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THE CONSTRUCTION OF THE FACILITY FOR THE TESTING OF THE TFTR NEUTRAL BEAM INJECTOR


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Summary

The prototype for the TFTR Neutral Beam Injection System (described elsewhere in the proceedings) has been assembled at the Lawrence Berkeley Laboratory, and is presently under test. The facility that services this injection system was described at the last symposium held in Knoxville, Tennessee, in October of 1977. This paper updates that earlier one, and discusses in detail some of the construction features of the shielding enclosure, the cryogenic supply system, control and computer area, and the auxiliary vacuum and utility supply system. In addition, the paper describes the target chamber, its beam dump and cryopanels, and the duct that connects the target chamber to the injector vessel.

Introduction

The prototype Neutral Beam Injection System for TFTR was designed at the Lawrence Livermore Laboratory. It has been installed at the Lawrence Berkeley Laboratory. This paper describes the features of the facility where it will be tested.

One of the reasons that lead to the decision to assemble and test the TFTR prototype beamline at the Lawrence Berkeley Laboratory was the availability of a site that could afford the following features: A working space sufficiently large enough to stage, assemble, and operate both a neutral beamline and the ion source's high-voltage power supply; access to a crane with sufficient capacity and lift to install cryopanels into the injector vessel, and handle the shielding that would be required around the test area; a floor area strong enough to support the load of the shielding enclosure; access to sufficient electrical power for high-voltage power supplies and operating equipment; a sufficient supply of cooling water and other utilities; and close proximity to shop facilities for the fabrication of ion sources and power supplies, etc. Of all the sites that were available at Berkeley, the one that best filled all these needs was the building housing the Laboratory's 184" Synchrocyclotron.

One of the older facilities on the hill, the 184" Synchrocyclotron is presently being operated as a medical accelerator for programs in U.L.'s Biology and Medicine Division. Over the past two decades, the 730-New helium ions from the accelerator have become the established treatment for certain pituitary diseases. Over 700 patients have received therapy at the synchrocyclotron for argromagia and Cushings's disease. Presently the National Cancer Institute and ERDM(DDR) are sponsoring a new program where patients are being treated with the accelerator's helium ion beam for various kinds of cancer.

A portion of the building that had housed physics experiments in past years was cleared of all material. The removal of this equipment and shielding provided a floor space inside the building of approximately 8000 ft^2. The area has a 24-ft x 25-ft access door from the street, and is serviced by two cranes: a 30-ton and a 5-ton hoist with 35-ft. lifts. Electrical utilities are readily available, and numerous trenches cross the floor space. Water circulating pumps and cooling towers with 8 Mwatt capacity are immediately outside the building. The 12-kv line and substation are nearby, and the fabricating shops are minutes away.

This report deals with some of the details of the facility that now houses the neutral beam injector and its target chamber:

- The Shielding Enclosure for the Neutral Beamline
- The Computer-Control Area
- The High-Voltage Power Supply Areas
- The Cryogenic Supply System for the Cryopanels
- The Auxiliary Vacuum System
- The Utilities Supply
- The Target Chamber and Beam Dump

The Neutral Beamline, the Target Chamber, and their connecting duct, are shown in Fig. 1. The Neutral Beamline, along with its components, is the subject of another paper at this conference and will not be covered here.

In locating the injector vessel inside of the shielding enclosure, consideration was given to allow workspace around the ion source area, and still provide crane access to the upper cover of the vessel and to the individual components.

In addition to providing space for the injector, the enclosure was made large enough to provide room for a target chamber which houses the beamdump that simulates the target plasma in the TFTR Tokamak. The Target Chamber is pumped by its own cryopanels, and is connected to the injector vessel by a vacuum box which simulates the duct at PPPL.

The walls and roof are built of 2-ft thick ordinary concrete. The inner dimensions of the vault are 24-ft x 66-ft, with a 20-1/2 ft ceiling. The blocks are of a modular 28-ft length, and weigh just less than 30 tons. They are fastened to an internal structural steel framework which is supported on caissons drilled to a depth as great as 30 ft. Notches have been cut into the roof blocks to allow access for the cryogenic transfer lines.

