INFORMATION BULLETIN

U.S. DEPARTMENT OF ENERGY'S
PRINCETON PLASMA PHYSICS LABORATORY
JAMES FORRESTAL CAMPUS, P.O. BOX 451
PRINCETON, NEW JERSEY 08543

LTX

Assembly of LTX Underway

PPPL's Current Drive Experiment-Upgrade (CDX-U) machine completed its last phase of experiments in July 2005. It is now being converted to a new device, the Lithium Tokamak Experiment (LTX), which will begin operation in early 2007. The LTX will continue promising, innovative work started on CDX-U in 2000, involving the use of pure lithium metal on surfaces facing or contacting the plasma. PPPL researchers believe that LTX may herald a new regime of plasma performance with improved stability, lower impurity levels, better particle and temperature control, and more efficient operation.

Members of the LTX team (standing from left) Tom Kozub, John Timberlake, Jeff Spaleta, Tim Gray, Vlad Soukhanovskii, and Craig Priniski; (seated from left) are Dick Majeski and Bob Kaita.

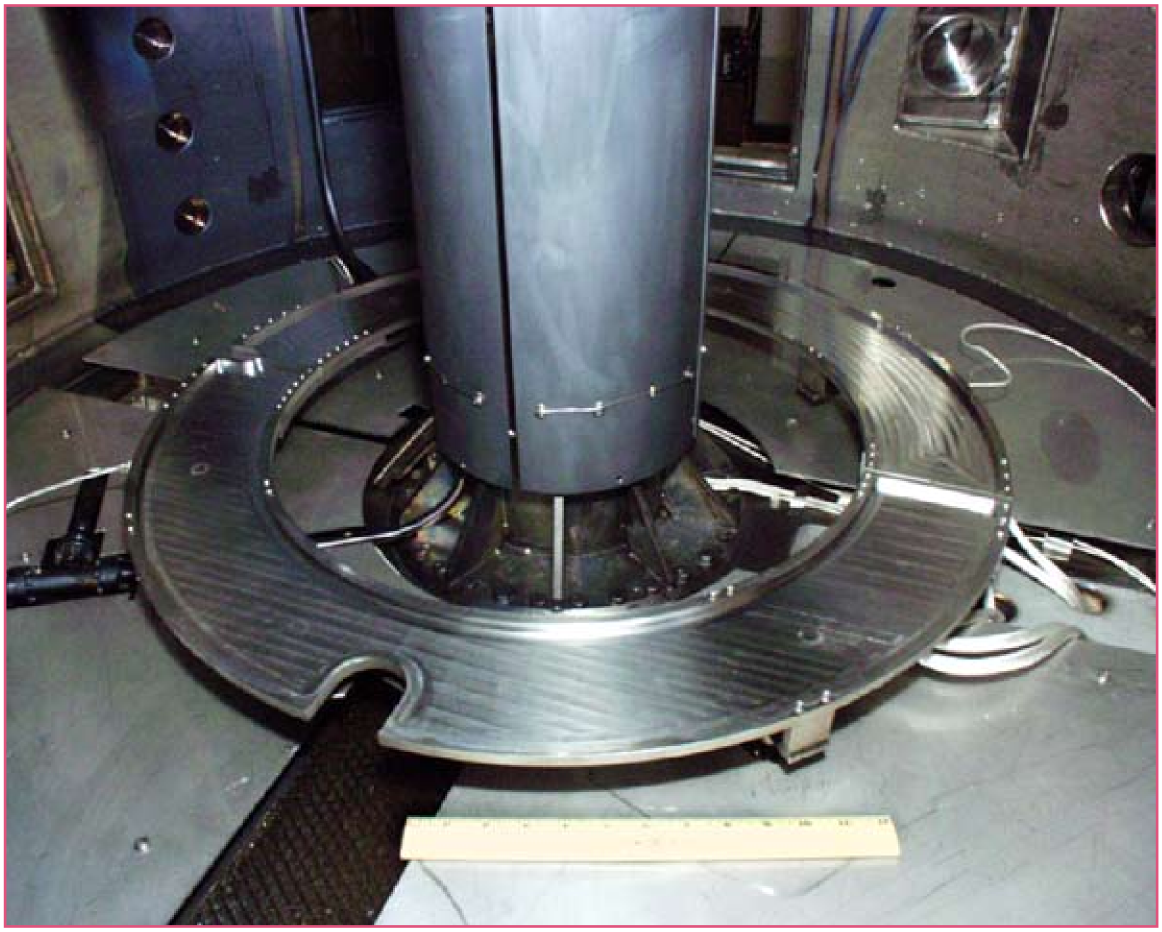
"Even in a small machine like LTX, we expect a dramatic change in plasma parameters, and that's what we're quite excited about," said Bob Kaita, one of LTX's co-investigators. This improved performance may be possible by enclosing the plasma in a heated, conductive shell coated with molten lithium on the inside, and shaped to conform to the boundary of the plasma.

