knoxville, TN.

I am writing to inform you of the status for the 21st TOFE meeting that will be held during the week of 9-13 November 2014, as an embedded topical meeting at the 2014 ANS Winter meeting. The meeting will be held in Anaheim, CA at the Disney Resort and Hotel. The call for abstracts has been issued, and the abstract submission deadline was extended until June 10, 2014. We currently anticipate that the meeting will run for three or three and one half days, beginning on the afternoon of Monday, November 10 and concluding on Thursday, November 13, 2014.

The technical program committee, chaired by Dr. Rajesh Maingi (PPPL) and Dr. Vincent Chan (GA), has identified a strong technical program, and are finalizing plans for the three plenary sessions, which will be on Tuesday, Wednesday and Thursday mornings of the meeting. We currently have commitments for plenary lectures from Dr. Diedrie Boilson on the status of ITER; Dr. Gianfranco Federici on the technology pathway to DEMO; Prof. Hidetoshi Hashizume on fusion engineering in Japan; Dr. G.S. Lee on the Korean fusion roadmap; Dr. Yuanxi Wan, on the Chinese CFETR status; Dr. Rick Kurtz on fusion materials; Dr. John Lindl with an update on the status of the National Ignition Facility and the path forward toward ignition; and Dr. Pete Pappano on the DOE OFES plans for fusion development.

We anticipate having an additional 16 parallel oral sessions of approximately 2 hour duration, in addition to poster sessions. The parallel oral sessions will include special topical sessions on Energy Development Facilities, which is being organized by Dr. Laila El-Guebaly (UW) and Dr. Chuck Kessel (PPPL), and the safety and environmental impact of fusion which is being organized by Lee Cadwallader (INL). These special sessions will be in addition to regular thematic sessions around the progress of major facilities, including the NSTX upgrade, power plant studies, plasma engineering and plasma materials interactions.

We have already made arrangements to have the conference proceedings published as two special issues of the journal Fusion Science and Technology, as in past TOFE meetings. The publication committee will be chaired by Prof. Jacob Leachman of Washington State University and Lee Cadwallader of the Idaho National Laboratory; and we will soon be finalizing the membership of the publication committee. If you are interested in volunteering to participate in the publication committee, please let me know by email (bdwirth@utk.edu).

In summary, I look forward to a successful meeting with the fusion energy community in Anaheim next November.

Call for Nominations – ANS-FED Awards, Nermin A. Uckan, Oak Ridge National Laboratory, Oak Ridge, TN.

The Honors and Awards Committee of the Fusion Energy Division of the American Nuclear Society [FED/ANS] is seeking nominations for two FED/ANS awards:

- **Outstanding Achievement Awards:** This award is for recognition of a continued history of exemplary individual achievement requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.
- **Technical Accomplishment Award:** This award is for recognition of a specific exemplary individual technical accomplishment requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.

Detailed descriptions of the awards (purpose, criteria, and procedure) and past recipients can be found at <http://fed.ans.org/awards.shtml>.

Note that the nominees will only be considered for the particular award for which they are nominated.

- **Nomination deadline is July 1, 2014**

The awards will be presented at the 21st ANS Topical Meeting on the Technology of Fusion Energy (21st TOFE), embedded in the ANS Winter Meeting and Nuclear Technology Expo to be held Nov. 9-13, 2014 in Anaheim, CA.

Nominations can be made by individuals and submitted anytime to the FED/ANS Honors and Awards Chair electronically at uckanna@ornl.gov. Nomination package must include

1. Nominee's CV
2. A description of exemplary achievement(s)
3. Support letter(s) and/or co-signature on the nomination form.

Incomplete submissions will not be considered. Details are available at <http://fed.ans.org/awards.shtml>.

Please send inquiries and nominations electronically to:

Nermin A. Uckan
FED Honors & Awards Chair
uckanna@ornl.gov

Nominators of 2010 and 2012 nominees are encouraged to update their 2010 and 2012 nomination packages and re-submit.

The **Outstanding Student Paper Award** will also be given at the 21st TOFE meeting through a separate process under the auspices of 21st TOFE. Details will be forthcoming in conjunction with the meeting announcement.

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

Fusion awards have been established to formally recognize outstanding contributions to fusion development made by members of the fusion community. The following awards (listed in alphabetical order) were available to the newsletter editor at the time of publishing this newsletter. We encourage all members of the fusion community to submit information on future honorees to the editor (elguebaly@engr.wisc.edu) to be included in future issues. The ANS-FED officers and executive committee members congratulate the honored recipients of the 2014 fusion awards on this well-deserved recognition and our kudos to all of them.

US DOE Awards

Two US Department of Energy Appreciation Awards were presented to:

- Dr. **Stanley Milora** of ORNL “For over three decades of dedicated service as an outstanding scientist, including the invention of the light-gas gun pellet injector concept and its application on many US and international facilities to demonstrate improved plasma performance; as an effective leader, including service as Director of the ORNL Fusion Energy Division, Director of the US Virtual Laboratory for Technology, and Chief Technologist for the US ITER Project Office; and as a strong public advocate of fusion energy science.”
- Dr. **Martin Peng** of ORNL “For pioneering contributions in the invention and application of the spherical torus approach for magnetically confining a high-temperature plasma, in leadership of US and world efforts in spherical torus research, and in identification and advocacy of ways in which the spherical torus can contribute to fusion energy development.”

ANS Student Award

The winner for the Best Presentation in the Fusion Track of the ANS Student Conference (held at Pennsylvania State University) is **Jonathon Coburn** from North Carolina State University. The title of his presentation is “Evaluation of Fusion Materials Ablative Behavior Under Simulated High Heat Flux Disruption Conditions from a High Energy Density Plasma Source.”

