U.S. Burning Plasma Organization e-News
June 18, 2007 (Issue 10)

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Dear Burning Plasma Aficionado:

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 (R. Nazikian rnazikian@pppl.gov) or assistant editor (Emily Hooks ehooks@mail.utexas.edu).

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

Director's Corner by J. Van Dam

Here are some updates, with commentary, about recent and upcoming USBPO activities.

ITPA Coordinating Committee Meeting: This meeting will be held June 18-20 in Cadarache, France. The US members of the ITPA Coordinating Committee are Erol Oktay, Ned Sauthoff, and Ron Stambaugh. Other US representatives at the meeting will be Wayne Houlberg, Ed Doyle, Tony Leonard, and Bruce Lipschultz, who are ITPA topical group chairs or co-chairs. Ray Fonck attended last year's meeting as the ITER Project Office chief scientist and USBPO director, and this year I will attend in the same capacity. Recall from last month's e-News that the US component of the ITPA is now integrated with the USBPO at the national level. On the agenda for this meeting are several presentations about the ITER design review, reports about the status and plans of the programs of the seven ITER partners, reports from the ITPA topical physics groups, and a discussion of the relationship of the ITPA with the new ITER international organization. Personally, I'm looking forward to seeing dirt being moved at the site where ITER is to be constructed.

APS/DPP Meeting: The USBPO has arranged for Dr. Guenter Janeschitz, head of the nuclear fusion program at Karlsruhe, Germany, to present a talk about the ITER design review activities in his capacity as the overall leader of the eight design-review working groups. This should be an informative talk, by a very stimulating speaker. More details about the date and time for this talk, in a special session during the APS/DPP Meeting in Orlando, FL. in November, will be forthcoming.

ITER design review: US scientists are becoming involved in design review-related research activities, through connections with several of the ITER design review working groups. The Department of Energy is issuing guidance about how to keep track of the levels of effort. By the time of the next monthly newsletter, more information should be available. The US contribution to the design review effort is vital, and the USBPO actively promotes it.

Examples of recent activities of Topical Groups: The USBPO topical group on plasma-wave interactions held an afternoon workshop on May 9, following the 17th Topical Conference on Radio Frequency Power in Plasmas, held in Clearwater, FL. Members of the USBPO topical group on modeling and simulation participated in the Fusion Simulation Project workshop, May 16-17, in Washington, D.C. Members of various USBPO topical groups participated in recent ITPA meetings on Pedestal (Garching), SOL/Divertor (Garching), Transport (Lausanne), Confinement Data Base and Modeling (Lausanne), and Steady-State Operation (Daejeon).

Test Blanket Module for ITER: A workshop sponsored by the Virtual Laboratory for Technology, a sister organization to the USBPO, was held May 30-June 1 at Oak Ridge National Laboratory. Nermin Uckan, leader of the USBPO topical group on fusion engineering science, served as a member of and the secretary for the review panel. Dave Petti, a member of the USBPO Council, did an excellent job chairing the review panel. I attended this workshop and was invited to function as a de facto member of the panel, so that USBPO views about test blanket modules could be represented. For me, it was a total-immersion crash course in nuclear technology—very educational! More information about this workshop can be found in a report in this issue of e-News.

Announcements

Review of US-ITER diagnostic measurement requirements by R. Boivin, J. Terry and S. Allen

The BPO Diagnostics Working Group has chosen as one of its first tasks a review of the measurement requirements for US-credited ITER diagnostics. In addition, this task calls for the evaluation of the performance of US ITER diagnostic systems based on their present level of design.

The US has presently 6 ITER-credited diagnostics to procure in kind: ECE, MSE, LFS reflectometer, Interferometer/polarimeter (tangential and divertor systems), imaging systems (upper visible and IR cameras), and the RGA.

Four working groups have been formed last year to help in undertaking this task. The groups and group leaders are:

Microwave systems: M. Austin (UT)
austin@fusion.gat.com
Imaging systems: J. Terry (MIT)
terry@psfc.mit.edu
Active spectroscopy: D. Thomas (GA)
thomas@fusion.gat.com
IR/FIR systems: J. Irby (MIT)
irby@psfc.mit.edu

Inputs from a variety of people are presently being sought and your participation is encouraged. Diagnosticians, experimentalists, modelers, theorists, etc, are requested to help review these measurement needs. Solicitations to the "Imaging systems" group and the "IR/FIR systems" group have been made. And responses are needed by mid-June since we desire that they be used in the ITER Design Review process, which is expected to begin in July 2007 for this topical area.

