NSTX CALCULATION

TITLE Integrated Thermal Analysis, Bakeout

CALC. NO. NSTX-CALC-13-10 DATE 2/14/97

ORIGINATOR A Brooks CHECKER ______ Rev. 0

PURPOSE:

This calculation describes heat flows and temperature rise expected during bakeout.

REFERENCES:

See attached.

ASSUMPTIONS:

See attached.

CALCULATION:

See attached.

CONCLUSION:

See attached.

NSTX

13-970214-AWB-01

TO: DISTRIBUTION
FROM: A Brooks
DATE: 14 February 1997
SUBJECT: Bakeout of Vacuum Vessel and Internals

This memo documents the analysis supporting the proposed bakeout scenario for the Vacuum Vessel, Center Stack and Plasma Facing Components

Requirements

The NSTX Vacuum Vessel and Plasma Facing Components must undergo a bakeout scenario which raises the Plasma Facing Components (Center Stack Tiles, Passive Plates and Divertor Tiles) to 350 C and the Vacuum Vessel to 150 C. The components must be brought up to temperature with 48 hours, held at temperature for 24 hours (?) and recooled to operating temperature with a 24 hour period.

Summary of Bakeout Approach

The Passive Plates, Divertors and Vacuum Vessel will be heated and cooled by flowing a fluid such as Dow Therm A thru tubes brazed to the surface of the components. This approach will also provides active cooling during normal operations. The vacuum vessel will have tubes approximately 1 cm id, spaced 10 cm apart over the entire exterior surface. Lengths of tubes will be determined based on limiting fluid temperature change during heating and cooling to control temperature gradients in structures A similar concept will be used on the back plates supporting the graphite tiles of the Passive Plates and Inboard and Outboard Divertors.

The Center Stack Tiles cannot be heated and cooled in this fasion because of space limitations. Instead the CS Tiles will be heated by radiation from the Center Stack Casing which will be ohmicly heated. The CS Tiles will be cooled by radiation to the cooled PP and VV. To protect the Center Stack Coils, the OH and PF1a coils must be cooled during the entire bakeout cycle.

Analysis

A 2D Axisymmetric ANSYS Thermal Radiation Model was used to determine heating and cooling requirements for the bakeout cycle. A steady state analysis was run first to establish the heating requirements to hold the VV at temperature. A transient analysis was then run to determine the temperature distribution during the bakeout cycle and to establish net heating and cooling requirements

Assumptions

The vacuum vessel is assumed insulated with the equivalent of 2.54 cm (1") of good (.025 w/m-C) insulation with ambient conditions of 25 C.

The Center Stack is insulated with 0.6 cm of Microtherm (.025 w/m-C) between the OH Coil and Center Stack Casing and 0.9 cm of Microtherm between the PF1a Coils (Upper and Lower) and the Center Stack Casing. The difference in thickness is chosen to closely match the difference in heating between middle and end sections of the Center Stack Casing. The electrical resistance of the smaller radius middle section of the center stack is higher than the larger radius end sections. The wall thickness of the Inconel 625 CS Casing is 0.4 cm at both locations. The electrical resistivitiy of the Inconel 625 is 1.30 μ Ohm-m.

The CS Tiles are mounted in such a way (TBD) as to provide a poor thermal contact with the CS casing. For this analysis only radiative coupling is assumed. The PP and Divertor Tiles are mounted to provide good thermal contact to their actively cooled bascking plates. The PP and Divertor Assemblies (Tiles and Backing Plates with Tubes) are assumed to be reasonably well thermally isolated from the VV. For the PP, this is readily accomplished with present standoff from the VV (conduction losses thru the supportsd are estimated to be less than ten percent of the radiative losses). For the Outboard Divertor, some attention needs to be paid to the support mechanism to minimize heat losses and potentially large thermal gradients in the VV. The Inboard Divertor is assumed integral with the Center Stack Casing (with the top and bottom flanges of the CS casing effectively forming the heated/cooled backplate of the inboard divertor tiles.

All interior surfaces are coupled radiatively. For the graphite tiles, an emissivity of 0.7 is assumed. For the Stainless Steel Vessel, Inconel 625 casing and copper backing plate, an emissivity of 0.27 is used. To simulate a radiation shield between the Passive Plates and the VV , a reduced effective emissivity (based on a single shield layer) of 0.0989 is used for the back plate facing the VV.

