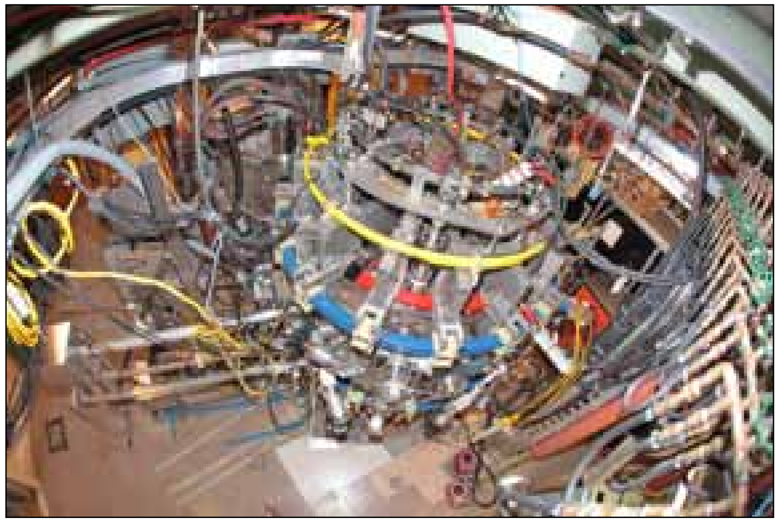
PRINCETON PLASMA PHYSICS LABORATORY
fact sheet

The Lithium Tokamak Experiment (LTX)



Bird's eye view of the Lithium Tokamak Experiment (LTX).

Nearly everybody knows about lithium – a light, silvery alkali metal – used in rechargeable batteries powering everything from laptops to hybrid cars.

What may not be so well known is the fact that researchers hoping to harness the energy released in fusion reactions also have used lithium to coat the walls of donut-shaped tokamak reactors. Lithium, it turns out, may help the plasmas fueling fusion reactions to retain heat for longer periods of time. This could improve the chances of producing useful energy from fusion.

Now, scientists are taking that idea a step forward. Perhaps liquid lithium could serve as a "wall" surrounding the magnetic fields and charged gases within them in fusion reactors.

The Lithium Tokamak Experiment (LTX) at the U.S. Department of Energy's Princeton Plasma Physics Laboratory is designed to be the first device in the world with a full, liquid lithium wall. As a first move toward this goal, LTX began operations with lithium wall coatings in 2010.

This follows up on promising work that took place on a previous device, CDX-U, which operated at PPPL from 2000 to 2005. CDX-U provided a first test of tokamak operation with liquid lithium pools contacting the plasma. The new machine may provide a far more hospitable environment for plasma, producing a hotter, better confined plasma, despite the modest size of the device.

"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 Robert Kaita, one of the machine's co-investigators. This improved performance may be possible because the LTX device is fitted with a liner which is designed to be fully coated with lithium on the inside, facing the plasma. The liner can be heated to melt the lithium coating, so that the entire wall facing the plasma will consist of molten liquid lithium.

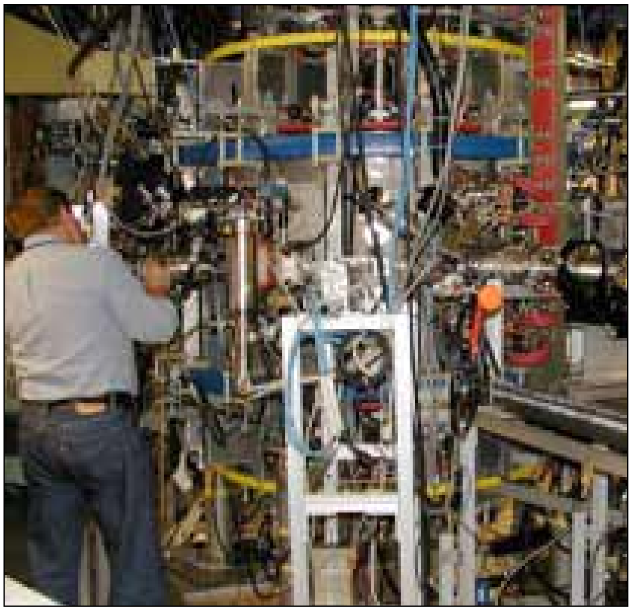
The eventual goal of the project is to develop an approach to a tokamak-based fusion reactor that is far smaller than devices being designed today. "We can imagine a reactor which would produce fusion power comparable to the ITER (an international project to design and build an experimental fusion reactor), but which would fit into a two-car garage (perhaps with a loft)," said Richard Majeski, the principal investigator for LTX.

