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# Accelerator & Fusion Research Division

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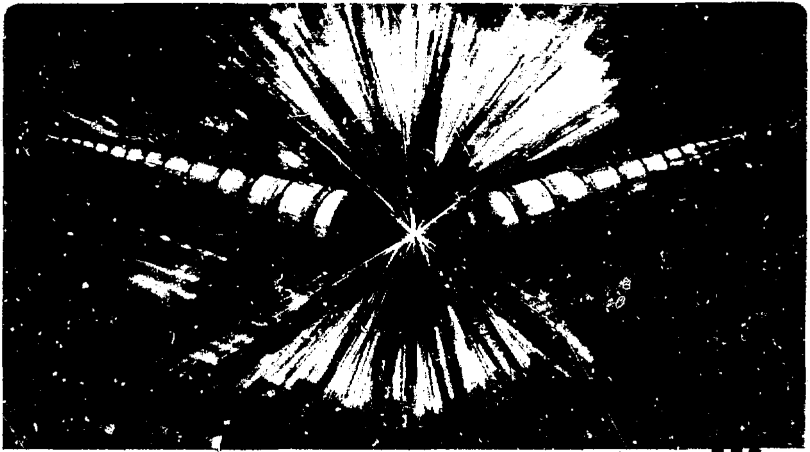
December 1983



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# THE DESIGN, FABRICATION AND OPERATION OF THE MECHANICAL SYSTEMS FOR THE NEUTRAL BEAM ENGINEERING TEST FACILITY

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## Abstract

The Neutral Beam Engineering Test Facility (NBETF) at the Lawrence Berkeley Laboratory (LBL) is a National Test Facility used to develop long pulse Neutral Beam Sources. The Facility will test sources up to 120 keV, 50 A, with 30 s beam-on times with a 10% duty factor. For this application, an actively cooled beam dump is required and one has been constructed capable of dissipating a wide range of power density profiles. The flexibility of the design is achieved by utilizing a standard modular panel design which is incorporated into a moveable support structure comprised of eight separately controllable manipulator assemblies. The thermal hydraulic design of the panels permits the dissipation of 2 kW/cm$^2$ anywhere on the panel surface. The cooling water requirements of the actively cooled dump system are provided by the closed loop Primary High Pressure Cooling Water System. To minimize the operating costs of continuously running this high power system, a variable speed hydraulic drive is used for the main pump. During beam pulses, the pump rotates at high speed, then cycles to low speed upon completion of the beam shot. A unique neutralizer design has been installed into the NBETF beamline. This is a gun-drilled moveable brazed assembly which provides continuous armoring of the beamline near the source. The unit penetrates the source mounting valve during operation and retracts to permit the valve to close as needed. The beamline also has an inertially cooled duct calorimeter assembly. This assembly is a moveable hinged matrix of copper plates that can be used as a beam stop up to pulse lengths of 50 ms. The beamline is also equipped with many beam scraper plates of differing detail design and dissipation capabilities.

## Introduction

Advanced high-power long-pulse neutral beam test facilities are required in order to carry out the development and qualification of components and systems for confinement experiments that are now in the active planning and decision making stage. To meet this need, the Neutral Beam System Test Facility (NBSTF)[1] at LBL was upgraded to the NBETF. The facility will satisfy the near term testing needs for long pulse positive ion plasma-source and accelerator development and was designed to accommodate a wide range of design reference beam parameters. The system is presently being used to test the Oak Ridge National Laboratory (ORNL) and the LBL long pulse sources to qualify them for use on the Mirror Fusion Test Facility (MFTF-B) at the Lawrence Livermore National Laboratory (LLNL). Further testing is planned for beams of up to 120 keV, 50 A with 30 s beam on times at 10% duty factor. The original NBETF project included a bending magnet and ion dump in the test stand equipment.[2] Midway through the construction phase, budget cuts necessitated the elimination of these components with the result that the original neutral beam dump must now dissipate the power of the mixed beam, ions plus neutral fraction. Because of the flexibility of the dump design, it was possible to accommodate this gross change in system specification. The original wide range of reference beam parameters had resulted in our adoption of a neutral dump that permits the heat absorption panels to be reconfigured, as dictated by the power density distribution of the beam under test. This feature, which was a major mechanical complication to the facility, has thus created the benefit of utilizing the test stand for the testing of sources, the specifications of which were unknown at the time of the system design.