Entry to the area is provided by two simple mazes at opposite corners of the enclosure. These openings were made as long as possible to prevent neutrons from streaming towards occupied work spaces. Surplus shielding doors are available, and will be installed should the dose levels not be found to be "as low as practicable".

The shielding blocks were built by a local contractor, on a flat casting slab. The expense of
using steel angles on all edges of the block was offset by the ease with which the forms were fastened, and checks made on dimensions before pouring. In addition, these angles afford edge protection during handling operations. The cost of the blocks, including transportation to the site and erection, was approximately $537/ycyd.3

The thickness of the concrete walls and roof of the shielding enclosure were determined by calculating the radiation flux that would come from the calorimeter in the injector vessel and the beam dump in the target chamber. Not considered were neutrons produced by d-d reactions in the neutralizer column, and neutrons from the dumping of the non-neutral beam. This decision was reached after observations at LBL's 150-keV Test Facility3 showed that the neutralizer column had a neutron emission of one-tenth that of the target. The surface temperature of the copper target plates were considered to be warm enough to prevent deuterium self-loading. During the beam pulse, half of the beam particles were considered to constitute the target atoms while the remaining half were incident on the target. With an expected beam current of 55A at 125 keV, and a beam pulse duration of 0.5 sec at a repetition rate of 12 pulses/hour, an assumed projected beam area of 85 cm² produced an emissivity of $8.2 \times 10^9$ neutrons per second.

Regulations required that no installations show a factor of 5 reduction from previous design requirements, so that at the outside of the shielding the dose equivalent should be no more than 1 rem/year based on a 40-hour week. The thickness of shielding deemed necessary to reduce the neutrons dose equivalent rate to 0.5 mrem/hour (av) or 3.5 m/ctt² was based on a minimum safe working distance of 5 ft from the target. With these criteria, a 2-ft thick wall and roof were determined to be suitable, thereby permitting unlimited access to the exterior of the shielding enclosure during operation.

The shielding vault was planned to provide the minimum size enclosure that would afford ample working space at a minimum cost. The crane had a 30-ton limit, and a 34-ft maximum lift. The floor had a 5000 PSF load limit. The ceiling of the vault was kept as low as practicable; not only for reasons of economy, but because of the stringent earthquake requirements.

The Control-Computer Area

When the cyclotron's outside shielding was removed,
the unused support pad was extended to provide the floor slab for a 2000-ft² building. This building houses the control room, the computer and technician workspace. The flat-roofed building is of simple framed construction, with a sheetrock interior and transite exterior.

The building is provided with a raised floor that gives access to the wiring and ducting to the computer and control areas. The floor is made of commercially-available carpeted panels supported on pedestals attached to the subfloor. Use of the carpeting reduces the noise level in the area and helps to minimize operator fatigue. A similar raised floor of plywood construction extends from the control room to the injector vessel.

Sheetmetal was adhesively bonded to the wall between the high voltage power supply and the control-computer room. It was similarly fastened to the floor slabs of the computer-control area and the high voltage power supply. All the edges were overlapped and soldered to form a continuous unbroken groundplane. All of the electrical conduits and ducting that enter the control-computer room are fastened firmly to the sheet metal and kept as close to it as possible. This minimizes noise-current pickup, and its transmission into areas that might be sensitive to it. The sheetmetal on the wall provides a barrier to radiated electromagnetic noise that might reach the area from the high voltage power supply.

Ventilation and air conditioning are provided by three roof-mounted units; two 5-ton units, one 7 1/2-ton unit. The ducting shares the overhead space with the lighting fixtures. We experienced our first heavy rains last winter, and were plagued with a succession of minor roof leaks that were difficult to locate and repair. They have been all taken care of, hopefully. At the start of the second winter, it will not be long before we find out.

The central room in the building is shared by the computer, tape decks, decwriter, disc and line printers. Fire protection is provided by a self-contained halide system located under the floor. Space at the rear of the control room accommodates storage lockers and a limited workshop area for electronics repairs.

The High-Voltage Power Supply Areas

In brief, it can be said that the components for the power supply occupy two separate areas: A 24-ft x 80-ft concrete pad outside the building, and a 1000-ft² screened area immediately adjacent to the shielding enclosure.