If you wish to have input in this assessment, please contact the appropriate group leader promptly. If you are not sure how you can participate, please contact Rejean Boivin (Boivin@fusion.gat.com), Steve Allen (allens@fusion.gat.com) or Jim Terry (terry@psfc.mit.edu). More information is available on the assessment solicitation, goals, process, and logistics on the BPO forum web site at https://burningplasma.org/forum.

Progress in ITER Physics Basis

Publication of the Progress in the ITER Physics Basis is now available online at http://www.iop.org/EJ/toc/0029-5515/47/6 (Note that all published papers are freely available for 30 days from the date of online publication.)

Reports

Summary of 2005-2006 ITER Physics Tasks undertaken by U.S. community
by N. Uckan

The final Task Report for each of the 2005-6 ITER Physics Tasks undertaken by the U.S. community participants was completed and submitted to the ITER Organization in January and April 2007 (in two parts). The U.S. Burning Plasma Organization was tasked with coordinating these Physics Tasks with the US ITER Project Office. There were five (5) subtasks that involved multi-institutional participants. Brief excerpts from each task are given here and the full report can be found on BPO forum.

Subtask 1: RWM control (by G. Navratil and J. Bialek)

The results from VALEN 3D finite element feedback control modeling were compared with results from the MARS and KINX codes for RWM control in ITER using the Scenario 4 plasma equilibrium. Except for the predictions at very high beta, the three codes were found to be in excellent agreement. In the high beta range, VALEN finds instability that cannot be corrected by feedback control, while MARS can extend the stable range with feedback control.

The ITER Team proposed analysis of a new coil configuration that consists of nine-picture frame coils placed outside the ITER double wall vacuum chamber around every other midplane port. The VALEN code was applied to this proposed external midplane control coil system using ITER Scenario 4. The results with VALEN showed that the proposed scheme stabilizes the RWM n=1 mode near the ideal-wall pressure limit.

Subtask 2: VDE, disruptions and their mitigation in ITER (by D. Whyte, R.Granetz, D. Humphreys, H. Strauss, S. Jardin)
The predictability of halo current width evolution, effectiveness of impurity penetration, and impurity species concentrations in the post-thermal quench (TQ) phase are considered for ITER. Analysis of DIII-D disruptions suggests that the effective halo current width is set by the plasma motion and current diffusion across open field lines in the post-TQ plasma. Halo currents were found to freely diffuse out to, and then be limited by, the plasma-facing components (PFC) of the wall.

High-pressure noble gas injection was shown to be a reliable, safe method for rapidly shutting down discharges in C-Mod and DIII-D. Both DIII-D and C-Mod show that "ballistic" penetration of the gas jet neutrals to the central plasma is not required for disruption mitigation. The results are encouraging for ITER. The installed gas jet on C-Mod, the same design as used on DIII-D, provided reliable disruption mitigation of thermal loads and halo currents at magnetic field and plasma pressure comparable to ITER.

Runaway electrons (REs) are suppressed in experiments (DIII-D, C-Mod), despite the fact that full collisional suppression of runaways is not met. Empirical extrapolation for RE suppression is encouraging for ITER.

Subtask 3: Fast particle confinement (by N. Gorelenkov)
For this task NOVA-K analysis was performed in order to evaluate the stability of TAEs driven by alphas and beam ions in monotonic q-profile ITER plasma. With off-axis NBI, TAEs were found to be weakly unstable, and stable for on axis NBI. The reason is that the location of the peak fast ion pressure coincides with the region of TAE localization for off axis injection. It seems plausible to control TAE instability by controlling the beam ion deposition and q-profiles with the current drive schemes planned for ITER.

Another part of the task was application of the M3D code for studying alpha particle stabilization of the n=1 in ITER. It is shown that alpha particle effects are stabilizing for the internal kink mode. However, the elongation of ITER reduces the stabilization effects significantly. The Fishbone instability branch has also been studied with the M3D code in ITER normal shear plasmas. Simulations showed that fishbones are stable in the presence of fusion alpha particles.