## Test Facility Description

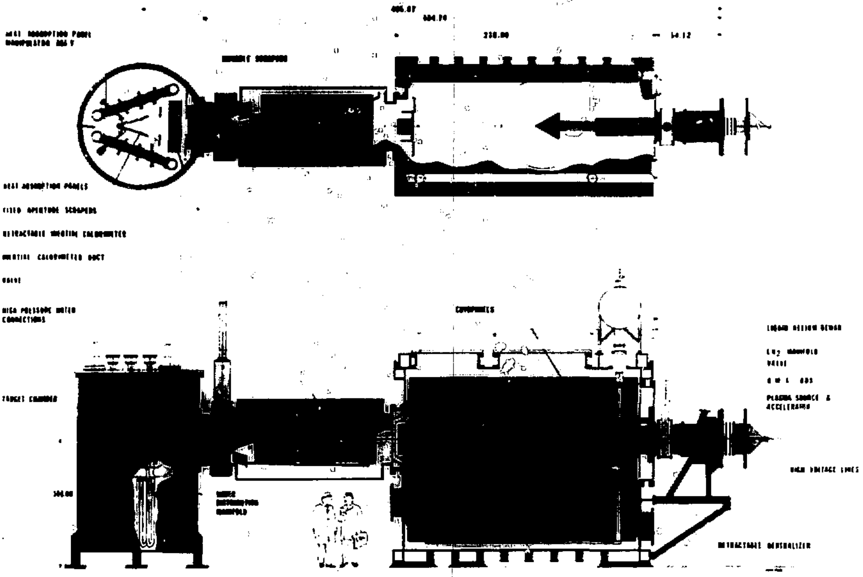
A side elevation and plan of the test facility is shown in Figure 1. As illustrated, the plasma source and accelerator under test are mounted on the far right of the facility and the accelerated mixed ion and neutral beam travels from right-to-left. During the first 2 m of travel, the beam is within the neutralizer section where the gas pressure is relatively high and the beam is neutralized by charge exchange collisions. To provide continuous armoring of the beamline, the neutralizer assembly is re-entrant to the source mounting valve and is capable of retraction when the valve is closed. The beam on leaving the neutralizer passes through the large cryopumped volume of the main vacuum vessel, into the inertial calorimeter duct, and finally into the target chamber. To provide flexibility in operations and improved diagnostics capability, the system can be operated in one of two configurations, one suitable for short pulses and the other for long pulse testing. For beam pulse lengths of less than approximately 50 ms, dependent on beam energy, the inertially cooled calorimeter is moved into the closed position and the beam energy is dissipated by its heat absorbing surfaces. During this mode of operation, the valve between the target chamber and the duct may be closed to permit maintenance within the target chamber during non-deuterium testing. For long pulse testing, the valve is opened along with the gates on which the inertial calorimeter plates are mounted. This permits the beam to pass on through to the actively cooled heat absorption panels of the long pulse beam dump. For each of these operating configurations, the facility water systems are designed to distribute cooling water to the components to meet the differing demands.

## Component Design and Fabrication

### Actively Cooled Long Pulse Beam Dump

#### Actively Cooled Panels

The heat flux levels and the long pulse length requirement made necessary the use of actively cooled heat absorption panels for this dump rather than the cheaper, more reliable, inertially cooled designs used in the past.[3] It was determined that a heat absorption panel capable of dissipating a surface heat flux of 2 kW/cm$^2$ would meet the needs of the facility. This power density was within the limits of available technology and thus reduced the technical risk to the project which was on a very tight schedule. The risk was however considered sufficiently high to justify going through a prototype phase prior to committing to production units. Two



CBB 839-8010

Figure 1 Neutral Beam Engineering Test Facility

industrially manufactured prototype heat absorption panels were tested on a neutral beamline at LBL as reported previously.[2] Following these tests, the panel manufactured by McDonnell Douglas Astronautics Company (MDAC) was selected for the production units to be used on the NBETF. The selection was based on minimizing the total system cost, including the cooling water system, whilst meeting the requirements of the LBL technical specification. The detail design of the MDAC heat absorption panel has been reported elsewhere[4] and the major parameters are given in Table 1. These panels are used in assemblies of five in the long pulse dump and individually as scrapers in other parts of the beamline where required by the heat flux levels. Amzirc was the selected material based on its strength retention at elevated temperatures and fatigue life. Copper electroplating which has been used in other fusion applications was eliminated from consideration due to the required manufacturing development time which was not consistent with the project schedule constraints. Furnace brazing was employed as the final assembly process. To minimize the water system flow rates and pressure requirements, the panels operate in the highly subcooled nucleate boiling region. The total flow requirements are further reduced by providing orifices at the exit of those panels which are located in positions where the heat flux level falls short of the 2 kW/cm$^2$ limit. The beam dump assembly, shown in Figures 2 and 3, is comprised of eight assemblies, each carried by a manipulator arm, and consisting of five MDAC panels. The five panels of each assembly are plumbed in parallel and supported by a combined supply and return stainless steel manifold. Thermal deflections of the individual panels are permitted through the use of bellville washers at the mounting bolts and bellows sections in the water connections. Water flow calorimetry is performed on each of the forty panels by water temperature increase measurement and flow calibrations. The water temperature is measured

Table 1

| | |
|---|---|
| Material | Amzirc Copper (0.2% Zr) |
| Actively Cooled Area | 21.5 cm x 20 cm |
| Heat Flux | 2 kW/cm$^2$ |
| Cooling Water Requirements | 3.66 ℓ/s at 1.45 MPa<br>0.72 MPa Drop<br>Max. Inlet Temp.: 43 °C |
| Design Life | >25,000 Thermal Cycles |
| Surface Material Loss Allowance For Sputtering | 0.73 mm |

