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November, 2003

VLT News

The Newsletter for the Virtual Laboratory for Technology

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Burning Plasma – Bringing a Star to Earth

In May 2002, the Department of Energy asked the National Research Council of the National Academies to carry out an assessment of a program of burning plasma experiments and its role in magnetic fusion research. A panel of eighteen members[i] was assembled to carry out the assessment with the assistance of three academy staff members[ii]. The panel held four meetings to gather input and discuss the report. An interim report was published in December 2002. The final panel report was issued in September 2003. The final report contained 170 pages including supplemental material. This article summarizes the main conclusions of the report.

The assessment was conducted in the context that fusion research sponsored by the Department of Energy's Office of Fusion Energy Sciences has made remarkable progress in recent years in understanding and controlling turbulence and instabilities that have led to improved plasma confinement. Theory and modeling are now able to provide useful insights into instabilities and guide experiments. Diagnostics can extract useful information about the processes occurring in high-temperature plasmas. The success of the US program can be attributed to its science-centered approach aimed at three goals; *1) to advance plasma science at the fundamental level; 2) to develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; 3) to pursue fusion energy and technology as a partner in the international effort.* In light of this progress the question arises, a burning plasma experiment is the next logical step for fusion research.

The Burning Plasma Assessment Committee was charged with carrying out an assessment of the importance of a burning plasma experiment, and an assessment of the readiness to undertake a burning plasma experiment, and an assessment of the plan for a burning plasma experimental program. The committee was also asked to make recommendations on the program strategy to maximize the output of such a program for the future development of fusion as an energy source. The committee reached three main conclusions.

A burning plasma experiment is critically needed to advance fusion science. The committee is pleased that the United States government has rejoined the ITER negotiations which the committee expects will be successful. If the negotiations are not successful, progress toward fusion energy requires moving ahead with some kind of international burning plasma experiment.

Undertaking a burning plasma experiment cannot be done on a flat budget. If the US is interested in the long-term energy goal and not only in ITER, the nation needs a science program based on some of the existing facilities; a technology program; a computation, simulation and theory program; and a university program. At a minimum, to capture the benefits of a burning plasma experiment, an augmentation of the US program covering all the US ITER construction and operating costs would be required.

If all goes well, the fusion program will move ahead with the ITER endeavor. In making this move the fusion community should focus on the opportunities this development will present and accept the limitations on the

level of activity possible within reasonable budget constraints. There needs to be a recognition that some of today's facilities will have to be shut down as time goes on and not all alternate concepts are affordable. Priorities will be set and, while this committee has not been asked to set them, it does recommend the community take part in a real prioritization process for the fusion program. The OFES must take the lead and bring the community to this consensus.

The committee made several specific recommendations and observations. The United States should participate in a burning plasma experiment. The US fusion program should participate in the ITER as the top priority in a balanced fusion program. The US should pursue an appropriate level of involvement in ITER, which at a minimum would guarantee access to all data from ITER, the right to propose and carry out experiments, and a role in producing the high-technology components of the facility consistent with the size of the US contribution to the program. If the ITER negotiations fail, as soon as possible, the US should continue to pursue the goal of conducting a burning plasma experiment with international partners.

A strategically balanced fusion program should be developed, including US participation in ITER, a strong domestic fusion science and technology portfolio, an integrated theory and simulation program, and support for plasma science. This effort will eventually require a substantial augmentation in fusion program funding in addition to the direct financial commitment to ITER construction. The fusion program should make a focused effort to meet personnel needs that will be required in the era of the burning plasma experiment. This effort should have the following goals: to attract talent to the field; to provide broad scientific and engineering training, specialized training, and training on large devices as required; to revitalize the university and fusion laboratory workforce. Undertaking a burning plasma experiment cannot be done on a flat budget.

To ensure the continued success and leadership of the US fusion program the content, scope, and level of US activity in fusion should be defined through a prioritized balancing of the program. A prioritization process should be initiated by OFES to decide on the appropriate programmatic balance given the science opportunities identified and the budgetary situation of the time. The balancing process also could be guided by a multi-year budget-planning path that projects funding growth. The prioritization process should be organized with the three elements of the fusion program in mind (see above).

Contributed by M. Ulrickson, SNL
(NRC Panel Member)

[1] The Burning Plasma Assessment Committee members were: John Ahearne, Sigma Xi Duke University, Co-Chair; Raymond Fonck, University of Wisconsin at Madison, Co-Chair; John Bahcall, Princeton University; Gordon Baym, University of Illinois at Champaign-Urbana; Ira Bernstein, Yale University; Stephen Crowley, Imperial College, London; Edward Frieman, SAIC; Walter Gekelman, University of California at Los Angeles; Joseph Hezir, EOP Group, Inc.; William Nevins, Lawrence Livermore National Laboratory; Ronald Parker, Massachusetts Institute of Technology; Claudio Pellegrini, University of California at Los Angeles; Burton Richter, Stanford Linear Accelerator Center; Clifford Surko, University of California at San Diego; Tony Taylor, General Atomics; Michael Ulrickson, Sandia National Laboratories; Michael Zarnstorff, Princeton Plasma Physics Laboratory, Ellen Zweilbel, University of Wisconsin at Madison.

[1] National Academies staff members were: Donald Shapiro, Director, Board on Physics and Astronomy; Timothy Meyer, Study Director (from August 2003); Michael Moloney, Study Director (May 2002 until July 2003).