Approach

Figure 1 shows the geometry of the 2D axisymetric ANSYS model used. The Center Stack Casing, Tiles and Insulation are modeled explictedly as are the VV, PP and Divertor Stuctures. The surface temperature at the inside of the Microtherm is fixed at the OH and PF1a temperatures (assumed to be 25 C) The Vessel is convectively coupled to both the ambient at 25C with an effective film coefficent of 0.833 w/m2-C representing the insulation and a film drop to the air, and to the heating/cooling fluid with an effective film coefficient of 170 w/m2-C driven mainly by inplane conduction thru the VV shell to the tubes. The PP and DV are convectively coupled to the heating/cooling fluid with an effective film coefficient slightly higher (300 w/m2-C) because of the copper backing. Interface Resistance between the Tiles and the Backplate is ignored at the PP and DV since it should be small (by design) compared to the film coefficents used.

Do to the effectiveness of the cooling, the time constants of the components are fairly small compared to the duration of the bakeout cycle. If the temperature of the heating fluid was stepped up imediatedly to 375C (it needs to be slightly higher than 350C to overcome lossed), then the structures would respond within a few hours, if suffcient heating were available. To limit the heat required to that required to hold the structuctures at temperature during the soak, the temperature of the heating fluid temperature will be ramped up during the initial 48 hours. For this analysis, the VV fluid temperature was linearly ramped to 120 C during the first 24 hours, followed by a linear ramp to 150 C during the next 24 hours. The heating for the PFCs was ramped first to 290 C followed by a ramp to

375 during the same time periods. Similarly, to minimize cooling capacity required, the fluid temperatures are gradually reduced during the cooldown period.

Results

The need to limit the Vacuum Vessel temperature to 150 C during the bakeout has driven the heating requirements due to the large thermal gradient between the pfc's and the vv. The vessel must now be cooled during the bakeout cycle. The heating required can be reduced somewhat by the additon of thermal shields in the space between the PP , DV and the VV.

The use of Microtherm at the centerstack has lowered the heat loss to the OH and PF1a coils significantly while reducing the required ohmic heating. But because of the lower VV temperature, about 20 percent of the Ohmic heating is radiated away (mainly near the midplane), making it more difficult to maintain a uniform temperature at the CS tiles. This also requires driving the CS casing temperature up a bit to compensate. The electrical DC resistance of the cold CS casing is 1.0 milli-ohms, requiring nominally 2.3 KA at 2.3 Volts. The resistivity of the inconel 625 should increase with temperature. That data was not available for this analysis but will be investigated.

Tables I thru III summarize the resultant temperature distribution achieved and the associated heating , cooling and heat losses.

The attached figures show the temperature contours during the soak, and transient plots of both the temperatures of the components and the heating/cooling required to each.

Table I Temperature distribution during 24 hour soak.

	Temperature, C (No Shield)		**Temperature, C (with Shield)**	
	Min	**Max**	**Min**	**Max**
Center Stack Tiles	337	355	338	354
Center Stack Casing	355	390	354	389
Protective Plates	364	368	366	369
Divertor Tiles	351	368	350	366
Vacuum Vessel	150	160	150	160

Table II Heating Requirements during 24 hour soak

	Heat Flow , KW (No Shield)	**Heat Flow , KW (with Shield)**
Center Stack Casing Ohmic Heating	5.3	5.3
Protective Plate Convective Heating	36.4	26.9
Divertor Convective Heating	13.4	13.4
Total	55.1	45.6

Table III Cooling and Heat Losses

	Heat Flow, KW (No Shield)	**Heat Flow, KW (with Shield)**
Vessel Heating Cooling (at 150 C)	-45.6	-36.3
Losses to OH	-2.8	-2.8
Losses to PF1a	-1.5	-1.5
Losses thru VV Insulation	-5.2	-5.0
Total	-55.1	-45.6

Figure Captions

Figure 1 Contours of Temperature Distribution During Soak Period (ie Steady State)