The concrete pad accommodates the Interrupter switch and step contactor, two 12 kV - 4.16 kV transformers, step tap-changers, step voltage regulator, phase shift transformers and two 3.38 MVA rectifier transformers. Power from this equipment is fed into the building via a transmission line enclosed inside a 6" rigid steel conduit. This conduit runs under the roadway outside the building where it then enters a 13-in x 24-in trench which brings it to the inside screened enclosure of the power supply.

The screened area of the power supply inside the building houses a number of major electrical components: The hot box containing the arc modulator, and the telemetry equipment for the arc, filament, accel, and gradient grid supply; the shunt regulator containing its control system, the ignitron crowbars, six parallel varistor stacks and their DP-15's and filament transformer; the MOV varistor string and its 4CW 50000C and filament transformer; the arc and filament power supply transformers in their respective SF₆ enclosures; the SCR switch; the crowbar; the IH reactor; and a dummy load unit. Two 30-ft high, 3-ft wide, moveable frames covered with 1/4-inch mesh hardware cloth. Besides providing a safety barrier to the high voltage equipment, the screen forms a barrier to radiated electromagnetic noise that might reach control equipment. As mentioned before, the screen has a barrier to the area.

At the start of the second winter, it will not be long before we find out.

The dummy load consists of an 8" diameter 10-ft length of PVC tubing filled with water. The overall resistive length of the load is 3 ft²; varied by moving an electrode at each end of the water column. To keep the cart-mounted assembly to a convenient length, the water path is bent in the middle like a hairpin. 4.5 gal/min of water provides cooling for an anticipated maximum 0.5-sec long, 80A 150-kV, pulse every five minutes. This water flow is in blocked, and a fusible plug provides temperature relief in the event of an accidental shutdown.

The Cryogenic Supply System for the Cryopanels

Three ion sources are installed on each injector vessel at Princeton. The total gas flow for these sources is estimated to be as much as 100 Torr liters per second per injector. Condensation cryopumping will be used to handle this gas load. Although only a single ion source will be tested at a time on the prototype at Berkeley, the full complement of cryopanels were installed on the injector. The design and operation of these cryopanels will be discussed in detail in another paper to be given at this conference.

The cryopanels consist of eight modules; four on each side of the injector, supported from the floor of the vessel. The liquid-helium cooled, vacuum-tight housing of the panels and its liquid-nitrogen temperature radiation shield are constructed of quilted double-walled stainless sheets. The liquid helium cooled cryopanels are gravity fed from a 750-liter dewar located atop the injector. No attempt is made, at LBL, to subcool the helium for operation lower than 4.2K in order to improve hydrogen pumping. The panels' lower dewar is made of cold-rolled carbon-steel, gravity-fed by liquid nitrogen that is gravity-fed from the U-shaped dewar also located on the injector cover.

The helium compressor was installed in July of 1978, and first run in September. The coldbox and expansion engines were installed in November 1978, and liquid helium made in early December. Vesting of the various components was carried out thru May 1979, and the first cooldown of the cryopanels occurred in July.

Minimum performance specifications for the refrigerator called for 200 watts without liquid-nitrogen precoo1ing; 300 watts with precoo1ing. As a liquefier it was to supply 80 liters per hour. Actual performance, based on preliminary tests, shows that the refrigerator will be capable of 95 liters per hour, or
475 watts with precooling. The excess capacity will provide speedy cooldown and liquefaction for filling the dewar and cryopanels. In addition, this will provide additional insurance towards overcoming any excess heat leaks resulting from poor vacuum, or from assembly errors.

The location of the two-expander coldbox is shown in Fig. 1. The vacuum insulated transfer lines travel to a distribution box mounted on the shielding wall. From there, they go to the 750-liter dewar atop the injector vessel and to the bayonets on the upper lid of the target chamber. Liquid nitrogen, supplied from a surplus trailer-mounted dewar outside the building, is supplied to the coldbox of the liquefier-refrigerator, the dewar atop the injector, and the cryopanels in the target chamber.

The skid-mounted, 400-EP, single-stage screw compressor and its oil removal system are located outside the building to reduce the noise level in the operating area.

### The Auxiliary Vacuum System

To eliminate the danger of contaminating the Ion sources or the Tokamak's vacuum chamber, it was decided to cryopump the injector vessel, and to minimize the use of mechanical vacuum pumps.

