TPX/TFTR NEUTRAL BEAM ENERGY ABSORBERS

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INTRODUCTION

The present beam energy absorbing surfaces on the TFTR Neutral Beams such as Ion Dumps, Calorimeters, beam defining apertures, and scrapers, are simple water cooled copper plates which were designed to absorb (via their thermal inertia) the incident beam power for two seconds with a five minute cool down interval between pulses. These components are not capable of absorbing the anticipated beam power loading for 1000 second TPX pulses and will have to be replaced with an actively cooled design. While several actively cooled energy absorbing designs were considered, the hypervapotron elements currently being used on the JET beamlines were chosen due to their lower cooling water demands and reliable performance on JET. Table I summarizes the size, location (relative to the source) and the peak power requirements of the various beam components.

HYPERVAPOTRONS

Figure 1. illustrates the basic configuration of a typical hypervapotron element that will be used on the TPX beamlines. The essential features of the hypervapotron design are the rectangular cooling water channel with the coolant flow running perpendicular to the 4mm deep grooves machined into the interior surface of the beam facing front plate. Cooling takes place within the normal turbulent flow forced convection regime and possibly into the low range nucleate boiling regime when the heat flux approaches 1.0 kW/cm^2 . The machined grooves provide a larger surface area than a smooth walled duct for enhanced heat transfer and also induce local eddy currents from the main flow channel to continuously flush the grooved cavities removing the heated water and any water vapor bubbles forming on the groove surfaces.

Material: Cu, Cr, Zr (CDA18100)

Fig. 1. Typical Hypervapotron Element

Various investigators have reported^{1,2,3} on the performance of the hypervapotron and based on these findings it appears that a flow velocity of 3 to 4 meters/second at a pressure of 4 to 5 Bar should be adequate to absorb incident heat fluxes of up to 1 kW/cm^2 provided the bulk fluid temperature rise is limited to 80°C and that the serial flow path length does not exceed 1 meter. To insure adequate safety margins, and keep the vapotrons operating well below their critical heat flux limits, all scrapers for the TPX neutral beam modification will be angled to the incident beam sufficiently to limit the peak incident power to less than 1.0 kW/cm^2 , and will be limited in length to 1 meter. It should also be noted that due to the extra heat

capacity of the finned geometry, the critical heat flux (to burn-out) is significantly higher than the departure from nucleate boiling point, and thus provides an additional margin of safety.

The typical scraper vapotron array elements will be spaced approximately 2 mm apart to allow for thermal expansion and ease of assembly. To prevent beam shine thru when the vapotron elements are oriented parallel to the beam, their sides will have a slight draft angle. The mounting arrangement for a typical scraper support is illustrated in figure 2. The forged-in (or brazed-in) tabs protruding from the rear of adjacent vapotron elements fit between fixed clevis brackets (for ease of assembly and preload flexibility, one bracket may be adjustable) with two partially compressed spring washers sandwiched in between to provide preload and also accommodate the lateral thermal expansion of the elements (approximately 0.4 mm). The holes in the clevis attachment at the far end will be slotted to allow for the longitudinal expansion of the vapotron elements.

Fig. 2. Typical Hypervapotron Mounting

The service life of the vapotron elements is dependent on several factors including sputtering erosion and fatigue. Since TPX will have a relatively small number of pulses, with the total number of beamline thermal cycles (injection + conditioning) not exceeding 10,000. Since the maximum calculated stress in the vapotron is less than 20 ksi, and the minimum specified yield strength of the CuCrZr is greater than 29 ksi, the vapotron elements will be operating within the 2/3 rd yield design allowables and should be well below any fatigue life limits. The 4mm thick front surface wall provides sufficient margin for sputtering and erosion.

SOURCE HOUSING SCRAPER

The source housing scraper is the first beam defining aperture intercepting the edges of the ion beam as it exits the source. Figure 3. illustrates the basic configuration. A rectangular array of dual hypervapotron elements will start at a distance of 24 cm from the source exit and will have vertical sides running parallel to the beam axis, while the top and bottom horizontally oriented vapotron elements will have a 2° tilt relative to the beam axis, producing an exit defining aperture of 42.22 cm high by 12.78 cm wide. The assembly will be supported near the exit end with a clevis arrangement illustrated as in figure 2, which will be anchored to the downstream side of the source housing flange. The entrance end will

be cantilevered out from the source housing flange with the array elements connected via the detail illustrated in figure 3 below.