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

During the past 12 months (from May 1, 2013 to April 30, 2014), FS&T received a total of 242 manuscripts. Of the 242 manuscripts, 39 were from North America, 64 from Europe (including Russia), 132 from Asia, and 7 from others, with the following breakdown: 185 have been accepted, 48 have been rejected/withdrawn, and 24 are under review/revision. FS&T stopped publishing and indexing FS&T *Transactions*.

The following dedicated issues were published during the period 5/1/2013 to 4/30/2014:

- IAEA Data Evaluation for Atomic, Molecular and Plasma-Material Interaction in Fusion – FS&T May 2013
- Open Magnetic Systems & Plasma Materials Interactions 2012 – FS&T *supplement* May 2013
- Proceedings of 20th TOFE 2012 – FS&T Aug. & Sept. 2013
- Lectures from 6th International ITER School – FS&T Jan. 2014
- Selected papers from 2nd IAEA-ITER TM on Analysis of ITER Materials & Technologies (2012) – FS&T March/April 2014.

The following issues are scheduled/planned for the remainder of 2014 and beyond:

- Selected papers from 16th ICFRM 2013 – FS&T Jul./Aug. 2014
- Selected papers from Tritium 2013 – FS&T regular issue (late 2014/early 2015)
- ARIES-ACT Special Issue – FS&T (late 2014/early 2015)

- Open Magnetic Systems & Plasma Materials Interactions 2014 – FS&T (mid-2015)
- NIF-NIC Special Issue – FST regular issue (mid-2015)
- Proceedings of 21st TOFE 2014 – FS&T regular issues (mid/late-2015)
- Selected papers from Tritium 2016 – FS&T regular issue (in 2017)
- Physics & Technology for Steady-State Operation – FS&T regular issue (in planning).

New with FS&T in 2014: ANS has started assigning DOI numbers to articles starting with the January 2014 issue. There is no timetable yet for historical/back issue DOI assignments. Also, ANS will be introducing ‘first-look’ article-based publishing – papers will be published online as soon as possible without waiting for a full issue to be compiled. This will make the final citable articles available faster.

ANS has completed scans of historical pre-1997 back issues for all its three scientific journals. Electronic access to FS&T is now available from 1981-to-current. As always, tables of contents and abstracts of papers can be accessed at <http://www.ans.org/pubs/journals/fst/>. Individual and library subscribers can access the full text articles at <http://epubs.ans.org/>.

Please send your comments on FS&T contents and coverage as well as suggestions for potential future topical areas that are timely and of interest to fst@ans.org.

ONGOING FUSION RESEARCH

Fusion Energy Systems Studies Group Examines the Fusion Nuclear Science Facility, Chuck Kessel, Princeton Plasma Physics Laboratory, Princeton, NJ.

The Fusion Energy Systems Studies (FESS) group (<http://fess.pppl.gov>) will spend the next 3 years examining the Fusion Nuclear Science Facility (FNSF). This facility, in the US fusion program view, is the first strongly fusion nuclear confinement device, taking advantage of both fusion nuclear and fusion plasma science developments. The primary purpose of the FNSF is to provide, simultaneously, the environment and the integrated components that we expect in a demonstration power plant, and ultimately a commercial power plant. This environment is quite complex, including fusion neutrons and the associated damage and transmutations, surface and volumetric heating, high temperatures, strong magnetic fields, pressures and stresses, hydrogen loading and permeation in solids, vacuum with plasma, interaction of coolants and liquid metals with solids, and significant gradients in these parameters through the thickness of components and in the poloidal direction. The components of the fusion core include the first wall, tritium breeding blanket, radiation shield, structural ring, vacuum vessel, heating and current drive launchers, magnets, cryostat, and diagnostics. From a basic point of view, the FNSF is a challenging mixture of multiple environment features, materials, and functions. In view of our commitment to successful ITER construction and operations, examining the fusion nuclear phase is essential to take advantage of our investment. The

technical gaps that exist between ITER and a demonstration power plant must be bridged with additional research and facilities.

In the overall pathway to the first commercial power plant, there are numerous activities in the US and international fusion programs, as shown in Fig. 1, shown with approximate dates and program durations. The plasma science activities are laid out roughly as we perceive them today, with the present shorter pulse tokamak experiments, the longer pulse Asian tokamaks, and ITER, providing the dominant confinement facilities where plasma science is advanced. Somewhere near or after the start of ITER DT operation, the FNSF construction could be completed and operation in DD would begin. The DD phase is intended to establish the ultra-long plasma durations required for the fusion nuclear missions of the device, and to the extent possible the plasma performance demonstration. The plasma science basis beforehand, from the confinement devices shown, is up to ~100-3000 s, largely available from JT-60SA, KSTAR, EAST, and ITER. The durations desired in the FNSF range from days to weeks, and the duty cycle associated with these plasma operations must increase significantly from the highest anticipated on ITER of 5%. Since the FNSF is nuclear ready, and all systems are designed for steady state operation, this provides an ideal platform for focused preparation of the plasma operating scenarios including plasma material interactions and power and particle handling, albeit based heavily on previous plasma demonstrations and simulations. Prior to the FNSF, a wide range of fusion nuclear science R&D is required to establish the technical basis for the facility, which includes fusion relevant neutron irradiation of several materials (as well as fission irradiation), liquid metal breeder flow science and material interactions, tritium behavior science and handling, plasma facing components and plasma material interactions, magnet development, and other enabling technologies. These constitute an integrated fusion nuclear science program, which provides the technical foundation to proceed with the FNSF, and some of these facilities will continue to operate during FNSF operation in order to support the advances in materials, operating environment, and design evolution. This R&D can be broken into two major components, fusion nuclear irradiation of largely single materials (which also includes fission irradiation), and a progressive level of integrated testing in non-nuclear facilities. It is not possible to combine these features in any significant way, and so the FNSF is the penultimate step in bringing all these aspects together, along with a neutron producing plasma. Simultaneously with experiments, the ability to simulate the various sub-systems, both individually and in an integrated manner must be developed, as this is the final product that is delivered to the commercial power industry.

