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TFTR Run to Start in September!

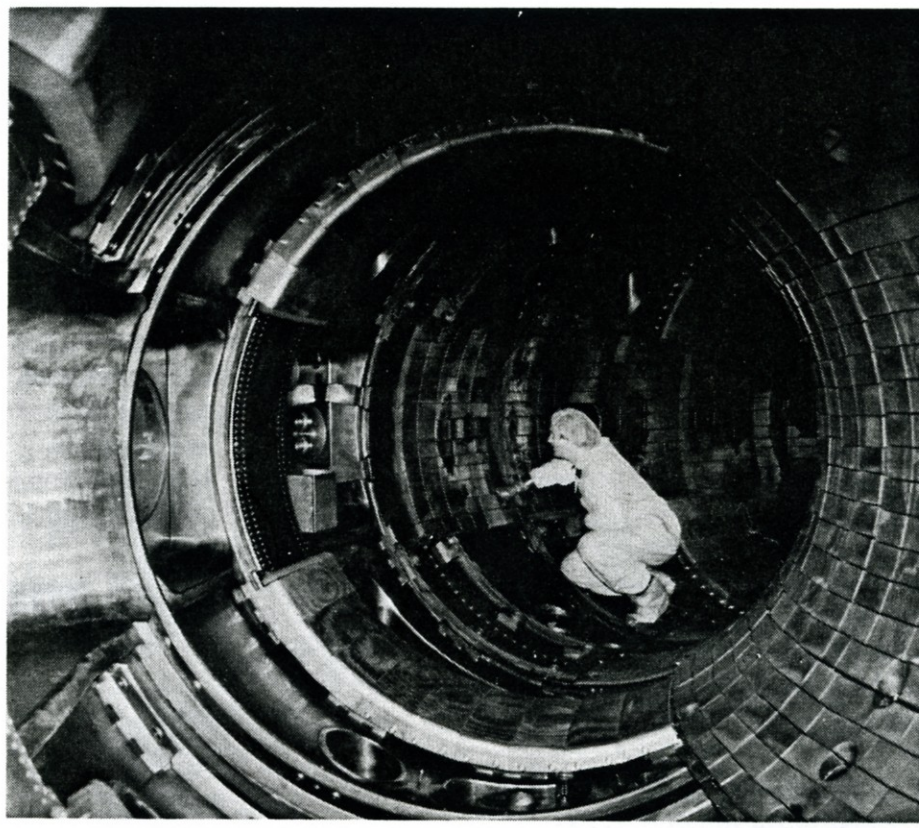
Deuterium-Tritium on Schedule for 1993-94

After a nine-month shutdown, TFTR is completing final preparations for an exciting three-month run starting September 3, according to Dale Meade, Deputy Director, PPPL.

Says Ken Young, Head, TFTR Diagnostics, "The overall physics purpose for the upcoming run is to study the transport properties of the plasma—that is, how the energy is transported across the magnetic field. In addition, we will be studying wall conditioning technique to find ways of reaching higher values of Q, and we will be increasing the ICRF (ion cyclotron range of frequencies) heating power."

On June 27 pumpdown began, with bakeout and systems tests in late July/early August, followed by neutral beam, ICRF, and machine conditioning in August. High power begin in experiments in September. (See Pumpdown Schedule on page 8.) If all goes as planned, the target date for introduction of tritium will remain firm for fiscal year (FY) 1993.

During the last run, and during the shutdown, TFTR staff has continued to extend their outstanding safety record to 3.5 years and two million work hours without a lost time accident. A number of achievements highlighted the last run, which was from April to October 1990. Several significant records were achieved during that run, both in physics and in machine operation.



Shown here is a view of bumper limiter tiles from a neutral beam port. The approximately 2000 tiles were removed for feathering and sanding during the shutdown, and then reassembled on the TFTR walls. Photo: Dietmar Krause

■ **Ten thousand plasma shots were fired during FY90** (October 1989–September 1990) nearly three times as many high power shots as during previous years. The high reliability of the power systems (see below) allows more high power shots. Better quality and an increased number of shots in turn provides the physicists with more useful data to understand the underlying transport process and develop methods to improve performance.

■ **The power systems operated at 96 percent availability.** Advances in power system reliability have been made yearly. For example, reliability was about 90 percent for FY89 and 80-85 percent for FY88.