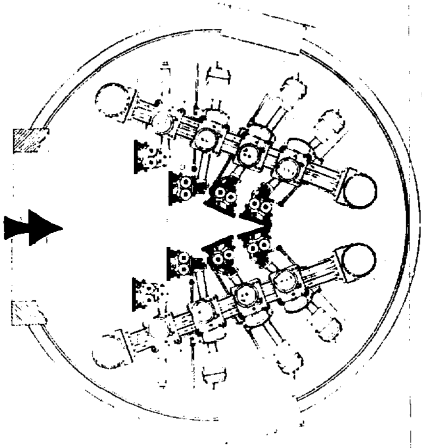


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Figure 2 Actively Cooled Beam Dump Assembly

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Figure 3 Beam Dump Assembly Installation

using ungrounded thermocouples to minimize the signal noise. Flow calibrations were achieved by individually calibrating each MOAC panel, with its appropriate orifice, if required, on the manifold assemblies to establish the pressure drop to flow characteristics. Following the final assembly of the panels onto the main beam dump, the complete system was calibrated by moving pressure transducers around the assembly to monitor the flow in the individual panels against the overall total system pressure drop.

## Panel Manipulators - Positioning Control

The need for positioning a segmented beam dump where the leading edge of any downstream panel must be accurately shaded by its upstream neighbor presented a precision positioning problem. A manipulator must correctly read out and position both panel rotation and linear travel along the beamline axis, otherwise, non-cooled portions of the heat absorption panel may be exposed and suffer damage from the beam. Also, as the angular position of the panels in some test beam cases could be as little as 4° to the beam, rotation errors in one direction could introduce heat fluxes much higher than allowable by design on the panel surface, and in the other direction could risk exposure of a non-cooled edge.

Our approach was to use a three axis positioning system for each panel assembly. The two linear axis components are translated along a pair of support ways with one axis traveling along the way and the other axis perpendicular to it. Each way is attached to two of the 21.6-cm-dia water supply and return pipes gimballed from the vessel cover. Panel rotation is provided through a gear box attached at one end of the linear travel axis; the gear box rotates the assembly, consisting of five heat absorption panels, a supply-return manifold, and a panel mounting structure. This smaller manifold assembly distributes coolant to the panels and provides locations for differential temperature measurement across each panel. It was determined that the required ±0.13 mm linear positioning could be achieved using conventional components: dc gear motors, precision spur gears and racks, ball bearings and precision shafting. This reduction drive system positions manipulators rolling on ball bearing wheels, preloaded against the support ways. Positional braking of each assembly for the two linear axes was inherent from the high impedance of the gear motors and the gear reduction drive train when at rest. For panel rotation, positional braking presented an additional problem. When torque was applied to the panel and gear box assembly from the force of the water hoses at pressure, excessive rotation from gear box backlash would allow the panels to rotate as much as 5°, far greater than the allowable tolerance of ±0.1°. A linear braking mechanism was added which would electrically release during rotational positioning, allowing free rotation and when de-energized would lock up the required rotational limit to ±0.1° of true position.

Position sensing was accomplished using potentiometers with anti-backlash gearing coupled to each of the manipulator's three axes. As an independent cross check to positioning, each manipulator also has a LVDT attached on each of its three axes and set to give maximum signal at some predetermined point. When passing this point, the output of the rotary potentiometer is compared to the initial reading taken at the time of calibration. In this way, any change in potentiometer readings with time will be detected.

All ball bearings and rotating components were degreased and treated with a Dicronite* dry lubrica-

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*Northwest Dicronite, Mt. View, CA 94043 tion process applied to reduce friction and prevent galling. This process was found to be compatible with the vacuum environment and to give the necessary lubricating qualities to allow smooth operation.

## Structure, Manifolding, Hoses

It was anticipated that the beam dump assembly would need periods of maintenance during the long term testing phase of NBETF, particularly in regard to relocating the heat absorption panels upon reaching the limit of their sputtering allowance. Efforts were made in the design to allow for easy removal of the assembly from its vacuum vessel by supporting the entire dump assembly from the vessel cover to permit it to be lifted out of the vessel with a crane for any necessary maintenance. This presented a problem in that the vacuum load on the 7.6 cm thick vessel cover introduced a deflection of around 0.5 cm which in turn would be transmitted to any support structure coupled to it. This would in turn induce stress in the structure and distortion of the critical alignment of the dump. This was overcome by a unique design which incorporated the four main 21.5 cm diameter coolant supply and return pipes into the main supporting structure. These four main cooling pipes were isolated from the deflection of the vessel cover by placing each of them on gimbals where they penetrate through the cover into the vacuum. Each gimballed pipe has a cover bellows which provides a vacuum seal and allows the vessel cover to rotate beneath the gimbal and pipe when under vacuum load. This design allows the cover to deflect under the vacuum load without introducing any structural stress which would affect the alignment of the NBETF dump.