The DT phases of a FNSF begin slowly, backing down (from those established in the DD phase) in plasma duration and duty cycle in order to allow significant diagnostic tracking of the integrated components as the fusion neutrons are seen for the first time (only single material fusion neutron exposure is expected prior to the FNSF operation). As the phases advance during the FNSF program, the neutron exposure increases primarily via longer plasma durations and higher duty cycles, the structural material would evolve to more advanced alloys, the operating temperature would increase, and design/operation would be optimized. Part of this study will be to examine the program on the FNSF in some detail, so that blanket and divertor testing strategies can be formulated. The length

of each phase in the program, its target parameters, the blanket/divertor concept being tested, integration of next generation or design update blanket/divertor concepts, and coordination with offline facilities such as the integrated blanket testing or fusion neutron material testing, are all factors in establishing a reasonable plan for the facility.

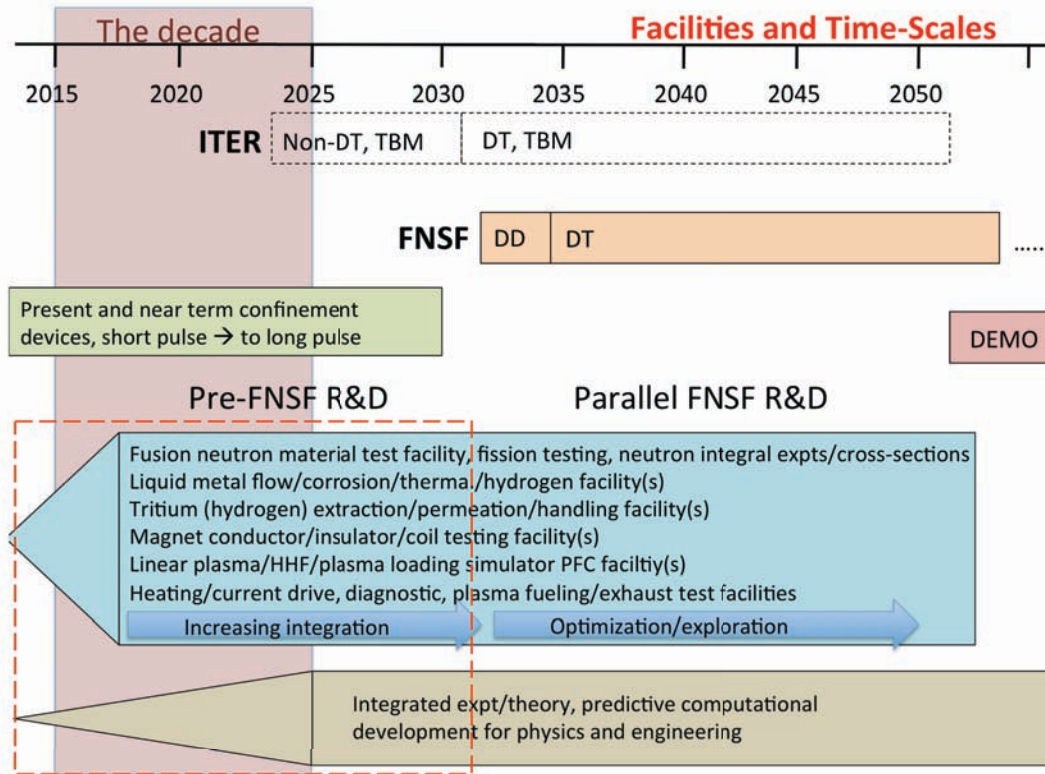


Fig. 1. A view of the evolution to a first power plant can be seen on an imagined time line with specific facilities identified, including the offline facilities and predictive capability developments, for the tokamak example. Here, present confinement devices refer to DIII-D, C-Mod, NSTX-U, JET, ASDEX-U (possibly others), and Asian long pulse confinement devices refers to KSTAR, EAST, and JT-60SA.

Although power plant studies exist and can provide a vision to the commercial realm, a demonstration power plant (DEMO) study is lacking. This activity will critically examine the specifications for DEMO that are presently being applied, and determine both a technical philosophy and technical parameters that are needed to convince utilities and associated industrial architects that a commercial power plant can be successful. This aspect is important because the pathway to commercial power involves two devices, the FNSF and the DEMO. These devices are not independent, and require an integrated development plan. At the end of the DEMO operation, no technical gaps should exist for any systems in the plant as compared to those to be used in a power plant. This does not mean that the DEMO must be precisely the same size or power or availability as a commercial power plant; however, it does mean that the projection/scaling from the

DEMO to the commercial plant can be made with high confidence. Meanwhile, the early phases of the DEMO may have to include some development to reach the maximum levels, and achieve the operations characteristic of a power plant (long continuous power production, routine maintenance, and efficient blanket and divertor change out). This depends on the extent to which the FNSF has approached DEMO and power plant-like levels for component lifetimes, plasma durations, and plant operations.