Changes Now Underway

"In LTX the biggest, most obvious change to the casual observer is the introduction of a shell consisting of a one-centimeter layer of copper with a 1.5-millimeter layer of stainless steel explosively bonded to its inner surface," notes Dick Majeski, an LTX co-investigator. The LTX shell consists of 28 segments that are welded together, with inner and outer support rings added. When assembled inside the CDX-U vacuum vessel, which will be reused for LTX, the shell will have vertical and horizontal gaps to limit the currents induced in the shell. New diagnostics and a new ohmic heating (OH) power supply are the only other substantial changes planned for the first year of LTX operation. More extensive upgrades will occur in later years.

Improved Performance

The new OH power supply will enable LTX researchers to program the rise and fall of OH coil cur-



Interior of the CDX-U with the toroidal tray installed.

rent. The change in the magnetic field caused by this current swing drives the plasma current. "Controlling the OH current is of paramount importance for LTX. With a lithium-coated shell, the LTX plasma will be much more efficient in using the power from the OH coils to drive the plasma current," noted Majeski. The loop voltage is the amount of voltage it takes to generate the LTX goal of 100 kA of plasma current. Far lower loop voltages will be needed to maintain the plasma current with the lithium shell. This prediction is based on results obtained in lithium experiments on CDX-U during the last three years.

The LTX researchers couple this experimental evidence with a solid theoretical explanation. "We expect the plasma temperature to be higher with lithium, but more significantly, we expect a 'fatter' current channel in the plasma. Without lithium, the current is highest in the middle of the plasma and falls off rapidly as you go toward the edge. With lithium, the current is expected to remain fairly constant across the plasma. For a given loop voltage, more current can flow through the fatter channel than through the usual skinny one," said Majeski.