Fig. 3. Source Housing Scraper

This scraper will intercept 4.8% of the total 8.4 MW beam power with the peak heat flux of 0.79 kW/cm^2 nominally, and 0.89 kW/cm^2 with a half degree source vertical misalignment. Since a large portion of this energy will be intercepted by the top and bottom vapotron elements, they will require the majority of water flow for this scraper. Approximately 12 GPM (0.75 l/sec.) of coolant flow with a mean stream velocity of 15 ft./sec. (4.6 M/sec.), will limit the bulk temperature rise of the fluid to 100° F . The flow requirements for the side elements will be less than 2 GPM each producing a total water demand of 40 GPM for this scraper.

THE OMA SCRAPERS

The center beam Optical Measuring Aperture (OMA) scraper is illustrated in figure 4. above, and will be similar in configuration to the source housing scraper with vapotrons oriented parallel to the beam axis. The scraper will run from 7 mm beyond the exit of the source housing scraper to the source isolation valve flange, and will have a exit aperture of 43.18 cm high by 14.62 cm wide. Since the top of the center beam scraper must permit a diagnostic top view of the beam, there will be two vapotron elements on top with a 75 mm gap in between to allow for the required 6.3 cm aperture at a viewing angle of 60° down the beam axis. The side beam OMA scrapers will be axially shorter than the center scraper. This is to allow the staggering of the larger 630mm source isolation valves. These side scrapers will have an additional aperture at the horizontal midplane arranged in a manner similar to the center scraper but without the downstream element. To protect the leading edge of the top down stream vapotrons on the center beam scraper, both upstream and

downstream elements will be tilted approximately 2° to the beam axis in a louvered fashion. The entire assembly will be supported by

Fig. 4. OMA Scraper

brackets anchored to the interior walls of the OMA enclosure at the exit and entrance in a manner similar to the source housing scraper support described above. Short cantilevered brackets will support the leading and trailing ends of the elements interrupted for the viewing apertures. The downstream end element attachments will be fixed while the upstream end attachments will use slotted holes to allow for thermal expansion of the vapotrons.

The peak power density (with 0.5° beam misalignment) on the OMA center beam scraper will be 0.6 kW/cm^2 at the top and bottom exit (without shadowing from the source housing scraper). The peak power on the top and bottom of the side beam OMA scrapers will be slightly higher at 0.614 kW/cm^2 due to their closer proximity to the source (again neglecting the partial shadowing effect of the source housing scraper). The total power intercepted by the center beam scraper will be 0.4% or 32 kW. The total power on the side beam scrapers will be 27kW. The total cooling water requirements for the center beam scraper will be 18 GPM (14 GPM for top and bottom and 4 GPM for the sides). The total cooling water required for the side beam OMA scrapers will be 16 GPM.

NEUTRALIZER CELL

The neutralizer cell vapotron elements will also be oriented parallel to the beam axis extending from the source isolation valve flange to a point 116cm beyond the 90" main enclosure flange. The two side beams will require additional 43cm long sections upstream to shield the rectangular nozzle which extends from the 630mm valve mounting flange to the 90" main enclosure flange. Since the neutralizer cell must contain a specific volume of gas for effective charge exchange, the small horizontal gaps required between vapotron elements to accommodate thermal expansion, must be sealed to prevent excessive gas leakage. This will be accomplished by

brazing a light gage stainless steel strip between adjacent elements. The aperture of the main neutralizer will be the same as the existing cell (15.32 cm. x 50.32 cm.).