Subtask 4: Effects of radiation transfer on divertor plasma (by B. Lipschultz)

The main purpose of this task was to measure and model the level of Lyman photon trapping (and photon transport) in divertor plasmas as close to the conditions of ITER as possible, thereby providing the best test of models in the ITER regime. Photon trapping appears to play a role in determining the plasma parameters, access to detachment, and pressure in divertors. The level of divertor Lyman alpha trapping is proportional to n_0L, where n_0 is the neutral density and L the divertor spatial scale length. The divertors of C-Mod, where the neutral density is high, and JET, which is large, provide valuable sources of data for ITER.

Subtask 5: ICRF heating and current drive (by E.F. Jaeger, P. Botoli, T.K. Mau)
The AORSA and TORIC full-wave electromagnetic field solvers were used to simulate ICRF heating in the ELMy H-mode Scenario 2 in ITER, as part of an international benchmarking activity of ICRF codes. In this heating scenario, ion cyclotron damping at the second harmonic of tritium and electron Landau damping are the primary absorption mechanisms in the absence of minority ^3He. An encouraging result of these numerical studies was the finding that only 1-4% of the ICRF power was absorbed on the non-thermal alpha particles. The presence of a Be resonance near the high field side plasma edge was also identified as a possible source of parasitic absorption, although both codes predicted the Be absorption to be low (< 4%).

Virtual Laboratory for Technology (VLT) Workshop (May 30- June 1) on ITER Test Blanket Modules (TBM) by Gene Nardella, Stan Milora and Nermin Uckan

The VLT conducted a workshop at Oak Ridge National Laboratory (ORNL) to address a series of questions as to the value and benefits that will be accrued by participating in the proposed ITER TBM program versus other possible approaches. To understand the situation better, the VLT Director formed a panel of nuclear/fusion technology experts that reviewed the proposed program as well as proposed scenarios of U.S. participation by the U.S. ITER TBM team.

ITER detailed technical objectives and performance specifications provide specific guidance for plasma performance and engineering performance and testing. In regards to *engineering performance and testing*, the formal language states that the device should:

- demonstrate the availability and integration of technologies essential for a fusion reactor (such as superconducting magnets and remote maintenance);
- test components for a future reactor (such as systems to exhaust power and particles from the plasma);
- test tritium breeding module (TBM) concepts that would lead in a future reactor to tritium self-sufficiency, the extraction of high grade heat and electricity production.

To carry out nuclear component testing relevant to a future fusion power plant, the ITER parties starting as early as the Conceptual Design Activities (CDA), have been working on a variety of TBM concepts consisting of various combinations of breeding material and coolants to test demo-relevant breeding blankets on ITER. There are three equatorial ITER ports reserved for TBM testing – two TBMs per test port (up to total a of 6 to be installed and tested at any given time). Almost all the TBMs will be fabricated from ferritic steel and will be installed in frames/shields made of the same materials as the basic ITER shield blanket. In the absence of any actual TBMs, these ports will be equipped with dummy TBMs. Historically, the TBM testing program has not been a part of the past 4-party ITER agreement, and it is not part of the present ITER Agreement with seven parties.

For proper integration with ITER operations, the TBM advocates (and some of the parties) are proposing to have TBMs installed and tested in ITER from the first day of hydrogen (H) operation. In addition, the French regulators have indicated that TBMs must be included in either the current ITER licensing process or as a separate piece. The ITER parties are now discussing various issues such as safety and licensing, the resources needed for additional TBM related infrastructure, partnering relationships, intellectual property rights, and physics performance related to the implementation of TBM testing. The topic is on the agenda for the upcoming ITER Interim Council meeting to discuss and agree on the framework for the TBM program.

To inform these negotiations, a review panel was established and this workshop was held at ORNL to understand the role and merits of the U.S. ITER TBM program and its value to the overall U.S. fusion nuclear technology (FNT) program. To help the discussions, 18 questions were developed, which were addressed by the US ITER TBM team. The U.S. Burning Plasma Organization's input was also solicited and considered during the discussions at the workshop. A set of findings and recommendations has been provided to the VLT Director for his consideration.