Mike Williams is former Head of the TFTR Heating Systems Division (now Head of the Engineering Department.) He observes, "Reaching 96 percent power reliability is a phenomenal achievement for this

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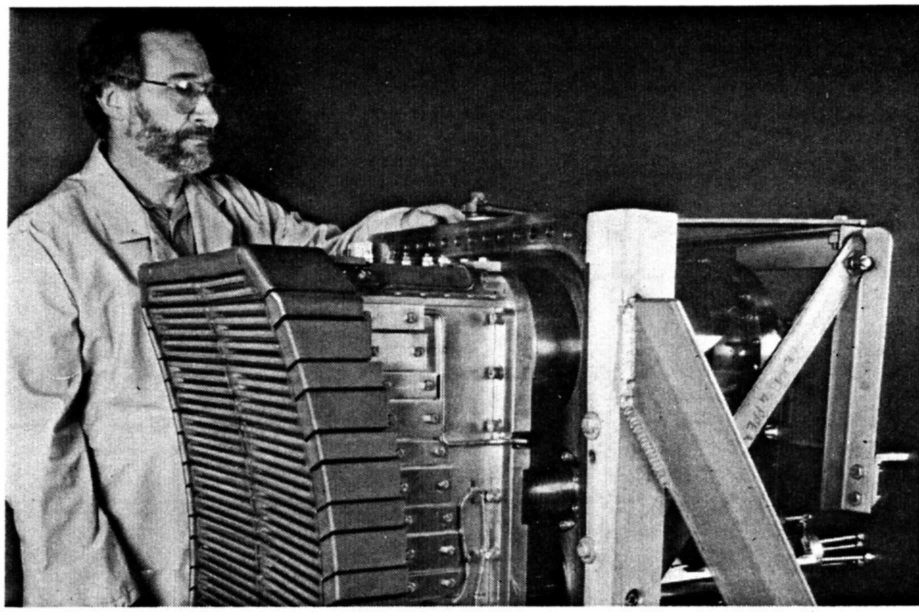
group. They have systematically addressed problem areas, and worked out the problems that have cropped up during operation."

■ **Neutral beam reliability remained high in FY 1990.** The neutral beam system provided world record power of 33 million watts—a remarkable achievement. Says Williams, "It took many small improvements by Neutral Beam staff to push the power up to the 33 MW (megawatt) level. This is more than we ever expected to get from TFTR."

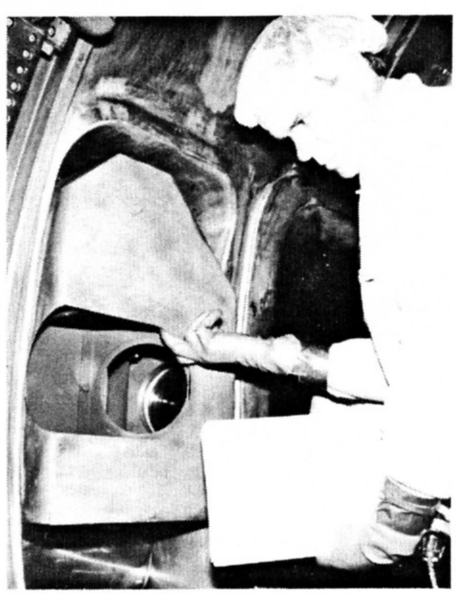
■ **The Ion Cyclotron Range of Frequencies (ICRF) met the DOE level-one milestone of 6.3 MW—the highest ICRF power yet achieved in the United States.** The ICRF is a relatively new system, having been in operation for only two years and is in the process of maturing and achieving improved reliability. The upgrade project underway during the present shutdown will approximately double present ICRF power. (See shutdown section pp. 4 and 5 for details on the ICRF upgrade.)

■ **A new world record was set for deuterium-deuterium (D-D) fusion power output.** D-D fusion power of 60 kW was produced, about 25 percent more than JET (Joint European Torus)—TFTR's major competition. Q values entered the 0.3-0.7 range when projected for what would happen in a deuterium-tritium (D-T) reaction. The Q value is the ratio of fusion-power output to auxiliary heating-power input. Breakeven is achieved when the fusion power obtained from the plasma is equal to the auxiliary power required to heat the plasma.



Joe Frangiapani, Senior RF Technician, checks the primary seal surface on an RF antenna cover plate. Radio waves, directed into the plasma by the antennas, act as a heating source.
Photo: Dietmar Krause

■ **The introduction of lithium pellets to condition the TFTR vacuum vessel walls has produced an unexpected major advance,** according to Rich Hawryluk, Head of the TFTR Project. In fact, the new world record for D-D, described above, was made possible in part by the fact that the injection of lithium pellets reduced carbon content in the plasma. Reduced influx of carbon impurities in turn has increased neutron flux by 20 percent. According to Joe Snipes, who collaborates with PPPL from a Massachusetts Institute of Technology (MIT) group, lithium comes out of the plasma and coats the limiter, which reduces carbon influx from the walls. The original purpose of introducing lithium pellets was to measure magnetic field profiles in the plasma.



