USBPO
U.S. BURNING PLASMA ORGANIZATION

eNews

April 16, 2010 (Issue 43)

CONTENTS

Dear Burning Plasma Aficionados:

This newsletter provides a short update on U.S. Burning Plasma Organization activities. E-News is also available online at http://burningplasma.org/enews.html Comments on articles in the newsletter may be sent to the Editor (Tom Rognlien trognlien@llnl.gov) or Assistant Editor (Rita Wilkinson ritaw@mail.utexas.edu).

Thank you for your interest in Burning Plasma research in the U.S.!

Director's Corner by Jim Van Dam

ITER International Summer School on MHD and Plasma Control

Here's another reminder to encourage graduate students, postdoctoral researchers, and young scientists to attend this Summer School (http://w3fusion.ph.utexas.edu/ifs/iiss2010/). Senior scientists are also very welcome to attend. This is the first time the ITER International Summer School is to be held in the US, and it probably will not return to this country for some time—so take advantage of the opportunity now. On-campus housing for the student participants is a bargain. **Registrations and abstracts are due by April 30.**

Reminder about the USBPO Council Election

The twelve members of the USBPO Council serve staggered three-year terms. Every year at this time, four members rotate off. An election is held to replace two of the members, with the other two being appointed. The Council's Nomination Committee, chaired by John Sarff, has finished collecting nominations from the USBPO membership and will soon propose a slate of qualified candidates to the Council. You will then receive a message about the voting procedure.

May I suggest that you take this opportunity to check your membership status, since only regular members of the USBPO may vote in the Council election. Membership is obtained by

signing up for one or more Topical Groups, via the USBPO web site (www.burningplasma.org). If you are uncertain about your membership status or if your email address has changed, please contact our Communications Coordinator, Jim DeKock (dekock at burningplasma.org).

ELM Control Brainstorming Session

In last month's issue of *eNews*, we reported that the ITER Organization had sent an urgent request to all Domestic Agencies in November 2009 concerning the need for further R&D work on ELM control in ITER. The message from ITER noted that it would also be valuable to identify alternatives to the method of resonant magnetic perturbation coils for ELM mitigation. The USBPO had circulated this message to the US community, and a number of scientists responded with comments.

Since ELM control is to be an agenda item at the STAC-8 meeting coming up in May, the USBPO recently held a community-wide discussion (by videoconference) of alternative mitigation methods. Tom Rognlien and Tony Leonard, leaders of the Pedestal and Divertor SOL Topical Group, and Chuck Greenfield, USBPO deputy director, organized this videoconference, which was labeled a "brainstorming session." Thirteen scientists presented brief, few-page summaries of various ideas. Then, everyone on the videoconference (35+ persons) participated in moderated discussions of the ideas, grouped into the four categories of (1) SOL/edge currents and modification to SOL layer, (2) modification of MHD equilibrium, (3) pellets and alternative operating modes, and (4) other. A summary of the videoconference will be presented at the ITPA Pedestal and Edge Physics topical group meeting (April 21-23, Naka, Japan).

USBPO Presentation at DOE Budget Planning Meeting

At the annual Fusion Energy Sciences Budget Planning Meeting (March 11-12, Gaithersburg, MD), I presented the talk "Progress and Plans of the US Burning Plasma Organization." The viewgraphs of this talk are posted on the UBSPO web site at http://burningplasma.org/reference.html and on the web page for the Office of Fusion Energy Sciences at http://www.science.doe.gov/ofes/Budget%20Planning%20Meeting%202010/FY12_BPM_Agenda.html. Those interested in the status of ITER project activities in the US may also wish to look at the talk by Suanne Herron and the talk by Erol Oktay, also available at the latter site.

By the way, the References section of the USBPO web site has been reorganized to make it easier for users to find items. The number of items posted here has become rather large; for convenience, they are now organized in several groupings.

International Collaborations

Last month, talks describing the role and activities of the US Burning Plasma Organization were presented at two meetings on international collaborations. Both talks are now posted on the USBPO web site (http://burningplasma.org).