As the eight heat absorption panel assemblies are required to be repositioned through as much as 90° rotation, it is necessary that the water supply and return lines feeding these assemblies must also accommodate this rotation. Mockup testing of 7.6 cm diameter hoses showed that a pair of 3 m hose lengths would permit the 90° rotation without undue distortion or excessive loading on the manipulator mechanisms. The hoses selected were constructed of stainless steel bellows reinforced by wire braid. These hoses couple the main supply and return manifolds to the manipulator and heat absorption panel assemblies while still not inhibiting their required positional movements.

## Calorimeter

As briefly described earlier, the calorimeter is located in the test facility beamline between the main vacuum vessel and the target tank at 9.0 m downstream from the accelerator. This component was designed to be a beam power density profile diagnostic for short pulse testing and when opened for long pulse running serves as wall armoring for the duct. It is also used to center the beam in the beamline as this is critical for the active dump. Figure 4 shows the duct and calorimeter removed from the beamline; the calorimeter is in the closed position and the view direction is in the beam direction. The primary heat absorption elements consist of twenty-four 30.4 cm x 50.8 cm x 1.9 cm thick copper plates mounted as two arrays on two moveable frameworks or gates. Each plate is cooled between beam shots by conduction to cooling water lines brazed on the back. Previous experience with inertially cooled beam dump designs has verified that thermally induced stress can exceed yield. This causes warpage of the panels that can increase with time. This problem has been minimized in our design by the use of small modular panels, rather than large, single units, and by using flexible mounting attachments to the gates. Both techniques reduce the panel constraint and thus induced stress. With the gates in the closed position, the panels in the center, and thus high heat flux region of the beam, are held at an angle of 6° to the beam axis. The overall size of the calorimeter is minimized by increasing this angle progressively for those panels in the outer regions of the beam. To ensure that no edges of panels are exposed to the beam, each panel upstream edge is shaded by its upstream neighbor. Thermal distortions of these panels are continuously monitored using LVDT sensing devices; this is used as a guideline by the test stand operators to judge when the maximum beam pulse length has been reached at which time the gates are opened and further testing is continued with the beam passing on through the duct to the actively cooled beam dump. An array of 153 thermocouples measure the local temperature increase of the copper plates and thus the beam power density distribution. The thermocouples are spot welded onto thin sheet stainless steel pads brazed to the back of the panels. We have used this technique on many beamline components as it provides a good surface thermal contact and thermocouple replacement is simple. The upper and lower walls of the calorimeter duct are protected by 9.5 mm thick water cooled copper plates.

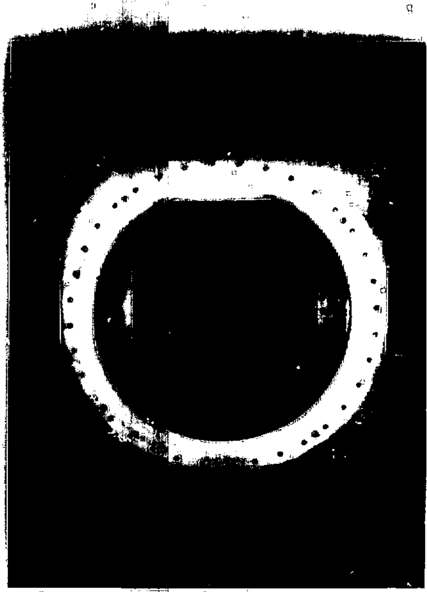

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Figure 4 Duct Calorimeter

The calorimeter was the first major beamline mechanical component to be installed during the test stand upgrade and was used as the only beam dump in the facility during the initial debugging of the power supplies.

## Neutralizer

To ease the severity of the design problem of long pulse operation at the neutralizer section, the 51 cm diameter souce mounting valve used on NBSTF was replaced with a new 61 cm diameter valve. Analysis of the heat flux in the region of the neutralizer and the solid angle to the accelerator grids made it essential that continuous armoring be provided over the entire neutralizer section. This requirement was met by adopting a moveable neutralizer design; the unit is re-entrant to the source mounting valve during beam operation and retracts to permit the valve to close. The neutralizer unit was designed to dissipate a local heat flux of 200 W/cm$^2$, and a total power of 1.1 MW. These parameters were established from extrapolations of data accumulated during the operation of NBSTF. The neutralizer is shown on its supporting framework in Figure 5. The internal dimensions are 17 cm x 50 cm x 123 cm. The neutralizer is a brazement of four 1.27 cm thick copper plates and cooling is provided by 6.4 mm diameter gun-drilled water passages at 12.7 mm spacing. The cooling passages pass circumferentially around the walls; thermocouples placed in the water passages and measuring the temperature rise of water flowing in a single circuit are used to verify centralization of the beam in the neutralizer. The neutralizer is pneumatically driven by a bellows which is evacuated to retract the unit or pressurized with ambient air to insert it into the valve aperture.