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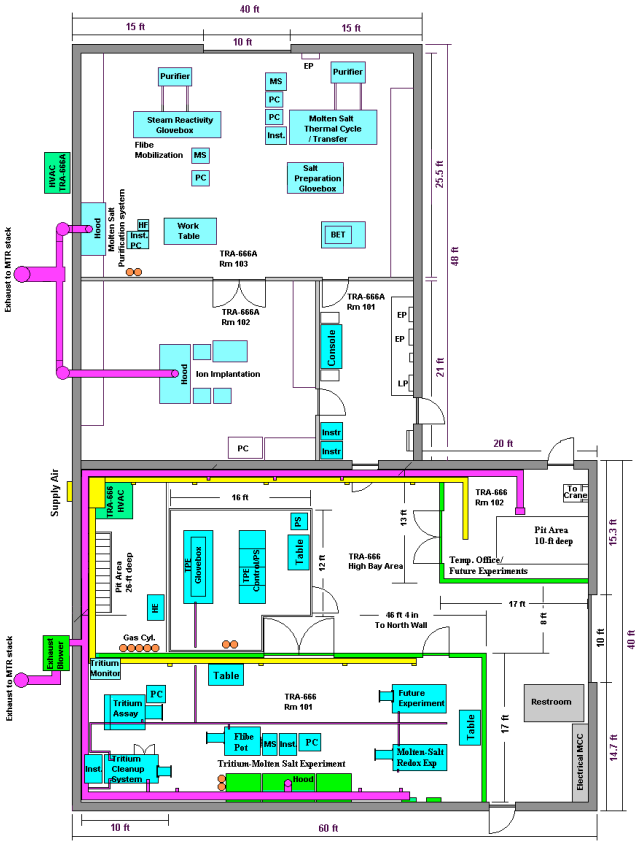
Fusion STAR Facility Nears Completion at INEEL

The Safety and Tritium Applied Research (STAR) facility, located at the Idaho National Engineering Laboratory (INEEL) near Idaho Falls, ID, is nearly complete and ready for operation. STAR is an updated and expanded facility designed to perform small to moderate scale tritium-related experiments for the fusion program. STAR is also a DOE National Users Facility- a designation that encourages national and international collaboration through simplified research agreements. Work at STAR generally focuses on fusion materials chemistry, tritium behavior, plasma-material interactions, and dust in fusion devices, with a balanced interest between pure science and technology applications. The core research staff at STAR comprises members of the INEEL Fusion Safety Program. Infrastructure and capabilities at STAR are intended to meet the needs of researchers that cannot safely and effectively implement experiments involving moderate levels of hazardous compounds and/or tritium at other institutions.

Figure 1. The STAR facility is located at the Test Reactor Area at INEEL. The building TRA666, shown below, was renovated and brought into service to house STAR. With nearly 4000 ft^2, the STAR footprint has room for many experiment and infrastructure systems, as shown in the floor plan given at right.



The STAR facility occupies about 4,000 ft^2 of floor space, providing ample room for experiment systems and supporting equipment to ensure safe, clean, and controlled operation. Figure 1 shows the physical structure housing STAR, as well as the facility layout. Several inert atmosphere gloveboxes are available for experiments requiring tightly regulated environmental conditions, isolation from hazardous compounds, and confinement of radiological materials. Less restrictive experiments are performed within vent hoods throughout the facility. Figure 2 shows example systems presently being utilized. A stack monitoring system is also used to measure airborne environmental release of tritium through the STAR ventilation system. STAR is classified as a radiological, low hazard facility with a tritium inventory limit of 15,000 Ci. Tritium handling services are provided by a catalytic Tritium Clean-up System (TCS) and a tritium Storage and Assay System (SAS), whereas inadvertent tritium release to room air and glovebox environments is monitored by an array of ionization chambers.

STAR's TCS is responsible for removal of tritium from the process streams of experiments and support systems, including glovebox inert atmospheres. It utilizes a palladium catalyst operating at 250-450˚C to oxidize tritiated compounds from the input process streams and has a demonstrated efficiency of 99.99%. Tritiated water is collected onto molecular sieve material that, when regenerated, allows a periodic and controlled method of waste disposition. In the STAR SAS elemental tritium gas delivered to the facility is assayed by a pressure-volume-temperature (PVT) technique with a high sensitivity beta-scintillation detector for tritium concentration measurements. Tritium gas is subsequently transferred to a uranium metal storage bed, where it is stored as uranium tritide until needed for experiments. Each experiment system will incorporate local tritium storage, either a metal-tritide bed or gas bottle, filled at the SAS. The TCS and the SAS are adjacent in the STAR facility layout, as shown in Figure 3.

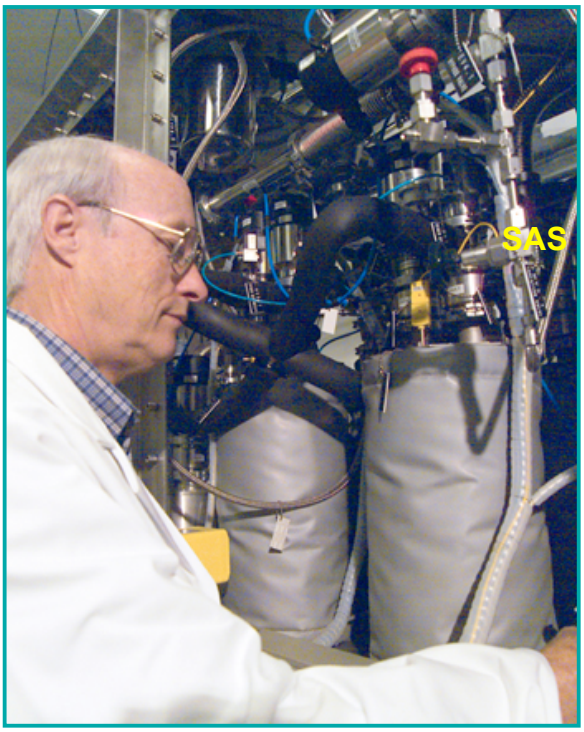
Safety and environmental concerns for future fusion power systems are widely recognized for being strongly dependent upon materials selection. The nature of fusion systems generally require advanced materials that often have associated chemical hazards. Basic research with these materials requires special care. STAR infrastructure and support systems allow research activities with such materials. Some materials presently in use or of planned use for experiments in STAR include beryllium (non-irradiated and irradiated), molten lithium and lead, molten fluoride salts (flibe, flinabe), and severe corrosive agents (hydrogen fluoride).