FIG. 5. Neutralizer Cell Assembly

The peak power impinging on the neutralizer cell elements will be 0.15 kW/cm^2 at the cell top and bottom exit, and the total power absorbed will be 0.84 MW. The assembly of 26 vapotron elements comprising each of the three neutralizer cells will require 75 GPM of cooling water supplied by two 1" vertical headers at the 90" main enclosure flange with two similar headers, for the return, at the cell exit. The individual vapotrons will be connected to the supply and return headers with 3/8" flexible stainless steel hose to permit easy assembly and allow for thermal deflection of the vapotron elements. The neutralizer assemblies will be supported by a cantilevered frame with lateral cross bracing between cells as in the existing support. The flange attachments to the vapotrons will be similar to the mounting details for the previously described scrapers with slotted holes at the downstream ends and plain pivot holes at the upstream ends. The Neutralizer assembly is illustrated in figure 5.

MAGNET SCRAPERS

The pre magnet side scrapers will be located just ahead of the entrance field clamp of the bending magnet at an angle of 45° to the horizontal axis of the beam. Two vapotron elements per side with a minimum aperture width of 15.3 cm., will be arranged in a louvered fashion at 15° (at a 45° plane to the beam axis) to provide shadowing for the magnet field clamps and pole piece. The upstream element will overlap the downstream element leading edge to provide shadowing for the less acutely angled side surface of the vapotron (the upstream side leading edge is in the partial shadow of the neutralizer cell and will receive a flux of only 10 W/cm^2). Upper and lower vapotron elements angled at 5° to the beam axis will provide shadowing of the magnet yokes. The existing edge cooled copper plates covering the magnet pole faces should be adequate since they are completely shadowed by the pre magnet scrapers and should not see any direct beam energy. The peak beam power on the magnet scrapers (at an effective grazing angle of 10.5°) will be at the exit of the downstream elements just below the beam horizontal axis and will be 0.79 kW/cm^2 . The total beam power absorbed will be 0.11 MW, requiring a total cooling water flow of 28 GPM per beam.

ION DUMP

The present full energy ion dump for the TFTR 2 second pulse neutral beam is a 2" thick curved copper plate which absorbs the beams' 7.5 MJ of ion energy via its thermal inertia. For the 1000 second pulse lengths of TPX operations, actively cooled surfaces will be required. The new beam dump design (see Figure 6.), will utilize the same type of vapotron elements as the beam scrapers. The basic geometry of the new dump will be similar to the existing one except for the addition of one meter in the height of the full energy and one third energy absorbers, and the tilting of the full energy dump surface by 5 degrees from vertical. The increased height and tilting of the dump is necessary to raise the interception point and decrease the incident angle of the full energy ion beam (thereby reducing the peak power density below 1 kW/cm^2). By operating the beam bending magnet at 2.32 kG the center of the full energy D^+ ions will intercept the beam dump surface approximately 128cm above the beamline horizontal center plane (approximately 28 cm higher than the existing beam dump with the magnet running at 2.2 kG). This will have the beneficial effect of reducing the incident heat flux on the dump surface by reducing the grazing angle of the beam and also will lengthen the distance from the beam focus to the point of beam impingement. The peak power density on the full energy dump will be 0.97 kW/cm^2 at approximately 30cm below the beam center incidence point for the center beam. The peak power density for the two side beams will be slightly less due to the compound angle of incidence on the curved full energy dump surface. (This added angular attenuation of the side beam power density is partially offset by the closer proximity of the side beam focus to the dump surface). To accommodate the taller beam dump the existing top 72" diameter flange cover plate will have to be modified by adding a 34" high 3/4 semi-circular top hat section.

The full energy ion dump will absorb nearly 90% of the total ion power of the beam. This dump will be comprised of two, nearly vertical cylindrical arrays consisting of 13 dual, parallel flow, hypervapotron elements each, assembled one above the other. Both arrays will be tilted 5 degrees from vertical with the vapotron elements slanted and slightly staggered at the end to produce a horizontal planer interface with the half energy array positioned just above it. The supporting structural frame will be fabricated from rolled mounting brackets staggered periodically to mate with the mounting tabs protruding from the rear of the vapotron elements. The curvature of the circumferentially rolled sections will be slightly elliptical to accommodate the 5 degree tilt.

Fig. 6 Ion Dump & Pre-Calorimeter scraper

Spring washers will provide compliance for the lateral thermal expansion. The support brackets on one end of each array will be

slotted to accommodate longitudinal expansion. Four vertical welded stringers will tie the curved sections together producing a semi-circular frame assembly.