The missions for the FNSF, and the metrics used to measure a specific FNSF design must be developed as a prerequisite to designing a facility. There are multiple philosophies that one can choose for the facility, such as a minimal mission of only producing neutrons at the smallest geometric size possible. This could be pursued to reduce the tritium consumption, and to provide early data at lower fusion neutron fluence. At the other end, a maximal mission would likely include electricity production as a requirement, and would significantly change the operating point. Several missions are identified for the FNSF, as well as metrics for measuring progress, including

- a) The strong advance of fusion nuclear fluence and damage,
- b) The application of long-term relevant fusion materials,
- c) Operation at high temperatures associated with efficient power extraction,
- d) Breeding of tritium at levels closely approaching or exceeding the consumption, losses, decay, etc.,
- e) The efficient tritium extraction, fueling and pumping of the plasma, and processing that meets all safety criteria with a high level of inventory prediction and control,
- f) To provide ultra-long plasma durations routinely with sufficient performance levels to advance the fusion nuclear requirements,
- g) To provide the enabling technologies that support plasma operation for the ultra-long durations,
- h) To demonstrate safe and environmentally friendly plant operations primarily with respect to tritium leakage, hot cell operation, onsite radioactive waste handling and storage,
- i) To pursue long term relevant subsystems with high efficiency operation to enhance power balance,
- j) To advance toward higher availability, including subsystem reliability and maintenance operations, along with accumulating reliability and failure data for future designs.

The detailed examination and definition of the FNSF will provide a new perspective on the required R&D to provide the technical basis to construct and operate the facility. Recent studies (http://bp.pppl.gov/pub_report//2012/PPPL-4736.pdf, and <http://science.energy.gov/~media/fes/pdf/workshop-reports/20120309/FESAC-Materials-Science-final-report.pdf>) have outlined R&D needed to advance the fusion nuclear science and supporting technologies. These research proposals will be critically examined with the goal of organization and prioritization, in light of the integrated facility, the program on the FNSF, and the overall pathway to commercial power.

The technical decisions made for the FNSF will be accumulated in a series of Technical Decision/Discussion Documents (TDDs). These will cover several critical topics where a major technical decision is made, the technical state of the art is discussed, down-selections are established, or options are discussed. In addition, a number of scientific areas will be initiated to improve and advance systems studies activities for the future. Some of these are:

1. Routine use of materials properties that contain irradiation, high T, stress, etc factors in them, even if they are predicted and not yet experimentally confirmed
2. Routine use of liquid metal breeder/coolant simulations of behavior in blanket designs
3. Routine analysis of tritium behavior in fusion core and critical components outside the core
4. Routine simulations of the edge plasma, with connection to core plasma, pumping and divertor geometry, and ultimately PMI
5. Routine assessments of disruption forces on primary structures, with progressive detail including blankets and divertors
6. Routine use of plastic analysis, birth to death component descriptions, fracture mechanics, and transient assessments in thermo-mechanics
7. Routine use of 3-D CAD-based neutronics allowing assessments of streaming and other complex geometry/material factors.

The FNSF activity will include working through the US Burning Plasma Organization to engage the physics community on the many important topics to establish a sound plasma physics basis for the facility, and to enhance the physics-engineering interface solutions that permeate integrated devices like this one.

INTERNATIONAL ACTIVITIES

Highlights of Fusion Technology and Material Activities at KIT,

Klaus Hesch, Karlsruhe Institute of Technology, Karlsruhe, Germany.

The Fusion Program at the Karlsruhe Institute of Technology (KIT) has its focus on providing the technologies and materials required for fusion, from present day plasma physics experiments up to ITER and DEMO, with a clear orientation towards commercial fusion power. Major elements are the fusion fuel cycle, electron cyclotron heating and current drive systems, superconducting fusion magnets and magnet components, materials and engineering for in-vessel components, i.e., blanket and divertor, as well as the related manufacturing technologies, plant engineering and modeling, and fusion neutronics. Some recent developments are presented here.

Fusion Fuel Cycle

Based upon the unique opportunities provided by the Tritium Laboratory Karlsruhe (TLK) with its closed tritium-processing loop on ITER-relevant scale, KIT has been leading the development of the fusion fuel cycle for over two decades, and has therefore been assigned responsibility for the European ITER contributions in the area of vacuum

pumping and tritium plant. So far, the build-to-print designs of the neutral beam cryopumps and the torus/cryostat cryopumps were delivered to ITER [1]. Both pump types are now being manufactured and will be validated via a 1:1 scale prototype. In the area of tritium plant systems, dedicated software for the optimized operation of the ITER combination of Water Detritiation System – Isotope Separation System has been developed and benchmarked against the experimental data collected over many years of operation of TLK, which replicates the ITER configuration [2]. While T pumping for ITER is relying on cryopumps, we have proposed a novel and innovative concept for the vacuum systems for the inner fuel cycle of DEMO, for meeting the long pulse / steady-state requirements of a power plant and to reduce inventories and processing times. It uses continuous pumps and introduces, via a hydrogen separation stage, a shortcut from the primary vacuum pumps to the fuelling systems. In particular, this “Direct Internal Recycling” concept for the D-T fraction of the reactor is based upon a combination of metal foil pumps, liquid metal driven diffusion pumps and liquid ring pumps [3]. For the DEMO outer fuel cycle, i.e., tritium extraction from the breeding blankets, we propose to rely exclusively on advanced processes (i.e., combination of zeolite membranes for pre-concentration of tritium and subsequent processing in a catalytic Pd-based membrane reactor - PERMCAT) in order to improve the overall tritium management. This has been supported by simulations and proof-of-principle validation experiments [4].