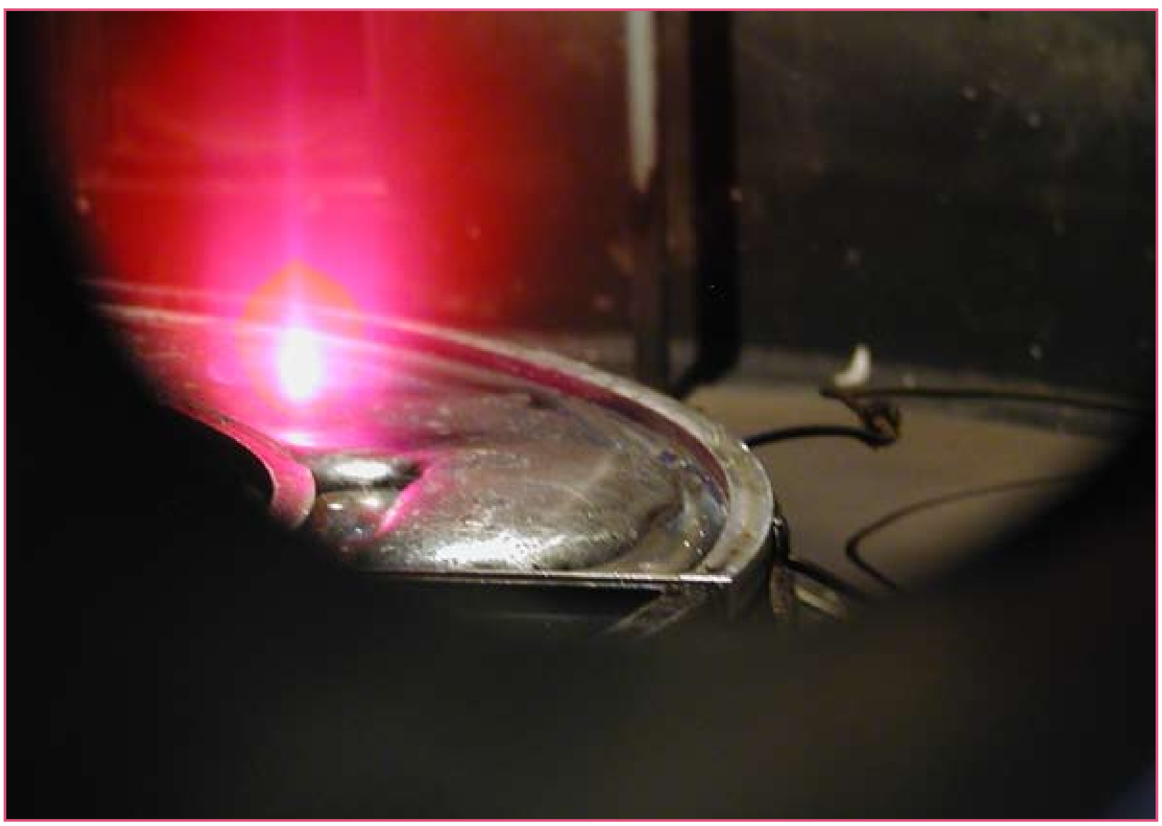
But why does lithium have such a big effect on the plasma? Majeski explains, "When the plasma hits the solid wall of a conventional tokamak, some of its particles are neutralized. These cool particles reenter the plasma where they are re-ionized. This "recycling" cools the plasma edge. With a lithium boundary, we expect the plasma to hit the shell and stay there, so there will be no recycling. The lithium will soak up the particles at the plasma edge, because lithium loves hydrogen." In fact, during CDX-U experiments, PPPL researchers produced a 30 percent recycling coefficient, the lowest of any magnetically confined plasma. This means that only 30 percent of the particles escaping the plasma reentered it. TFTR's lowest recycling coefficient was 70 percent. Without edge cooling, researchers expect uniformity in the plasma temperature and therefore a fatter current profile. In a fusion reactor, this would mean that the whole plasma could participate in the reaction, not just its hot core. An important added bonus is the fact that lithium absorbs impurity elements such as carbon and oxygen that can enter the plasma from the wall and cool it.

The decrease in the plasma temperature between its core and its edge — the temperature gradient experienced in conventional tokamaks — causes instabilities detrimental to performance. The loss of plasma confinement from these instabilities should disappear in LTX. Furthermore, without recycling, researchers will have external control over where particles enter the plasma. For example, they can choose the size and velocity of pellets of frozen hydrogen or deuterium injected into the plasma. This will determine how far the pellets can go before they vaporize, and enable physicists to study particle transport to a far greater extent in LTX than ever before possible.

Applying Lithium

To prepare for LTX experiments, physicists developed different ways to coat the inside walls of CDX-U with lithium. They utilized a toroidal tray of liquid lithium situated at the bottom of the plasma. The most obvious technique was to simply heat the tray above the 400 degrees Celsius required for lithium evaporation. To effect this, they tried heating the lithium with an electron beam. It provided roughly a kilowatt and a half of power on a spot about six millimeters across — amounting to a power density of 50 megawatts per square meter. The duration of this intense electron-beam was 240 seconds, comparable to the plasma lifetime in ITER. According to Kaita, "The heat loads delivered were more that those expected at the plasma contact region in ITER. We thought this enormous, localized power would quickly heat the lithium immediately under the beam and evaporate it. Surprisingly we observed evaporation only after all of the lithium in the tray was liquefied and its entire volume exceeded the evaporation temperature. We took motion pictures with visible and infrared cameras that showed all of the lithium swirling rapidly. Evidently the intense heat of the electron-beam was quickly distributed much the same way stirring makes all the soup in a pot reach the same temperature. This 'self-stirring' is thought to be driven by either thermal or electromagnetic forces, but the cause is still under investigation."