Inside the vacuum vessel, Doug Loesser, Tokamak Operations Engineer, checks the beam emission spectroscopy diagnostic. The shield is in the open position as it would be for viewing the plasma.
Photo: Dietmar Krause

■ **A new diagnostic that measures fluctuations in plasma density was used for the first time on TFTR during FY90.** The diagnostic—beam emission spectroscopy (BES) is a collaboration between Ray Fonck of the University of Wisconsin and PPPL. It measures plasma density fluctuations by observing fluctuations in the light emitted from an energetic neutral beam as it undergoes collisional excitation with the plasma ions.

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The brightest line in the visible spectrum is observed. Says Steve Paul, "The fact that the light being detected is in the visible region permits use of a high-throughput lens and spectrometer system, which is very important in achieving the signals required for measurement of low-amplitude fluctuations. Visible imaging also permits the use of fiber optics, which transmit the light away from the tokamak, so that diagnostic development can continue when TFTR is operating."

■ **A prototypical measurement using a single channel of the microwave reflectometer was carried out.** This preliminary assessment determined that microwave reflectometry is a powerful technique for measuring plasma density fluctuations in tokamaks. Important information about plasma stability and transport can be derived through comparison of electron density fluctuations measured at different locations and detected by the reflectometer, beam emission spectroscopy, and microwave scattering. Ernesto Mazzucato heads the group working on reflectometry.

Major Projects Completed during Busy Shutdown

During this long shutdown period several major projects have been completed. Harry Bush, TFTR Shut-Down Manager, noted, "We have tried to complete as many tasks as we possibly could, to minimize the amount of work to be done during the next shutdown." He adds, "The process of working with the Tiger Team was a major project in itself, and we committed much time, energy, and resources to that during this shutdown. We are pleased to have been able to do that work and still accomplish our shutdown goals."

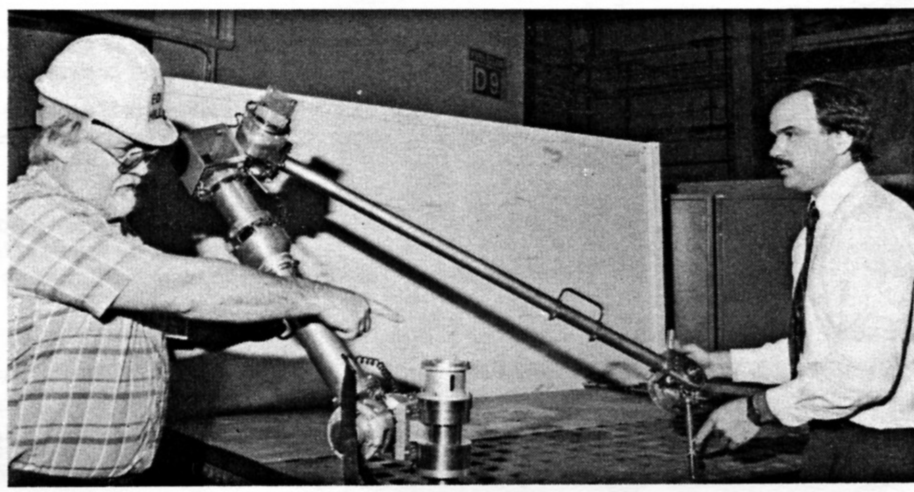
Tasks completed since November that are described here are: upgrading the ICRF limiter; detailed measurements of the bumper limiter; sanding the bumper limiter tiles; upgrading the RF limiters; repairing the toroidal field (TF) coil leaks; and rebuilding the neutral beam transformers.

A new diagnostic was added, the Motional Stark Effect, and other diagnostics were enhanced and maintained.

Naturally, many other tasks have been completed behind the scenes.

Limiter System Projects

The TFTR limiter system is made up of two separate groups of carbon-carbon (and some graphite) tiles—the bumper limiter group, and the radio-frequency (RF) limiter group. These tiles are called "limiters" because they limit the size and shape of the plasma and absorb all power put into the plasma.



Ed Hill, 3rd (left) and Doug Loesser calibrate the measuring arm prior to use in the vacuum vessel.
Photo: Dietmar Krause

The Bumper Limiter

The TFTR bumper limiter is a toroidal belt limiter that covers the small major radius side of the vacuum vessel. Improvements in its design during recent years have allowed production of plasmas with auxiliary heating power over 30 MW for one second and over 20 MW for two seconds without large bursts of carbon influx due to limiter tile damage.