The panel noted that the value of an ITER TBM should be considered in the context of the knowledge base needed for an ultimate fusion energy system. In recognizing the value of integrated testing on ITER, the panel recommended that 1) the U.S. maintain the option for participation in the ITER TBM program, if at all possible, and 2) the fusion nuclear technology program be strengthened to make participation in ITER a success. The panel also recommended that if the U.S. decides to participate in the ITER TBM program it should do so in a way that minimizes the risk exposure given the state of the technology at this point. With respect to the issues raised by the BPO members, the panel noted that there has been limited examination of the impact of the TBM on ITER operation and its ability to accomplish the physics mission. Specifically, preliminary calculations indicate that the ITER TBMs can handle disruptions via modest design changes to accommodate resulting loads. Because the TBMs will have ferritic steel as a structural material, producing non-axisymmetric magnetic fields (error fields) inside the vacuum vessel of up to 2%, additional analysis is necessary to understand the potential effects to operation.

Feature Article

Status of US-BPO integrated coil analysis for ITER by J. Menard

To significantly enhance the ELM and RWM control performance in ITER, the MHD topical group of the US BPO has been engaged in an extensive physics analysis effort attempting to find magnetic field coil systems for ITER capable of ELM suppression using RMPs and stabilization of RWMs using active feedback control. An initial goal of the BPO effort was to assess if improved RMP, RWM, and error-field correction (EFC) were simultaneously possible with a single coil system. One important result of the BPO analysis is that due to the large currents and spectral flexibility required for ITER EFC, the coils optimal for RMP and RWM control cannot easily replace (but can supplement) the present EFC coils for error field correction. While not being able to replace the present EFC system, several attractive coil options have been identified that offer performance significantly surpassing the performance of the ITER EFC coils for RMP and RWM applications. Importantly, several coil sets studied were found to provide good ELM and RWM control simultaneously. The two most favored coil sets of the more than nine sets studied are described below.

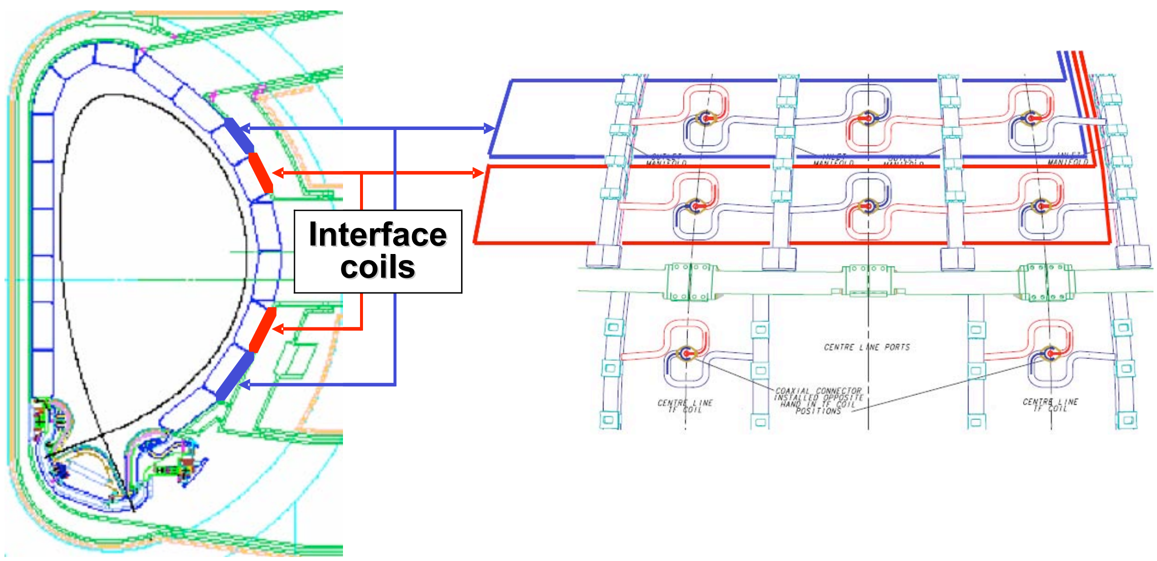

Figure 1 - Geometry of possible blanket-module/vessel-wall "interface" coils for applying Resonant Magnetic Perturbations (RMPs) to suppress Edge Localized Modes (ELMs) and actively control Resistive Wall Modes (RWMs) in ITER.

