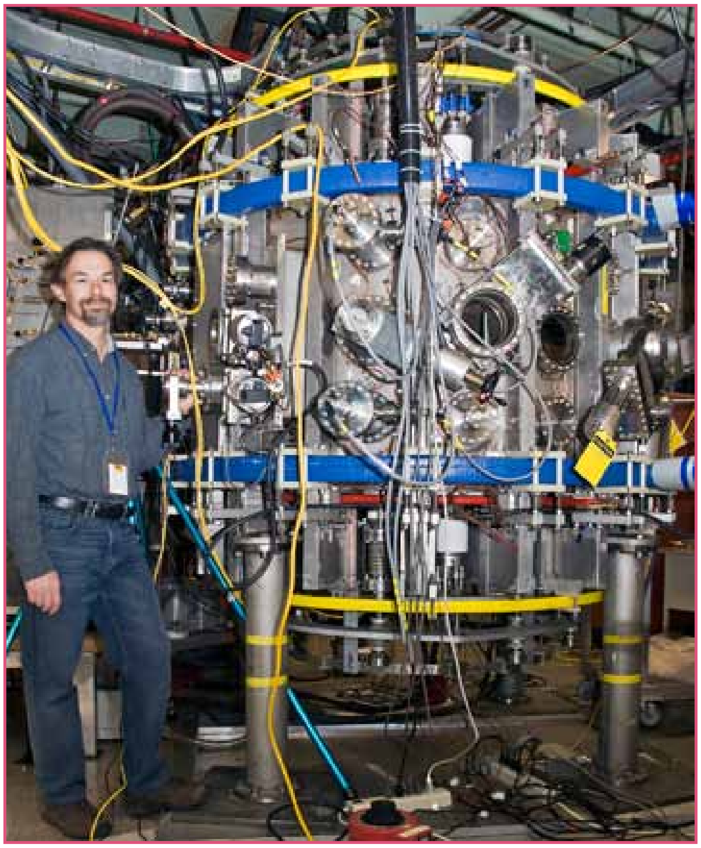
INFORMATION BULLETIN

PPPL
PRINCETON PLASMA
PHYSICS LABORATORY

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

LTX

LTX Experiment Achieves First Plasma



Dick Majeski at the Lithium Tokamak Experiment.

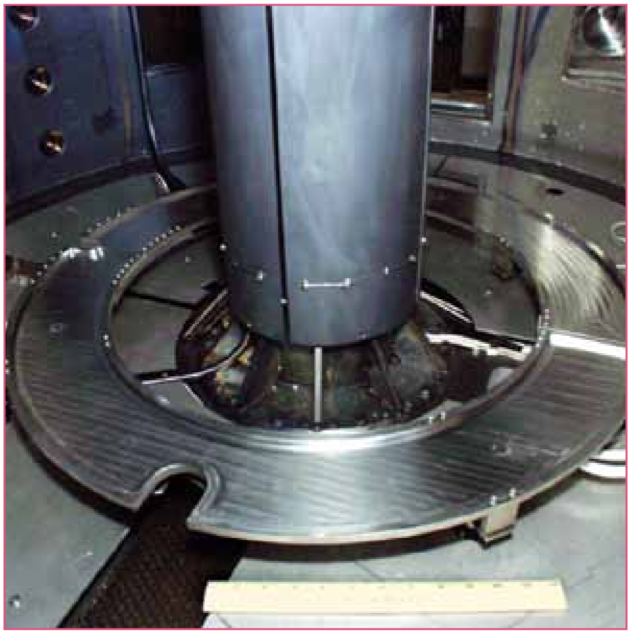
The Lithium Tokamak Experiment (LTX) produced its first plasma in September, 2008. The new device will continue the promising, innovative work started on CDX-U in 2000, involving the use of pure lithium metal on surfaces facing or contacting the plasma. PPPL researchers believe that LTX may herald a new regime of plasma performance with improved stability, lower impurity levels, better particle and temperature control, and more efficient operation. "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 because the LTX plasma is enclosed in a heated, conductive shell coated with molten lithium on the inside, and shaped to conform to the boundary of the plasma.

In CDX-U, there was a circular, lithium-filled tray on the bottom of the vacuum vessel. This enabled tokamak plasmas, for the first time, to be operated in the presence of a large-area liquid-lithium plasma-facing component (PFC), and a substantial improvement in the energy confinement was observed. The CDX-U experiments were concluded in 2005, and the construction of LTX began.