Design improvements have included: shaping the limiter to be circular at the midplane within 0.5 mm; shaping tiles near diagnostic cutouts to reduce local power flux; and replacing graphite tiles in areas prone to disruption damage with carbon-fiber composite tiles.

Alignment Measured

Now the question becomes, can the bumper limiter withstand 50 MW of power input for two seconds? To answer this question, the shape and location of the limiter with the respect to the toroidal magnetic field must be known, according to physicist Kingston Owens,

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Major Projects Completed

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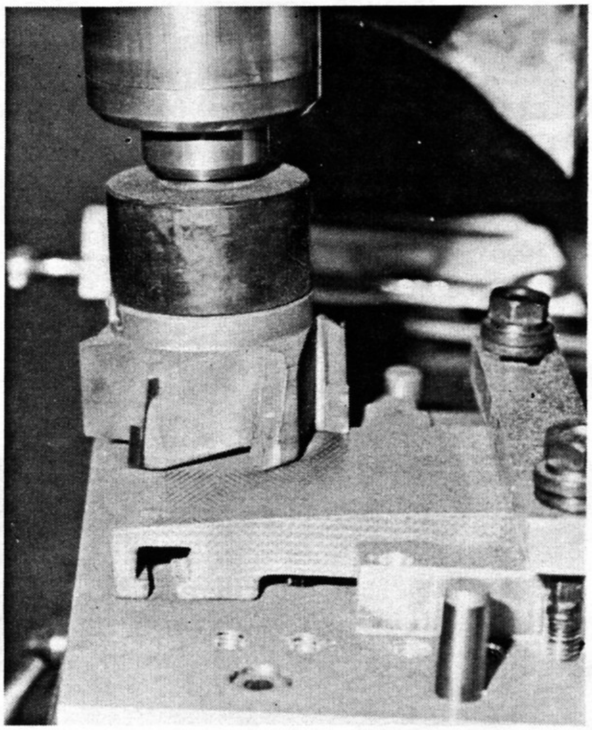

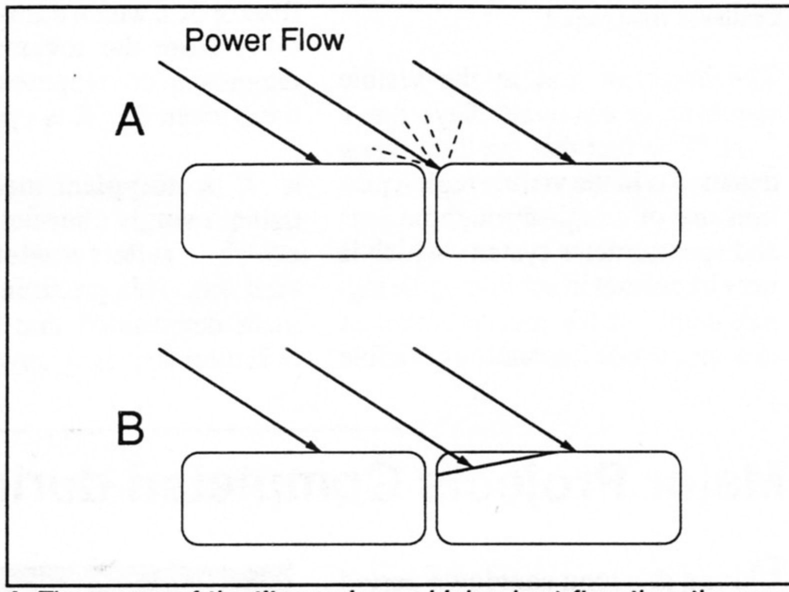

A. The corner of the tile receives a higher heat flow than the upper surface and is overheated.

B. Beveling the tile puts the edge in the shadow of the next tile over. The heat flow to the beveled surface is lower and overheating does not occur. Drawing: Kingston Owens

Here a tile is being beveled (or feathered) to lower the edge so that it will be protected by the next tile (see illustration above). The tile is resting on a jig, while a cutter bevels the edge. Photo: Dietmar Krause

Leader of the Bumper Limiter Alignment activity. (If part of the limiter protrudes slightly into the plasma, it could overheat at powers below 50 MW, and release impurities into the plasma.

Owens, along with Tokamak Operations Engineer Doug Loesser, performed these measurements during the last opening. Explains Owens, "We took magnetic and mechanical measurements inside the vessel using a measuring arm to determine the position and orientation of all the approximately 2000 tiles on the bumper limiter and the RF limiter to an accuracy of plus or minus 0.75 mm or better. Using these measurements, we can calculate the local power flux to the limiter, permitting us to estimate limiter performance at the 50-MW power levels."