The half energy ion dump will be oriented horizontally just above the full energy dump and will consist of an array of 11 dual, parallel flow vapo-trons. The top support frame connections will be similar to the full energy dump assembly described above. The third energy ion dump will consist of two arrays of 11 dual, parallel flow vapo-tron elements oriented vertical directly opposite the full energy dump. These two flat arrays, mounted one above the other, will extend from the lower surface of the half energy dump down to the top exit of the bending magnet and will intercept the third energy ion component of the beam along with any lower mass or lower energy ions.

ION DUMP COOLING SYSTEM

Since the curved full energy dump spans only 110 degrees of arc there will be sufficient clearance on the sides of the dump assembly to run two 3 1/2" IPS vertical downcomers feeding the 624 GPM of water required for cooling. Four 2 1/2" IPS branching supply headers will be curved half-way around the back of the lower dump array supplying the left and right, upper and lower dual vapo-tron elements via graded flexible metal hose. The cooling water will exit the lower vapo-tron elements at the bottom entering 2 1/2" IPS curved, semi-circular return headers which connect to vertical risers running up and through vacuum feed-thrus in the top hat cover plate. The upper vapo-tron elements will also be attached via flexible metal hose to an upper return header located above the half energy dump array. Flexible, braid-reinforced corrugated metal hose will be used to mechanically decouple all the water piping from the vacuum feed-thrus. Two 1 1/2" IPS headers will be used for the supply and return of the 108 GPM flow required for the horizontally positioned half energy vapo-tron array, located just above the full energy dump. Four 1 1/2" IPS headers will be required to supply 200 GPM of water for the flat, vertically oriented third energy dump array located directly opposite the full energy dump. The total cooling water required for the system will be 932 GPM. Optimization of water utilization by selectively reducing the flow to vapo-tron elements that are less severely heated may reduce this flow by as much as 20%.

PRE-CALORIMETER SCRAPER

The pre-calorimeter scraper is required to define the cross section of the incident beam on the calorimeter. The scraper assembly will provide separate apertures for each of the three beams (sources), and must provide calorimetric instrumentation capability to measure the beams' horizontal alignment. The top and bottom scraper elements extend from the magnet exit to the calorimeter aperture to provide shielding for the off-normal event of energetic heavy ions (+/-) in the beam at the entrance of the bending magnet. The assembly is a stand-alone structure attached to the NBI box and is not removable as an integral unit with the calorimeter assembly (as is the case with the present TFTR design). The scraper assembly provides three 22.2 cm. wide by 57.4 cm. high beam apertures at 535 cm. from the source, each centered on the respective beam axis.

The edge-to-edge distance between adjacent vertical apertures is 11.4 cm. This space is sufficient for two side-by-side vapo-tron elements oriented facing the beams head-on. The peak flux at the aperture edges is less than 200 w/cm², and is dropping off rapidly with horizontal distance from the beam axis. Assuming 200 w/cm² average power density (ie. no spatial attenuation) over the panel surface gives a total incident power per panel of ~ 70 kW; at this power level a water flow rate of 10 gpm/element will yield about 30 deg. C water temperature rise. The panel water inlets will be at the bottom, with the outlet lines at the top having thermocouple wells for water

temperature measurement. The water headers will be supplied by water feed-throughs in the bottom of the beam box.

CALORIMETER

The calorimeter is required to withstand the full beam power flux from the three sources (neutrals only) for pulse durations up to 1000 seconds (steady state). In the event that the bending magnet is inoperative, the calorimeter is required to withstand the full combined beam power flux of neutrals and ions from the three sources for the response time of the fault detection/protection system. The calorimeter must also provide calorimetric instrumentation capability to measure the energy and the beam profile. For the purposes of the calorimeter design the following power handling levels are targeted:

Average Power

- Steady State (1000 sec.): 9 MW/Beam Line (3 MW/Source)
- Fault Condition (TBD sec): 21 MW/Beam Line

Peak Beam Power Density

- Steady State (1000 sec.): 6.8 kW/cm² (calculated)
- Fault Condition (TBD sec): 16.3 kW/cm²