The 13th EU-EURATOM Coordinating Committee Meeting was held March 16 at the US Department of Energy headquarters in Washington, DC. Representatives from DOE, EURATOM, and US and European fusion research programs participated in the daylong discussion of the various collaborative activities between the US and Europe. A topic of special interest was the US-Europe Energy Council, launched in November 2009, which held a meeting in Brussels later the same week. There are plans to include fusion in one of the nine working groups of this Council.

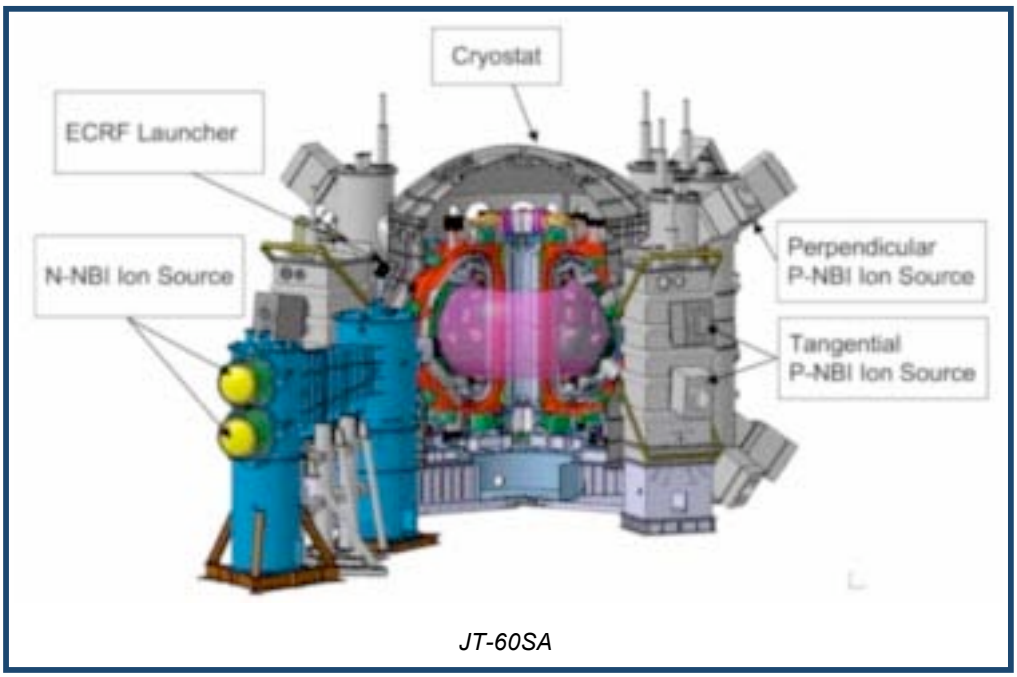
The 28th US-Japan Executive Secretaries Meeting was held March 24 in Germantown, MD. The Japanese participants were from the Ministry of Education, Science, and Technology (MEXT), National Institute for Fusion Science, and Japanese Atomic Energy Agency. The US participants were from DOE and major US fusion energy science programs. The recent US-Japan collaboration activities carried out under the three subprograms of Fusion Physics

Coordinating Committee, Fusion Technology Coordinating Committee, and Joint Institute for Fusion Theory were reviewed, and the proposed activities for this year were approved for submission to the US-Japan Coordinating Committee on Fusion Energy (CCFE). The meeting of the CCFE will be held in Daejeon, Korea, in October of this year, in conjunction with the IAEA Fusion Energy Conference. One item on the agenda for the upcoming CCFE meeting will be the celebration of the 30th anniversary of US-Japan fusion science collaborations. A special report is being planned about research highlights that have resulted from these collaborations.

In a related activity, the USBPO has set up a small working group, led by Mike Zarnstorff, which is charged with looking for opportunities for international collaborations that are specifically related to burning plasma science.

JT-60SA Facility Web Site

A web site has been launched for the JT-60SA experimental facility (http://www.jt60sa.org/), which is under development. The site lists the scientific and technological objectives of JT-60SA, provides a schedule for its construction and initial operation, summarizes what has been achieved in procurement and assembly, and describes how this project relates to the ITER Project. The name JT-60SA means "Super Advanced," because (1) the facility will have superconducting magnetic field coils and (2) it will study so-called advanced modes of plasma operation.