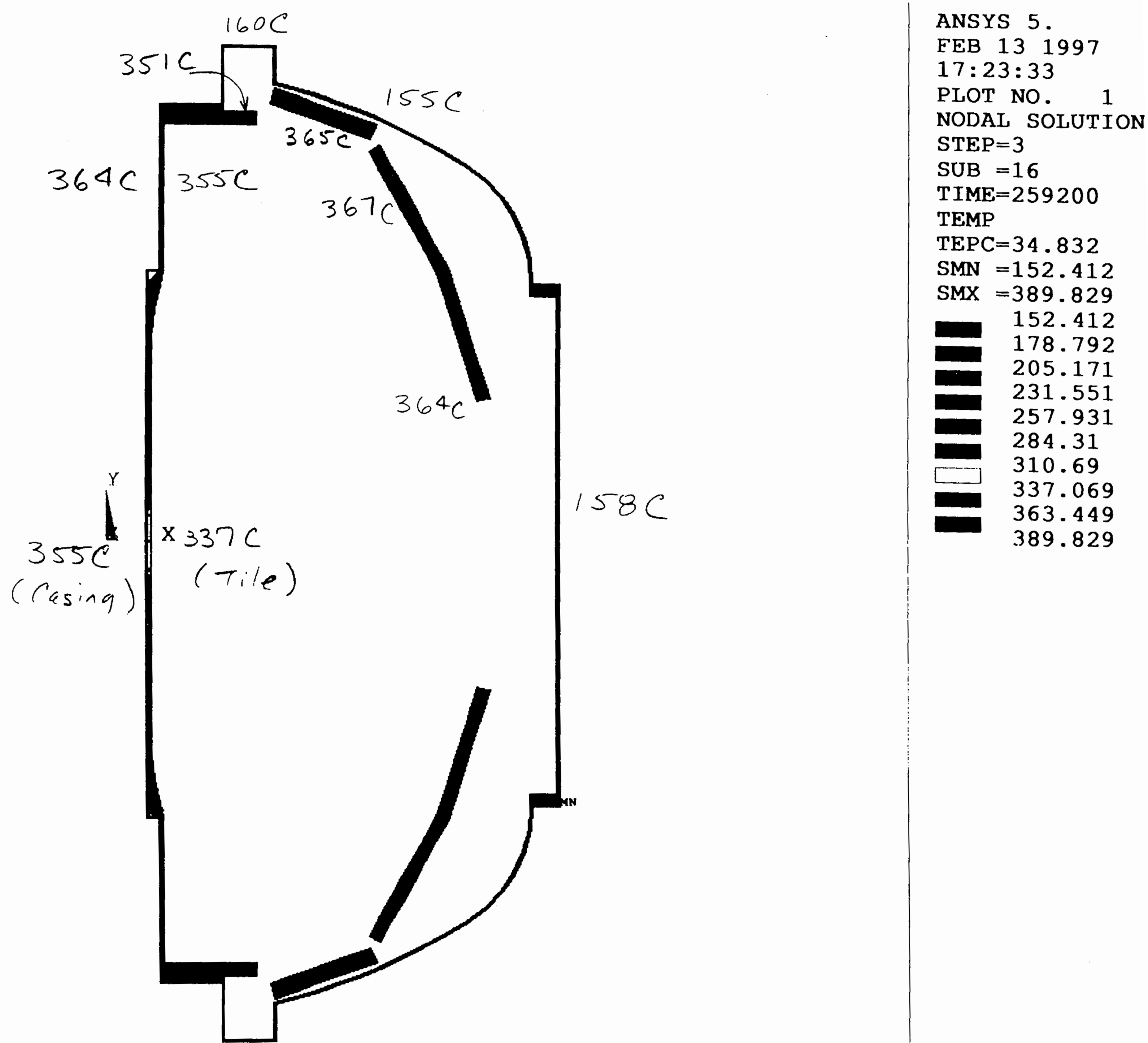
Figure 2 Transient Temperatures resulting from ramping of fluid temperatures and CS ohmic heating.