Bumper Limiter Tiles Sanded and Machined

Once the initial measuring was complete, the sanding and machining of the TFTR bumper limiter tiles was undertaken. Sanding the tiles and feathering the exposed tile edges eroded by the plasma during the last run is part of the effort to reduce the carbon influx into the plasma. Edges are sanded so that they are lower than the adjoining tile, and are thus protected from plasma bombardment.

According to Jim Chrzanowski, Lead Engineer for Tokamak Operations, this was a major job, because each of these approximately 2000 tiles had to be removed. However, before removal, the tiles whose edges were to be feathered had to be mapped and marked for proper modification. Of the tiles, 1200 were: (1) feathered to remove sharp edges to further decrease heat flux; (2) sanded to remove all traces of metal buildup from the previous run; (3) polished with scotchbrite; (4) handwiped with alcohol; 5) cleaned ultrasonically with an alcohol bath; and (6) baked out at high temperatures. The remaining tiles underwent all processes excepted feathering.

All this was accomplished in a machine shop set up inside the Test Cell just for this purpose. For protection from radiation and carbon dust hazards, all the work was done in glove boxes with special filters and vacuum cleaners to remove all residue. Once cleaning was completed, the tiles were placed in their individual compartments in their "egg carton" crates for transport back to the vacuum vessel. The machinist crew did an exceptionally accurate and fast job, completing all machining two weeks ahead of schedule.

RF Limiters Upgraded to New Configuration

The Ion Cyclotron Range of Frequencies (ICRF) is a plasma heating source that uses high-powered radio

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Major Projects Completed

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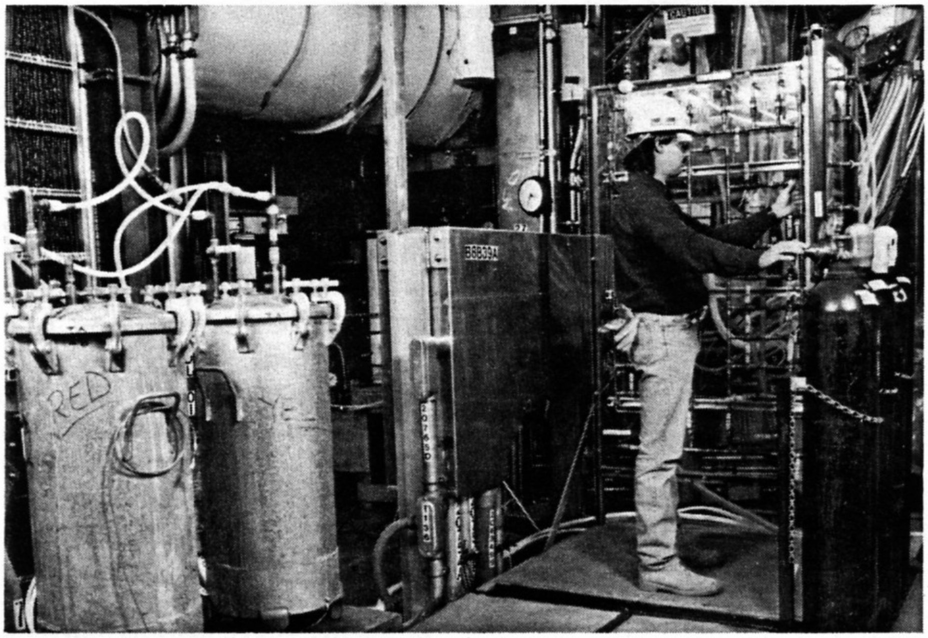

TFTR Technician Mike Anderson checks the nitrogen pressure on the sealant injection equipment during epoxy injection into a toroidal field coil to seal water leaks. The two epoxy tanks are at left. Nitrogen cylinders (right) draw epoxy into the coil.
Photo: Dietmar Krause

transmitters to introduce energy into the plasma in the form of radio waves. Radio-frequency heating is particularly useful in reaching the *center* of the plasma, especially for high plasma density—where neutral beams tend to deposit energy further out. At present, two RF antennas positioned on the vacuum vessel direct the radio waves into the plasma.

RF limiters, which are partial poloidal rings, protect the antennas from bombardment by the plasma. During the shutdown, a major upgrade was made to the RF limiter system, increasing the number of rings from two to eight. The new rings have carbon-carbon tiles—nine above and nine below the vacuum vessel midplane.

According to Doug Loesser, who oversaw the process, a room with assembly benches was set up right in the Test Cell to accomplish the upgrade.