The STAR facility is also the new home of the Tritium Plasma Experiment (TPE). Originally built at Sandia- Livermore and eventually moved to Los Alamos National Laboratory, TPE is used to study the impact of tritiated plasmas on proposed materials for plasma-facing components. STAR provides all infrastructure and support systems needed to allow continued studies with TPE, particularly in support of a burning plasma experiment. TPE is expected to have the greatest throughput of tritium in the STAR facility. Because of its size and unique capability for testing hazardous materials exposed to tritium plasmas, a separate enclosure was erected in STAR to isolate TPE from other experiment areas (see Figure 4).

The key components related to the STAR infrastructure were installed in FY03. In FY04, following completion of staff training and integrated system testing, a management and operations assessment will be performed to demonstrate the ability of the facility to function as planned within the prescribed operating and safety envelopes. For more information, please contact David Petti (pti@inel.gov) or Robert Anderl (raa@inel.gov).

Contributed by P. Sharpe, INEEL

Photos from the new STAR Facility at INEEL



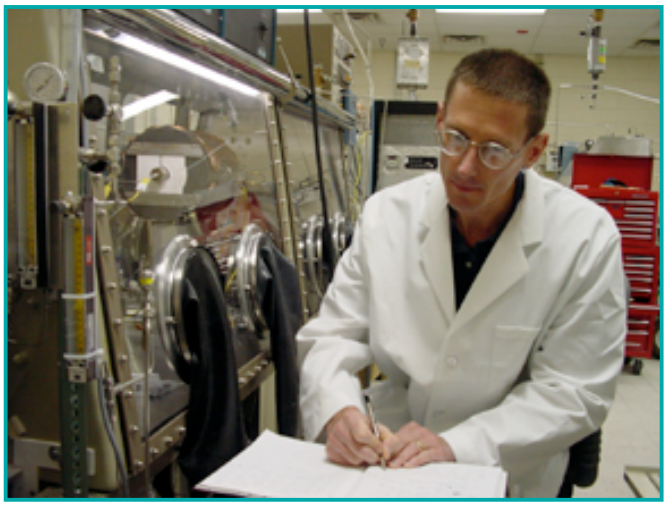


Figure 2. Fusion Safety Program Staff researchers Robert Anderl (left) and Bob Pawelko (above) work with experiment systems in STAR.

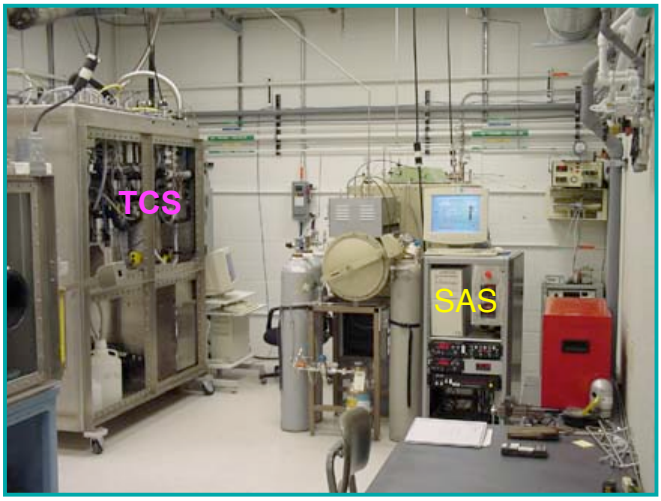


Figure 3. STAR's Tritium Cleanup System (TCS) is responsible for tritium removal from experiment and support system process streams. The Storage and Assay System (SAS) provides tritium inventory control and accountability for the facility.

Figure 4. This PermaCon enclosure will house the Tritium Plasma Experiment, used to study material response when exposed to tritiated plasmas. Isolation of the experiment system allows the study of hazardous materials such as beryllium.

Magnetic Diversion of Expanding Laser Plasma

The idea of using magnetic fields to confine or divert high-energy ions emanating from IFE target explosions has been considered from the early days of IFE power plant studies. Although fundamental research has been performed to help understand the basic physics involved in plasma and ion expansion across magnetic fields, the ability to implement magnetic diversion under IFE-relevant conditions is still highly uncertain.

At UC San Diego we are performing experimental studies to characterize the expansion dynamics of laser ablation plumes into several magnetic field configurations, including fields aligned with or transverse to the expansion direction, and a curved field with the axis of symmetry parallel to the expansion direction. Plasma is produced in a vacuum chamber (base pressure ~10^{-8} Torr) using 8-ns pulses from a Q-switched Nd:YAG laser supplying power density in the range of 5–50 GW/cm^2. An iron-core magnetic trap was fabricated to provide transverse and axial magnetic fields (see Fig. 1).

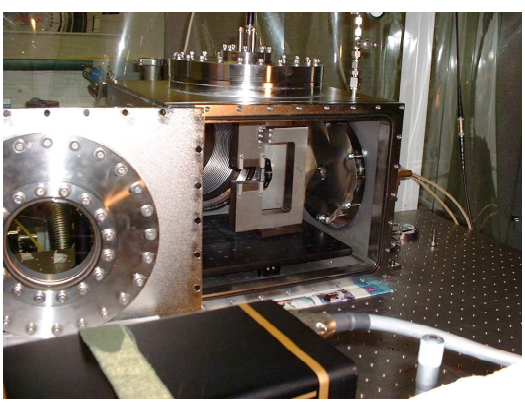


Fig. 1. Schematic of the magnetic trap used for transverse and axial field experiments.