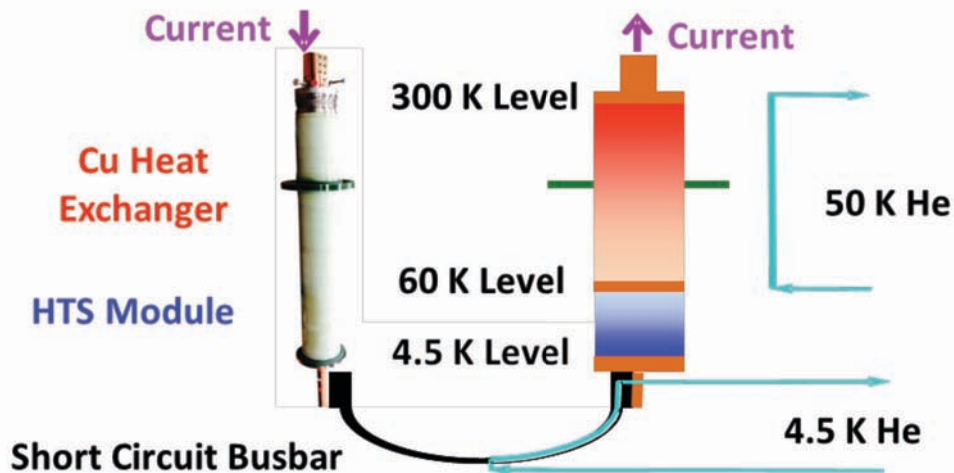
Electron Cyclotron Resonance Heating and Current Drive

KIT is developing sources and antennas for electron cyclotron resonance heating and current drive (ECH&CD). For the stellarator Wendelstein 7-X (W7-X), we have developed, together with our industrial partner Thales Electron Devices, 1 MW, CW gyrotrons operating at 140 GHz, which now have reached series production maturity. On this basis, we are developing, in a consortium with European partners (EGYC), the European 1 MW, CW gyrotrons for ITER with an operation frequency of 170 GHz [5]. For conducting the microwave radiation into the ITER plasma, we are developing the related microwave antenna, i.e., the so-called ECH Upper Launcher, within another European consortium [6]. For power plant scale reactors, higher operation frequencies will be required for efficient current drive, and higher unit powers in order to reduce complexity, investment costs and installation space. KIT is pioneering these approaches by advancing the technology of coaxial-type gyrotrons, aiming at operation frequencies far beyond 200 GHz and unit powers of 2 MW and more [7]. In short pulse operation, 2.3 MW has already been reached with a 170 GHz prototype, jointly developed by EGYC. Frequency tuning will be essential for localized plasma stabilization, avoiding movable parts close to the plasma and exposed to the fusion neutron load, making use of the spatial dependence of microwave absorption in the plasma on the frequency. This has to be accompanied by the development of broadband transmission windows. We have obtained, on the basis of a 170 GHz tube, output powers between 880 and 1000 kW for the frequency range between 120 and 170 GHz, and in parallel have developed the necessary broadband diamond disc Brewster windows [7].

Fusion Magnets and Magnet Components

The high temperature superconductor (HTS) material REBCO (Rare-Earth-Ba-Cu-Oxide) allows high currents at very high magnetic fields around 14 Tesla and therefore provides for future fusion machines a promising substitute for the low T_c superconductors used for ITER. While the design of a high current conductor in the 10 kA range is quite challenging, this could pave the way for the use of HTS for efficient commercial fusion power plants. KIT has developed an AC optimized conductor (“Roebel-type”) that was tested at CERN reaching 12 kA at 6 T and 4.2 K. Furthermore, a superconducting twisted stacked cable from MIT and a coaxial cable from Advanced Conductor Technology were collaboratively measured in the KIT test facility with encouraging results [8]. Current leads (CL) are needed to transfer the coil current from room temperature to the 4 K level inside of the cryostat of a fusion machine. CL with HTS inserts save 60% to 80% of cooling power as compared to conventional copper CL, thus allowing an economic operation of the magnet system. The stability of such current leads with high voltage insulation even under Paschen conditions, currently at the edge of technological development, is essential for safe and efficient operation. KIT has designed, built and successfully tested a 68 kA HTS-CL demonstrator for ITER using BiSCCO (BiSrCuCa-Oxide). As a result, KIT was asked to design, build and test the CL for W7-X (see Fig. 1). In 2013, the last of the 14 series current leads were finalized, tested and delivered to W7-X [9]. In parallel to these activities, the development of CL for the tokamak JT-60SA was started in the frame of the Broader Approach cooperation EU - Japan.

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Fig. 1. HTS current lead: photograph (left) and temperature distribution (right) in “couple-test arrangement” with short-circuit busbar.

Structural Materials for Blanket and Divertor

The European reference material for ITER TBMs and helium cooled DEMO blankets is the reduced activation ferritic-martensitic (RAFM) steel EUROFER, a KIT based development [10], which presently undergoes a broad based characterization and qualification program including the largest EUROFER neutron-irradiation database [11] and a variety of demonstrated forming and joining technologies [12]. To increase the application temperature window towards 650°C and beyond, ferritic-martensitic Oxide-Dispersion Strengthened (ODS) steels as well as ferritic ODS steel developments have been launched [13]. Thorough characterization of mechanical properties and microstructure of EUROFER97 and of ODS steels have been performed both in the non-irradiated state as well as after neutron irradiation up to 70 dpa [14].

The mechanical properties of EUROFER97, its ODS variants and other RAFM steels have been thoroughly studied after neutron irradiation within the SPICE, ARBOR-1 and ARBOR-2 irradiation programs [15]. The effects of helium have been simulated by irradiation of boron-doped EUROFER based steels [16]. Irradiation induced defects including dislocation loops, voids and helium bubbles and their interactions with dislocations and boundaries have been studied quantitatively by analytical TEM methods up to 32 dpa [17]. An appropriate hardening model has been applied to correlate irradiation induced defects with changes in the mechanical properties, and Lattice Kinetic Monte Carlo and rate theory models have been developed to describe the nucleation and growth of helium bubbles in RAFM steels under neutron irradiation [18]. The size distributions of the helium bubbles have been calculated for different levels of helium content, and the production rates by taking into account different microstructural sinks [18]. The broad database obtained at KIT on isothermal low cycle fatigue now provides solid knowledge on the correlations between irradiation damage (dpa) level, temperature, strain range and fatigue life [19]. Thus, a Temperature Operation Window of EUROFER97 and other RAFM steels between 350 and 550°C has been determined.