Engineering Challenges Met

In LTX, the evaporation of a thin layer of lithium on the inner shell surface creates a "wall" of lithium, which will be kept liquid by heaters in the shell. Significant technical problems had to be solved to squeeze the four heated shell sections, two new internal magnetic field coils, and about 120 magnetic sensors, together with their mounts and cables, into the old CDX-U vacuum vessel. Leonid Zakharov, another of LTX's co-investigators, specified the requirements for the internal magnetic field coils and the magnetic sensors. They are needed to control the plasma position and determine its "equilibrium" configuration. Zakharov was also instrumental in developing the theory that predicts the advantages of lithium walls. "Drawing on the experience and exceptional skills of the LTX team and PPPL shop staff, we were able to surmount many challenges by using creative synergy at a cost significantly below the approved budget," noted Tom Kozub, who led the engineering effort.

The fabrication of the shell segments and their mounting hardware, the vacuum vessel modifications, and the manufacture of new magnetic field coils took more than two years. An external vendor supplied only two pairs of new magnetic field coils.



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

All other components, including the shell segments and the remaining new magnetic field coils, were fabricated at PPPL. This reduced costs, allowed for a much better integration of the subsystems, and a faster manufacturing schedule. "We had a small, but dedicated, team of engineers, technicians, and students who put in long hours to make the successful assembly of LTX possible," says Kaita.

Preparations for Lithium Experiments Now Underway

With the achievement of first plasma, a main focus is now the implementation of the first phase of a new, computer controlled ohmic-heating (OH) power supply. When complete, plasma currents up to 400 kA will be possible, with as much as a 100-millisecond "flattop." A multipoint Thomson scattering system for measuring electron temperature profiles, a key diagnostic, will become operational in the near future. Other diagnostics that are being mounted on LTX include a tangential bolometer array for measuring the power radiated from the plasma, and arrays of ultraviolet and X-ray detectors. A microwave interferometer will also be installed for line-averaged density measurements. Graduate students are responsible for several of these systems.

The next few months will be devoted to the preparation of these diagnostics and the new OH power supply. LTX will be ready for liquid lithium wall experiments next spring.

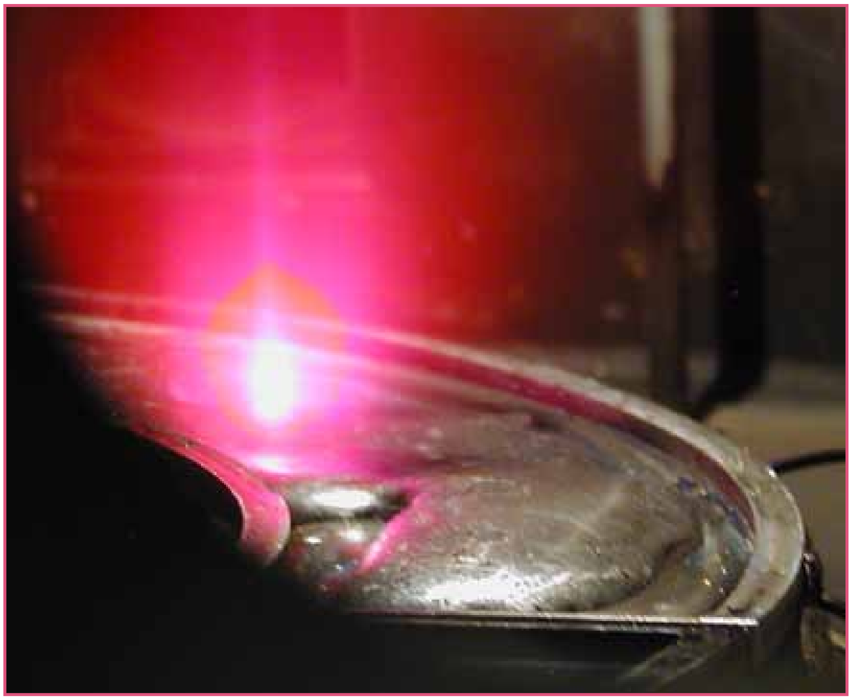
Improved Performance Anticipated

The new OH power supply will enable LTX researchers to program the rise, "flattop," and fall of the plasma current, which is controlled through the loop voltage induced by the OH system. "Fine control over the loop voltage 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 Dick Majeski, also an LTX co-investigator. The loop voltage is the amount of voltage it takes to generate the LTX goal of up to 400 kA of plasma current. The CDX-U experiments demonstrated that, with a lithium wall, only a very small loop voltage is needed to drive a large plasma current — plasma current production is much more efficient.

The LTX researchers couple the CDX-U 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. The fatter channel has less electrical resistance," 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 ~50% percent recycling coefficient, the lowest of any magnetically confined plasma. This means that with just the toroidal lithium tray in CDX-U, only about half of the particles escaping the plasma re-entered it. With the greater wall area the lithium shell provides, LTX is expected to do a lot better. In contrast, the lowest recycling coefficient for the Tokamak Fusion Test Reactor (TFTR) was 85%. Without edge cooling, researchers expect uniformity in the plasma temperature. 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 caused by these instabilities should not be a problem in LTX. Furthermore, without recycling, researchers will have external control over how particles fuel the plasma. With recycling, most of the fueling occurs at the plasma edge, and cannot be controlled. With no recycling, the fueling will be due entirely to the injection of gas, or frozen hydrogen pellets, or neutral beams of high-energy hydrogen atoms, and will be under the control of the researchers.