JT-60SA

JT-60SA is a satellite tokamak, designed to support the operation of ITER and also to investigate how to optimize fusion power facilities to be built after ITER. One of the R&D projects in the Broader Approach Agreement between Japan and Europe, JT-60SA is being built in Naka, Japan, using the infrastructure of the existing JT-60U experimental facility.

Update on New Appointments

At the US ITER Project Office (Oak Ridge, TN):

- Wayne Reiersen (PPPL) has been named Magnet Systems Team Leader. He had been serving as Interim Manager for Magnet Systems, following the retirement of John Miller. Wayne joined the U.S. ITER Project Chief Engineer's Group in 2007.

- Janet Bivens is the new Senior Project Controls Analyst. She succeeds Wayne Steffey (now USIPO Project Controls Manager). Previously she had been Finance Officer for U.S. ITER. She joined the Oak Ridge National Laboratory staff in 2000.

At the European ITER Domestic Agency (Barcelona, Spain):

- Dr. Frank Briscoe has been confirmed as head of the EU-DA Fusion for Energy (F4E) agency. The March issue of *F4E News* has an article about him at http://fusionforenergy.europa.eu/f4enews/march2010/spotlight/in_the_spotlight.html.

Fusion videos

In the mid-1970s, the Russian Soviet Center for Science Film produced a documentary on the early years of fusion research You can see this documentary by clicking on the link at http://www.iter.org/newsline/Pages/125/1824.aspx. A short video interview with Vladimir Mukhovatov, now a staff scientist at ITER, about the documentary is also posted here.

"Fusion is Energy's Future"

An interview with Professor Steve Cowley, director of the Culham Centre for Fusion Energy, is featured in a recent ITER Newsline (http://www.iter.org/newsline/Pages/126/SinglePage.aspx). In the interview, he discusses what needs to be done on the path leading to commercial fusion energy

Professor Cowley also can be seen and heard in an interesting video of a talk that was presented in July 2009 at a conference in Oxford and published in December 2009 on the TED website (http://www.ted.com/talks/steven_cowley_fusion_is_energy_s_future.html).

March 2010 photograph of the ITER site

Courtesy of the ITER Newsline (April 2 issue), the photograph below, provided by Agence ITER France, shows the ITER site at present, with the Visitor Center at the right and the ITER Headquarters Building in the rear on the right side.

ITER site as of March 2010

BPO Topical Group Highlights

The Diagnostics Topical Group seeks to facilitate U.S. efforts to plan, design, and implement experimental diagnostics in existing and future fusion devices (leaders are Steve Allen and Jim Terry). This month's research highlight from Jim Terry and colleagues describes a new diagnostic recently installed on Alcator C-Mod that is making accurate measurements of heat flux to material surfaces.

IR Thermography on Alcator C-Mod

J.L. Terry, B. LaBombard, and D. Bunner (*MIT- Plasma Science and Fusion Center)*

A major element of DoE's Joint Facilities Research Milestone for 2010 is measurement of the heat-flux "footprints" on the divertor targets of C-Mod, DIIID [1], and NSTX [2]. This milestone work is well underway and its present status will be summarized in the May issue of the *eNews*. The "footprints" are being measured on these devices using infrared (IR) thermography. While the technique is not new, being a standard diagnostic on most of the world's major tokamaks, many details need to be included for accurate measurements. On ITER, IR thermography is to be used as the primary diagnostic for a number of important measurements, including

- heat-load profiles on the divertor plates
- maximum divertor surface temperature
- first-wall surface temperatures

One of the ITER diagnostic systems "credited" to the US is IR and visible imaging from the upper vacuum chamber ports. This US-supplied diagnostic system will view the outer divertor target from six of the upper ports, with each of the six periscope modules displaced toroidally from the target section it views. The initial design for this system was performed by LLNL, through a project headed by C. Lasnier. A report on the design is reference [3].