Achieving prototypical ion energies and plasma conditions which exist immediately following an IFE target explosion requires an ignited, high-gain target facility. However, valuable information can be obtained using short-pulse laser ablation plumes if the key plasma parameters are similar to those of IFE expansions. In fact, expansion of IFE target debris is similar to that of a laser-produced plasma in that the parameters are highly dynamic and vary through many orders of magnitude. The initially hot, dense plasma is highly collisional. The expansion rapidly converts thermal energy into directed kinetic energy, and leads to a relatively collisionless later stage of expansion. It is this later stage (>50 ns) that can be simulated well using laser-produced plasma.

Figure 2 illustrates the highly transient nature of the plume expansion. The plasma thermal and directed β ($\beta_d=4\pi nMV^2/B^2$) were measured using spectrocopic techniques at a distance 1 mm from the target surface.

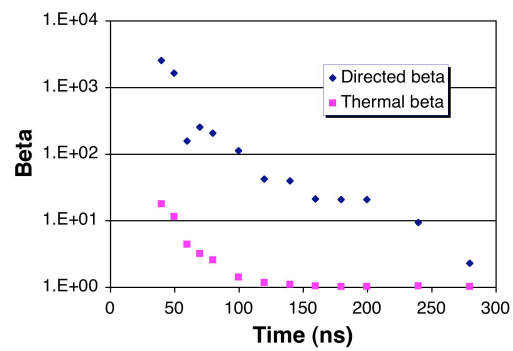


Fig. 2. Time evolution of plasma beta 1 mm from the target surface.

In the early phase of the plume expansion, β_d is on the order of a few thousand, which is in the regime of diamagnetic expansion. Diamagnetic currents exclude the magnetic field from the interior of the plume, and act on the plasma through the **J**×**B** force. This force can simultaneously accelerate and decelerate different regions of the plume depending on the direction of the diamagnetic currents. In the latter phase of the plume expansion, or non-diamagnetic limit, the plasma cools and the field is able to diffuse rapidly across the boundary.

Plasma emission begins near the target soon after the laser photons reach the surface. Plume imaging was performed using an intensified CCD camera placed orthogonal to the plasma expansion direc-

tion. Visible radiation from the plasma was recorded integrally in the wavelength range 350-900 nm with 2-ns minimum gate time. Figure 3 shows plume images at various times both with and without a transverse field applied.

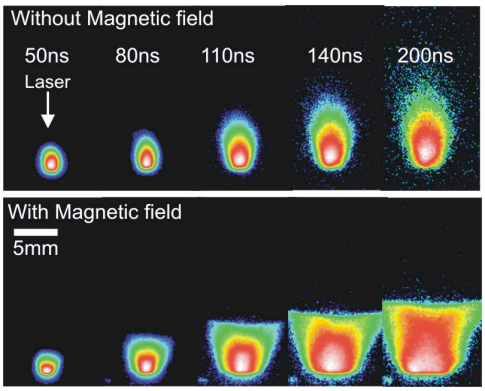


Fig. 3. Plume images in the presence and absence of a transverse magnetic field.

Significant changes were observed in the plume dynamics, including enhanced emission, confinement of the plasma, and guiding of the expansion along field lines. In the presence of magnetic field, plume propagation is considerably slowed and confined in a direction perpendicular to the target surface. The magnitude and effect of the interaction mainly depends on the properties of the outer layer of the plume, which shields the interior of the plasma from the magnetic field. While the kinetic pressure of the plasma is greater than the magnetic pressure, the plasma penetrates through the region occupied by the magnetic field. As the plume expands, the pressure decreases and hence the resistance offered by the magnetic field increases. Plasma confinement and stagnation take place when the kinetic pressure and plasma pressure balance.

Figure 4 shows the position-time (R-t) plot obtained from the imaging data. The symbols represent experimental data points and the curves represent the best fit. Without a magnetic field, the plume front expands adiabatically with a linear behavior with time (the straight-line fit in the graph corresponds to R t).

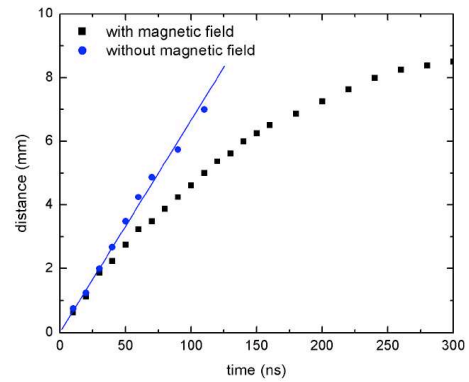


Fig. 4. R-t plots obtained from plume images with and without a transverse magnetic field.

The confinement increases the collision frequency of the charged species both by confining them to a smaller volume and by increasing their oscillation frequency. Hence, the constraint of the cross-field expansion by the magnetic field results in thermalization and a higher pressure in the confined plasma.

For the case of a transverse field, detailed spectroscopic data have been obtained on the various neutral and ionized species in the plasma. For example, the temperature of the plume is found to increase due to Joule heating and adiabatic compression. In addition, imaging results have been obtained for alternative magnetic geometries, including axial and cusp-like fields.

Contributed by M. Tillack, UC San Die

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ORNL Extruder Cooled With Cryocooler and Successful D_2 Extrusions Achieved

Cryogenic extruders cooled with flowing liquid helium (LHe) are commonly used for long-pulse pellet injection applications. On experimental fusion devices in the laboratory or in the field, the cost and problems associated with LHe dewars and/or plant cryogenic systems can be appreciable, including up to thousands of dollars per day and often limiting pellet operations. Thus, a pellet system with a single cryocooler (or even multiple ones) is an attractive option because operating costs are very low after the initial procurement, and operations are simplified and independent of other systems.