Explains Randy Wilson, Head, RF Antenna Operations, "These new RF limiters were installed partially in preparation for two additional ICRF antennas that will be added during the next opening. We now have eight rings of limiters placed approximately equidistant around the vessel. New ICRF transmission lines have also been added to provide power for the two additional antennas. Once one additional RF limiter ring and all four antennas are put in place in early 1992, we hope to be able to reach 12.5 MW of ICRF power." (The highest reached with two antennas has been 6.3 MW.)

In addition, the two existing RF limiter rings were upgraded to the same configuration that the new rings have, and supporting mounts have been redesigned and strengthened. Explains Wilson, "The purpose of the upgrades is to better protect the vessel wall and the two RF antennas from higher amounts of power to be reached in the future—up to 50 MW of auxiliary input during two second time periods of plasma operation."

Coil Leaks Repaired

In TFTR, 20 doughnut-shaped coils surround the vacuum vessel. These toroidal field (TF) coils provide a strong magnetic field which stabilizes the plasma. To cool the coils, water runs through 1500 feet of copper conductor inside each coil. A miniscule leak that allows water to escape into the insulation and degrade it could make the coil malfunction. In such a high-voltage environment, any water leakage could also be damaging.

Jim Chrzanowski was the cognizant engineer for coil leak repair during this shutdown. He remembers

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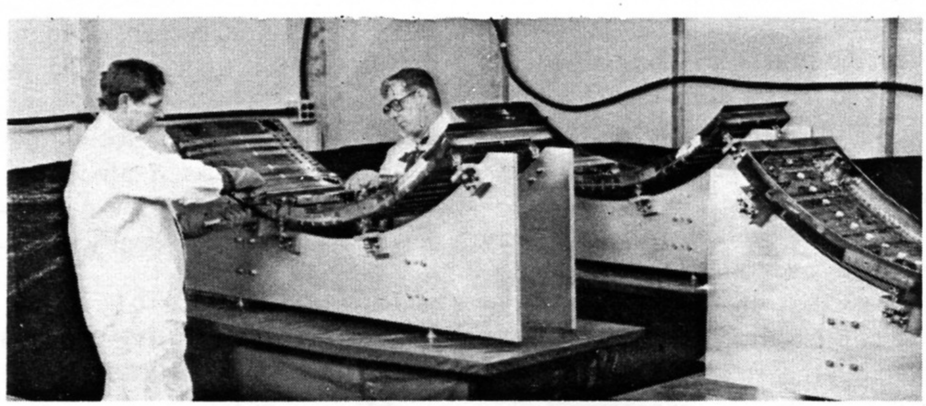

In the assembly room especially set up in the TFTR Test Cell, Bob Mucha (left) and Bob Shoemaker adjust the tile mounts on one of four templates used to assemble the new RF limiter segments.
Photo: Dietmar Krause

Major Projects Completed

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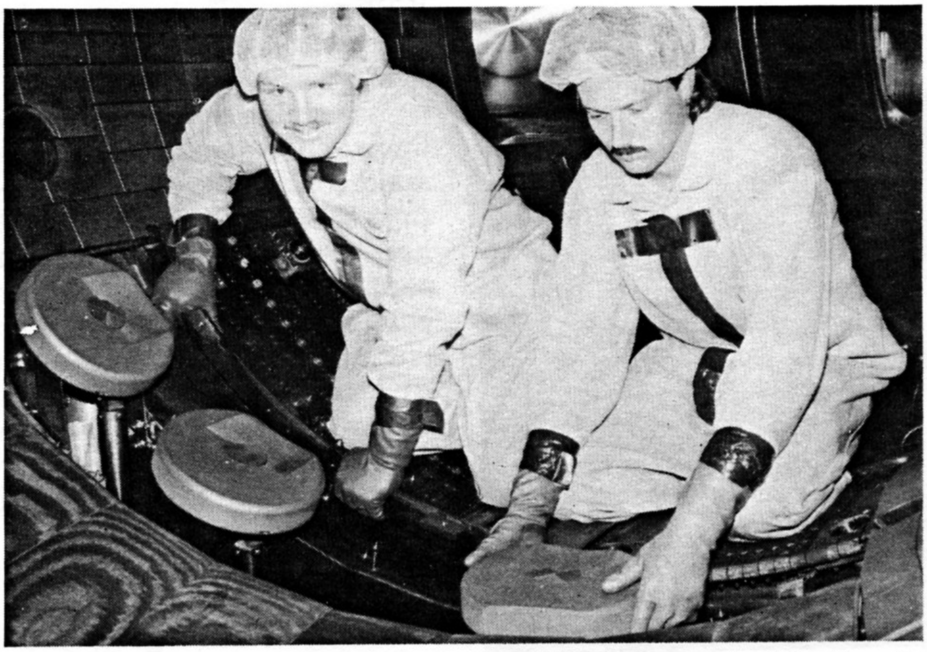

Inside the vacuum vessel, Bob Horner (left) and Mike Anderson check the Escaping Alpha Ray diagnostic, which measures the rate that alpha particles leave the plasma. During shutdown, all diagnostics were checked and adjusted.