With the 2010 Research Milestone as motivation, C-Mod upgraded its divertor IR thermography and its capabilities for measuring the divertor heat loads and heat-flux footprints. In the process, we found a number of challenging issues that will also be faced when making similar measurements on ITER. These issues, and our experience in addressing them, are the subject of this report. The shared issues include:

- grazing angles of incidence for magnetic field lines intersecting the targets
- closed divertor geometry with near vertical targets
- oblique observation angles
- shiny, low emissivity refractory targets (W for ITER, Mo & W for C-Mod)
- possible movement or shaking of the image during operation
- low-Z surface films, changing with time
- extremely high peak heat fluxes

The field lines striking perfectly aligned divertor targets in C-Mod would do so at angles between 0.5 and 1.5 degrees. However, the outer divertor sections are not perfectly aligned, and the combination of grazing field line angles and imperfectly aligned targets results in strong heating of leading edges, asymmetric heat loads, and shadowing of some target surfaces. In order to make valid measurements of the parallel heat flux onto the targets in C-Mod, we have installed, within the field-of-view of the IR periscope, a 6 degree toroidal section of the outer divertor that has a 2 degree toroidal ramp. Thus, this ramped section is not shadowed by construction. The ramped section has been instrumented with calorimeters, surface thermocouples, and thermocouples embedded within the target tiles. Although the spatial

density of the thermocouples is not large enough to provide detailed heat-flux footprints, they are *crucial* for the thermography, since they are used to provide *in-situ* intensity-sensitivity calibrations for the IR system, which does have the spatial and temporal resolution needed for the footprint measurements. The calorimeters and thermocouples also provide important checks on the temperature time-history inputs to the heat-transport analysis of the target, as well as checks on the analysis itself. The measured IR surface temperatures are imposed in the heat-transport model only for the plasma pulse time. Then, after continuing the model calculation past the time needed for the individual tiles to equilibrate (>20 seconds after the pulse), the computed tile temperature rise is compared to (and should equal) the rise measured by thermocouples. Similarly, the incident energies associated with the IR temperature time-histories are compared to those measured by the calorimeters.

A cross-section of C-Mod's outer divertor target is shown in Fig. 1(b,c). When the targets are viewed from above, the closed divertor geometry necessitates that the view must be displaced toroidally. In C-Mod the viewing angles of the target are large, ranging from 35 to 80 degrees away from normal to the target surfaces. Bench calibrations show that the emissivity from a Mo surface increases sharply as the view angle increases beyond about 55 degrees. While this effect is present in the C-Mod measurements, another source for significant variation in surface emissivity is also present—changing low-Z surface coatings (e.g., boron). A clean Mo target surface has a low emissivity (~0.2), but the coatings increase the emissivity significantly, making *in-situ* calibrations necessary. Additionally, we observe non-thermal emission (both from the plasma and as a result of reflections from the relatively shiny Mo surfaces) that contaminates the measurement of surface emission. To correct for these effects, we subtract the non-thermal emission by measuring emission from the target region that is shadowed from the plasma heat flux by the toroidally ramped section.