## Beam Scrapers

Several differing designs of beam scrapers are employed in locations throughout the beamline. They are located so as to provide complete line-of-sight protection from the exit grid of the accelerator all the way to the actively cooled beam dump. Three basic designs have been used, brazed-on cooling lines, gun-drilled interior passages, and MDAC panels. For heat flux dissipation of <100 W/cm$^2$, the brazed cooling line approach is adequate. For higher heat fluxes, increased surface area is needed and we thus adopted gun-drilled interior passages as our design. We used this technique up to 1.0 kW/cm$^2$ beyond which it became necessary to use the MDAC panels. The most severe scraper requirement in the beamline occurs at the entrance to the source mounting valve in the Optical Mass Analyzer (OMA) section. In this region, scrapers must be provided to protect the entrance of the neutralizer. MDAC panels were used to protect the top and the bottom of the neutralizer entrance. For each side which is in the narrow dimension of the beam, we used three nesting scrapers, cooled using gun-drilled passages and designed to operate in the subcooled nucleate boiling region at heat fluxes up to 1 KW/cm$^2$. Figure 6 shows the components of these scrapers prior to final brazing.

## Source Mounting

The design goal in the source mounting area was to make the source as accessible as possible. The long pulse sources to be tested on the facility have a considerable number of cooling water lines and electrical cables that must be attached. Quick disconnects are provided where possible and self sealing fittings were used on the water lines. For operation above 80 kV, a clear vinyl bag can be pulled over the accelerator insulator section to provide a SF$_6$ enclosure. The accelerator is steered using the original mechanism used on NBSTF and the required motion is provided by a rectangular welded bellows of inside dimensions 28 cm x 64 cm. Figure 7 shows the source installation without the SF$_6$ jacket in place.

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Figure 5 Installed Neutralizer

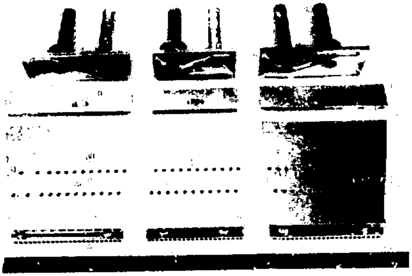

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Figure 6 OMA/Neutralizer Entrance Side Scrapers

## Cooling Water Systems

The test stand cooling water is supplied by several systems depending on the needs. During short pulse testing, the cooling water to all the exposed surfaces is supplied by the Laboratory low conductivity water system (LCW). During long pulse testing when the actively cooled dump has to be used, cooling water is supplied to it, the neutralizer, and the OMA scrapers by the Primary High Pressure Cooling System (PHPS) built for the test stand. In addition, the laboratory city water system is automatically activated during a power failure or on loss of LCW supply pressure, to prevent freezing of components exposed to the cryopanels.

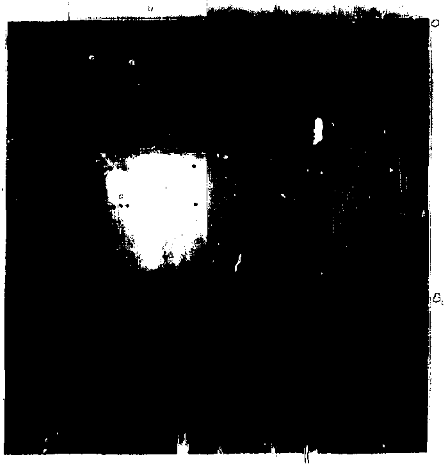

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Figure 7 Source Mounting

During long pulse testing but for moderate beam-on times of 10 s or less, the PHPS pump is operated at a constant speed. For longer beam-on time at a 10% duty cycle, the PHPS pump is cycled up and down in speed to save energy.

During change over between LCW and the PHPS, the water lines are flushed to prevent contamination of the Laboratory LCW system.

Primary High Pressure System

The PHPS is a closed loop system, a schematic of which is shown in Figure 8. It was designed to satisfy the original NBETF design parameters which included a separate 8 MW ion dump. The main pump, driven by a 1500 HP electric motor through a variable speed hydraulic drive, supplies water to the test stand from the cold side of a divided reservoir. The water is returned to the hot side of the reservoir, where 63 ℓ/s is passed through a heat exchanger and dumped into the cold side. The remainder of the heated water spills over the partition and mixes with the cold to give the temperature range required by the active dumps. The cooling tower loop supplies cooling water to the main heat exchanger as well as to the variable speed drive.

The variable speed drive allows the pump to be operated at any speed between 3460 r/min and 720 r/min. For constant speed operation, the pump is run at the lowest speed that gives the required pressure and flow, thus resulting in the minimum power usage. The pressure reducing valve, back pressure valves and the bypass piping allow the final adjustment to the pressure and flow. Though not presently in use, there is the capability to raise the entire system pressure by pressurizing the reservoir up to its design pressure of 1.65 MPa.

During a series of beam shots, at a 10% duty cycle, the pump is run at high speed when the beam is on and cooling water is required, and at low speed for 90 of the cycle time between beam shots when cooling water is not required. Figure 9 shows the pressure measured at the inlet and outlet of the main dump manifold during one cycle.

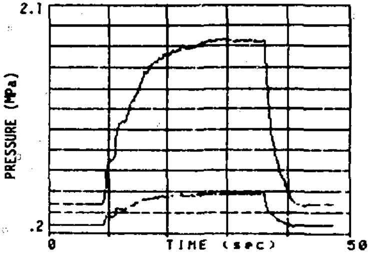

Figure 9 Inlet and Outlet Manifold Pressure

The pump performance test curve is shown in Figure 10. Also shown are the calculated pump curves for various speeds and the present high (2950 r/min) and low (720 r/min) speed operating points. The measured flow agrees reasonably well with the flow shown by the manufacturer's pump curves at the operating points.