Photo: Dietmar Krause

that in 1989, when the first coil leak was detected via droplets of water exiting the coil, anxiety ran high. TFTR Operations were stopped, and an unscheduled opening lasting six months occurred, while a technique was developed to stop the leak. Many people from the Lab worked together with outside vendors to develop a solution.

Explains Chrzanowski, "Because tiny leaks deep inside the 1500 feet of conductor are nearly impossible to pinpoint, it was decided to treat the entire coil. The technique is derived from a simple concept, but it requires great care to perform. However, it can be completed rather quickly."

First, a sealant made of epoxy and clay is fed into the coil, which takes about 45 minutes. Then the coil is pressurized for about an hour, forcing the sealant into any tiny cracks that may be (or become) leaks. Next, excess sealant is flushed out with water, and the coil is allowed to cure at room temperature for 48 hours.

In one instance, another technique was used because the leak was reachable from the outside. A tiny crack had formed in the TF coil coolant passage. It was found by extending a boroscope—a small camera on a flexible arm—into the area. The crack could then be filled with sealant from the outside.

Since the first leak in 1989, five of the 20 coils have been treated for leaks. During the present opening, two have been treated. While the development of leaks in the TF coils remains a concern, the techniques developed have proven satisfactory thus far, and a trained crew of technicians is on hand to deal with future leaks.

Neutral Beam Transformers Rebuilt, Other Upgrades Made

Many of the components of the TFTR Neutral Beam (NB) injection system were designed for a ten-year lifespan. Therefore, to prepare for the future, and especially for the introduction of D-T operation, many system upgrades and much preventive maintenance will be required. According to Al von Halle, Head, Neutral Beam Operations Branch, "During the last run, the TFTR neutral beam system had the highest system availability and shot-to-shot reliability ever. Yet further improvement is still necessary to optimize for tritium operation."

The beam group has made great strides towards improvement during the shutdown. For example, notes von Halle, "By the end of July all of the 13 transformer rectifiers rated at 12 MVA (megavolt amperes) each were dismantled, upgraded, and rebuilt to address a problem found when one unit failed during the last run. In conjunction with this, all 12 of the coaxial cables that deliver the 180 kilovolt (kV) output of each transformer rectifier to the power conversion building were replaced after degradation of the insulation on five of the cables was discovered."

"Many of the internal beamline components were also upgraded, including the four beamline calorimeters and the second of the four ion dumps," adds von Halle. "Also, we improved the efficiency of the helium refrigerator with a new heat exchanger and upgraded the neutral beam water systems with new flow switches. These upgrades are examples of our constant efforts to fine tune all systems for increased reliability and repeatability."

Diagnostics Added, Upgraded

At present, close to 50 diagnostics are used to measure a wide variety of plasma properties, according to George Labik, Section Head, Diagnostics Engineering Branch. The detailed analysis of

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TFTR Prepares for Upcoming Run

Pumpdown Is Now Underway

After a flurry of last-minute activities, TFTR was closed on June 27 so that final start-up activities could be completed. According to Start-Up Coordinator Bill Blanchard, "The goal of many of these activities is to clean the machine of impurities—such as water, CO and CO_2. The idea is to create a vacuum that is as clean as possible, thus preparing the way for plasmas that are as free of contamination as is feasible."

In addition to the operations described here, staff for various subsystems have been at work behind the scenes during the shutdown preparing for experimental operations. These systems are large and complex, and personnel must complete more than 50 procedures in preparation for operations. They include: the Torus Vacuum Pumping System (TVPS); the Energy Conversion System (ECS); the Water Systems; the Motor Generators (MGs); CICADA, (the computer system); and various diagnostics.

The activities outlined below will be completed this summer, in the approximate order in which they are listed.

TFTR Start-Up Activities

Pumpdown evacuates the air from the vacuum vessel, bringing it from atmospheric pressure to a high vacuum. Initially, the air is pumped down to about 50 mTorr with mechanical and blower pumps. Eight turbo molecular pumps then bring the torus to a high vacuum. Finally, the vessel is leak-checked and air leaks are sealed.