KIT has developed the so far most advanced concept for a He-cooled divertor solution, relying on a combination of W and EUROFER-ODS as structural materials, and jet impingement cooling [20]. As the overlap of the operation temperature windows of tungsten and ODS is narrow, irradiation impact may reduce or even remove the viable operation temperature range for this concept. Hence, new materials solutions are sought. A very promising approach is the use of ductile, tungsten-based sandwich-type materials for the structural parts exposed to the highest temperatures. Using laminates of thin tungsten foils and interlayers / fillers of other metals, we could lower the brittle-to-ductile transition by several hundred K, as compared to bulk tungsten material. Still, a high mechanical strength can be preserved up to high temperatures, limited by the melting temperature of the interlayer or the recrystallization temperature of the tungsten (see Fig. 2) [21]. Irradiation behavior is not yet known and has to be tested urgently. With the temperature margin introduced between the brittle-to-ductile transition of the laminates and the upper operation temperature limit of reduced activation steels, we are, however, confident that a sufficiently wide operation temperature window for divertor applications can be maintained even with the neutron doses expected over some years of operation.

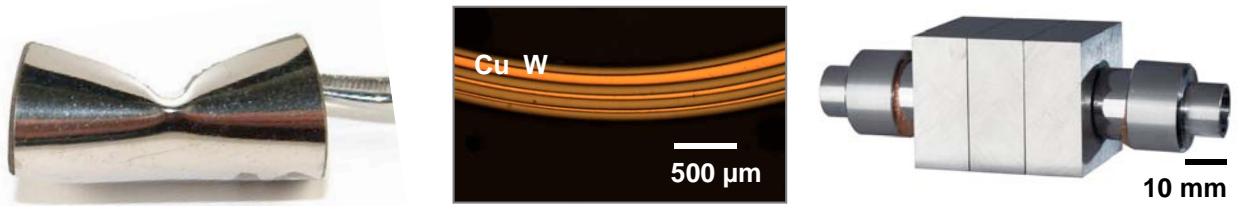


Fig. 2. W laminate pipe; left: ductility at 300°C; middle: cross section; right: high heat flux test mock-up with W shielding blocks, connected to steel pipes, mimicking divertor target.

Breeding Blanket Development

KIT has been developing concepts and practical solutions for the breeding blanket in a fusion reactor for more than 3 decades. In particular, the Helium Cooled Pebble Bed (HCPB) concept has been in the focus of our interest [22], while we have also been developing, and contributing to, liquid breeder concepts [23, 24]. After consolidation of the engineering design basis of the European Test Blanket Modules for ITER (TBMs) by a consortium led by KIT in the frame of several contracts under the European Domestic Agency for ITER, F4E [25], this has reached the phase of manufacturing and testing of prototypes in large facilities. We have made a dedicated effort to explore and establish manufacturing routes (i.e., advanced welding techniques, hot isostatic pressing, spark erosion, to name just a few) for the material and the specific geometries required for the TBMs. Several mock-ups in different scale and detail (e.g. First Wall, single Breeder Units, part of the stiffening grid assembly, etc.) are being manufactured (see Fig. 3), and appropriate test parameters and procedures are under definition [26, 27].

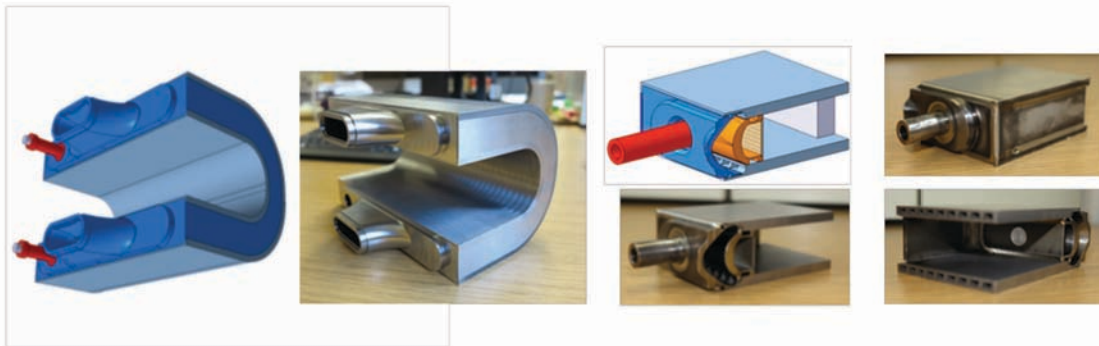


Fig. 3. “Short Breeder Unit” mock-up and components of HCPB TBM development.

The HCPB breeding concept requires providing ${}^6\text{Li}$ in the form of ceramic pebbles (lithium orthosilicate and / or lithium metatitanate) for generating T through a neutron reaction. These pebbles have to fulfill certain requirements in terms of size distribution, thermo-mechanical stability and T release, where mechanical stability and T release are influenced in opposite ways by the fraction of open porosity in the pebbles. We have developed a melt-spraying process for producing lithium orthosilicate pebbles with well-controlled size distribution [28], and set up a related test facility, allowing optimization of the process and of the thermo-mechanical stability by varying the lithium metatitanate content [29].

Acknowledgements

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KSTAR Prepares for New Campaign, Myeun Kwon, National Fusion Research Institute, Daejeon, S. Korea.

KSTAR (Korea Superconducting Tokamak Advanced Research) operation plan is a national program to be rolled out in four phases up until 2025. The first phase (2008-2012) aims to achieve basic machine performance as a superconducting fusion research device. Key research achievements to date include the world’s first successful plasma initiation in a superconducting device in 2008; the world’s first successful H-mode access for a superconducting device in 2010; and its 17-second long-pulse operation under high-performance phase in 2012. These achievements of long-pulse operation under challenging operational conditions have reinforced the status of KSTAR as a central pilot device to ITER.