Figure 3 Result Transient Heating and Cooling Required for Bakeout cycle

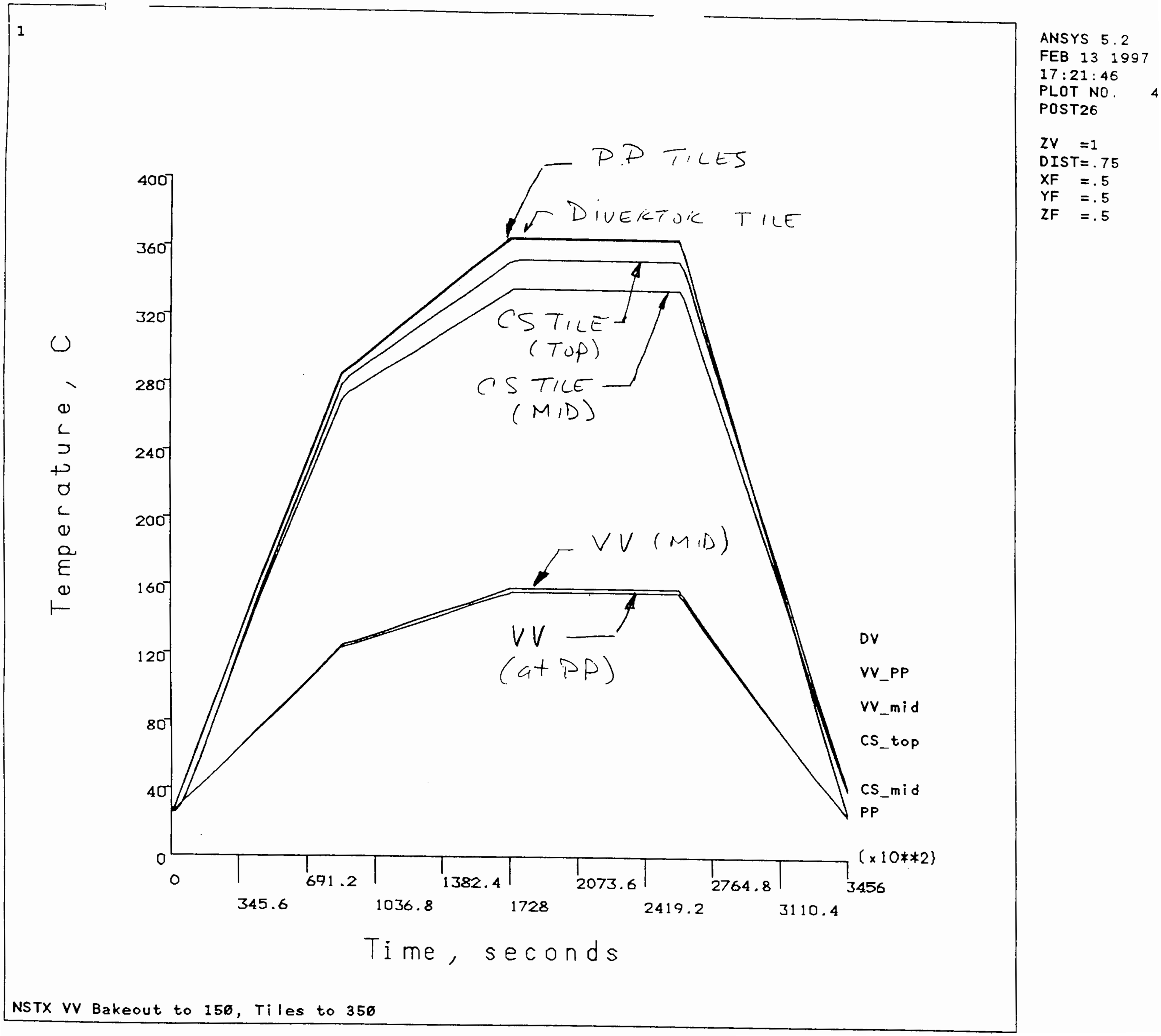
cc:

J Citrolo	H M Fan	P Heitzenroeder	C Neumeyer
M Ono	J Robinson	J Spitzer	R Parsells