Power Usage

The power usage calculated using manufacturer's supplied efficiencies is as follows:

Main Pump - Design 1025 kW
ΔP = 2.6 MPa, 315 ℓ/s, 3460 r/min

Main Pump - Present High Speed 728 kW
ΔP = 2.0 MPa, 220 ℓ/s, 2950 r/min

Main Pump - 10% Duty Cycle
0.1 x 728 + 0.9 x 128 = 188 kW
High Speed = 2950 r/min
Low Speed = 720 r/min

In all the cases, a total of 72 kW is added to the above figures for the hydraulic drive oil pump (6.8 kW), reservoir pump (28.4 kW), and cooling tower pump (41.4 kW).

Cooling Water Temperature

The calculated reservoir water temperature is shown in Figure 11. The calculations were for a 170 keV, 65 A, 10% duty cycle beam, the original test stand specification. Note that the 10 s beam with constant speed pump operation is the controlling case for the cooling system design.

Control

The system is operated under computer control. The main pump chain incorporates safety switches that prevent the pump from being started or shuts it down if: lubricating oil pressure and flow are too low or the temperature too high; the valves in the high pressure loop are closed; the water pressure is too high; excessive mechanical vibration; and beamline vacuum failure, indicating a water leak.

The beam chain prevents the beam from being fired or shuts it down if water flow and pressure are too low or if cooling water temperature is too high.