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

Applying Lithium

To prepare for LTX experiments, physicists developed ways to introduce lithium into CDX-U. They utilized a toroidal tray of liquid lithium situated at the bottom of the plasma. The tray was fitted with electrical heaters to melt the lithium, and the plasma edge was brought into contact with the lithium in the tray. The temperature of the tray was high enough (up to 400 degrees Celsius) to cause some of the liquid lithium to evaporate and coat the rest of the inner surfaces in CDX-U. Another approach was to heat 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 300 seconds, comparable to the plasma lifetime in ITER. According to Kaita, “The heat loads delivered were more that twice 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 or oven containing lithium that is heated resistively, and has an aperture that allows lithium to be sprayed around the machine. This method was also successfully tested in CDX-U. LTX includes provisions for testing all of these application techniques, but for the near term will employ a few millimeter deep reservoir of liquid lithium in the bottom of the hot shell. Plasma will contact this pool of liquid lithium, and evaporation from the pool will also coat the remainder of the inside surface of the shell – much as in CDX-U. Unlike CDX-U, however, the interior wall of LTX - the shell - will be heated to keep the lithium coating molten.

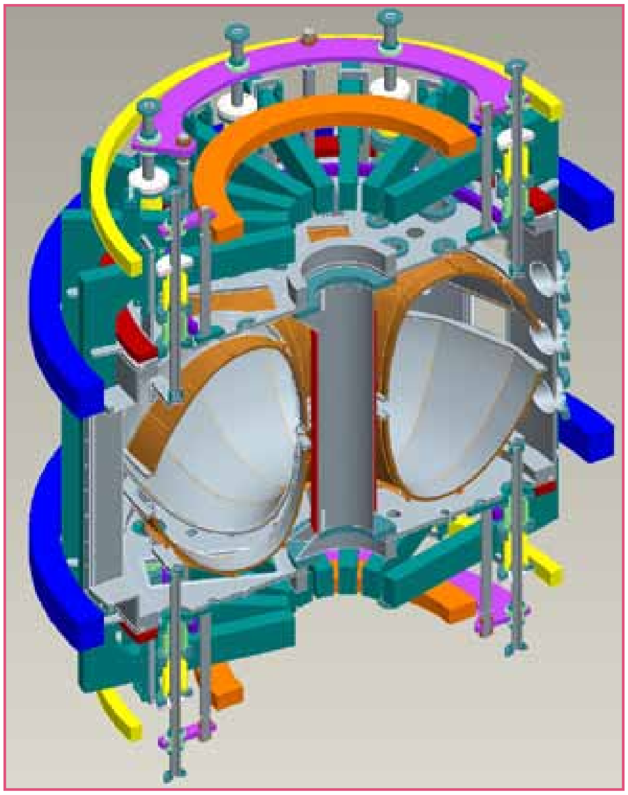
The molten lithium coating on most of the LTX shell will only be a few ten-thousandths of a millimeter thick, thin enough to be held in place by its own surface tension. The coating will be continuously renewed by evaporation from the reservoir. Good results were observed in CDX-U with the deposition 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. Independent control of the heating systems on the upper and lower shell halves of LTX means that the thickness of the coating can be easily controlled. If there's too much lithium on the upper shell half, the temperature can be increased until lithium is evaporated from the upper to the lower shell half. If there's too little lithium, the temperature of the lower shell half can be increased to more thickly coat the upper shell half

Future Experiments

After the initial year of operation, LTX will cease experiments to allow various upgrades. In 2010, LTX will be fitted with a new shell whose inner surface has been sprayed with a thin coating of porous molybdenum. Physicists have shown that molybdenum will act like a sponge, soaking up the lithium and allowing greater amounts to be held on the shell surface.

A neutral beam injector (NBI) will be added to LTX for the next phase of experiments, planned to begin in 2011. The NBI is the same apparatus used in large fusion experiments to send a stream of energetic particles into plasmas to heat them. In LTX, the particles from the NBI will be able to penetrate and fuel the core of the discharge. This process is expected to create a plasma which, if surrounded by a liquid wall, will be hot from the center to the edge. Such a situation is very desirable for a fusion reactor, and this prediction can be tested on LTX.

Graduate student Laura Berzak prepares to install magnetic pickup coils on the plasma-facing surface of the internal shell.



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

The LTX Team

In addition to Bob Kaita, Dick Majeski, Leonid Zakharov, and other staff from PPPL, investigators from Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, University of California - San Diego, and Johns Hopkins University are also participating. There are also several graduate students in the Program in Plasma Physics in Princeton's Department of Astrophysical Sciences who are doing research on LTX.

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