While pipe guns with only a limited number of pellets (typically one to four) can easily be cooled by a cryocooler, long-pulse pellet injectors present a more challenging task for the relatively small cryogenic refrigerators. The apparatuses required for long-pulse pellet operation are, in general, larger and more massive with much greater heat loads.

In a development effort at Oak Ridge National Laboratory (ORNL), a standard extruder has been modified and mated with a GB-37 cryocooler (Cryomech, Inc.). This work was in collaboration with Prof. John Pfotenhauer at the University of Wisconsin. A schematic of the new hardware is shown in Fig. 1(*a*), and a photo of the experimental equipment (without the thermal insulation) is shown in Fig 1(*b*). In the tests performed to date, the copper shield shown in Fig. 1(*a*) has not been used. A cooldown curve is shown in Fig. 2, and it took ≈6 h for the apparatus and D_2 gas/solid charge to reach operating temperatures of ≈15 K. The bumps (or temperature rises/falls) at the end of the curves in Fig. 2 correspond to individual extrusion cycles. A photo of the initial 1-mm-diam D_2 ice extrusion is shown in Fig. 3(*a*), and a similar photo after a few minutes of continuous extrusion is shown in Fig. 3(*b*). Without an accelerator stage (pneumatic or centrifuge) to remove the extruded ice, it collects in the chamber, forming a "sinuous shape" like continuous winding ribbon. Three full batches (≈2 cm^3 each) of ice were extruded with each lasting a few minutes, and videocassette recordings were made of the extruded ice.

ORNL 2003-369C EFG

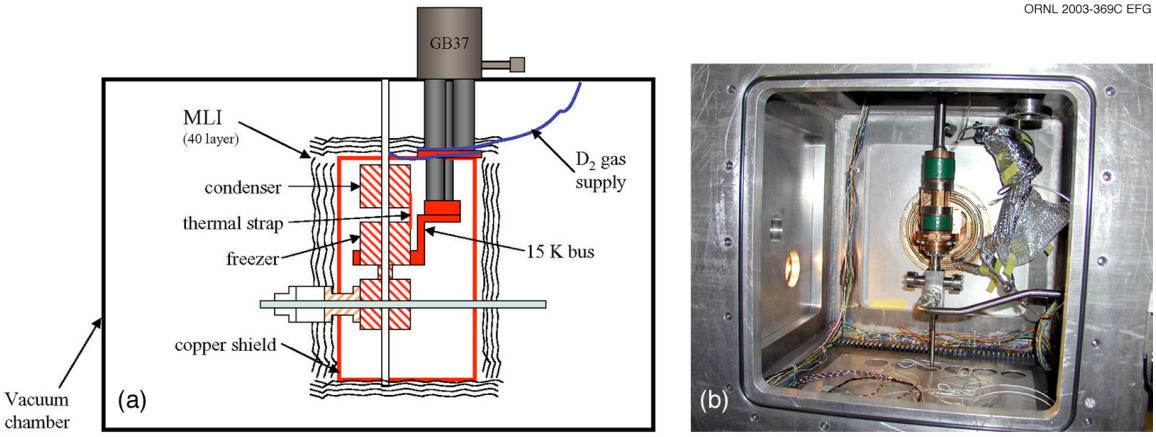

Fig. 1. Extruder with cryocooler: (*a*) schematic and (*b*) photo of cryostat.

During the next few years, one objective of the ORNL plasma fueling program is the development of a reliable centrifuge pellet injector as a prototype for ITER. The plan calls for the prototype to be installed and used in experiments on DIII-D, with the key goal of efficient high-field-side fueling with small pellets and high repetition rates. The apparatus described here should be adequate for feeding a centrifuge accelerator with 1-mm-diam pellets at frequencies approaching 50 Hz. In addition to the high fueling rate, the injector would reduce the propellant gas handling issues of the present pneumatic injection system used on DIII-D. The present ITER pellet injector design includes centrifuges operating at 50 Hz with 3-mm pellets and high-field-side pellet injection as the standard fueling mode. For high-field-side injection on either DIII-D or ITER, the pellet speeds will be limited to a few hundreds of meters per second to survive the transport through the curved guide tubes. The only key difference in the systems would be the longer pulse capability (>1000 s) of the ITER injector. The cryocooler technology should be applicable to the ITER pellet injector; however, this would probably require multiple cryocoolers. Such a system would simplify testing of ITER pellet injection components in the lab and minimize operational costs.

Contributed by S. Combs, ORNL

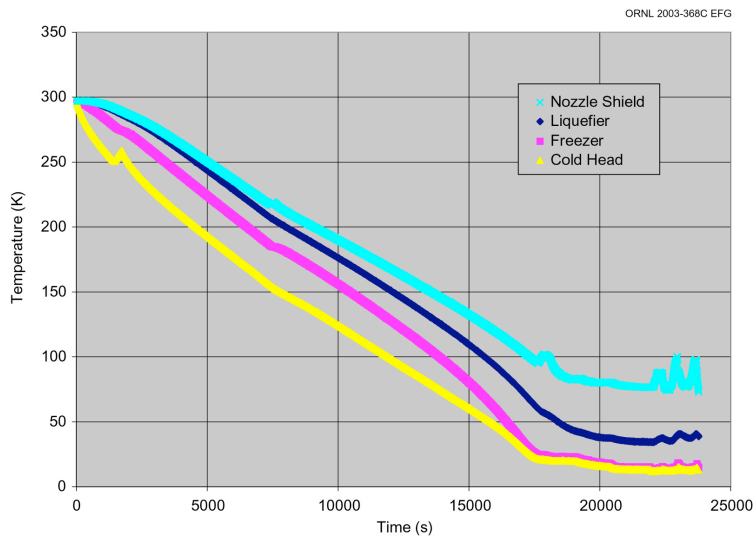

Fig. 2. Cooldown history of extruder components with cryocooler.

