SEVENTH WATER REACTOR SAFETY RESEARCH
INFORMATION MEETING

8. November 1979
Gaithersburg, Maryland

First Results of Large Scale Pressure Suppression System Experiments at the GKSS Facility

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- Invited Paper -

1. Introduction

At the beginning of 1979 GKSS started pressure suppression experiments in a large scaled test facility with 3 vent pipes. This configuration corresponds closely to a plant MK-II in geometric scaling values as vent diameter of 0.61 m, pool area to vent of 5.4 m^2 and vent submergence of 2.8 m (Fig. 2).

A description of the test facility design is given in /1/.

Fig. 1 shows the general arrangement of the facility and the measure points, discussed in this report.

Fig. 2 gives comparative design data for the full scale test facility and plants like MK-II and KWU 69.

The general objective of the experimental program, which was prepared together with the German institutions (GRS, KWU, KfK) and the USNRC, is to provide plant like and confirmatory data on this three vent arrangement in order to determine and quantify physical phenomena and compare the experimental results from this multiple vent configuration to the results of unit cell arrangements (PSTF, GKM II Fig. 2). Special objectives of this experimental research are to investigate pressure oscillations and pressure spikes during nearly air free steam condensation, and induced phenomena like wall-interaction, and lateral vent loads, vent clearing, pool swelling and air carry over.

A detailed description of the test program, its objectives and the test matrix is given in /2/; Fig. 3 shows the test matrix.

At the present time the scheduled three pre-tests with 3 vents have been conducted in order to take this large test facility into operation. It is the same arrangement as it will be for the majority of the planned main tests but with lower blowdown conditions in the pressure vessel. The general operating conditions of the pre-tests are shown in Fig. 4.

2. First Experimental Results

These 3 pre-tests produced optically and electronically recorded data, which yielded first experimental information about pressure suppression dynamics and associated physical phenomena /3, 4, 5, 6/.

- Drywell

Due to the initial transient mass flow rate with start peaks of about 25, 41 and 58 kg/m^2 s the pressurization rate of drywell at test VM 1, VM2 and VM 3 increases from 0.8 to 1.15 and 1.26 bar/s (Fig. 5). The vent clearing time of 1.2 s is nearly the same in these three tests. During the following air carry over period water swings at the exit of the vent pipes, while pressure and temperature increase to levels of 2.3 bar and 120 °C (Fig. 5, 6 and 7).

About 1 minute after starting the test suddenly a significant changing in pressure and temperature transients is observed (Fig. 6 and 7), which are characterized by an oscillation of about 0.4 to 0.2 Hz. Nearly 140 s after blowdown start the drywell atmosphere shows superheated conditions of about 10 °C above equilibrium.

The measured temperatures at the drywell walls indicate an intensive heat transport through the vessel material (Fig. 8).
First evaluations show that before vent clearing has finished, in the steam and air atmosphere heat transfer coefficients in the range of 10^4 W/m^{2}K at the inner walls are to be expected /7/.

- Wetwell

During vent clearing the pressure below the vent exit at the pool bottom rises with a gradient of 9 bar/s (VM 3) (Fig. 9). The end of the clearing time is characterized by a significant dual peak which has also been observed in other pressure suppression tests /8/.
The pressure trend with respect to time during vent clearing and air carry over closely corresponds to the drywell pressure while pressurization in the wetwell atmosphere caused by pool swelling and air carry over is in phase opposition (Fig. 10).

The equal pressurization histories of drywell and wetwell indicate a strong coupling between drywell and pool already in this period of blowdown, but also later on.

Similar to the drywell transients, in the first time period of about 1 minute the pressure in wetwell atmopshere increases to a level of 2 bar. Then a sudden pressure instability occurs followed by the above-mentioned oscillation with a relatively stable frequency (Fig. 11).

Records of the TV-camera indicate that these pressure oscillations are induced by chugging events. The TV-cameras have observed the exit of the 3 vents and the water level. According to these optical information directly after a steam collaps and chugging the water level falls down about 30 cm caused by water flowing back into the 3 vents. This phenomenon forces about 5 m^3 wetwell water to flow up and down inside the vents, effecting the indicated pressure oscillations with amplitudes of about 0.2 bar in the drywell and 0.1 bar in the wetwell atmosphere (Fig. 12).
The chugging frequency decreases during the approximately 400 s blowdown transient from 0.4 to 0.2 Hz.

These chugging events occur simultaneously at the exit of the 3 vents (Fig. 13).

The obtained detailed video records and high speed films with framing rates of 1000 fps show that during chugging steam flows from the vent exit about half a diameter down into the water with a conical or zylindrical shape. Then the steam condenses, the steam front goes back into the vent with a ring-shaped steam front at the inner vent wall. This annular steam front collapses abruptly and the vent is closed by water flowing up.

The vent exit pressure indicates that this chugging event produces a pressure decrease of nearly 0.4 bar followed by a pulse with amplitudes in the range of 3 bar, and an attenuated oscillation of nearly the same frequence of about 35 Hz within the 3 tests (Fig. 14).

These events occur with a high degree of simultaneity:
nearly the same gradient in the pressure decreasing period, that means a nearly simultaneous collaps of steam at the three vent exits; the pressure peaks from the three vents are close together in a period of less than 10 milliseconds, that means a nearly simultaneity in inducing dynamic loads to the vents and into the pool.

- Expansion room

The pressure history is comparable to the characteristics of the drywell and wetwell transients (Fig. 15).
The temperature increases in these three pre-tests nearly at the same time of about 1.3 s and with a gradient of 20 °C/s to a level 15 °C above the start value (Fig. 16).
This quick increase is induced by the compression effect of pool swelling and by air carried over from the drywell.
After about 10 s the temperature decreases caused by the expansion effect of the down falling water level, because pool swelling has finished.
In the following time period the temperature increases again effected by the carried over, steam heated drywell air.

In the long time period the temperature continuously slows down to the start level indicating a small oscillation. This oscillation starts when chugging phenomena occur.

3. Conclusions

These three multivent pre-tests have shown that the GKSS pressure suppression test facility works efficient under blowdown conditions and is qualified for simulating the containment response of a BWR during a hypothetical loss-of-coolant accident, and is a contribution for understanding its dynamics.

The first test results indicate that steam chugging events occur as very significant phenomena, and with a strong simultaneity at the three vents exit. The events induce characteristic dynamic loads to the three vent pipes and to the wetwell structure.

But nevertheless, these initial results also show that further efforts are necessary to enhance the usefulness of the main test results. Such efforts are required for:

- specific high frequent pressure transducers to confirm the measured pressure pulses and oscillations with respect to their spikes and frequency,
- additional pressure transducers for direct vent inside, wetwell bottom and wall measurements,

- protection of high sensitivity pressure transducers to temperature transients,
- experience in high speed underwater photography,
- sufficient light supply for underwater steam bubble photography,
- time correlation between the pressure signal and the high speed films of a chugging event.

Up to the end of this year it is planned to finish the first 4 main tests of the matrix (Fig. 3).
The goal of this test set is to investigate the special influence of the wetwell initial water temperature on the chugging events.
Two of these four tests are already conducted, so that the program will perform the time schedule.

4. References

/1/ E. Aust, H.D. Fürst, H.-R. Niemann:
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GKSS 79/E/8, Januar 1979

/2/ E. Aust:
Druckabbauversuche auf dem PSS-Versuchsstand der GKSS
- Basisprogramm über Mehrrohr-Versuche für Druckabbausysteme von Landanlagen -
GKSS 78/I/15, Mai 1978 (unveröffentlichter Bericht)

/3/ J. Vollbrandt:
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/4/ E. Aust, H.D. Fürst, H.-R. Niemann, H. Schwan, J. Vollbrandt:
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- Bericht über den Vorversuch VM 01 -
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/5/ E. Aust, H.D. Fürst, H.-R. Niemann, B. Puch, H. Schwan, J. Vollbrandt:
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- Bericht über den Vorversuch VM 02 -
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/6/ E. Aust, H.D. Fürst, H.-R. Niemann, B. Puch, P. Sattler, H. Schwan, J. Vollbrandt:
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- Bericht über den Vorversuch VM 03 -
(unveröffentlichter Bericht, z.Zt. im Druck)