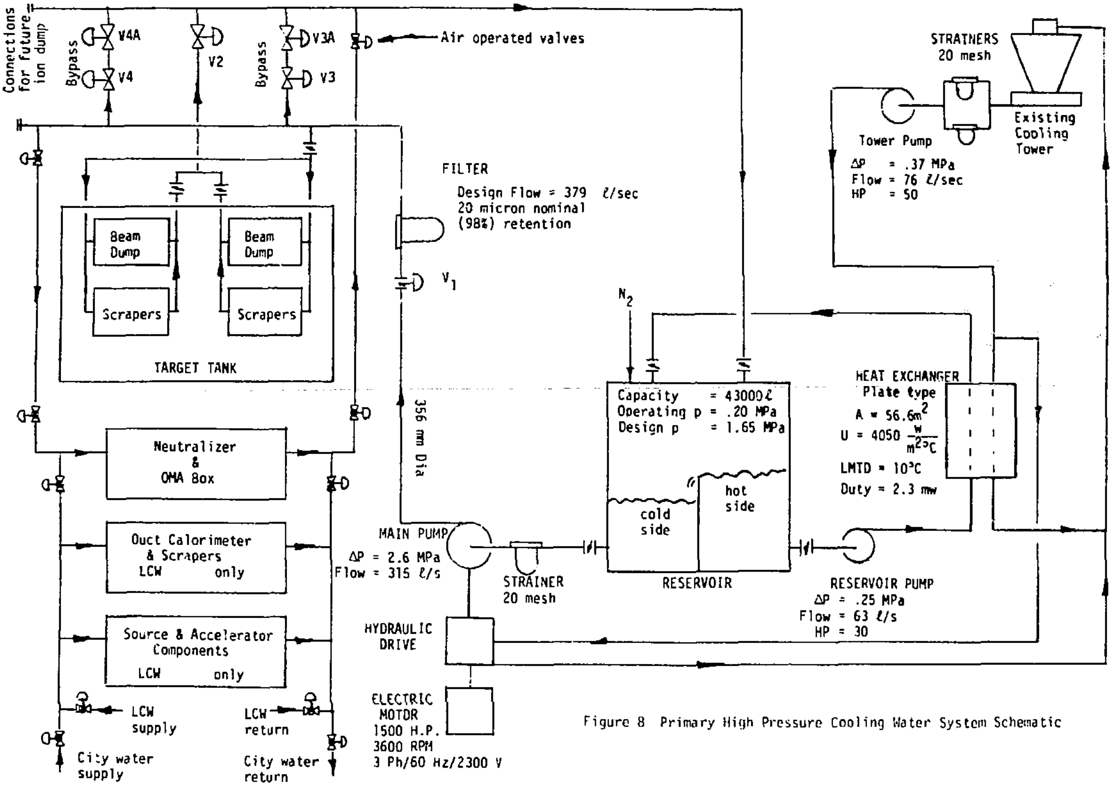

Figure 8 Primary High Pressure Cooling Water System Schematic

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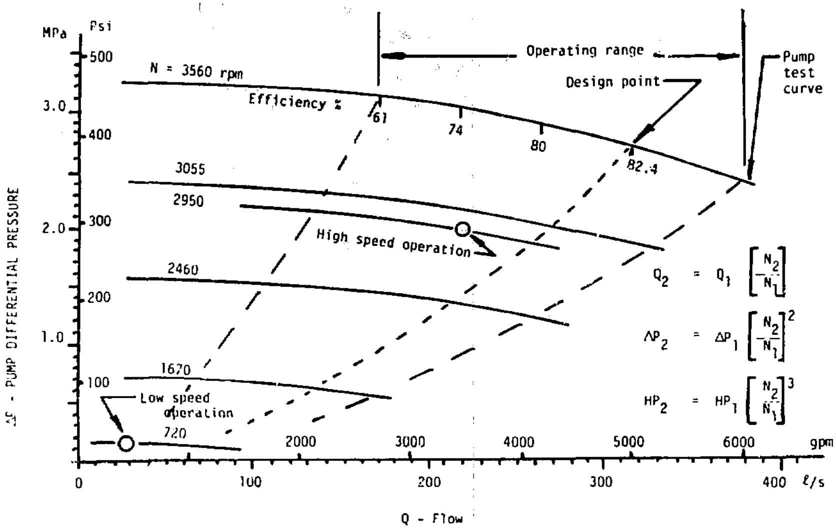

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Figure 10 Main Pump Performance Characteristics

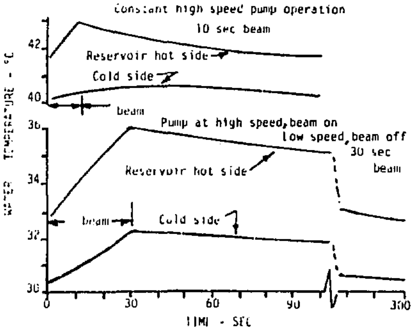

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Figure 11 Calculated Reservoir Water Temperature

The hydraulic drive output speed is controlled by the position of an electric actuator driven scoop tube, which determines the oil level in the impeller.[6] The electrical signal to the actuator is proportional to the scoop tube position and therefore the output speed. With this open loop control, the pump high speed repeatability is better than ±1.5% resulting in the repeatability of flow and pressure of ±1.5% and ±3.0% respectively.

The pressure control valves V1, V2, V3/3A, and V4/4A are air actuated, positioned by pressurizing the actuator through a manually adjusted pressure regulator. Once the valves have been set for any given high speed selection, they do not have to be readjusted.

### Materials and Water Treatment

Only stainless steel and copper are used for the piping between the filter elements and the beam dumps. Carbon steel is used for all the remaining piping and equipment. The carbon steel was cleaned by circulating a NALCO 2568 (sulfamic acid) solution. The system was neutralized, rinsed, and passivated using NALCO Eliminox which is an oxygen scavenger. A positive nitrogen pressure was kept in the system at all times. The system was finally filled with low conductivity water (LCW) and NALCO 2592 (borate buffered sodium nitrite) corrosion inhibitor. This was acceptable as the cooling water has no requirements on its conductivity, the LCW was used to keep the undesirable mineral content as low as possible. The final cooling water has a 800-850 ppm $NaNO_2$ concentration (3.9 gm NALCO #2592/ℓ = 1000 PPM $NaNO_2$), a Ph of 11, and a conductivity of $4.4 \times 10^{-3}$ ohm/cm.

### Shielding

The original 61 cm thick concrete shielding blocks used for NBSTF were retained for neutron shielding of the facility. The only modification was the removal of the entrance maze, at the source mounting region, and its replacement by a 61 cm thick water filled sliding door.

## Cryosystem

The original cryosystem and cryopanels used on NBSTF are used for the NBETF; this system has been described previously.[4]

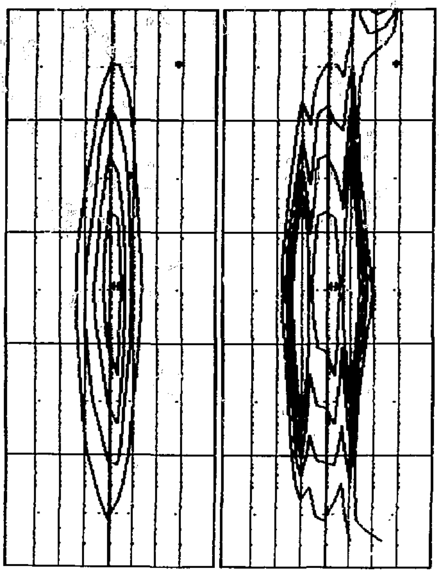
## Operating Experience

The facility was commissioned in April, 1983 and since then has been the test bed for two long pulse source designs for the new 30 s beamlines planned for MFTF-B, one was an ORNL design and the other was the LBL Long Pulse Accelerator. Sample beam profile data taken during these tests is shown in Figure 12. We have found that the optical qualities of the beam can be determined on the calorimeter for pulse lengths greater than 10 ms and on the actively cooled long pulse dump for pulses of 200 ms or longer. Because of the required flushing of the water lines on changing from one mode of operation to another, some 10 minutes delay in beam operation is needed; during this time, the source is operated with arc only.

As the ORNL and LBL sources have significantly different beam dimensions and power density profiles, it is necessary to reconfigure the panels of the long pulse dump when the source is changed. This is achieved remotely with the target chamber under vacuum and takes about four hours. This time is insignificant compared to the some two weeks needed to install a source and to debug the instrumentation.