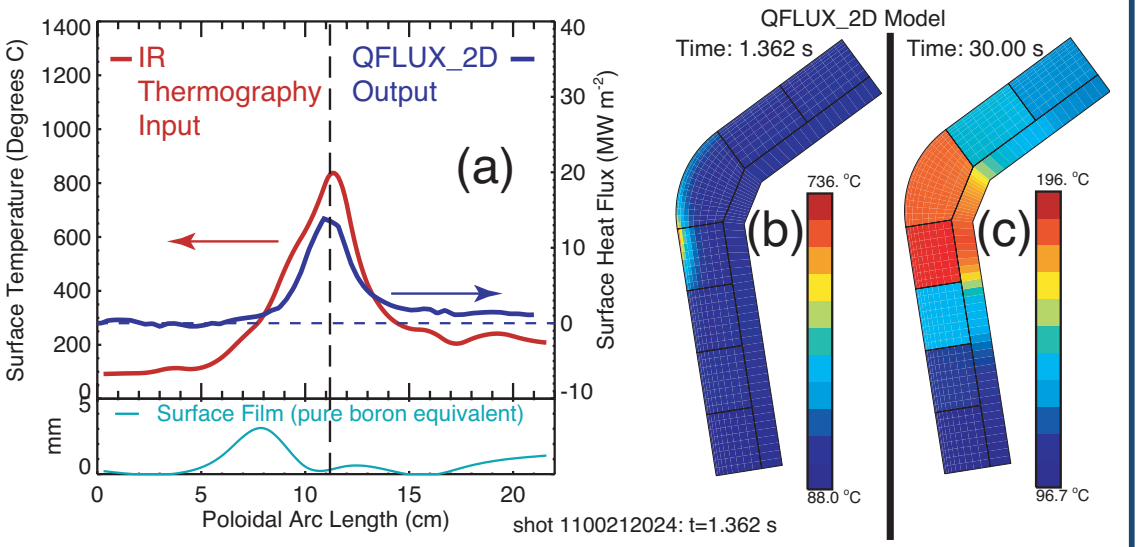


Figure 1 – (a) Surface temperature profile from thermography and heat-flux footprint determined using a 2D heat transport model. Also shown is the thickness profile of the hypothetical surface coating. (b) Temperature profile in the target at the same time as the profiles in (a). (c) Temperature profile in the target 30 s after the pulse; note different color scales between (b) and (c).

The target is viewed through an ~3 m long periscope that is held securely inside and outside the vacuum vessel. The periscope presents an image to the IR camera that is mounted on the concrete "igloo" that surrounds C-Mod. Because of small movements of the tokamak during the discharge pulse (and especially during plasma disruptions), the image measured by the camera

shakes. Stabilization and registration of the image at the single-pixel level is crucial for quantitative thermography. Image-stabilization algorithms have been developed and are run between experimental discharges. These algorithms depend on maximizing the cross-correlation between "edge"-detecting filtered images. Registration of view is accomplished by constructing a wire-mesh computer representation of the objects that are visible in the field-of-view (e.g., the target tiles) and by projecting it onto the camera's image plane.

As mentioned above, the Mo divertor target surfaces do not remain clean in the tokamak environment. Different surface coatings are produced by periodic boronizations and by plasma surface interactions with both tokamak plasmas and daily pre-operation "discharge cleaning" plasmas. As a result and as noted above, the bench calibrations that relate detected IR intensity to Mo tile surface temperature and viewing angle did not produce accurate target temperatures. The needed sensitivity calibrations are produced after each tokamak pulse by taking IR camera data and tile thermocouple data for at least 20 sec after the discharge termination, at which time the individual tiles have thermally equilibrated. The temperatures of the tiles 30 s after the pulse are shown in Fig. 1 (c). The IR calibration is such that the intensity-derived temperatures are those measured by the thermocouples long after termination of the discharge. However, the surface emission is not the only thing complicated by changing surface coatings. The thermal conductivity of the coating is important for modeling the thermal transport and producing a heat-flux footprint. Following references [4,5], this effect is included in the model by adjusting the thickness of an assumed "boron" coating until physically unrealistic negative heat fluxes are eliminated in response to changing measured surface temperatures. The assumption that the coating is "boron" is irrelevant for the resulting heat-fluxes. A typical result for the heat-flux footprint profile, the surface temperature profile, and the coating "thickness" in a C-Mod high confinement (H-mode) discharge is shown in Fig 1(a).

The goal of the IR thermography is to measure surface temperature profiles and heat-flux profiles. Following the steps above, this is now being done successfully on C-Mod. Examples of these profiles are shown in Fig 1(a). They illustrate the last of the issues listed above, i.e., the high parallel (to the magnetic field) heat-fluxes on C-Mod. Peak surface-normal heat fluxes greater than 10 MW/m^{-2}, corresponding to parallel heat-fluxes > 200 MW/m^{-2}, are typical in both high confinement H-modes and RF-heated, low-confinement L-modes, and surface temperatures in excess of 1000^{o} C are often measured on the ramped tiles.

References

1. C. J. Lasnier, *et al.*, Nuclear Fusion **38** (1998) 1225.
2. R. Maingi, *et al.*, J. Nucl. Materials **363-365** (2007) 196.
3. www.pppl.gov/usiter-diagnostics/Instrumentation-Packages/Upper-IR-Visible-Cameras/ICP006779-A%20ITER%20Camera%20Report%20(LLNL).pdf
4. A. Herrmann, 28th EPS Conference on Contr. Fusion and Plasma Physics (2001).
5. P. Andrew, *et al.*, J. Nucl. Materials **313-316** (2003) 135.

This work was supported by U.S. DoE Cooperative Agreement No. DE-FC02-99ER54512.