The second phase (2013-2017) began in 2013, with the objective of developing the technologies for extended operation and playing a unique role as a pilot device for ITER.

To achieve this, the KSTAR team will continue the momentum on improving plasma stability and integrated control of KSTAR operation while addressing key pending issues for high performance long-pulse operation.

KSTAR operation for 2014 will be begun in June and is expected to continue until December. The main operational objectives are to achieve and demonstrate the long-pulse and control capability at high performance by extending the pulse length up to 50 seconds (with similar shape to ITER's) and also by increasing plasma current beyond 1 MA. In this regard, the neutral beam power is increased up to 5.5 MW; the plasma facing components have been carefully upgraded for machine protection during highly destructive disruptions. A motor generator system with capacity of 200 MVA and 2 GJ for extended operation of PF magnets up to 13 Wb is under commission and will be tested with a superconducting magnet load during the last stage of the 2014 campaign.

Unique characteristics of KSTAR, i.e., low ripple and error field, were discovered previously and will be further identified using a full compass scan in the coming campaign. The operation boundary of $n=1$ RMP ELM suppression will be explored, focusing on long-pulse sustainment and also applicability at low collisionality and low q_{95} below 3. In addition, many interesting physics topics including rotation source/damping, ELM dynamics and stimulated L-H transition will be investigated, utilizing a combination of local perturbation techniques such as ECH and SMBI with 2-D imaging fluctuation/rotation diagnostics. In this regard, the power supplies for the in-vessel control coils will be upgraded with several broadband switching power amplifiers with specifications of 5 kA, 10 kHz to facilitate the in-vessel control coils for the error field studies such as dynamic ELM control, RWM control, and rotation controls.

The preparations for the coming experimental campaign are under way with more than 100 domestic and international experimental proposals to be covered. Figures 1 and 2 display external and internal views of the KSTAR experiment.

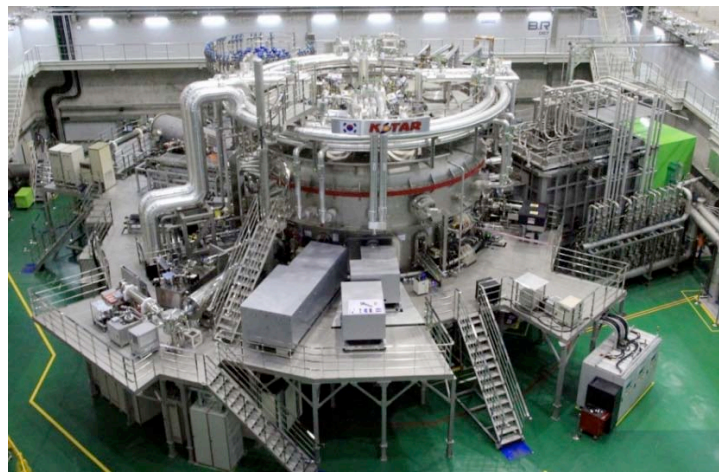


Fig. 1. Bird-eye view of the KSTAR tokamak device (https://www.nfri.re.kr/english/research/kstar_operation_01.php?tab=1).

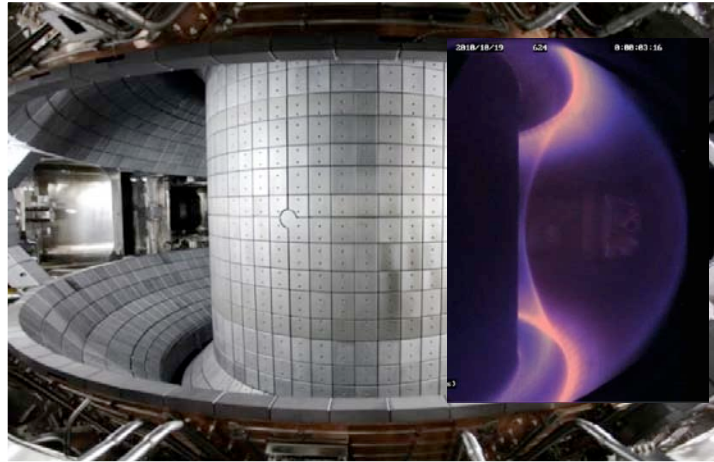


Fig. 2. Internal view of the KSTAR showing the graphite PFC tiles on double-null divertor and passive stabilizer, and visual image of the plasma.

US ITER Report, Ned Sauthoff, US ITER Project Office, Oak Ridge National Laboratory, Oak Ridge, TN.

The ITER project continues to make progress in on-site construction, in off-site fabrication of components for the tokamak and the plant, and in management and process reforms aimed at improving effectiveness of the integrated project team consisting of the ITER Organization and the seven Domestic Agencies.

At the ITER site, slab pouring under the Diagnostics Building and the Tritium Building slab is nearly complete. Pouring of the slab that will support the tokamak itself is scheduled to start in July 2014. EU-DA has placed the main contracts for buildings and site infrastructure; commencement of many of the buildings (including the Assembly Hall, Site Services Building, electrical buildings and the B2 walls of the Tokamak Complex) is expected in the second half of 2014. Storage space for near-term deliverables is under construction. A second ITER Test Convoy that included testing of the 35 km maritime section of the journey was completed.

The Chinese Domestic Agency is on schedule for many of their systems: 2 Toroidal Field Conductors and 5 Poloidal Field Conductors have been completed; on schedule are the Shield Blanket, the Correction Coil (for which manufacturing equipment has been commissioned), the Feeder Conductor (for which several prototypes have been produced), Magnet Supports, AC/DC Converter, RPC-HF, Gas Injection System, Glow Discharge Cleaning System, and their assigned Diagnostics.