/7/ H. Schwan:
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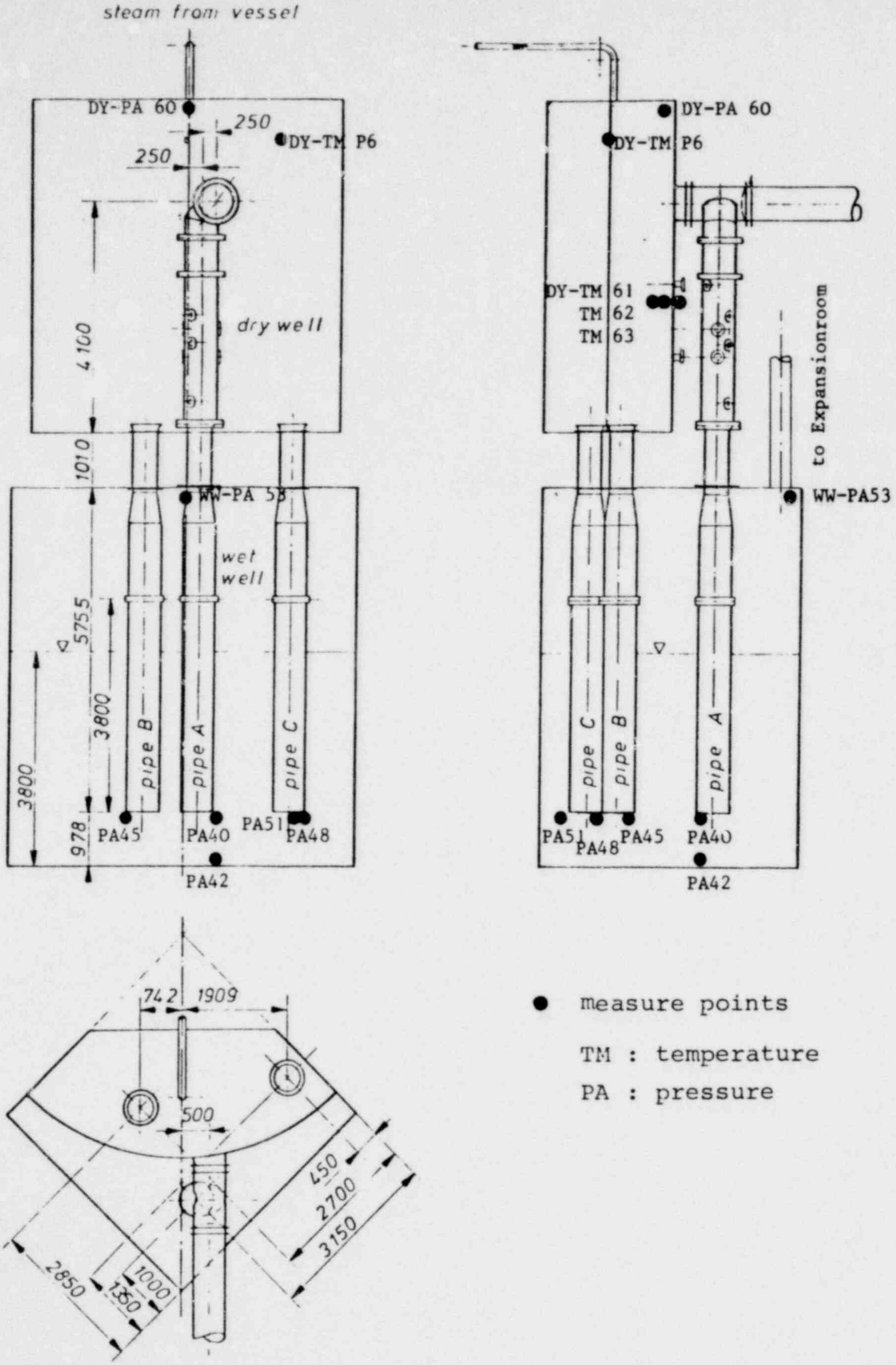
/8/ W. Lai and E.W. McCauley:
Air scaling and modeling studies for the 1/5 scale MARK I BOILING WATER REACTOR PRESSURE SUPPRESSION EXPERIMENT
UCRL-52383, Jan. 1978



3 vent configuration of the GKSS test facility and measure points mentioned in fig. 5 to 16

FIG. 1

Parameter	UNIT	MK II Plant 1	KWU 69 Plant 2	GKM II-Test 3	PSTF-Test 4	GKSS-Test 5
Number of vents	-	98	62	1	1	3
diameter	mm	600	610	610	610	610
$\frac{\text{dry well volume}}{\text{vent}}$	m^3	64	61,3	54	53,6	20
$\frac{\text{pool volume}}{\text{vent}}$	m^3	41,1	~ 43	~ 43	~ 20	21,5
$\frac{\text{pool area}}{\text{vent}}$	m^2	5,3	6,3	6,3	3,2	5,4
vent submergence	m	3,9	2,8	2,8	2,7	2,8
bottom clearance	m	3,7	~ 4	~ 4	3,7	1

1) Values based on La Salle

2) Values based on KKI

3) KWU-GKM II-test values

4) GE-4T-test values

5) GKSS-3 vent-test values

Fig. 2 COMPARISON DESIGN DATA FOR PLANTS AND FULL SCALE PRESSURE SUPPRESSION FACILITIES

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PARAMETER	UNIT	PRE-TESTS			MAIN-TESTS												
		VM1	VM2	VM3	M1	M2[1)]	M3	M4	M5	M6	M7	M8	M9[2]	M10	M11	M12[2)]	3 additional unspecified tests
Numer of vents	-	3 ABC	→	→	→	→	→	→	→	→	→	→	→	1 A	1 A	2 B u.C	
diameter	mm	610	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
dry well volume	m^3	56	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
pool area	m^2	16,2	→	→	→	→	→	→	→	→	→	→	→	5,4	5,4	10,8	
vent submergence	m	2,8	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
bottom clearance	m	0,98	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
liquid level in pool	m	3,78	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
water filling $\cdot 10^3$	kg	64	→	→	→	→	→	→	→	→	→	→	→	21,3	21,3	42,7	
$\frac{\text{dry well volume}}{\text{vent}}$	m^3	20	→	→	→	→	→	→	→	→	→	→	→	60	60	40	
$\frac{\text{pool area}}{\text{vent}}$	m^2	5,4	→	→	→	→	→	→	→	→	→	→	→	→	→	→	
transient mass flow rate, initial value	$\frac{kg}{m^2 s}$	25	41	58	100	→	→	→	→	→	75	[illegible]		100	100		
temperature range in pool	^oC	25 to 55	→	→	→	→	40 to 70	60 to 90	25 to 55	→	→	→		25 to 55	25 to 55		
wetwell back pressure	bar	2	→	→	→	→	→	→	1	3	2	→		2	2		

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1) repeat test

2) repeat test with max. load conditions

Fig. 3 TEST MATRIX FOR the GKSS multivent Testprogram.

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Parameter	Unit	VM1	VM2	VM3
steam vessel				
initial pressure	bar	41	66,1	84,6
initial temperature	°C	250	280	298
initial mass flow rate peak	kg/m^2s	25	41	58
Dry well				
initial pressure	bar	1	1	1
initial temperature	°C	22,5	25	25
wet well				
initial pressure	bar	1	1	1
initial temperature above water	°C	27	27	26
initial temperature under water	°C	25	25	25

Fig. 4 thermal operating conditions of pre-tests

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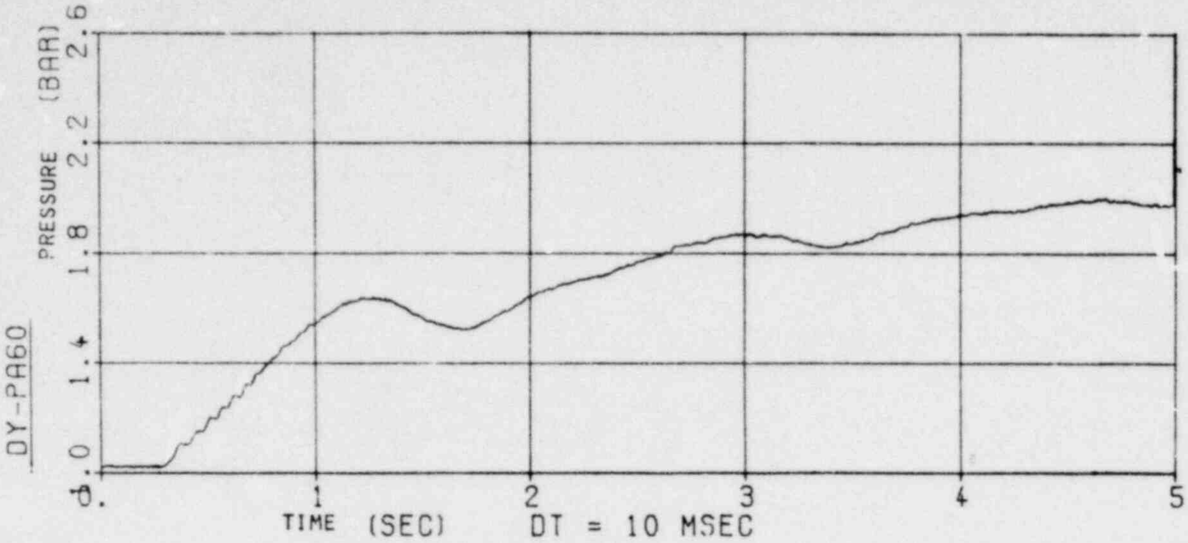