NSTX File



NSTX Bakeout to 150, Tiles to 350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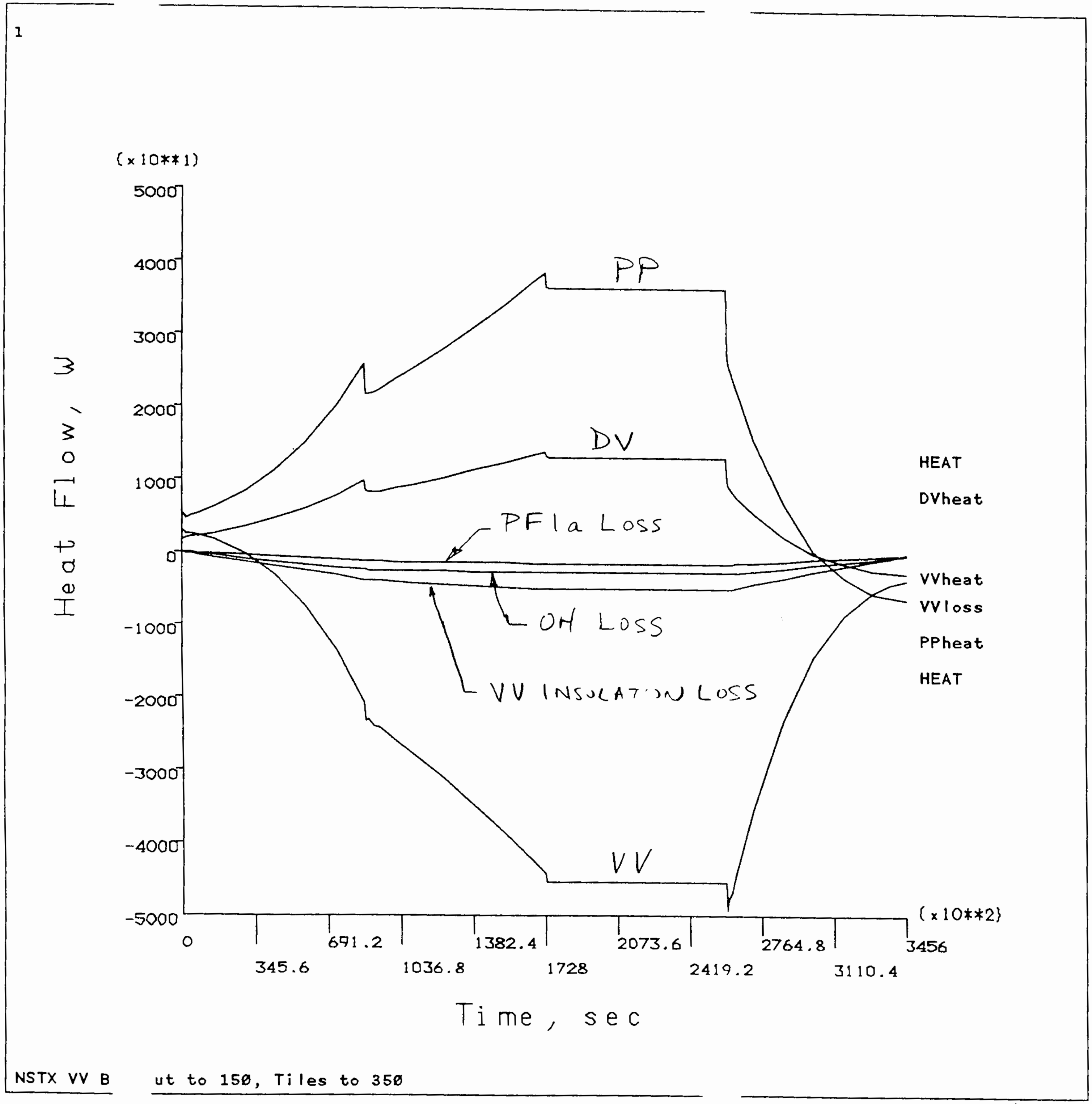
FEB 13 1997
17:21:46
PLOT NO. 4
POST26
ZV =1
DIST=.75
XF =.5
YF =.5
ZF =.5
P.P TILES
DIVERTOR TILE
CS TILE (TOP)
CS TILE (MID)
VV (MID)
VV (at PP)
DV
VV_PP
VV_mid
CS_top
CS_mid
PP
Temperature, C
0
40
80
120
160
200
240
280
320
360
400
0
345.6
691.2
1036.8
1382.4
1728
2073.6
2419.2
2764.8
3110.4
3456
(x10**2)
Time, seconds
NSTX VV Bakeout to 15Ø, Tiles to 35Ø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FEB 13 1997
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POST26
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XF =.5
YF =.5
ZF =.5
(x10**1)
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
Heat Flow, W
PP
DV
PFla Loss
OH Loss
VV INSULATION LOSS
VV
HEAT
DVheat
VVheat
VVloss
PPheat
HEAT
(x10**2)
0
345.6
691.2
1036.8
1382.4
1728
2073.6
2419.2
2764.8
3110.4
3456
Time, sec
NSTX VV B ut to 150, Tiles to 350