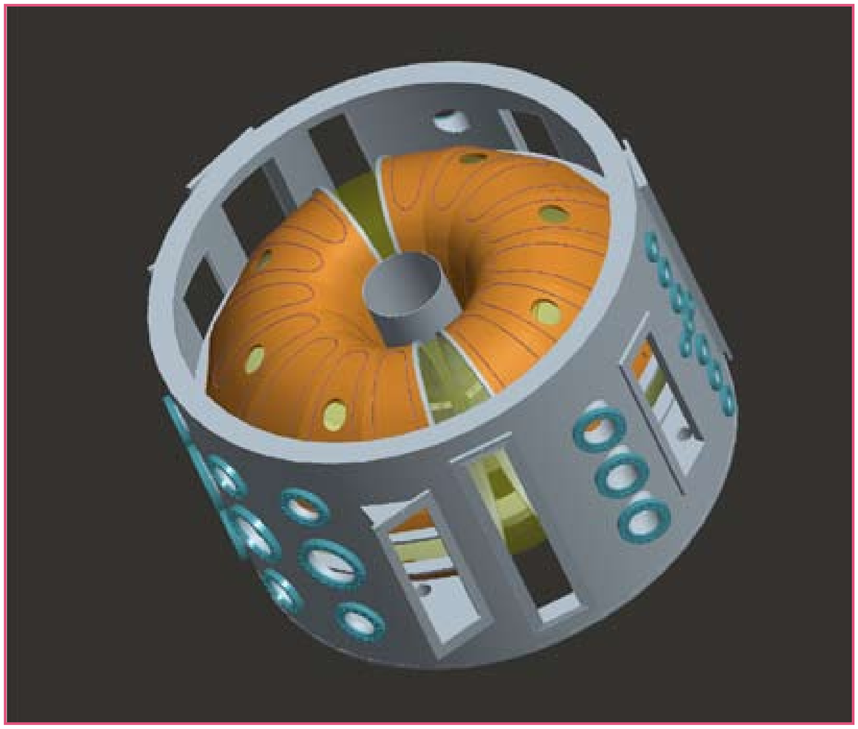
Another technique for coating lithium is one developed by PPPL's Dennis Mansfield. It consists of a can of lithium that is heated resistively and sprays lithium around the machine. This method



Photograph of the electron-beam striking the lithium in the toroidal tray in CDX-U.

was successfully tested in CDX-U. Researchers plan to compare the electron-beam and the resistively heated can in LTX. The electron-beam will enter from the top of the shell and focus on a small lithium spot at the bottom of the shell. Eventually there could be as many as four electron-beams in LTX. The resistively-heated can could be deployed at two locations through opposite ports on the mid-plane of the device.

The molten lithium coating on the LTX shell will only be a few ten-thousandths of a millimeter thick, light enough to be held in place by its own surface tension. The LTX team will have the option of recoating the shell after each shot, or after several shots. Good results have been observed in CDX-U with the deposition of 100 or 200 Angstroms (1 A = 10^{-7} mm) of lithium between every shot. The thickness was measured by a quartz crystal deposition monitor — a little crystal oscillator that changes its frequency depending on the weight it supports.



Computer-generated drawing of LTX shell inside former CDX-U vacuum vessel.

Future Experiments

After the initial year of operation, LTX will cease experiments to allow various upgrades. As noted above, LTX will afford greater control over how and where particles enter the plasma, so improved studies of particle transport will be possible. For this reason, a pellet injector will be added to LTX for the second phase of experiments, planned to begin in 2008. The injector will permit particles to be deposited at specific locations, for example at the core of the plasma, so that their movement can be observed. The injector will also be used to fuel the plasma with the same kind of particle deposition control. Researchers also plan to install a new pair of poloidal field coils. The existing set is not sufficient to hold the plasma equilibrium with the higher plasma currents expected during the second phase.

In addition, LTX will be fitted with a new shell whose inner surface has been sprayed with a thin coating of porous molybdenum prior to the 2008 run. Physicists believe that molybdenum will act like a sponge, soaking up the lithium and allowing greater amounts to be held on the shell surface.

The LTX Team

In addition to Bob Kaita and Dick Majeski, LTX Co-investigators include PPPL's Leonid Zakharov and Sergei Krasheninnikov of the University of California, San Diego (UCSD). Oak Ridge National Laboratory's Larry Baylor, Rajesh Maingi, and M. Gouge are developing the LTX pellet injector.

Other staff, from PPPL, UCSD, Lawrence Livermore National Laboratory, Johns Hopkins University, Sandia National Laboratory, and the University of Illinois at Champaign-Urbana, are also participating.

The PRINCETON PLASMA PHYSICS LABORATORY is operated by Princeton University under contract to the United States Department of Energy. For additional information, please contact: Information Services, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08543. Tel. (609)-243-2750, e-mail: pppl_info@pppl.gov, or visit our web site at: www.pppl.gov .