The Calorimeter instrumentation will measure the vertical dispersion characteristics of the beam using water calorimetric techniques, and additionally measure both the vertical and horizontal beam profile characteristics using thermocouples placed near the surface of the heat absorbing elements. The heat absorbing elements of the calorimeter are single channel water cooled Cu-Cr-Zr vapo-tron elements. The calorimeter, shown in Figure 8, consists of three "vee" sections of stacked 1 m. long panels installed with their long axis horizontal. This panel orientation and single channel design were chosen to maximize the vertical resolution of beam power profile measurement by monitoring the bulk water temperature rise in the individual elements. The included angle of the vees is 16° reducing the peak incident surface heat flux to below 1.0 kW/cm². The nominal external dimensions of the hypervapo-tron panels are 2.5 cm. x 6.4 cm. x 1 m long. A 10 cm. section is angled at 8° to form the mating interface between opposing panels at the crotch of the vee (see Figure 8).

The proposed panel cross section has overlap features along the sides to prevent beam shine-through between panels. The three vee modules of the calorimeter are essentially identical. The axis of each vee is aligned with the centeraxis of the respective source. The calorimeter assembly is designed to fit through the existing 132 cm. diameter port in the top of the TFTR beam box, and to be handled as an integral unit with the port cover for the purposes of installation and removal. The calorimeter modules are 13 vapo-tron elements high and present a 25 cm. wide by 82.5 cm. high projected heat absorption area normal to the incident beam. The height of the calorimeter is set by the extreme beam rays (bottom of source - top of pre-calorimeter scraper aperture and vice versa) which intercept the crotch of the vee at about 40.7cm. from the horizontal midplane. Due to geometric shadowing by the pre-calorimeter scraper, combined with the normal vertical fall-off of the power density away from the beam axis, the total power deposition on the top two and bottom vapo-tron elements will be low (see Fig. 9).

The nominal cooling water flow rate for the calorimeter is ~700 gpm based on 9 MW average power input and ~ 50 deg. C bulk water temperature. The water temperature rise per panel was estimated as a function of vertical position using the calculated power density distribution of the beam. With a 10 deg. C inlet temperature and 3.5 bar back pressure, the central panels (with the highest heat load) will have outlet temperatures of 40 deg. C below the local boiling point in the return lines. The maximum hypervapo-tron surface temperature is

estimated conservatively to be about 375 deg. C. From the cooling water system perspective, the calorimeter is a high flow rate, low pressure drop device. The flow requirements will not be limited by the available water system pressure (140 psig supply and 50 psig return). The water manifolding and distribution piping for the calorimeter is sized for a nominal total flow rate of 700 gpm on the basis of maintaining the flow velocities below 15 fps. A rough estimate of the

Fig. 7. Calorimeter - Elevation

Fig. 8. Calorimeter - Plan View

pressure drop (between external supply and return connections to the system) for 700 gpm is less than 30 psi. The design can accommodate over 900 gpm without change.

The hypervapotron panels of the calorimeter are assembled into vee modules. The opposing panels are clamped together at the vertex of the vee by stainless steel clamping plates which are preloaded by bolts through spring washer stacks. The modules have a frame consisting of top and bottom "shelves" and three vertical members just outside the corners of the hypervapotron vee assembly. This frame locates the vertex of the panel subassemblies and supports the open ends; this support permits axial expansion of the panels and a predetermined amount of lateral movement. The frames of the adjacent modules are bolted together and become part of the overall calorimeter structure. At assembly, the support ears on the back edges of the elements (located at about 70% of the free span towards the open end of the vee) are tied across module-to-module by means of loose-fitting clevises attached to a vertical member. At the outer sides of the calorimeter assembly, vertical strongbacks are attached to the top and bottom frame structures and all the "inter-module" connections are made to these strongbacks.

The cooling water header weldment is designed to be a stiff "box" structure so it can serve as the connecting structure between the actuator struts and the calorimeter. The header weldment is attached to the actuator struts with Conflat flanges. The calorimeter assembly is in turn bolted to this structure to complete the connection to the actuator struts.