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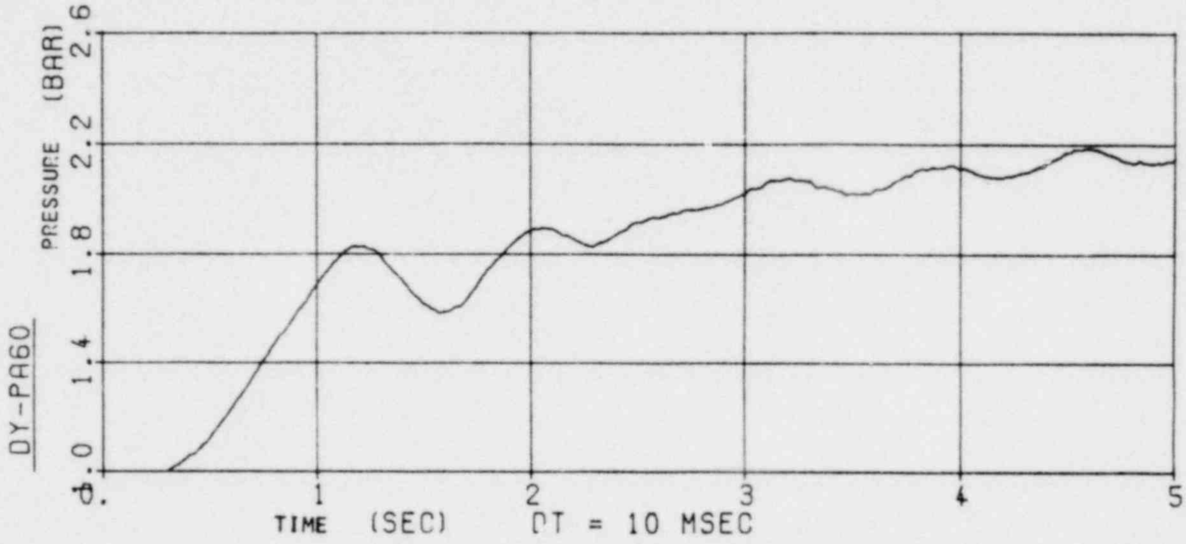

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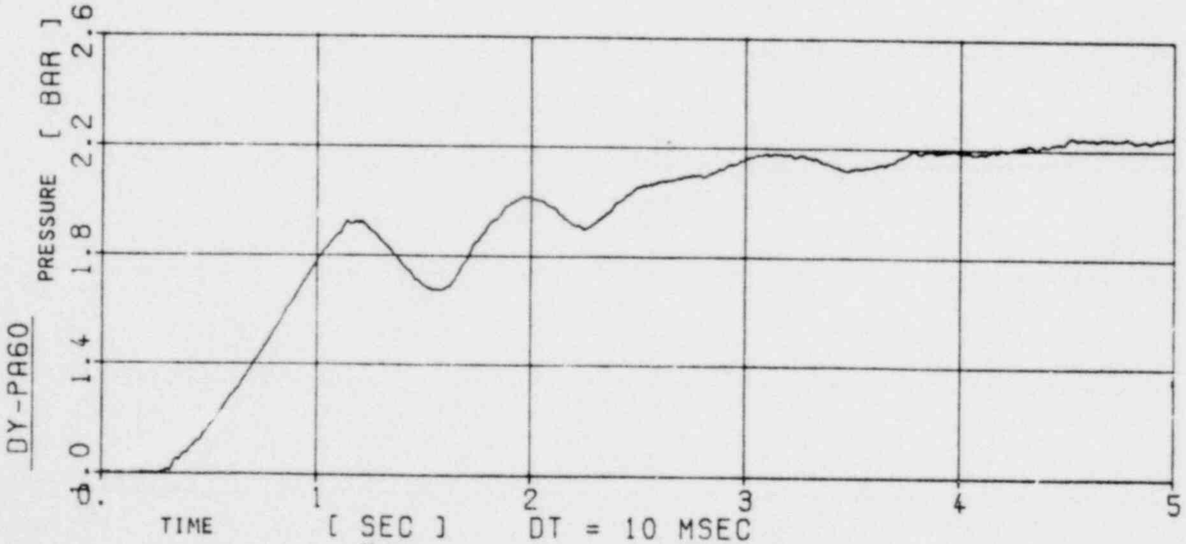

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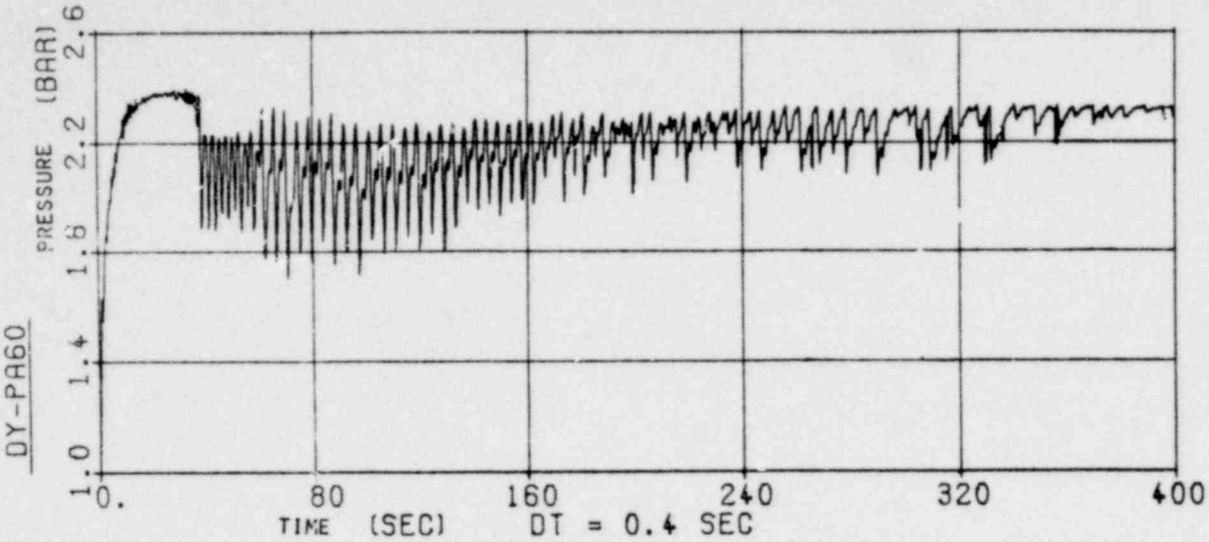
FIG. 5

DRYWELL PRESSURE HISTORY (SHORT LINE)



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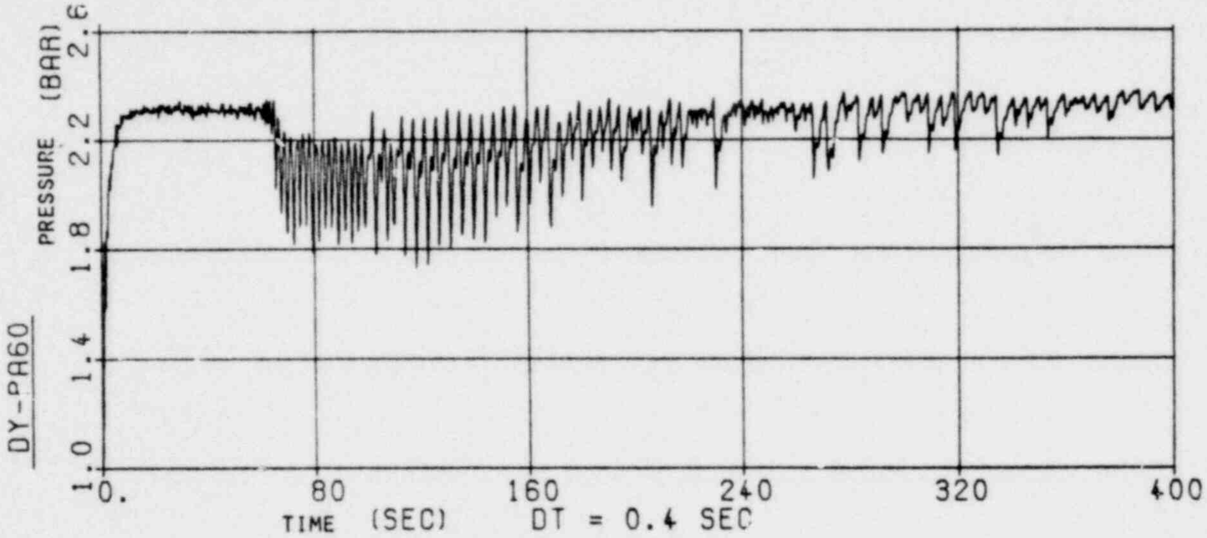