Tokamak Scrub involves a thorough cleaning (scrub) of the machine. Every area is checked for such items as nuts or bolts that might have been dropped. In addition, every aspect of the tokamak is checked to make sure it is in its proper configuration. For example, if a cable is slightly askew, it is put in its place.

Bakeout heats the vacuum vessel up to 150 degrees centigrade, driving out impurities that have collected on the internal surfaces during shutdown.

Glow Discharge Cleaning (GDC) cleans internal surfaces of the vacuum vessel by bombarding the inside walls of the vessel with helium atoms to knock out impurities.

Diboronization is done by applying boron to the internal surfaces of the vacuum vessel—again using a GDC process. The coating reduces the release of impurities from the walls during plasma shots. During the last run period diboronization reduced the time needed for Pulse Discharge Cleaning (PDC) from 11 days to one day. This increased the time available to do experiments. It is expected that diboronization will continue to reduce or eliminate PDC time.

Coil Testing of the Toroidal Field Coils and Poloidal Field Coils is accomplished by running current through them to be certain that the Energy Conversion System is working as it should. During coil testing, many of the other subsystems, such as CICADA, Water Systems, and MGs, are also in full operation and are being tested for reliable operation.

Pulse Discharge Cleaning (PDC) achieves two types of cleaning. First, low-powered plasmas are pulsed out every few seconds, impinging on the limiter and the walls and cleaning off impurities. At the same time, this process heats the bumper limiters to 250 degrees centigrade, effectively "degassing" or boiling the gases out of the walls.

Disruptive Discharge Cleaning (DDC) is similar to PDC, except that energy from *high-powered* plasmas is released into the limiters in a controlled fashion to drive out any additional wall impurities.

Neutral Beam Injection (NBI) Testing and Operations is where the neutral beam heating systems are conditioned up to high power and are given a trial run to make certain all systems are fully operational and to condition ion sources up to the levels required for injection operations.

Helium Conditioning is a process where helium plasmas are run in order to deplete the limiters of deuterium. (Deuterium is absorbed into the bumper limiter tiles during D-D runs.) Helium conditioning is necessary to avoid the release of the deuterium from the limiters during supershot experiments.

ICRF Conditioning prepares the Ion Cyclotron Range of Frequencies (ICRF) antennas for high power operations.

Experimental Operations — TFTR run begins!

Major Projects Completed

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plasma properties is carried out to compare the overall behavior with its theoretical expectations. Says Labik, "A number of additional new and upgraded diagnostics designs are to be put in place before the D-T operations phase. In addition, to prepare for D-T operations, diagnostics that are now being used are being fine-tuned, and preventive maintenance is being done."

New Diagnostic Installed

During this shutdown period, a new major diagnostic, the **Motional Stark Effect** (MSE), was added. According to Ken Young, Head, TFTR Diagnostics, the MSE data will fill an important gap in information needed to relate experimental observations to theoretical predictions concerning fluctuations in plasma stability. He notes, "The MSE provides us, for the first time, with the ability to measure the shape of the magnetic field so that we can begin to see how the plasma affects it."

Explains MSE Project Head Fred Levinton, "The motion of neutral beam particles across the magnetic field creates an electric field on the beam atoms. The electric field orients the atoms so that emitted light from the atoms is polarized along the electric field direction. The MSE diagnostic measures the magnetic field pitch angle from the orientation of the polarized light emitted from the neutral beam."

He adds, "This angle tells us what the distribution of the current is in the plasma. This current distribution, which determines the magnetic field shape, is important to know because it can affect the plasma stability and confinement. MSE measurements may also be able to help us distinguish the various sources of current—such as from neutral beams, ohmic heating, and bootstrap current."

The MSE diagnostic is being developed in conjunction with Fusion Physics and Technology. It was first developed on PBX-M.

Other Diagnostics

In addition to the usual enhancing and maintenance work, a variety of other diagnostics-related work also occurred during shutdown.

■ The **Microwave Reflectometer** was upgraded by increasing the number of channels from one to three. The reflectometer measures fluctuations in electron density at different locations across the major radius of the plasma.

■ Additional **MIRNOV Loops**—a diagnostic used to measure magnetic fluctuations—were also installed.

■ An upgrade was made to the **Beam Emission Spectroscopy** (BES) Diagnostic described on page 2. The BES measures plasma turbulence.

■ Hundreds of **Thermocouples** located around TFTR were mapped and their functioning checked, according to Research Physicist Alan Janos. A thermocouple is a device that measures temperature, helping TFTR staff monitor how hot a given area of the machine gets during a plasma shot.

HOTLINE

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