## Bellows Failures

The most serious interruptions of operations were experienced during the LBL accelerator test. This occurred due to water-to-vacuum leaks in the bellows at the supply and return fittings of the MDAC panels in the active dump assembly. As the active dump is a highly congested large assembly, it is an extremely difficult system to leak hunt. During our initial commissioning, it took almost two weeks to find a leak which was eventually traced to a MDAC panel. To reduce this time, operations were continued until each leak became so large as to be a visible water drip with the system pressurized and up-to-air. The water treatment chemicals were also found to aid in the process as light blue powder could be seen in regions where the water had evaporated. At this time, the leaks were incorrectly diagnosed as being as a result of bellows over-compression during assembly. As the problem had become so serious, and as the ORNL test program did not require any long pulse operation for six weeks, it was decided that all the bellows would be replaced with units that could be removed and easily replaced. These bellows sub-assemblies were to be brazed assemblies which was the same joining technique used on the original bellows. During hydrostatic testing of the prototype replacement unit, it was observed that yielding was occurring in the bellows at 1.4 MPa. Consultation with the manufacturer revealed that the bellows material strength was achieved through cold work and thus brazing would anneal the material and should not be employed. To rectify this problem, the bellows sub-assemblies were changed to a welded design. The modified design was able to withstand 2.9 MPa during hydrostatic testing. The yielding of the original bellows assemblies during hydrostatic test had not been observed as these tests were performed remotely for reasons of safety. The test stand is now operational with all brazed bellows replaced by removeable welded sub-assemblies. To date no problems with the new design have been experienced.



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08/12/83 02:14
Beam-on Time 30.854 s
Shot 96855

Est. Power Density
(H) Max. 715 W/cm$^2$
Min. 0 W/cm$^2$

Contour Levels
Watts/cm$^2$
572
429
286
142

(*) 2 Bad Sensors

$I_{Accel}$ 40.3 A
$V_{Accel}$ 80.8 kV

Figure 12 Sample Data From Actively Cooled Dump

## Long Pulse Cooling Requirements - Reflected Energetic Particles

During the first months of operation, the diagnostics were effected by large noise signals on the thermocouple readouts of the actively cooled dump. This problem was traced to drain currents in the leads of the grounded thermocouples. These have now been replaced with ungrounded sensors; however, as the lead time for these was long, attempts were made at the time to improve the situation. Thin stainless steel shields had been provided on the back of the MDAC panel assemblies to provide shielding from the plasma. It was observed that several caps securing the thermocouples were contacting these shields, thus providing additional paths to ground. To isolate the thermocouples, thin organic insulator material was pop-riveted to the shields. Inspection of this insulation subsequent to further long pulse testing revealed that severe charring had occurred. Thermocouples on the heat shields were installed and further testing indicated extremely high temperatures of around 400 °C were being reached on the shields. This indicated heat fluxes to these surfaces of about 1.0 $W/cm^2$ and they were located in regions where reflected high energy particles could impact. Although these heat fluxes were very low, the total energy absorbed during a long pulse was more than the thin stainless could dissipate. During our shutdown to replace the bellows, all the shields were replaced with 3.1 mm thick copper and the conduction path to the cooled water manifolds was improved. This experience has emphasized the severe cooling requirements that must be met for long pulse operation.

## MDAC Panels

To date the MDAC panels are performing as designed, indicating no presence of thermal hydraulic problems. Heat fluxes up to 1.6 $kW/cm^2$ have routinely been dissipated over several thousand beam shots. A few panels did develop small vacuum leaks at braze joints in regions of discoloration. Analysis performed at MDAC showed the presence of copper nitrate. This is attributed to the nitric acid etching of stainless bolts used for fixturing during the braze process. Residue of this acid would attack the copper and give the observed result. Improved cleaning of components prior to brazing will eliminate the problem. All leaks are easily fixed using the TIG brazing technique with the original braze alloy consisting of 61.5 AG, 24 Cu and 14.5 In.

## Summary

The upgrade of NBSTF to the long pulse NBETF has greatly increased the complexity of the mechanical systems. With the exception of the bellows leaks, the system has performed well and will in the future produce essential information needed for the design of long pulse neutral beam heating systems. It has identified the need to take into consideration the low heat flux on components resulting from reflected energetic particles-heat fluxes, that have been of no significance in the short pulse beamlines that have so far been fabricated. The adoption of a moveable long pulse beam dump has given great flexibility to the facility and has made possible the testing of sources that are beyond the original specifications for the beamline. The original beam dump was to dissipate 5 MW; we now believe that potential Tokamak Fusion Test Reactor (TFTR) long pulse beams can be tested on the facility up to 8.4 MW. The limits are expected to be dictated by the beam scrapers during the testing of focused beams.

Future plans for the facility include a major reconfiguration to test the Pure Beam concept for the MFTF-B beamlines and further positive ion testing up to 120 keV. As presently planned, the major mechanical systems are to be incorporated where feasible into a new Negative Ion Test Facility, beginning in April, 1985 when the testing needs of the Positive Ion Program have been met.

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