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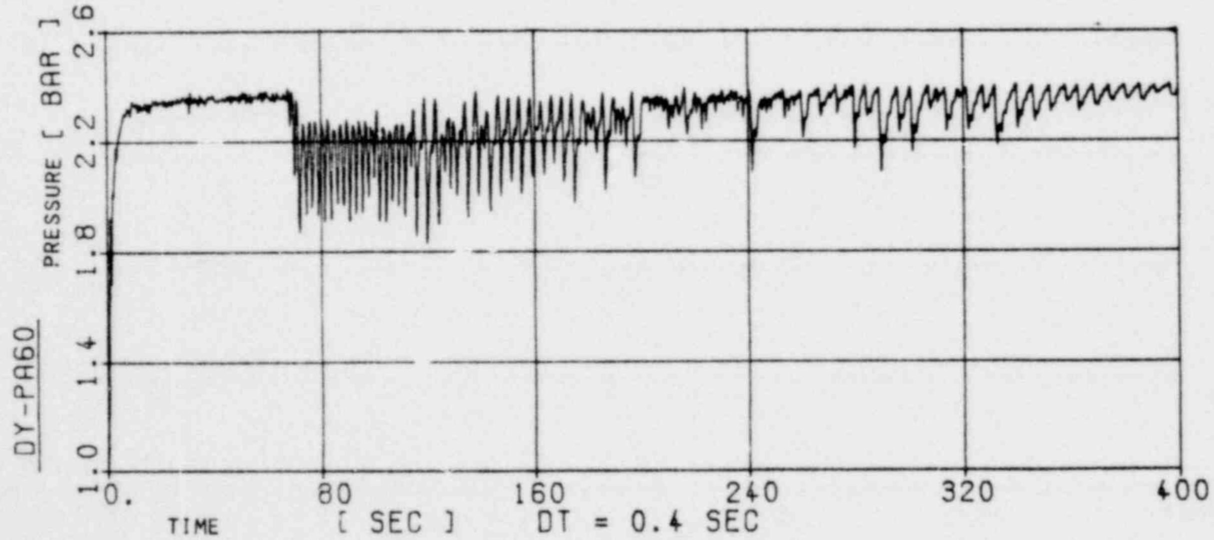
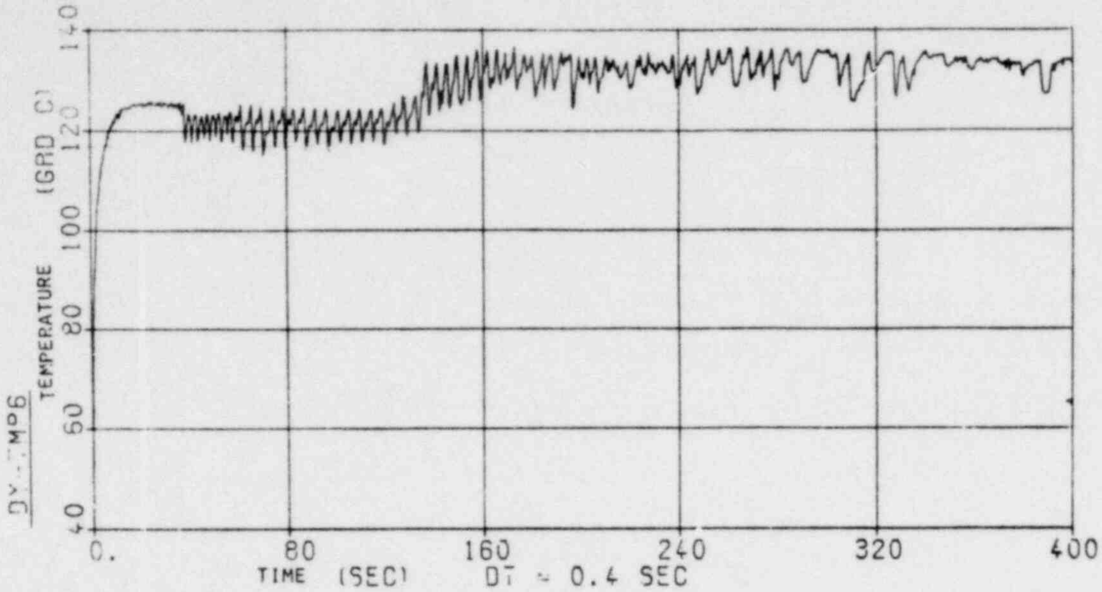


GKSS PSS-TEST VM 03 FIG. 6

DRYWELL PRESSURE HISTORY



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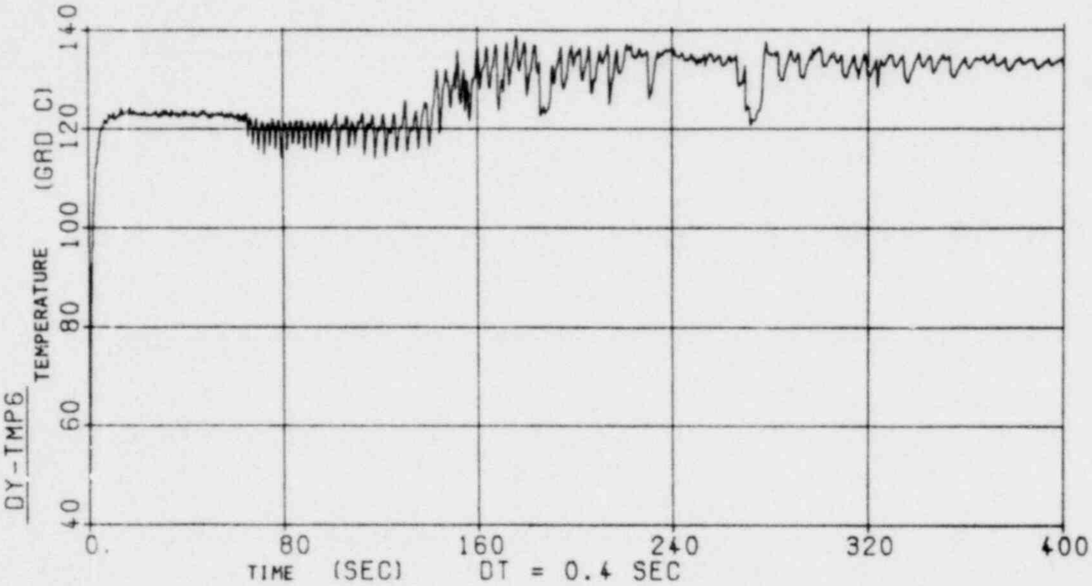

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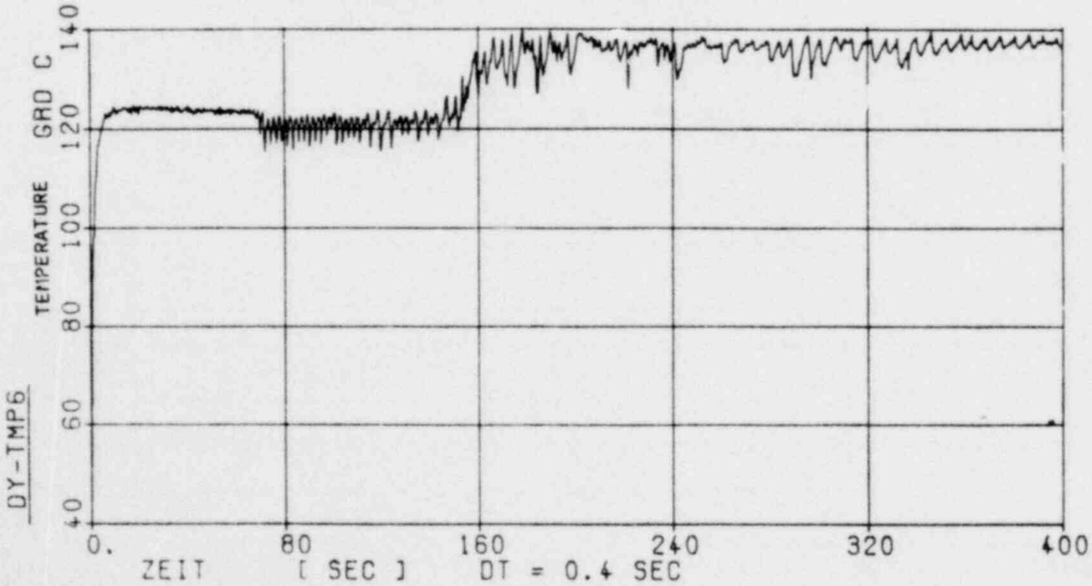

GKSS PSS-TEST VM 03 FIG. 7

DRYWELL TEMPERATURE HISTORY

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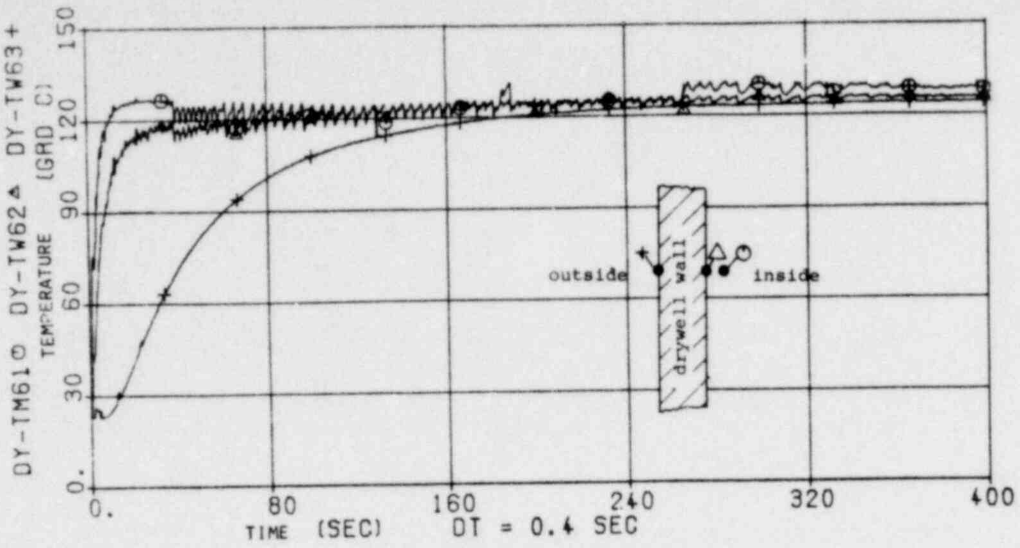