NB/TORUS TRANSITION DUCT SCRAPER

The NB/Torus duct entrance scraper is required to define the overall cross section of the three beams entering the duct, and provides one aperture encompassing the three beams. The assembly is a stand-alone structure attached to the NBI box and is not removable as an integral unit with the calorimeter assembly (as is the case with the TFTR design). The scraper assembly provides one 72 cm. square aperture at 671 cm from the source

The scraper assembly consists of a simple "window frame" of two side-by-side single channel hypervapotron panels per edge. The panel dimensions are 5.6 cm wide by 1 m long and the heat absorbing surfaces are normal to the NBL axis. The top and bottom panels are ahead of the vertical side panels so that the corners overlap. The water fittings are on the ends of the panels. The flow rate per panel is about 10 gpm for a total of ~80 gpm. The water connections at one set of opposite corners of the assembly are all inlets and at the other corners, outlets. The water headers will be supplied by water feed-throughs in the bottom of the beam box. All the hypervapotron panels will be supported from a frame structure. The panels will have "ears" on the back side near the ends which will be bolted/pinned to the structure; the panels will be free to expand axially and to bow laterally without restraint.

POWER DENSITY CALCULATIONS

Preliminary power density calculations were performed for the beamline components using a single gaussian distribution with a 1/e divergence angle of 0.5° in the horizontal (X) plane and 1.5° in the vertical (Y) plane. These results are summarized in Table 1 and represent the unshadowed power densities on the various energy absorbing surfaces of the beamline scrapers. Since all scrapers downstream of the Source Housing Scraper will be shadowed to a greater or lesser degree by the scrapers upstream, these peak power densities can be considered an upper bound on the actual peak power impinging on the various scraper surfaces. Actual power density distributions, inferred from recent measurements on the TFTR beams⁷, suggests that the beam energy is evenly divided in two gaussian distributions, one with a narrow divergence angle and one

with a much wider angle. Revised power density calculations assuming the two gaussian beam with vertical divergence angles of 1.5° and 6.2° and a 50/50 energy split, tend to indicate higher total power being absorbed on the beam scrapers but slightly lower peak power densities (ie. the edge beam power is more evenly distributed due to the two divergence angles). This somewhat higher power on the scrapers will also result in reduced power on the Ion Dump and Calorimeter. The flow rates in the vapotron elements necessary to meet the cooling requirements of these higher values of total absorbed power on the scrapers have been used in preliminary sizing of component piping.

TABLE I. TPX NEUTRAL BEAM APERTURES & POWER LOADS:

UNSHADOWED POWER DENSITY (Div. X= 0.5° , Div. Y= 1.5°)

COMPONENT	X [cm]	Y [cm]	Z [cm]	P _{sides} (kW/cm ²)	P _{top&bot} (kW/cm ²)
SOURCE GRID	12.00	43.70	0.00	-	-
SOURCE HOUSING SCR-ENTR	13.98	46.00	28.00	0.068	0.094
SOURCE HOUSING SCR-EXIT	11.60	42.22	75.00	11.100	11.260
QMA SCRAPER-ENTR	14.62	44.00	75.70	0.042	1.760
QMA SCRAPER-EXIT(center beam)	14.62	43.18	132.33	0.843	8.687
QMA SCRAPER-EXIT(side beam)	14.62	43.18	115.92	0.537	8.781
MAIN FLG SCR-ENTR(side beam)	16.18	44.46	131.19	0.079	7.014
MAIN FLG SCR-EXIT(side beam)	14.62	44.46	166.75	1.626	7.225
NEUTRALIZER-EXIT(center beam)	15.32	50.32	279.42	2.688	4.181
NEUTRALIZER-EXIT(side beam)	15.32	50.32	290.59	2.840	4.309
VERT. MAG SCR.@TOP-EXIT	15.30	-	384.73	4.008	-
VERT. MAG SCR.@MIDPL-EXIT	15.30	-	441.39	4.329	-
VERT. MAG SCR.@BOT-EXIT	15.30	-	484.49	4.584	-
PRECAL. SCR-TOP(center beam)	-	89.40	452.31	-	0.023
PRECAL. SCR-TOP(side beam)	-	89.40	465.62	-	0.029
PRECAL. SCR-EXIT(center beam)	19.68	60.00	535.45	1.794	2.996
CALORIMETER SCRAPER	12.94**	72.14	671.12	0.692	1.724
FAST VALVE SCRAPER	12.94**	80.02	696.44	0.775	1.067
ABSOLUTE VALVE SCRAPER	17.18**	76.00	757.66	0.118	1.601
TRANSITION DUCT-ENTR	13.14**	88.80	863.32	1.193	0.938
TRANSITION DUCT-EXIT	21.36**	78.72	926.82	0.046	1.737