In CDX-U, the bottom of its vacuum vessel contained a circular, lithium-filled tray. This allowed a tokamak plasma, for the first time, to be contained by what is known as a "large-area liquid-lithium plasma-facing component" or PFC. During a series of experiments in 2005, researchers recorded that the energy confinement time of the reactor (an important measure of performance) increased by a factor of six, representing the largest improvement in energy confinement for a tokamak plasma heated by internal currents ever observed. The success spurred the construction of LTX.

Engineering Challenges Met

LTX is designed to operate with a pool of liquid lithium, similar to the lithium-filled tray used in CDX-U. In the new machine, lithium evaporates onto the inner liner surface, making a full "wall" of liquid lithium. The temperature is maintained just above the melting point by heaters. Lithium is so light -- it is the only metal that floats on water -- simple surface tension is enough to pin down a film of molten metal film on the liner wall.

Since the liner operates at high temperature (300 – 400 °C, or up to 750 °F), and everything inside the tokamak is exposed to lithium, it was necessary to use only materials which are both heat- and lithium-resistant in LTX. Signifi-



October 2010 photograph of LTX, at the time of the first lithium experiments, with Tom Kozub hard at work.

cant technical problems also had to be solved to squeeze the four heated liner sections (weighing a total of 1,000 pounds), two new internal magnetic field coils, and about 120 small magnetic sensors, together with their mounts and cables, into the compact vacuum vessel. “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,” said Thomas Kozub, another of the co-investigators for LTX, who led the engineering effort.

It took more than two years to make the liner segments, their mounting hardware, new magnetic field coils, and to modify the vacuum vessel and assemble of the device. PPPL staff made most of the machine components. This reduced costs, improving integration of the device’s subsystems and speeding up the manufacturing cycle. “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,” Kaita said.

First Lithium Experiments Successfully Completed

In October 2010, technicians coated the LTX liner with lithium for the first time. During the process, the vessel interior glowed red from energized lithium atoms. Immediately after, researchers collected positive results. “We haven’t yet matched the performance of the best of the CDX-U discharges,” Majeski said. “But we’re approaching that point. So far only thin coatings of lithium have been applied, but this summer we will be putting in enough lithium to form a pool in the bottom of the liner.”

The 2010 experiments employed a cold, unheated liner, resulting in a solid lithium coating, rather than one of molten metal. Still, the use of solid lithium coatings increased the magnitude of the plasma current in LTX by as much as four or five times, and increased the duration of the plasma on a similar scale. The experimenters employed a diagnostic technique known as Thomson scattering using a high-powered, ruby laser, to measure the temperature of the plasma.

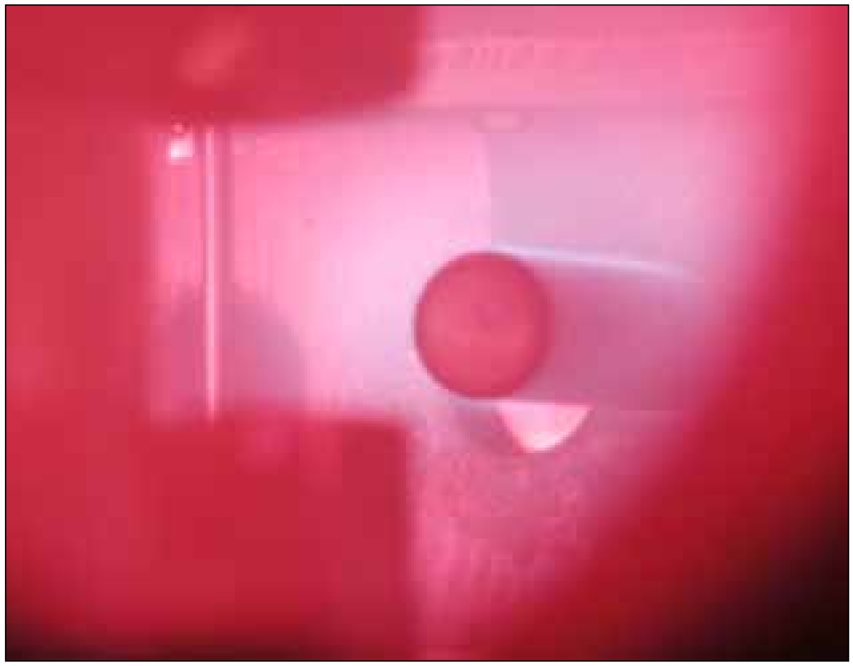
Preparations for the Second Phase of Lithium Experiments Now Underway