REPORTS

Summary Report of the Meeting of the ITPA Topical Group on MHD Stability

A. Sen (India), E. Strait (U.S.) and Y. Gribov (IO)

The ITPA Topical Group on MHD Stability held its fourth meeting at the National Institute for Fusion Studies (NIFS), Toki, Japan during March 8 -12, 2010, in conjunction with the US-Japan workshop on "Physics of MHD Control of Toroidal Plasmas". The meeting was hosted by

NIFS(Toki) and supported by Japan/US Cooperation in Fusion Research and Development. There were 52 participants (2 from the ITER Organization (IO), 27 from Japan, 6 from the EU, 3 from India, 3 from China, 1 from Korea and 10 from the US). In addition there were 11 remote participants who joined the meeting using video-conferencing facilities (6 from the EU and 5 from the US).

The first three days of the meeting were devoted to presentations from participants of both the Topical Group and the US-Japan Workshop on various outstanding scientific issues in tokamaks and helical systems and their implications for ITER design and operation.

The importance of three-dimensional effects was a major theme at this meeting, and a number of presentations highlighted their relevance for ITER. There was also an attempt to bring out the commonality in the underlying physics issues between tokamaks, helical systems, and other toroidal devices, as well as the possible advantages of employing ideas and tools developed for helical systems to gain further understanding of tokamak behavior and to optimize their performance. Experimental results from several tokamaks demonstrated the significance of applied 3-D magnetic fields as a useful tool for the study and control of MHD stability: control of locked modes, control of plasma rotation profile, triggering/suppression of edge-localized modes (ELMs), neoclassical tearing mode (NTM) stabilization, resistive-wall mode (RWM) stabilization, error-field control, and de-confinement of runaway electrons. The application of 3D numerical tools for stability studies of "rippled" tokamaks was presented, where the cause of rippling could be due to symmetry breaking perturbations arising from error fields, ELMs, magnetic islands (NTMs), RMPs, etc. Finally, in interesting overview talks, the genesis and evolution of the helical system concept was delineated, and the inherent strengths of this magnetic configuration was discussed. Some innovative modifications of the tokamak configuration (such as slightly inclined or twisted magnetic field coils) were put forward for potential improvement of the stability and steady state properties of the tokamak.

A presentation on the ITER Research Plan summarized the issues to be addressed in the near future in order to implement it in an effective and optimized manner. In particular it was emphasized that extensive experimental and theoretical R&D is required in the areas of control of MHD stability, avoidance or prediction of disruptions, mitigation of heat loads on the divertor caused by disruptions, and reliable suppression of runaway electrons produced during disruptions. Several presentations discussed recent work in understanding halo current physics during disruptions, disruption mitigation by massive gas injection, and position control of a runaway electron channel. Other talks summarized progress in several approaches to disruption avoidance, including NTM stabilization. Recent results in RWM control and dynamic error-field correction were compared between tokamaks and reversed-field pinches (RFPs).

The final two days of the meeting were devoted to reports and in-depth discussions on the various ITPA joint experiments as well as the activities of the 6 working groups that were constituted at the last meeting in Culham (see the Dec. 2009 *eNews*). Interim reports from most of the working groups are expected within the next few weeks. Several new joint experiments and working groups were suggested, on topics including RWM control, error-field thresholds in plasmas with ITER-relevant ratios of plasma-to-magnetic pressure (beta), control schemes for disruption avoidance, and 3-D physics. These proposals will be considered in more depth at the next meeting.

The next meeting of the MHD Stability Topical Group will be in Seoul, Korea (during October 18-20, 2010) immediately after the IAEA Fusion Energy Conference in Daejeon, Korea.

Recent Change in US Scope for ITER First Wall Modules

R. Nygren, M. Ulrickson(Sandia National Laboratories), and M. Hechler (US ITER Project Office)

Who will design and manufacture the ITER first wall modules has been the subject of negotiations by the ITER Organization (IO) with its Domestic Agencies (DAs) since the initiation

of the ITER project. During this time, the US scope on design and R&D has evolved among several sets of modules. Earlier in FY 2010, the US scope included the manufacture of a certain subset of the first wall components, as well as their design and R&D. Recently, the Russian Federation, together with China, agreed to manufacture what are now called the Enhanced Heat Flux (EHF) first wall panels, which had been included in the US scope. These Enhanced Heat Flux panels are to be placed in regions of ITER (e.g., the upper first wall) for which the conceptual design review for the ITER first wall in February 2009 specified higher heat loads (up to 5 MW/m^2).