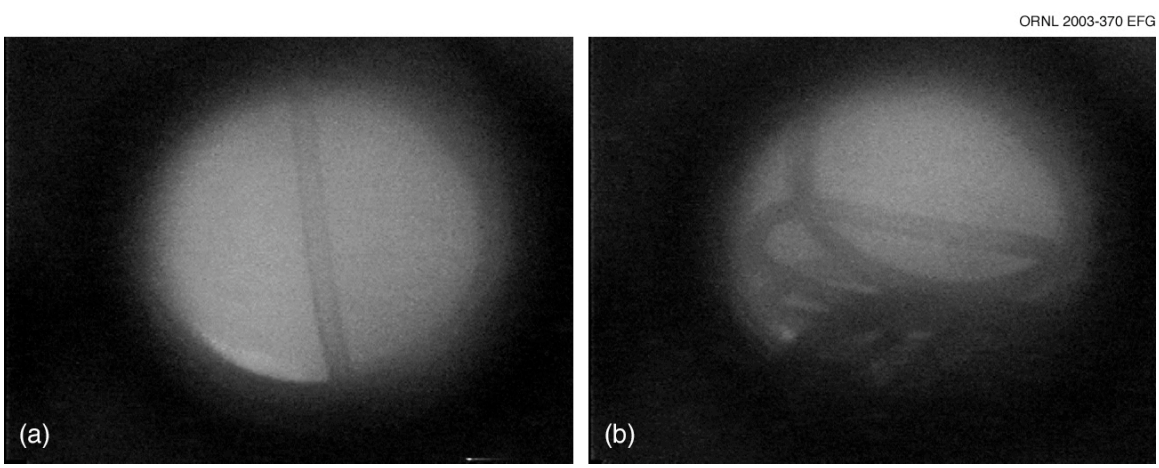

Fig. 3. Photos of D_2 ice: (*a*) initial extrusion and (*b*) few minutes into extrusi

Quantifying Probabilistic Safety Assessment

Since their inception in the 1970's and 1980's, probabilistic risk assessment (PRA) and probabilistic safety assessment (PSA) have demonstrated their advantages for nuclear fission plants. The DOE has also used PSA to good advantage. To capitalize on this success, DOE STD 6002-96 directs PSA and PRA approaches. As is often pointed out, fusion does not have a recognized component failure rate database to quantify these analyses. However, there is an ongoing International Atomic Energy Agency task to provide these data. Subtask 5, "Failure Rate Database," collects and analyzes data for fusion component failure rates. Subtask 5 participants have developed a computerized database that resides at ENEA-Frascati under Dr. Pinna's care. Task participants harvest applicable data from published sources, including particle accelerators, the fission and aerospace industries, and others. Recent work also includes data analysis from the JET Active Gas Handling and Vacuum Systems (T. Pinna et al., FUS-TN-SA-SE-R-058, Feb. 2003), and the DIII-D vacuum system (L. Cadwallader and P. Petersen, *Fus. Sci. Tech.*, **44** (2003) 382-387). Task participants are also beginning to validate individual values by comparing them to independent data sources. A few failure rate values can be compared to values published by the military. For other components, comparisons of one fusion data set, such as JET data, can be compared to another, such as DIII-D data. Tritium component failure rates are also compared from one facility to another. More work in both harvesting published data and tokamak data analysis is planned. Near term tasks include harvesting data on remote handling equipment. The next tokamak data analysis tasks include the JET neutral beams and power supplies, and DIII-D diagnostic devices. These data support public and personnel safety studies for next-step machines, such as ITER and FIRE, as well as NCSX and other designs.

Contributed by L. Cadwallader, INEEL

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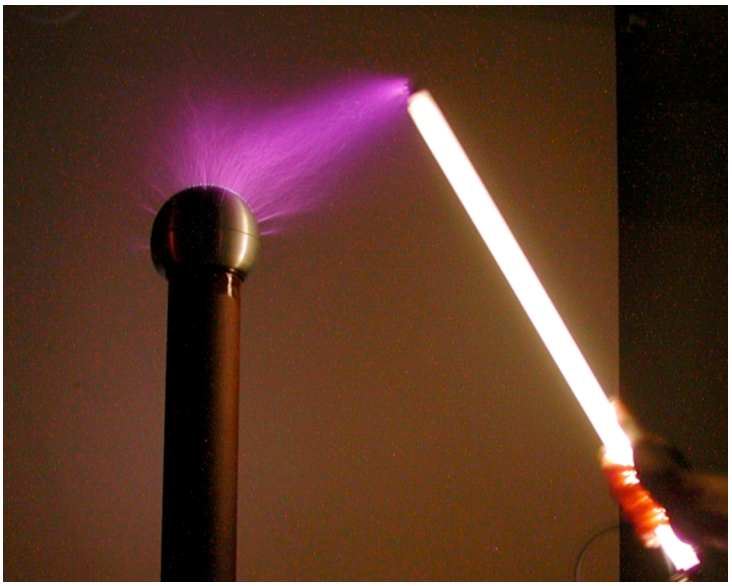
Albuquerque Teachers and Students Participate in APS Teachers' Day and Plasma Expo

The annual Teachers' Day and Plasma Expo for 2003 was held in Albuquerque, New Mexico in conjunction with the American Physical Society's Division of Plasma Physics annual meeting held October 27-31, 2003. Oak Ridge National Laboratory was the lead institution in the organization of this year's educational outreach event which is sponsored by APS and the U.S. Department of Energy. 76 teachers from Albuquerque and around the state participated in the Teachers' Day workshops and over 1,000 students and teachers attended the Plasma Expo.



May the Force Be With You—
Students experiment with Tesla coil and plasma filled light saber at Plasma Expo 2003.