To rough-pump the vessel to the point where the cryopanels can be chilled, two mechanical pumps are used. One is a Stokes Model 1722 two-stage unit: A rotary oil-sealed 300-cfm, Model 412 vacuum pump backed by a 1300-cfm rotary lobe dry high vacuum booster. The second vacuum pump is also a Stokes Model 412 300-cfm vacuum pump. The roughing line has a trap of refrigerated copper wool used to prevent oil migration from the mechanical pump. For atmospheric pressure, the injector can be rough-pumped to 100 mTorr inside of an hour, at which time the turbo pump is valved in, taking the vessel to its uncooled base in the high 10⁻⁷ Torr region. It takes approximately eight hours to cool the cryopanels to 77K, and about twelve more hours to cool to 4.29K, after starting the refrigerator. The base pressure of the tank upon cooldown, is in the low 10⁻⁸ Torr region. The pumping time required to reach this base pressure varies, depending upon the amount of water vapor in the chamber and the length of time that it has been exposed to air. To keep the pumpdown times as short as possible, the vessel is always returned to atmosphere by first partially letting up with dry nitrogen, followed by filtered air. Should anyone wish to enter the chamber, adequate safeguards are taken to provide further ventilation, to ensure that the oxygen content is kept above minimum levels.

The vacuum system is protected by a system of interlocks that protect the chamber and individual vacuum components against serious damage, should there be failure of any of the supplied utilities or any part of the system, or upon any operational error.

The cryopanels in both the injector and target chamber have been supplemented by 3509 liter per second (air) Leybold-Heraeus turbomolecular pumps, each backed by a Leybold-Heraeus 26 liter per second oil-sealed rotary piston pump. Various supplementary vacuum pumping systems were examined and of all systems considered, the performance of a turbomolecular vacuum pump was preferred. Although the initial capital investment high, there will be net savings in maintenance costs for the life of the experiment, over a mercury and oil vapor diffusion pump or titanium bulk-sublimation/ion pumps. The turbopump can handle large gas loads on a continuous basis and achieve the desired vacuum pressures. Maintenance on the pumps is expected to be minimal. When used on TFR, occasional oil changes will be needed to be made in a controlled manner in case of tritium contamination. The pumps are compact, and on the prototype, will be mounted close to the vacuum vessels to reduce conductance losses.

Although turbopumps are often connected to other systems without valves, interlocked pneumatically-operated valves have been placed in the line between our turbopumps and their vacuum vessels to lessen the danger of contamination to the cryopanels. At this time, it is deemed not necessary to provide a refrigerated trap over the turbopump to reduce the movement of oil into the vacuum vessels. However, if it is seen at a later time that one is desirable, room has been left in the connecting piping to accommodate it.

### The Utilities Supply

The items that require cooling on the injector are: The Ion source and accelerator, the neutralizer, the magnet, the Ion dumps, the beam scraper, the photodiode array, and the calorimeter. With one source at a time in operation, the Ion dumps, scrapers, and calorimeter will require only one-third the water required at the PPFL location, although their piping will be installed full-size. Downstream of the Injector, the ductbox, liner, and the beamdump also require cooling.

There are two cooling towers adjacent to the building. They provide a total capacity of 8 mwatts; 4.1 mwatts tower water, 3.7 mwatts low-conductivity water. Their piping circuits already existed in the building, close to the shielding vault. Only the manifolding and short runs of piping to the injector, duct and target chamber were needed.

Since there is raised decking between the shielding wall and the injector vessel, it was convenient to run the water lines in this space. The deck is built of small sections of movable plywood, and there is ready access to the valves, filters, flow interlock switches, etc.

The water supplied to each component is measured with a turbine flowmeter whose rotor spins with a rotational speed proportional to the flow velocity. An electro-magnetic pickoff detects the passage of each rotor, and generates a pulse; thus the frequency of pulses is proportional to the volumetric flow. A differential temperature transducer is mounted on both the supply and return lines and measures the true difference in water temperature between those two points. The combined signals of these two devices is integrated to give the total energy delivered to the device.

In order to provide a convenient calibration for these instruments, a 10-ft section of each return line is made of thin-walled stainless tubing, insulated from ground. This section of tubing can be resistively-heated by a power supply, and the wattmeter output compared to the combined readings of the flowmeter and temperature transducer.