With the introduction of lithium coatings, a main focus now is the improvement of vacuum conditions and the elimination of residual water from the vacuum chamber. “Water is a principal enemy of lithium,” Majeski said. “Our first test of coatings on a hot (300 °C) liner indicates that the liquid lithium reacts too quickly with small amounts of water remaining in the vacuum vessel to be useful during plasma operations.” Once lithium has reacted with water, and formed chemical compounds like lithium hydroxide, it becomes inactive. Instead of improving plasma performance, it can act as a source of impurities and make the plasma worse. So additional systems to remove water from the vacuum system walls by baking the chamber at elevated temperatures are being added. This is in addition to the heaters for the liner. Once water is liberated from the inside of the vessel by baking, it will be pumped by a newly developed set of pumps, designed to remove water using liquid lithium absorbers.

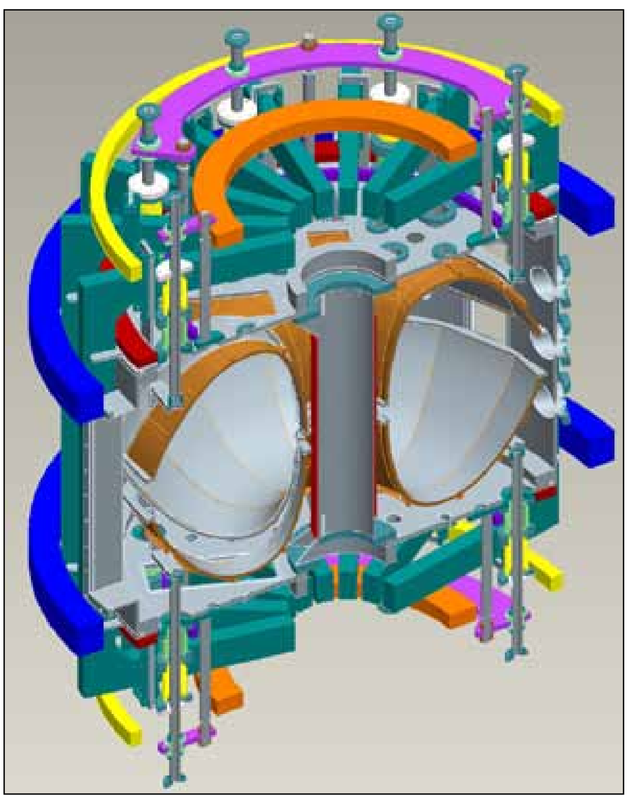
Lab staff are upgrading the machine’s power supplies, which generates a large current in the plasma to heat it and keep it confined in the resulting magnetic field, a task that should be completed by September. When the power supply is finished, it will permit operation at plasma currents of up to 200 – 300 kA (up from the present value of 70 kA), lasting for up to 100 msec (up from the present 20 msec). The Thomson scattering system, which can measure both the electron temperature and the density in the LTX plasma, was brought into operation in December 2010 by a graduate student, Craig Jacobson, and will be an essential diagnostic for upcoming experiments. Other diagnostics already in place include two microwave interferometers, many detection systems for visible and ultraviolet light (which give information about impurities in the plasma), and an electric probe, which is used to diagnose conditions in the plasma edge. A new diagnostic in LTX uses an infrared laser to take holographic images of fluctuations in the plasma density. This diagnostic, which produces a “3D movie” of plasma motion, was developed by a small business in Tennessee. Another Princeton University graduate student, Erik Granstedt, is helping to implement the diagnostic on LTX.