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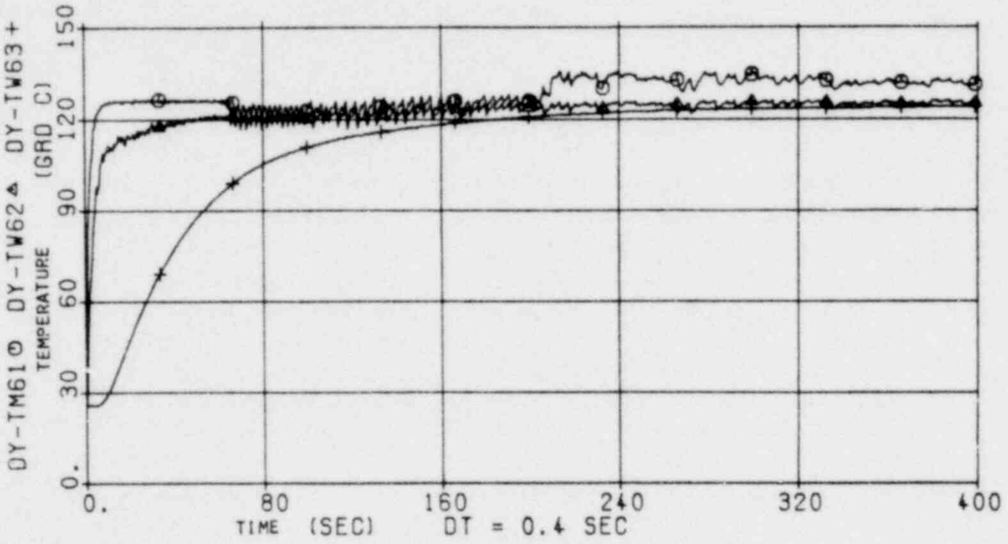

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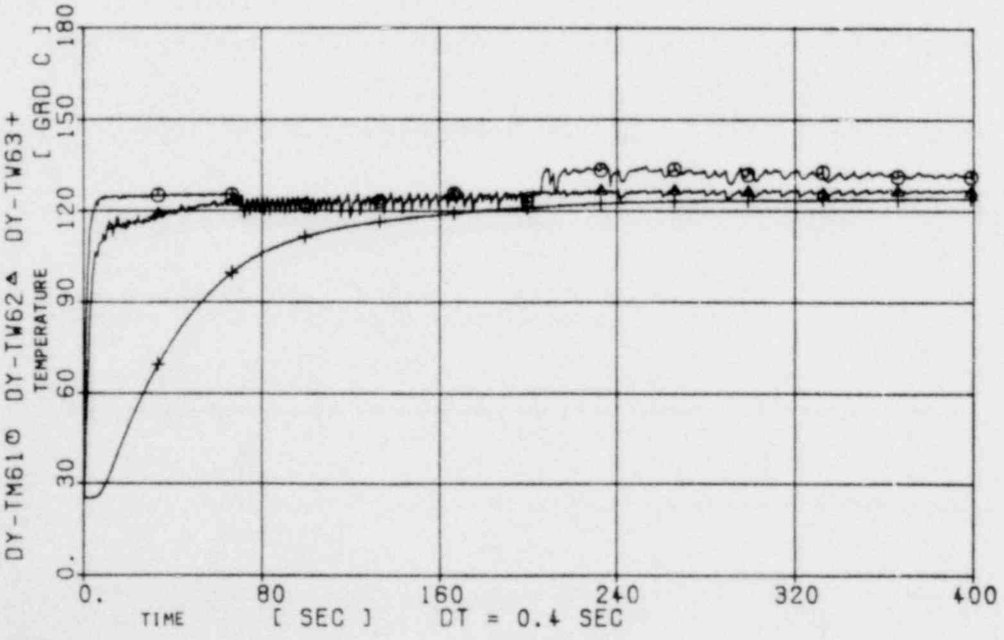

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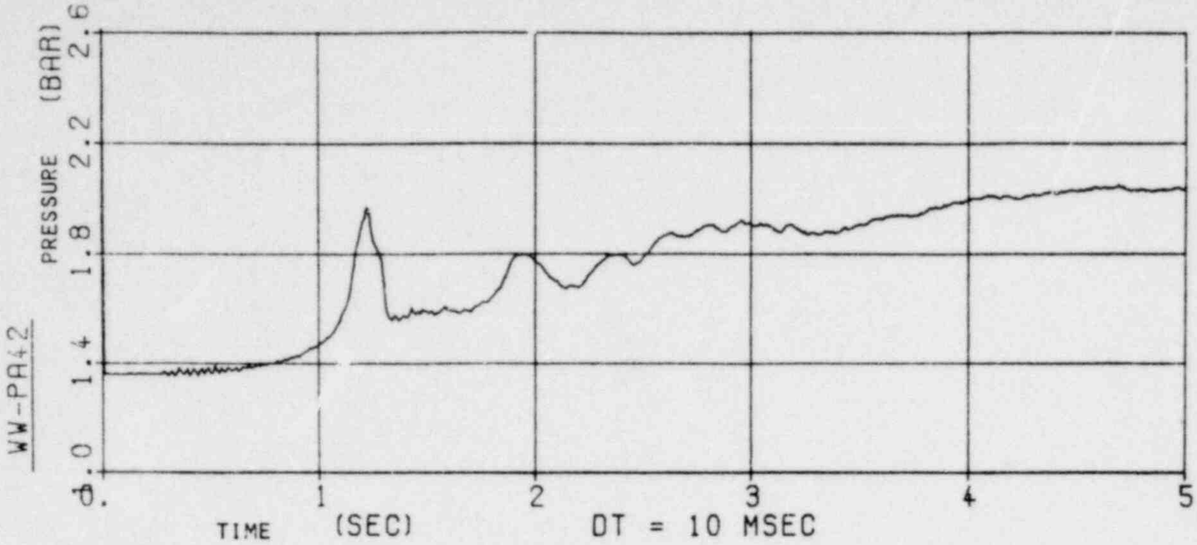
FIG. 8

DRYWELL WALL TEMPERATURE HISTORY



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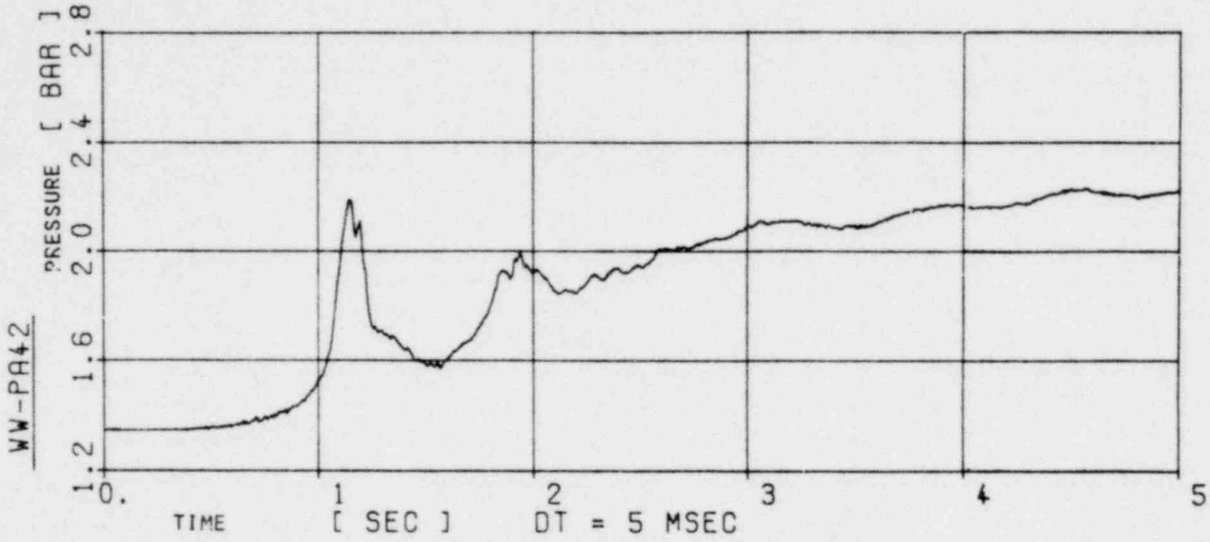