Teachers Day presented a day of workshops for middle and high school teachers that presented various topics in plasma physics research. The teachers who attended had the opportunity to meet and talk with research physicists from research centers, laboratories, academia, and industry and participated in workshop presentations designed especially for middle and high school science teachers. A variety of resource materials such as plasma balls and video tapes about plasma physics were given to the teachers to be used in the classroom. Workshops presented by scientists from participating institutions included plasmas and fusion science, fluid instabilities, the electromagnetic spectrum, radioactivity, and the nature of matter.

The Plasma Expo is held as an adjunct to Teachers' Day and is also open to members attending the APS/DPP meeting and the general public. This exhibition focuses on hands-on science education and ttendees can participate in science activities and talk with scientists in the field of plasma physics.

The University of California, San Diego's fusion energy research program presented a variety of interactive demonstrations including experiments in fluid dynamics and the electromagnetic spectrum, a portable plasma experiment demonstrating the action of magnetic fields on confined plasma, and experiments using the electromagnetic spectrum.

P. Stewart, UCSD

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Enabling Technology Program Highlights for July 2002 - March 2003

The VLT News has been given permission from the Office of Fusion Energy Sciences to publish Enabling Technology program highlights that are delivered monthly to the Director of the Office of Science (SC-1).

These highlights from laboratories and institutions participating in the Enabling Technology Program report on accomplishments or events from the program that are significant enough for reporting to SC-1, focusing on long-term research that is relevant to improving the vision for fusion energy, and near term experiment support that improves performance and accomplishes tasks such as enabling new physics regimes. The impact on other OFES activities and international fusion R&D efforts is an important part of highlight reporting, as are the contributions of various laboratories and other facilities to multi-institutional efforts.

The highlights which follow have been sent to SC-1 from March 2003 to July 2003, with the most recent highlight noted first:

7/03: New Collaboration with Europe on Fusion Materials Irradiation Effects

The leading concepts for structural internals of fusion power systems are based on ferritic steels with compositions tailored to avoid elements that produce significant induced radioactivity from nuclear transmutations. In a fusion environment, ferritic steels will need to withstand energetic neutron bombardment for long times without substantial deterioration of mechanical properties. The principal effects of energetic neutron bombardment are damage to atomic lattices (i.e., displacement of atoms from normal positions) and production of gases that can adversely influence pathways of microstructural evolution. Of greatest concern is helium (He) because it can accumulate at grain boundaries, leading to embrittlement and increased risk of fracture. While it is possible with fission reactor irradiations to gain great insight into the effects of displacement damage in fusion environments, it has been difficult to study He effects because of the low He production rates in fission reactors due to the much softer neutron spectrum compared to fusion neutrons.

In a new collaboration with the European Union (EU), an experimental technique will be used to increase He production rates with isotopically-tailored ferritic steels in which Fe^{54} replaces naturally occurring Fe isotopes. The EU will, for the sum of about 500 $K, purchase 100 grams of Fe^{54} and fabricate specimens to be irradiated in ORNL's High Flux Irradiation Reactor (HFIR), while the US will design and fabricate the irradiation capsule and carry out the irradiation according to a mutually agreed upon experiment plan. This HFIR irradiation, which could begin by the end of 2004, will provide important data for validating and guiding the development of predictive models for irradiation response of ferritic steels in the simultaneous presence of atomic displacement damage and significant He accumulation, although the rate of He production relative to atomic displacement damage will be less than that which is expected to occur in a fusion environment.

7/03: DOE's Los Alamos Site Office (LASO) Approves Downgrade of the Los Alamos National Laboratory (LANL) Tritium Systems Test Assembly (TSTA) Facility to a Radiological Facility

On June 18, LASO approved a request from LANL to downgrade TSTA from a Hazard Category 2 Nuclear Facility to a Radiological Facility. This was the last major milestone of the TSTA Stabilization project before it can be transferred from the Office of Science (SC) to the Office of Environmental Management (EM). In the near future, SC and EM personnel will conduct a walk-through of TSTA to determine whether it is

ready to be transferred. To get to Radiological Facility status, LANL had to reduce the tritium inventory of the facility from over 140 grams to less than 1.6 grams.

This three-and-one-half-year activity, which included the removal of all bulk tritium, tritiated water, and over fifty tritium-contaminated high inventory components/systems from the test cell area, will be finished at the end of July within the budget and schedule identified by LANL in their Project Plan. This activity, which included recovering about half of the tritium inventory for reuse and disposing of over seventy containers of waste at a DOE disposal site, was also completed without serious injury or radiological exposure to any worker, and there were no unplanned radiological releases.

TSTA was built to develop and demonstrate the deuterium-tritium fuel cycle technology for next step fusion devices as well as conduct tritium testing of different fusion components and systems. In the world's fusion research programs, TSTA was unique since it was the only tritium facility which could conduct integrated testing of the fusion fuel cycle. TSTA successfully and safely demonstrated the capability of processing over 1 kilogram of tritium per day which is approximately one tenth the rate of the ITER Tritium Plant. In addition, over its operational lifetime TSTA handled over 2 billion curies of tritium in its systems with less than one curie per day average release. The database from its operation was critical to the design of the ITER Tritium Plant.

5/03: Liquid Surface Technology for Plasma Experiments

Recent experiments in the CDX-U (Current Drive Experiment-Upgrade), a small torus at the Princeton Plasma Physics Laboratory, have provided important data on the feasibility of liquid surface plasma-facing components. Such components are promising long term concepts for fusion power systems due to their capabilities for high surface heat and particle removal, as well as long lifetime, compared to solid surfaces. Opportunities have been identified for near term deployment of this liquid surface technology, particularly using flowing lithium, which is a strong absorber of hydrogen. Several issues associated with the use of this liquid surface technology were addressed in the CDX-U experiments, which were conducted in collaboration with scientists from the University of California, San Diego. A toroidal tray near the bottom of the CDX-U was filled with liquid lithium, exposing plasma discharges to a large surface area of the liquid. With improvements made recently to achieving a high degree of surface cleanliness, it was observed that substantial levels of particle removal were taking place and that plasma current and discharge duration were increased by 30% relative to discharges without the lithium.