Internal coils are very advantageous for RMP applications, since close proximity of the coils to the plasma helps localize the applied fields to the plasma boundary. The most flexible coil set with a reasonable number of coils for RMP consists of an array of 36 coils that reside at the interface between the back of the blanket modules and the front of the inner-most vessel layer. The array considered consists of 9 coils distributed toroidally in 4 poloidal rows just above and below the midplane ports of ITER at blanket module positions 12, 13, 16, and 17. Cross-sections of ITER showing the location and span of these "interface" coils (red and blue lines) are illustrated in Figure 1.

This coil set can provide the desired field pattern for RMP for the three representative operational scenarios of ITER assessed by the BPO – namely: Scenario 2 = "ELMy H-mode", Scenario 3a = "hybrid", and Scenario 4 = "steady-state". The required current is relatively modest ≈ 40kA-turns per coil for n=4 RMP. This coil set achieves the smallest non-resonant magnetic field components near the plasma boundary important for avoiding plasma rotation damping. For reference, the two largest non-resonant side-lobe amplitudes are less than 60% of the amplitude of the resonant lobe. This coil set also minimizes the resonant fields that can generate core magnetic islands if the plasma rotation is insufficient to shield the islands. Using vacuum field estimates, core island widths ≤ 5cm are calculated. For n=1 RWM control in Scenario 4, VALEN analysis indicates a marginal β_N of 3.65 is achievable with 100's of kW of control power using the interface coils with standard control techniques. The estimated peak coil current using interface coils is 10-20kA-turns. Overall, the interface coils offer very good RMP spectral purity and control and RWM control with significantly larger β_N margin and much lower power than achievable with the EFC coils.

The interface coils described above obviously represent a significant perturbation to (or redesign of) the present ITER blanket/vessel interface region. A less drastic alternative to the interface coils is to install coils at the ends of the midplane and upper port-plugs just behind the plug shields. These coils are likely the least perturbative to the ITER design, and are presently the highest priority coil set for analysis within Working Group #1 (WG1) of the ITER design review working groups. A cross-section of ITER showing the locations of candidate "port-plug" coils (orange lines) is given in Figure 2.

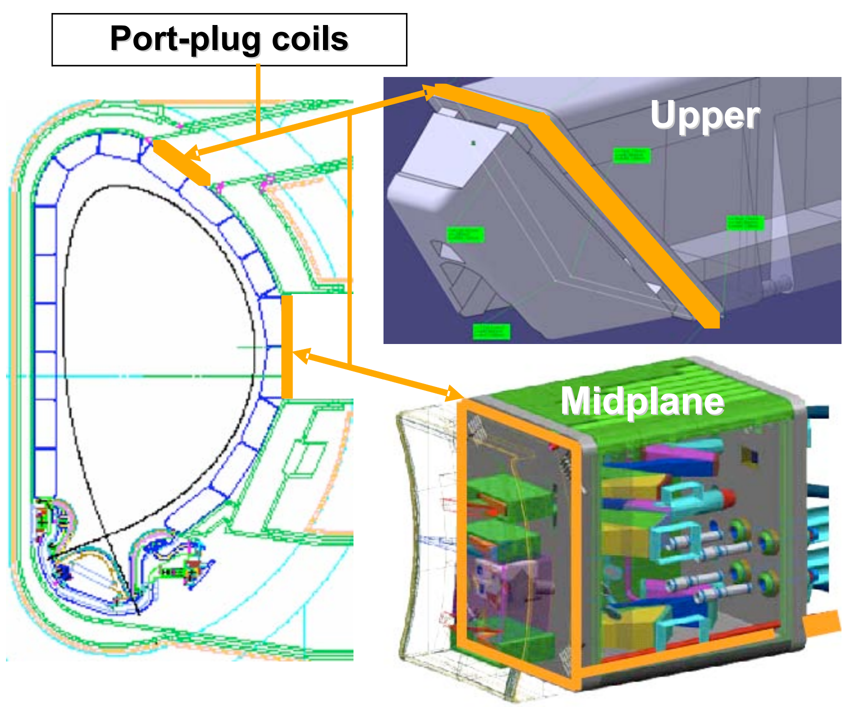

Figure 2 - Geometry of proposed "port-plug" coils for applying RMPs and controlling RWMs.