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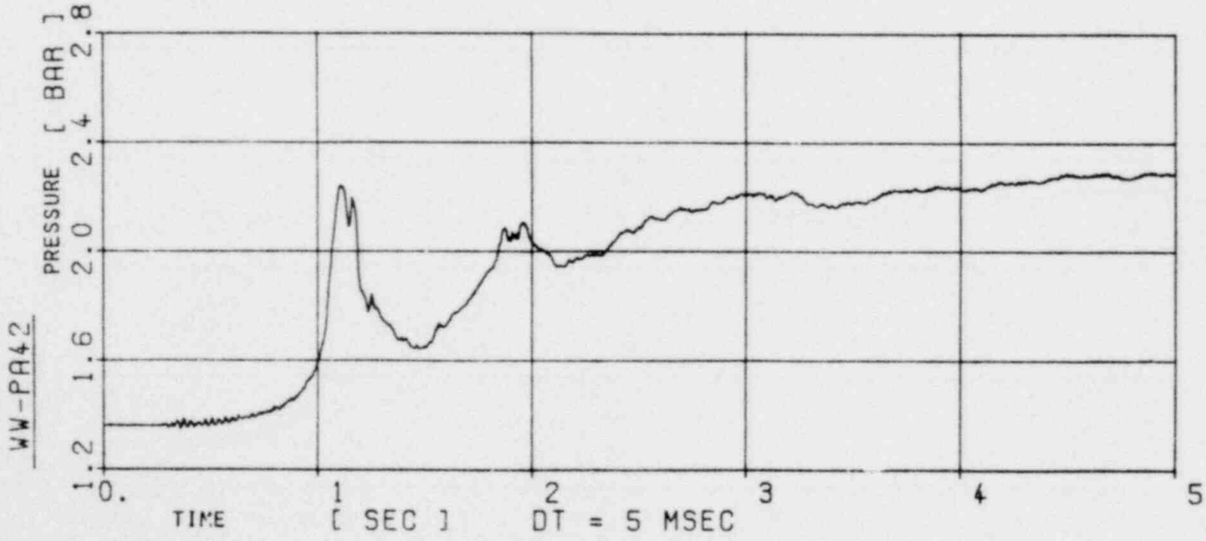

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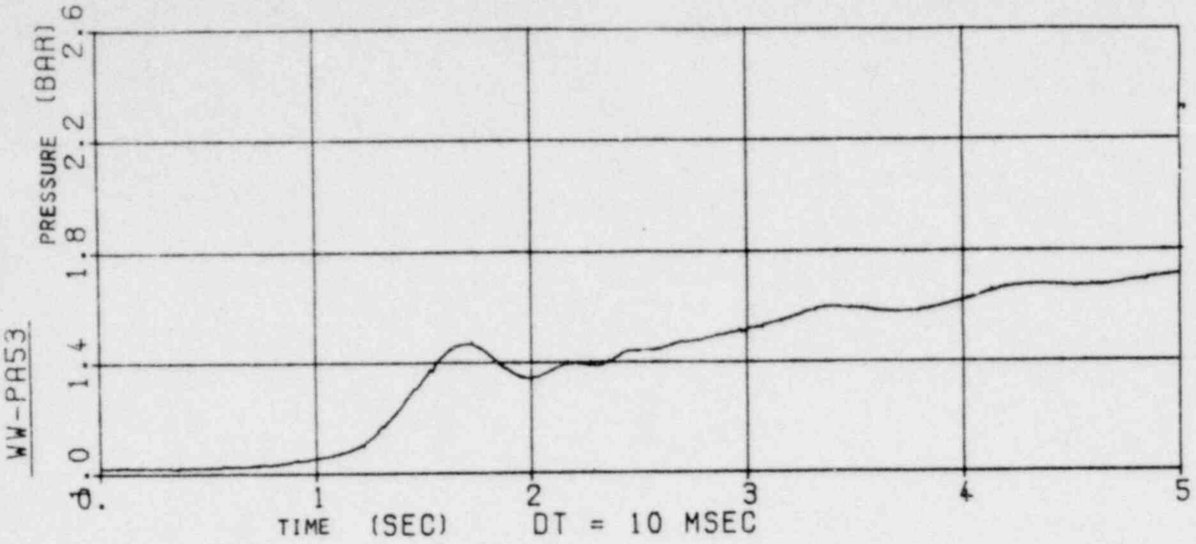
FIG. 9

VENT EXIT PRESSURE HISTORY (VENT A, BOTTOM)



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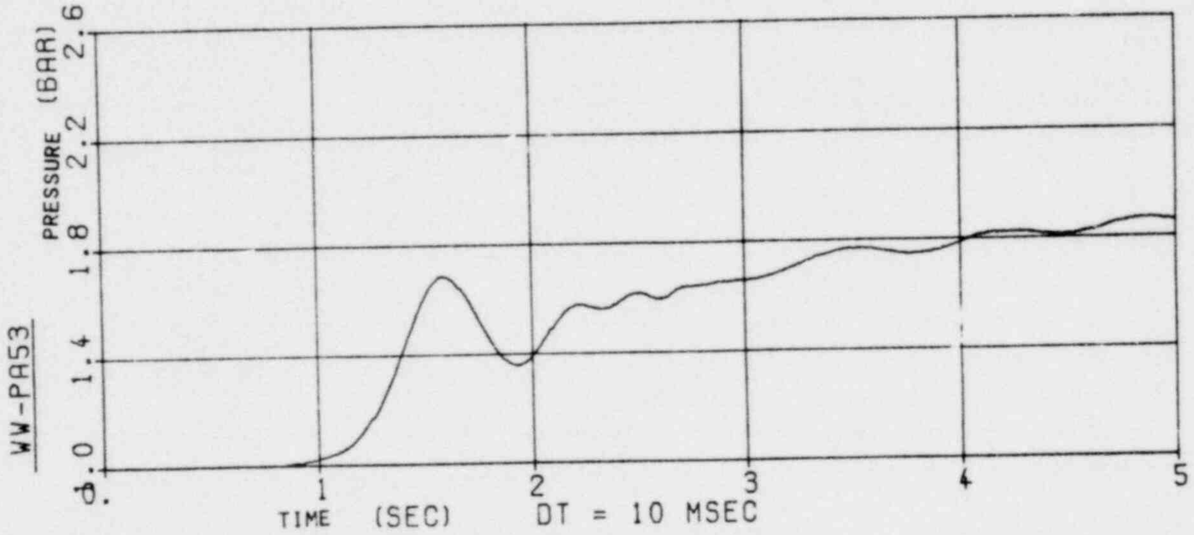

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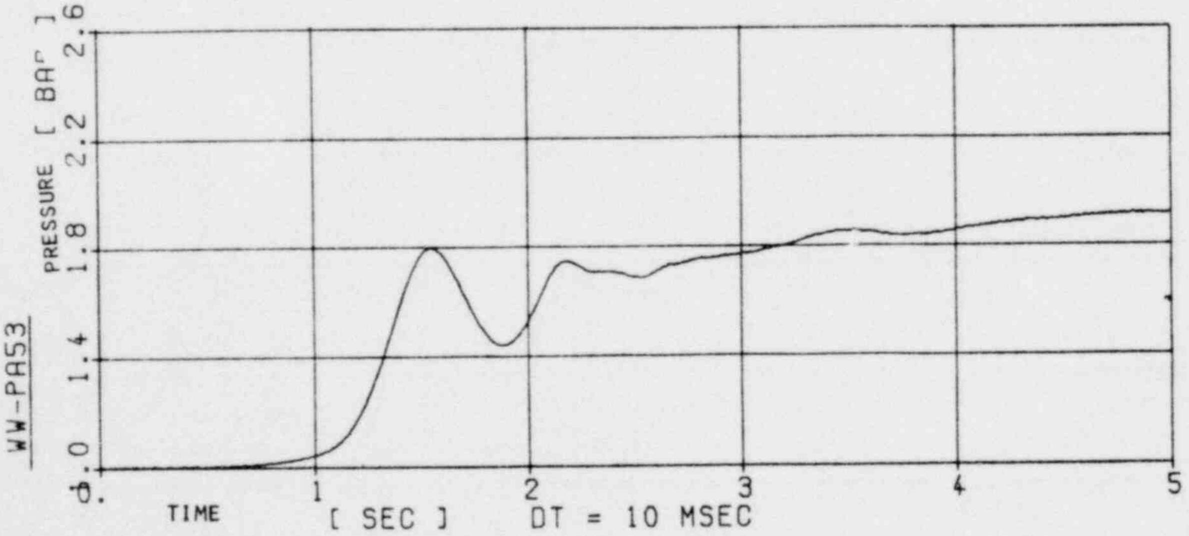
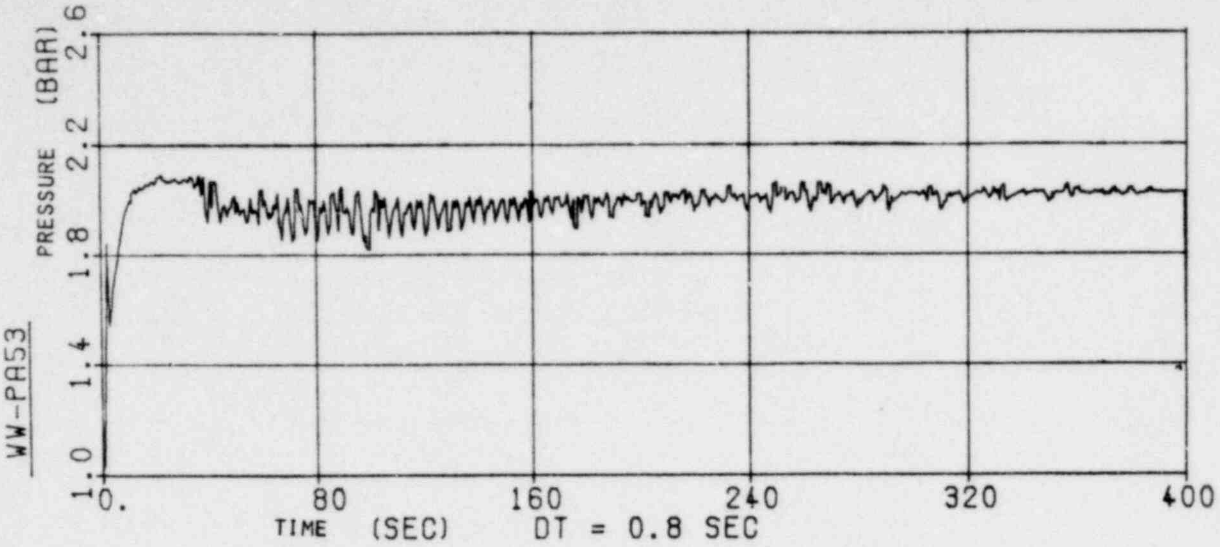