Future experiments will quantify changes in the discharges produced during plasma operations with the liquid lithium tray. In parallel with these plasma-liquid interaction experiments in the CDX-U, good progress is being made in related research to address other issues of using flowing liquid lithium surfaces for machines like NSTX, such as the effects of magnetic fields on high-speed lithium jets and films.

5/03: Progress in Developing High Power Antenna for Plasma Heating with Radio Frequency Waves

Researchers at Oak Ridge National Laboratory (ORNL) and Princeton Plasma Physics Laboratory (PPPL), in collaboration with the European Fusion Development Association (EFDA), have begun testing a high power prototype (HPP) of an advanced antenna for heating burning plasmas to high temperature with radio frequency waves. The HPP antenna, which was designed and fabricated by this collaborative team, is a full-scale quarter section of an "ITER-like" design. Based on test results, a full scale antenna will be fabricated in collaboration with EFDA for installation on the Joint

European Torus in 2005. The HPP antenna, which will launch radio frequency waves at up to 9 megawatts per square meter, incorporates design features that would enable operation in rapidly changing plasma edge conditions. The current generation of antennas cannot function under such hostile conditions. The new antenna system will enable simplification of control and improvement in reliability of launching systems used in high performance fusion plasmas, including ITER. The HPP antenna will provide a test bed to evaluate critical elements of the advanced antennas, including current and voltage limits and verification of load tolerant impedance matching network characteristics.

Testing will be conducted by ORNL on their Radio Frequency Test Facility in collaboration with PPPL and EFDA staff. The HPP antenna will be tested from 30 to 55 megahertz, the frequency range relevant to ITER, at sufficiently high power to determine voltage limits. These tests will allow researchers to study the physics and technology of ion cyclotron resonance heating in high performance plasmas with parameters close to those expected in a fusion power systems.

3/03: US-EU Collaboration to Investigate Tritium Retention in ITER Plasma-Facing Materials

The accumulation of tritium in plasma confinement devices can negatively impact many aspects of burning plasma experiments, from limiting operating time to tritium inventory issues that can affect licensability. A major influence on tritium accumulation is retention by codeposition of tritium with materials that have been eroded from plasma-facing surfaces. There are now large uncertainties in the prediction of codeposition rates due to the limited understanding of how mixtures of eroded plasma-facing materials react to plasma bombardment and how that reaction influences the codeposition of hydrogen isotopes with eroded mixed materials. To increase this understanding for ITER conditions, the US is collaborating with the EU to investigate mixed-material erosion and codeposition with plasma-facing materials to be used in ITER (i.e., carbon, beryllium, and tungsten). Experiments are being conducted in an edge plasma simulation facility, called PISCES-B, located at the University of California, San Diego. Earlier research with PISCES-B, which is unique in its ability to operate with beryllium materials, has provided important data on plasma erosion of beryllium and carbon materials and has identified the conditions for formation of carbonaceous films on beryllium surfaces.

Since hydrogen isotope retention in beryllium/carbon mixed material layers and carbonaceous redeposited films can significantly increase tritium accumulation, the ability to mitigate these retention processes will be very important for ITER. In the first phase of collaborative experiments, studies are being conducted on beryllium-seeded deuterium plasma interaction with graphite and tungsten surfaces to guide development of computational tools for predicting erosion and redeposition processes.

The most recent PISCES-B experiments, carbonaceous deposits were reduced when beryllium impurities suppressed chemical erosion of graphite plates which could significantly reduce film formation and tritium retention. This and the understanding gained from future experiments can potentially be used to identify means for mitigating formation of carbonaceous deposits to a degree that tritium retention and accumulation will not be a major interference with ITER operations or licensing.

For more information on the Office of Fusion Energy Sciences Program, visit their website at:
http://www.ofes.science.doe.gov/

For more information on the Enabling Technology Program participating institutions, visit the VLT website at:
http://vlt.ucsd.edu

VLT Calendar of Events

DATE	MEETING	LOCATION	CONTACT
17-18 Nov 2003	FESAC Meeting	Quality Suites Rockville, MD	albert.opdenaker@science.doe.gov
17-20 Nov 2003	PFC/ALPS Semi-Annual Meeting	Hyatt Regency Oakbrook, Illinois	rosa@anl.gov
19-21 Nov 2003	FPA Annual Meeting	Capitol Hill Club, Washington, DC	Fpa@compuserve.com or http://fusionpower.org
7-12 Dec 2003	ICFRM-11	Kyoto Int'l Conference Hall, Kyoto, Japan	http//icfrm.iae.kyoto-u.ac.jp
15-17 Dec 2003	ITER Divertor Meeting	JAERI, Naka, Japan	tiveyr@itereu.de
29-30 March 2004	FESAC Meeting	Marriott Gaithersburg Gaithersburg, MD	albert.opdenaker@science.doe.gov
12-17 Sept 2004	7th Int'l Tritium Conf.	Baden-Baden, Germany	
14-16 Sept 2004	Topical Meeting on Tech of Fusion Energy	Monona Terrace Madison, WI	http://fti.neep.wisc.edu/tofe or http://fed.ans.org
20-24 Sept 2004	23rd SOFT	Venice, Italy	http://soft2004.igi.cnr.it
22-27 May 2005	ISFNT-7	Tokyo, Japan	sekim@fusion.naka.gaeri.go.jp or http://isfnt.naka.jaeri.go.jp/default.htm