However, for RMP applications, the relative simplicity of the port-plug coils comes at the cost of significantly higher coil current, comparatively poor spectral flexibility for RMP, and larger non-resonant and resonant perturbations in the plasma core. For 7 coils in the midplane ports and 9 coils in the upper ports, the required current per coil is 280kA-turns using n=4 RMP. The larger current of the port-plug coils relative to the interface coils is the result of having fewer coils and the fact that the port-plug coils have smaller radial-field-producing area. If more ports are made available (this is presently being assessed by IO and USBPO) for coils than assumed in the existing BPO studies, the maximum current per coil will be reduced. For the port-plug coils, the non-resonant side-lobe amplitudes are 1.3 times higher than the amplitude of the resonant lobe. Thus, since magnetic braking is expected to scale as δB^2, the port-plug coils would generate 4 times more magnetic drag relative to the 36 coil "interface" array. The core resonant field perturbations are projected to be 50% higher relative to the interface coils and therefore produce vacuum island widths of up to 6cm.

Using only the midplane port coils for RWM feedback, VALEN analysis indicates a marginal β_N of 3.85 is achievable using the same proportional feedback gain as was used for the interface coils. The midplane port-plug coils therefore offer the highest RWM control β_N found for ITER thus far, and this control is again achievable with relatively small feedback power levels of 100's of kW with coil currents of 10-20kA-turns. However, this high β_N is only achieved if the port-plug coils are sufficiently close to the plasma. For instance, if the coils are shifted 20cm radially away from the plasma so the coils are more effectively coupled to the inner-most vessel wall and less effectively to the plasma, the RWM control β_N is degraded to 3.5.

As should be evident from the discussion above, detailed engineering considerations of where coils can actually reside in ITER will impact the relative performance of the various options considered. Many interactions with the ITER physics and engineering groups have significantly aided in the understanding of the constraints on possible internal coil systems for ITER. Additional engineering resources are being pursued within the U.S. to assist the IO in assessing the viability of the coil systems described above.

BPO-Related Meetings

Jun 4-8
6th IAEA TM on Ctrl, DAQ & RP
Inuyama, Japan
http://tm2007.nifs.ac.jp/

Jun 6-8
4th IAEA TM on ECRH Physics & Technology for ITER
Vienna, Austria
http://www-naweb.iaea.org/napc/physics/meetings/4ECRH.htm

Jun 17-22
34th IEEE Int'l Conference on Plasma Science and the 16th IEEE Int'l Pulsed Power Conference – ICOPS 2007
Albuquerque, NM
http://www.ece.unm.edu/ppps2007/

Jun 17-21
22nd Symposium on Fusion Engineering – SOFE 2007
Albuquerque, NM
http://sofe22.sandia.gov/

Jun 20-22
2nd IAEA TM "First Generation of Fusion Power Plants - Design and Technology"
IAEA, Vienna, Austria
http://www-naweb.iaea.org/napc/physics/meetings/TM32812.html

July 2-6
34th European (EPS) Conference on Plasma Physics
Warsaw, Poland
http://www.eps2007.ifpilm.waw.pl/

Sep 9-15
Energy Conversion Systems in Tokamak Reactor
Erice - Italy

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

Sep 24-28
International Conference on Burning Plasma Diagnostics
Villa Monastero, Varenna, Italy
http://www.ispp.it/

Sep 26-28
11th IAEA Technical Meeting on H-mode and Transport Barrier
Tsukuba, Japan
http://www-jt60.naka.jaea.go.jp/h-mode-tm-11/

Sep 30-Oct 5
8th Int'l Symp. on Fusion Nuclear Technology - ISFNT-8
Heidelberg, Germany
http://iwrwww1.fzk.de/isfnt/

Nov 12-16
49th APS-DPP Meeting
Orlando, FL
http://www.aps.org/meetings/unit/dpp/index.cfm

Dec 10-14
13th International Conf. on Fusion Reactor Materials
Nice, France
http://www-fusion-magnetique.cea.fr/icfrm13/index.html

For more 2007 Fusion Research-related events, visit the USBPO Upcoming Events page online at http://burningplasma.org/events.html.