GKSS PSS-TEST VM 03 FIG. 10

ABOVE SURFACE PRESSURE HISTORY



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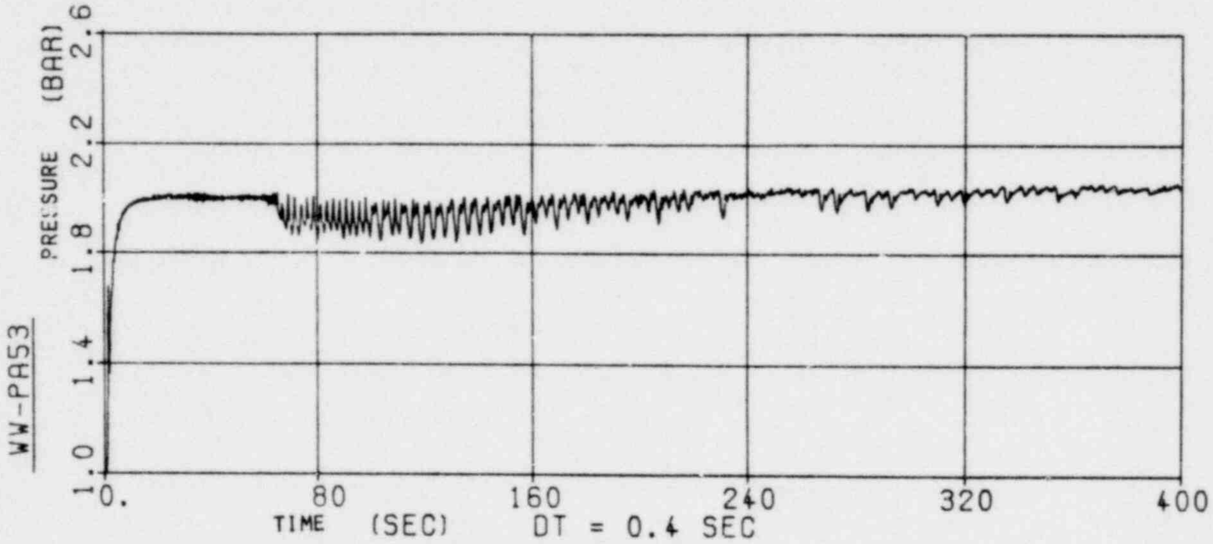

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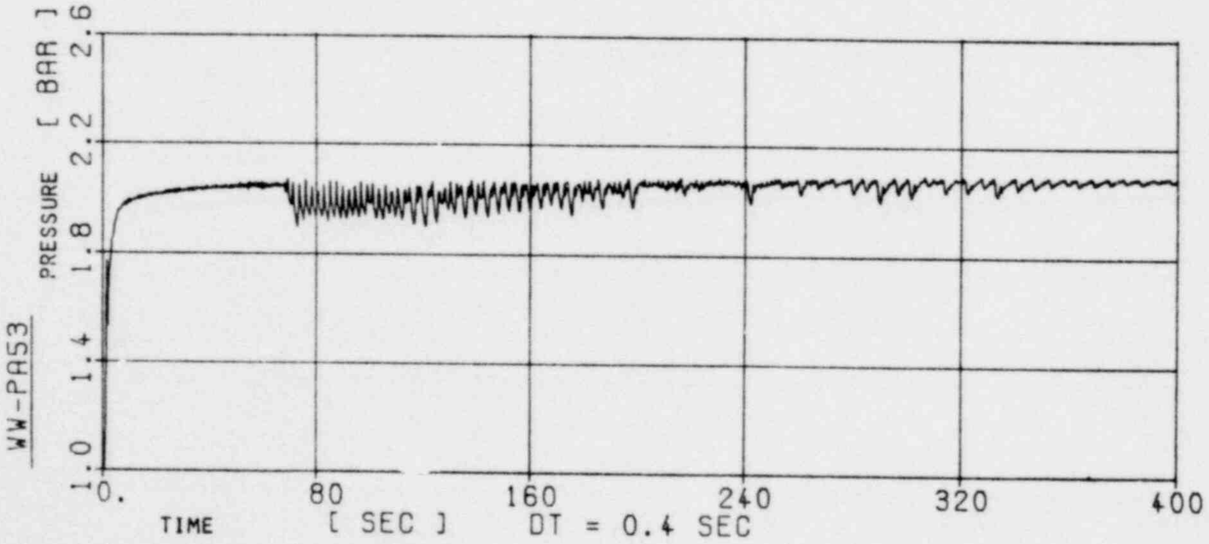

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PSS-TEST VM 03

FIG. 11

ABOVE SURFACE PRESSURE HISTORY

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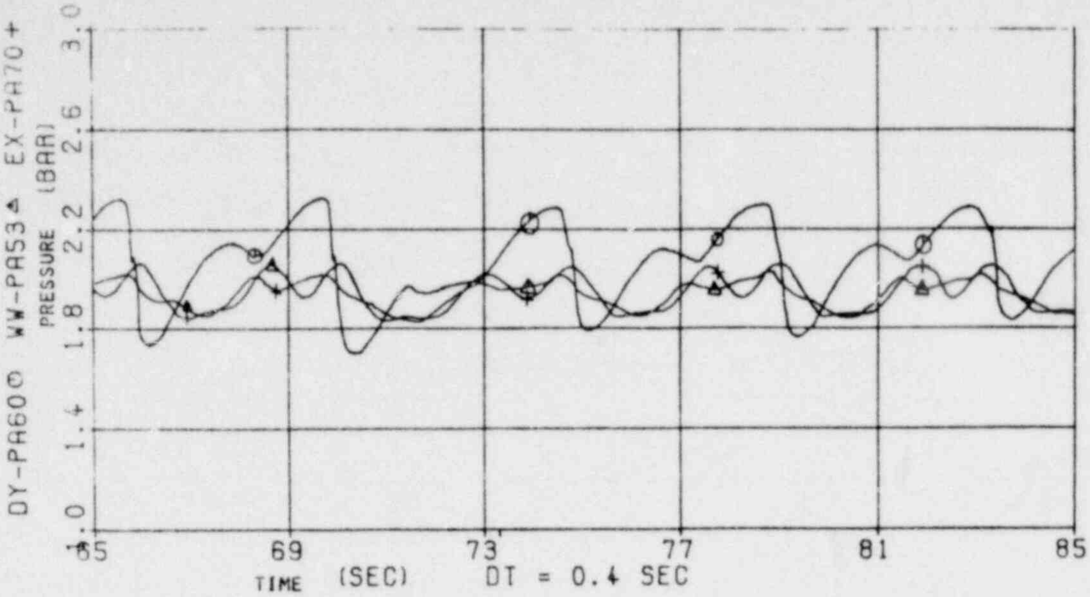

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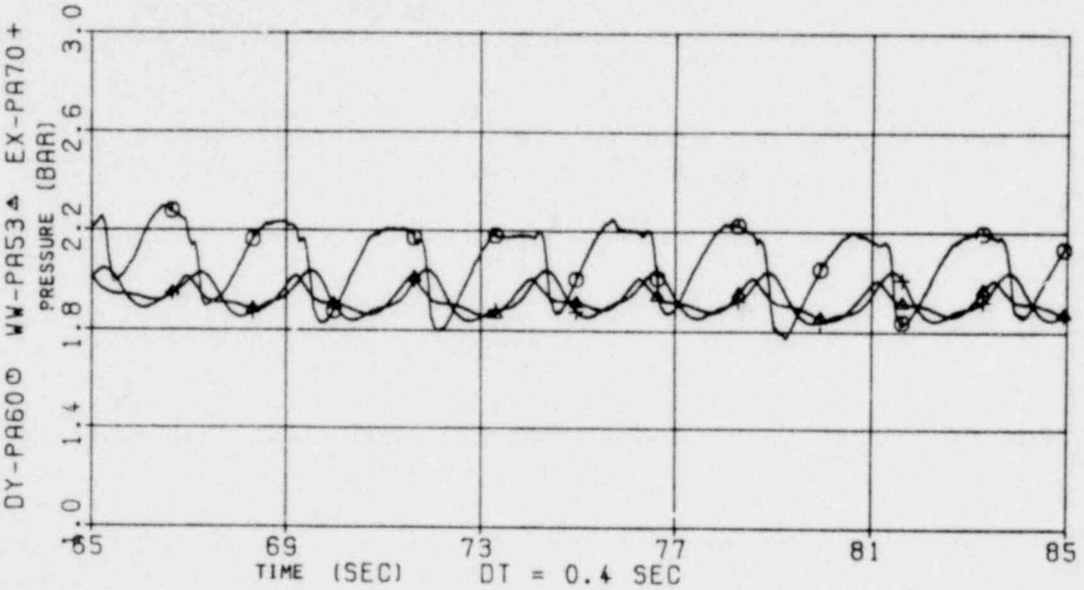