**DIMENSION FROM SIDE BEAM CENTER AXIS TO NEAR EDGE.

(ALL DIMENSIONS IN CM.)

To optimize water consumption, and minimize the numbers of vapotrons required, the shadowing by upstream scrapers must be accounted for. Optimization of the Ion Dump and Calorimeter must also account for the power absorbed in upstream scrapers. Figure 9 is a plot of the power density of the neutralized portion of the beam at the entrance to the calorimeter. This result is based on the single gaussian beam divergence of 0.5° in the horizontal (X) plane and 1.5° in the vertical (Y) plane, and as such represents an upper bound on the power deposited on the calorimeter (The total neutral power contained in the beam assumes a 47% neutralizer efficiency of the full 8.4 MW of beam power-ie. no scraper losses).

F.E.A. THERMAL/STRESS ANALYSIS

To predict the performance of the Hypervapotron elements an FEA analysis was carried out using MSC/NASTRAN⁸, a general purpose finite element computer code. A segment of the vapotron was modelled (see figure 8.) using hexahedral solid elements with the appropriate Cu-Cr-Zr material properties and symmetric boundary conditions. Since the TPX pulse length is 1000 seconds, and the vapotron thermal time constant is 300 msec, the problem can be treated as steady-state. A uniform internal heat transfer coefficient was calculated based on the correlations found in reference 2 and applied to

the interior wetted surfaces. A peak heat flux of 1000 Watts/sq. cm. was uniformly applied on the front vapotron surface. The bulk fluid temperature varies from 84 to 86 deg. C and reflects the water temperature near the exit of a 1 meter long vapotron element with an average flow velocity of 3 m/sec. and an inlet temperature of 10 deg.

Fig. 9 Power Density @ The Calorimeter (Z=600cm)

The results of the thermal analysis yielded a front surface temperature of 283 deg. C, with a peak interior surface temperature of 140 deg. C at the groove base side channels. If the static fluid pressure at the exit is maintained at or slightly above 3.5 bar, only minimal nucleate boiling will occur. Figure 10 is a contour plot of the temperature distribution in the model. A solution for the static stresses generated in the model due to the thermal gradients and the applied hydraulic internal pressure, yields a peak Von-Mises stress of 19 ksi at the corners between the side and front walls(see Fig. 11). The results of the analysis indicate operating stresses below the the design allowables for the Cu-Cr-Zr material.

Fig. 10. Vapotron Temperature Contours

MSC/NASTRAN-VER.67 PLOTTED ON: 04/21/93 PLOT
time = 0.10000E+01
fringes of eff. stress (u-m)
min= 9.609E+02 in element 142
max= 1.903E+04 in element 1249

Fig. 11 VonMises Stress Contours

The transient response of the most intensely loaded vapotrons were investigated to determine the minimum time necessary to detect and react to a loss of coolant fault condition. Assuming a maximum allowable surface temperature of 600 deg. C, the results indicate that the response time of the protection system should be no greater than 0.2 seconds.

SUMMARY

This paper has described the changes necessary to the present TFTR Neutral Beamline energy absorbing components to upgrade them for 1000 second pulse length operations. Due to the long pulse lengths and relatively high heat fluxes most beam facing surfaces will have to be actively cooled. Based on their successful operation on JET beamlines, with power densities at or below 1 kW/sq. cm., Hypervapotrons have been considered the most economic and reliable energy absorbing elements for this application.

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Fig. 12 TPX Neutral Beam Elevation

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