The ITER Blanket Integrated Project Team (BIPT) handles the integration of the blanket. This Integrated Project Team has three design teams, which respectively address the following first wall modules:

- Enhanced Heat Flux first wall modules
- Normal Heat Flux first wall modules
- Shield Blanket modules.

Mike Ulrickson (US Domestic Agency) leads the Enhanced Heat Flux Design Team, Francesco Zacchia (EU Domestic Agency) leads the Normal Heat Flux Design Team, and Fu Zhang (ITER Organization) leads the Shield Blanket Design Team. Mike Ulrickson also serves as the US coordinator for all three of the BIPT design teams, as well as for the ITER/BIPT analysis group that is led by Rene Raffray (UCSD).

Announcements

Submit BPO-related announcements for next month's eNews to Tom Rognlien at trognlien@llnl.gov .

Upcoming Burning Plasma Events

2010 Events

April 19-21
Sherwood Fusion Theory Conference (abstracts due **Feb. 16)**
Seattle, Washington USA

April 20-23
Integrated Operational Scenarios ITPA Meeting
Princeton, New Jersey USA

April 21-23
ITPA Pedestal and Edge Physics Topical Group Meeting
Naka, Japan

April 26-28
ITPA Energetic Particles Group Meeting
Garching, Germany

May 10-14
18th ITPA Diagnostics Topical Group Meeting (before HTPD)
Oak Ridge, Tennessee USA

May 16-20
18th HTPD Topical Group Meetings
Wildwood, New Jersey USA

May 19-21
STAC-8
Cadarache, France

May 24-28
19th International Plasma Surface Interactions Conference (abstracts due **Nov. 20**)
San Diego, California, USA

May 31-June 4
4th ITER International Summer School (abstracts due **April 30**)
Austin, Texas USA

June 20-24
37th IEEE International Conference on Plasma Science (ICPOS 2010)
(abstract submission extended to **Jan. 23**)
Norfolk, Virginia USA

June 21-25
37th European Physical Society Conference on Plasma Physics (abstracts due **Feb. 27)**
Dublin, Ireland

June 28-29
ITPA Coordinating Committee Meeting
Cadarache, France

Aug 30-Sept 3
Theory of Fusion Plasmas Joint Varenna-Lausanne International Workshop
(abstracts due **June 18**)
Varenna, Italy

Sept 27-Oct 1
26th Symposium on Fusion Technology (SOFT2010)
Porto, Portugal

Oct 11-16
23rd IAEA Fusion Energy Conference (U.S. synopsis due **Feb. 8**)
Daejeon, Korea

Week of Oct 18-20
ITPA Energetic Particles Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-20
ITPA Transport and Confinement Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-21
ITPA Divertor and SOL Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-21
ITPA Integrated Operation Scenarios Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-21
ITPA MHD Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-21
ITPA Pedestal and Edge Physics Meeting (in conjunction with IAEA FEC)
S. Korea

Week of Oct 18-22
ITPA Diagnostics Topical Group Meeting (in conjunction with IAEA FEC)
Japan

Week of Oct 18-22
ITPA Pedestal and Edge Physics Topical Group Meeting (in conjunction with IAEA FEC)
S. Korea

Oct 24-29
9th International Conference on Tritium Science and Technology
Nara, Japan

Nov 7-11
19th Topical Meeting on the Technology of Fusion Energy (TOFE 2010)
(embedded with 2010 ANS Winter Meeting)
Las Vegas, Nevada USA

Dec 15
IEA-ITPA Joint Experiments Planning Meeting
Videoconference

2011 Events

Spring
ITPA Transport & Confinement Topical Group Meeting (following US/EU TIF)
San Diego, California USA

Directories of Other Plasma Events

IEEE Directory of Plasma Conferences
Fusion Ignition Research Experiment (FIRE) Physics Meetings

Please contact the administrator with additions and corrections.