The European Domestic Agency is making progress on Buildings and Site Infrastructure (as described above) and Power Supplies, Magnets, Vacuum Vessel, Plasma-Facing

Components, Heating and Current Drive (including Power Supplies), Remote Handling, Cryogenics, Fuel Cycle, and Diagnostics.

The India Domestic Agency is progressing on In-Wall Shielding Blocks that are captive inside the 2 walls of the vacuum vessel, the Cryostat (for which the Cryostat Base Section work has started and the Cryostat Building at the ITER site is nearly complete), the Vacuum Vessel Pressure Suppression Tanks, Component Cooling Water System, Cryolines and Cryodistribution components, power supplies for Ion Cyclotron and Electron Cyclotron Gyrotron systems, the power supply for the Diagnostic Neutral Beam, and their assigned Diagnostics.

The Japanese Domestic Agency is active on the Toroidal Field Coil (winding, structure, and conductor), Central Solenoid Conductor (to be provided to the USDA for winding), Outer Vertical Targets of the divertor, Blanket Remote Handling, Electron Cyclotron Gyrotrons, High Voltage Bushing, and the Neutral Beam Power Supply.

The Korean Domestic Agency is making Toroidal Field Coil Conductors, Vacuum Vessel sectors and Equatorial and Lower Ports, Blanket Shield Blocks, Machine Assembly Tooling, Thermal Shield, AC/DC Converters, its diagnostics, and the Tritium Storage and Delivery System.

The Russian Domestic Agency is fabricating and/or delivering Toroidal Field Conductors, part of the Poloidal Field Coil system, Upper Ports, Blanket First Wall and Module Connections, the divertor Dome, Plasma-Facing Component Tests, Busbars and Instrumentation, Electron Cyclotron Gyrotrons, its diagnostics, and port-plug test facilities.

The United States Domestic Agency is working on the Toroidal Field Conductor (having finished fabrication of all strand and having produced both dummy and active cable and an 800-meter conductor with copper strands to test the processes), Central Solenoid Modules, Supports and Assembly Tools (where tools for module manufacture have been ordered and many accepted and ready for installation in the factory at General Atomics), Tokamak Cooling Water System (where 5 safety-important drain tanks will be shipped to the ITER site in December for installation in the basement of the Tokamak Building), Steady-State Electric Network (where components for construction-site power are being shipped to the site), Diagnostics, Heating and Current Drive Systems, Vacuum System components, and the Tritium Exhaust Processing System.

In November 2013, the ITER Management Assessor submitted a report that identified nearly a dozen recommendations, which have been adopted by the ITER Council and translated into action plans that were approved by the Council in February/March 2014 and are being implemented.

For further information, please visit the ITER website: www.iter.org.

RECENTLY PUBLISHED FUSION BOOKS

T. Dolan, “Magnetic Fusion Technology.” Springer Press
(<http://www.springer.com/shop>). ISBN 978-1-4471-5556-0.

G. Miley and **S. K. Murali**, “Inertial Electrostatic Confinement (IEC) Fusion: Fundamentals and Applications.” Springer Press (<http://www.springer.com/shop>). ISBN 978-1-4614-9337-2.

CALENDAR OF UPCOMING CONFERENCES ON FUSION TECHNOLOGY

2014:

ANS Annual Meeting
June 15-19, 2014, Reno, NV, USA
<http://www.ans.org/>

19th Pacific Basin Nuclear Conference (PBNC-2014)
August 24-28, 2014, Vancouver, Canada
www.pbnc2014.org

28th Symposium on Fusion Technology – SOFT-2014
September 29 – October 3, 2014, San Sebastian, Spain
<http://www.soft2014.eu>

56th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
October 27-31, 2014, New Orleans, LA, USA
<http://www.apsdpp.org>

ANS Winter Meeting
November 9-13, 2014, Anaheim, CA, USA
<http://www.ans.org/>

ANS 21st Topical Meeting on the Technology of Fusion Energy – TOFE-2014
November 9-13, 2014, Anaheim, CA, USA
<http://www.ans.org/>

2015:

39th International Symposium on Advanced Ceramics and Composites
(for Sustainable Nuclear Energy and Fusion Energy)
January 25-30, 2015, Daytona Beach, Florida, USA
<http://ceramics.org/meetings/39th-international-conference-and-expo-on-advanced-ceramics-and-composites>

17th International Conference on Emerging Nuclear Energy Systems (ICENES-2015)
May 10-14, 2015, Antalya, Turkey
<http://www.icenes2015.org>

26th Symposium on Fusion Engineering – SOFE-2015
May 31 – June 4, 2015, Austin, TX, USA
Jean-Paul Allain (allain@illinois.edu)

ANS Annual Meeting
June 7-11, 2015, San Antonio, TX, USA
<http://www.ans.org/>

12th International Symposium on Fusion Nuclear Technology - ISFNT
September 14 – 18, 2015, Jeju Island, S. Korea
<http://www.isfnt-12.org/sub01>

17th International Conference on Fusion Reactor Materials – ICFRM17
October 20-26, 2015, Aachen, Germany
Christian Linsmeier (ch.linsmeier@fz-juelich.de)

ANS Winter Meeting
November 8-12, 2015, Washington, DC, USA
<http://www.ans.org/>

57th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 16-20, 2015, Savannah, GA, USA
<http://www.apsdpp.org>

2016:

ANS Annual Meeting
June 12-16, 2016, New Orleans, LA, USA
<http://www.ans.org/>

11th International Conference on Tritium Science and Technology – Tritium-2016
April 17-22, 2016, Charleston, S. Carolina, USA

ANS Winter Meeting
November 6-10, 2016, Las Vegas, NV, USA
<http://www.ans.org/>

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