Once absorbing liquid lithium walls are substituted for solid walls in a tokamak, it is necessary to provide fuel for the plasma, in order to replace particles lost to the walls. One of the LTX graduate students, Dan Lundberg, has constructed a unique injector to provide this fueling. This device, called a molecular cluster injector (MCI), injects what can be described as frozen hydrogen snow into the plasma. The MCI starts with hydrogen gas, cooled by liquid nitrogen. The gas is cooled some more, until frozen clusters of hydrogen form as the gas flows through a small nozzle into the edge of the plasma. It seems paradoxical that fueling a hot plasma with frozen gas results in the best performance, but the frozen clusters penetrate much farther into the hot plasma than a simple gas puff would, and provide fueling where it is most effective.

Graduate students are heavily involved in the LTX research project – in fact, they are responsible for all of the diagnostics on LTX, and operate the tokamak as well.



View of the interior of LTX during the plasma glow procedure which deposited lithium coatings on the liner. The bright red-colored glow is characteristic of lithium.



CAD drawing of LTX prepared by PPPL designer Bruce Paul.

Further Performance Improvements Anticipated

But why does lithium have such a big effect on the plasma? Majeski explains, "When plasma hits the solid wall of a conventional tokamak, all of its particles are neutralized. These cold particles reenter the plasma, where they make many passes through the plasma edge before they are re-ionized. This 'recycling' of hot plasma particles into cold gas cools the plasma edge. With a lithium boundary, we expect the plasma to hit the liner and stay there, so there will be no recycling. The lithium will soak up the particles at the plasma edge, because lithium loves hydrogen."

During CDX-U experiments, PPPL researchers produced a ~70% percent recycling coefficient, the lowest yet measured in any magnetically confined plasma. The CDX-U tray had an area of only 0.2 square meters, whereas the area of the liner in LTX is 5 square meters. With the greater wall area the lithium liner provides, LTX is expected to do a lot better. Experimenters are targeting recycling coefficients in the 10 – 20% range. In contrast, the lowest measured recycling coefficient for the Tokamak Fusion Test Reactor (TFTR), the first experiment to use lithium wall coatings, 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 drop in the plasma temperature between core and edge — the temperature gradient seen in all present-day tokamaks — causes instabilities which reduce performance. The anomalous loss of plasma confinement caused by these instabilities might be eliminated 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 snow, or neutral beams of high energy hydrogen atoms, and will be under the control of the researchers.

Future Experiments

A neutral beam injector (NBI) will be added to LTX for the next phase of experiments, planned to begin in late 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. The results of the neutral beam experiments should provide a first indication of just how small a future fusion reactor with a liquid lithium wall might be.

The LTX Team

Majeski is the Principal Investigator of the LTX project. Kozub is a co-investigator, as are Kaita and Leonid Zakharov. Starting in 2011, Oak Ridge National Laboratory has a major role in edge plasma investigations in LTX, with a team led by Rajesh Maingi. Tommy Thomas from Third Dimension, Inc. of Oak Ridge, Tennessee has developed the Digital Holography diagnostic. Other corporate partners in the experiment include Plasma Processes of Huntsville, Alabama and Ultramet of Pacoima, California. A number of staff from PPPL, Johns Hopkins University, the University of California at Los Angeles, Lawrence Livermore National Laboratory, and the University of California at San Diego, also participate. In addition to the graduate students conducting thesis research on the machine, part of the Program in Plasma Physics in Princeton's Department of Astrophysical Sciences, numerous other graduate and undergraduate students from a number of institutions have participated in the program.

Interior view of LTX during a vent to install diagnostics. Graduate student Laura Berzak can be seen looking through a rear port on the vacuum vessel. Laura has since defended her Ph D. thesis, and is presently an APS Congressional Fellow.

The Princeton Plasma Physics Laboratory is operated by Princeton University under contract to the U.S. Department of Energy. For additional information, please contact: Office of Communications, 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**.