Typically, the flow to each circuit is momentarily stopped just before each beam pulse to insure that no cooling occurs during the pulse itself. After the temperatures have been observed and recorded, the flow is resumed and the flowmeter and temperature readings taken to determine the total energy delivered to each component.
The majority of the cooled beamline components are inserted thru the lid of the injector vessel. To allow for ease in removing each item for servicing, its water lines are easily disconnected after blowdown. Since all lines exit thru the lid, it is difficult to inspect but all of the water is shown from each circuit, especially in those circuits that have a number of parallel paths. All components in the injector radiate to the cryopanses, presenting the danger of water freezing in the cooling tubes, and certain precautions must be taken to prevent this from happening. All water circuits are therefore not stopped before cryopanses are cooled, and are not shut down until the cryopanses are warmed up. Once the water is flowing in each circuit, it is not turned off because of the residual amount that might freeze. Should there be a power failure causing the circulating pumps to shut down and the supply pressure to drop, a system of interlocks closes the main LCW supply and return valves, and allows city water to be admitted to each circuit and thence to drain. The ion source is not subject to freezing, and so in the event of a power failure, its circuits are isolated, and are re-opened after power is restored and the city water swept from the system. There might be a time when a circuit is left dry during the cryopanel cooldown. Due to the mass of the component and its lowered temperature here, it is possible that water sublimated to the circuit might freeze. For this reason, such a circuit is kept dry until the cryopanses are warmed up to room temperature.

The Target Chamber and Beamdump

The ductbox forms the vacuum barrier between the injector vessel and the target chamber. The interior liner to the box is constructed to accurately simulate, in every possible respect, the internal dimensions and apertures of the actual ducts to be used at PPF. It is made of 1/8-inch thick stainless steel, has cooling tubes brazed to its outer surfaces, and is sufficiently instrumented with thermocouples so that the incident power flux striking the inner surfaces can be measured.

The ductbox is a simply shaped vacuum chamber with a demountable top lid that allows full access to the interior. This box is larger than the limits set by the inner liner, and so provides room for instrumentation, cooling tubes, and possible changes to the liner's outlines.

The target chamber is an upright cylinder, of 100-inch inside diameter; its 155-inch liner height allows room for two standard cryomodules to be suspended side-by-side from its lid. The target chamber and ductbox form one space which can be isolated from the injector vessel with a 42" diameter gate valve. This combined volume is pumped by the cryomodules in the target chamber. The requirement for an 8-hour reserve of cryogenic fluids determined the sizes of the helium and nitrogen reservoirs on the injector vessel. There is no such requirement for the target chamber; therefore, the reservoirs for both the nitrogen and helium are relatively small (1-1/2 ft³) vessels, suspended from the lid of the target chamber.

It may be desirable, at some later time, to attempt to simulate the stray magnetic fields at TFTR. For this reason, it was decided to avoid the use of magnetic materials, and to construct both the target chamber and ductbox of aluminum. Several ion gauges and a residual gas analyzer can be installed on each vessel. Fast ion gauges on the duct will be used to monitor the pressure during beam pulsing, as well as gas pulsing with the beam off.

A circular pickup (Rogowski) coil, placed at the downstream end of the duct will be used to measure the flux of re-ionized neutrals. The ballistic beam dump in the target chamber will be made of a 3/4-inch thick copper plate with cooling tubes brazed to its rear surface. Type-E thermocouples will be used to monitor its temperatures and indicate beam outline and loading. A viewport in the wall of the target chamber allows the use of an infra-red scanner. A 1/4-inch diameter hole will be drilled thru the head dump for each of the three ion sources. This will allow a measurement of the distribution of ion species, by mounting a magnetic analyzer on any of the three ports on the rear of the target chamber.

Conclusion

At the present time, the injector vessel and its components are being installed and the cryopanses cooled down. High-voltage tests are being made on the ion source. The shielding has been installed, except for the few roof blocks over the injector which have been left out for the sake of convenient access to the lid of the vessel. The duct box and liner are nearing completion. The target chamber is on hand, and the cryopanses will soon be hung from its lid. The target chamber will have its beam dump installed, and be ready for full operation by 1 March 1980.

References