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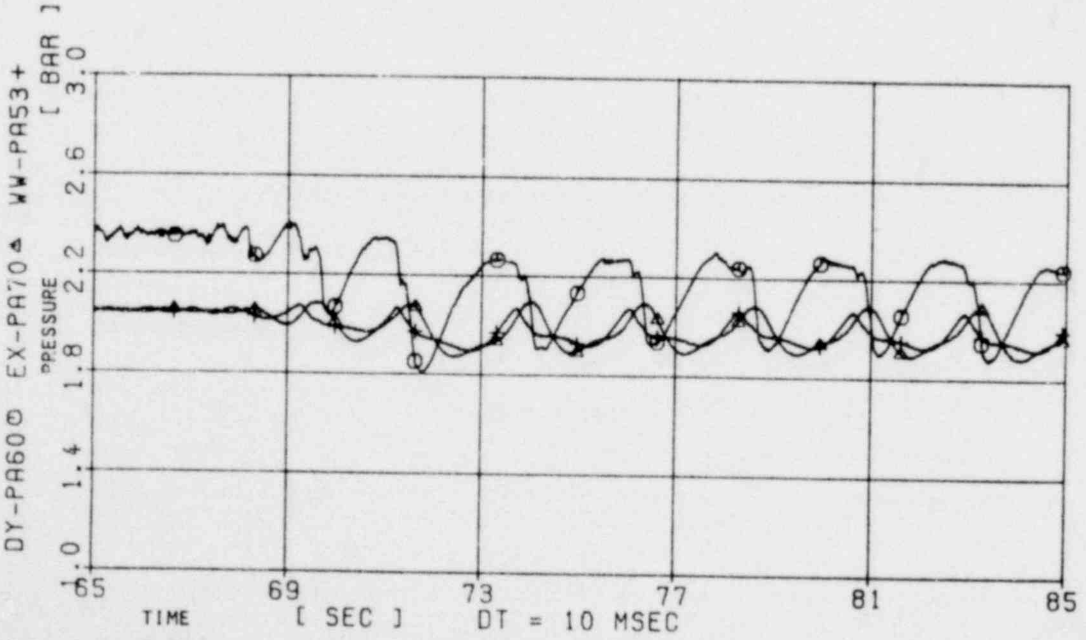

GKSS PSS-TEST VM 03 FIG. 12

DRYWELL, WETWELL, EXPANSIONROOM PRESSURE HISTORY

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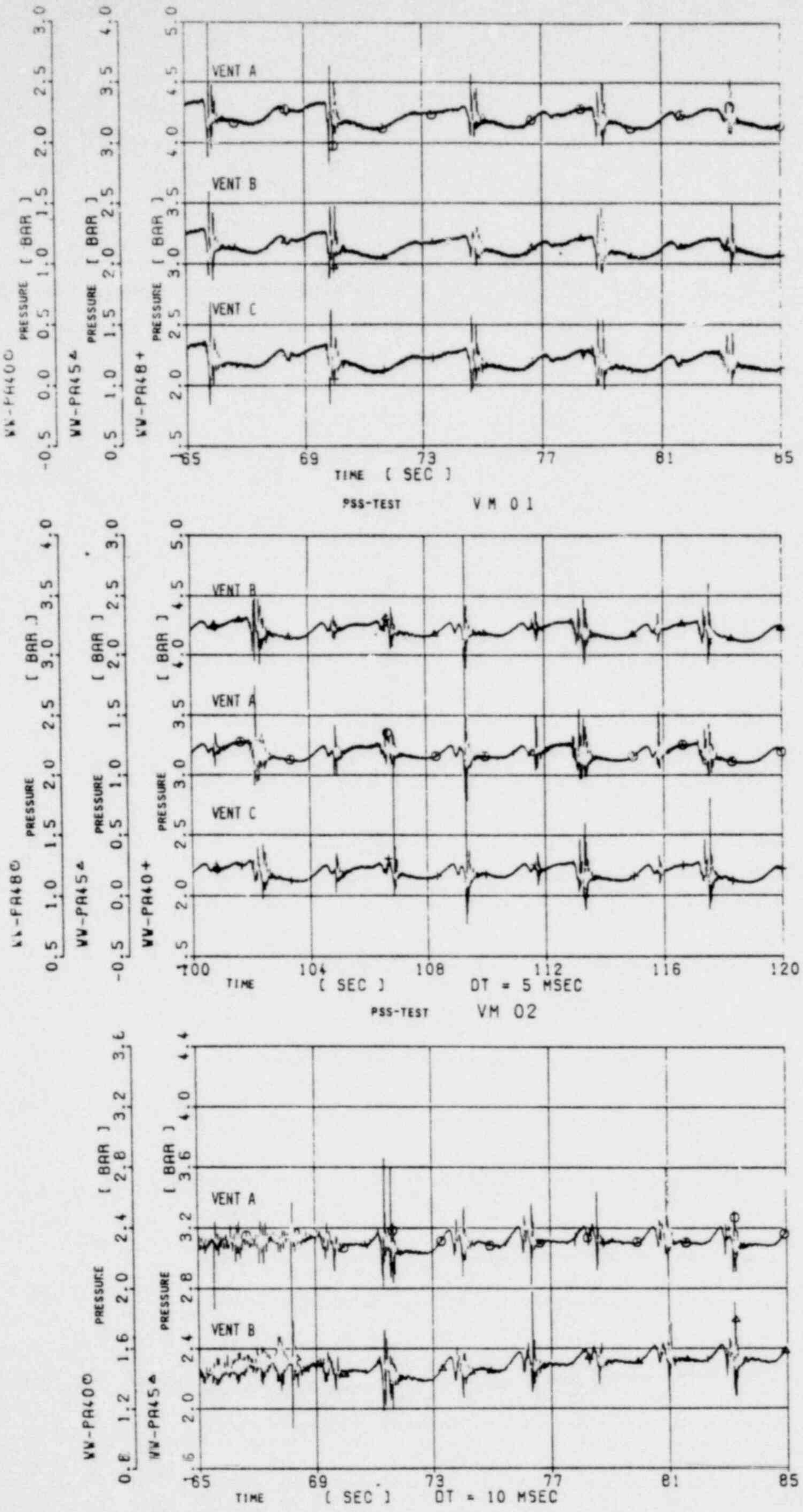

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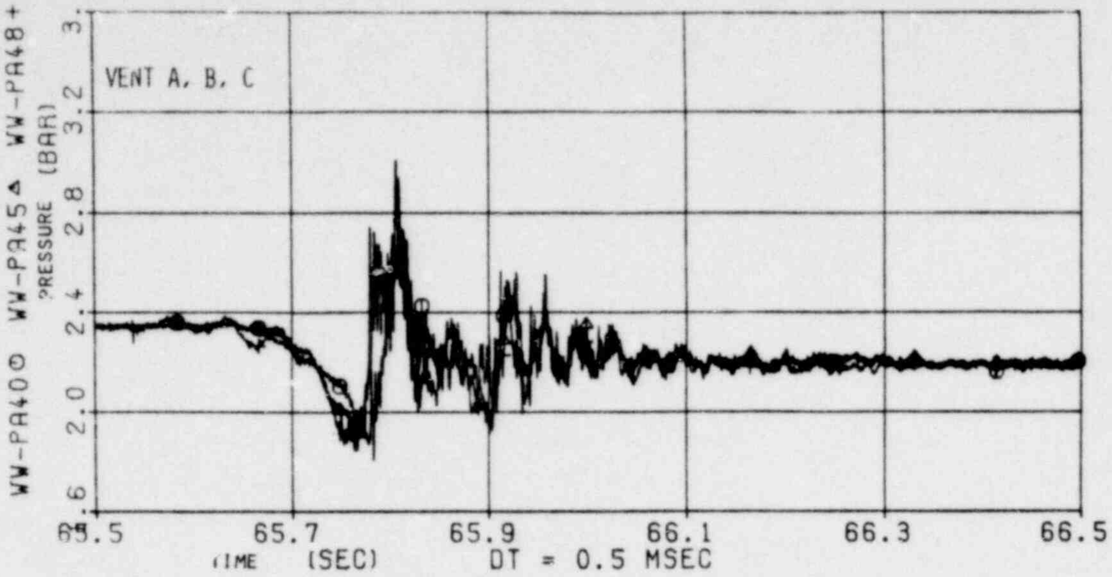
FIG. 13

CHUGGING EVENTS AT THE EXIT OF THE 3 VENTS



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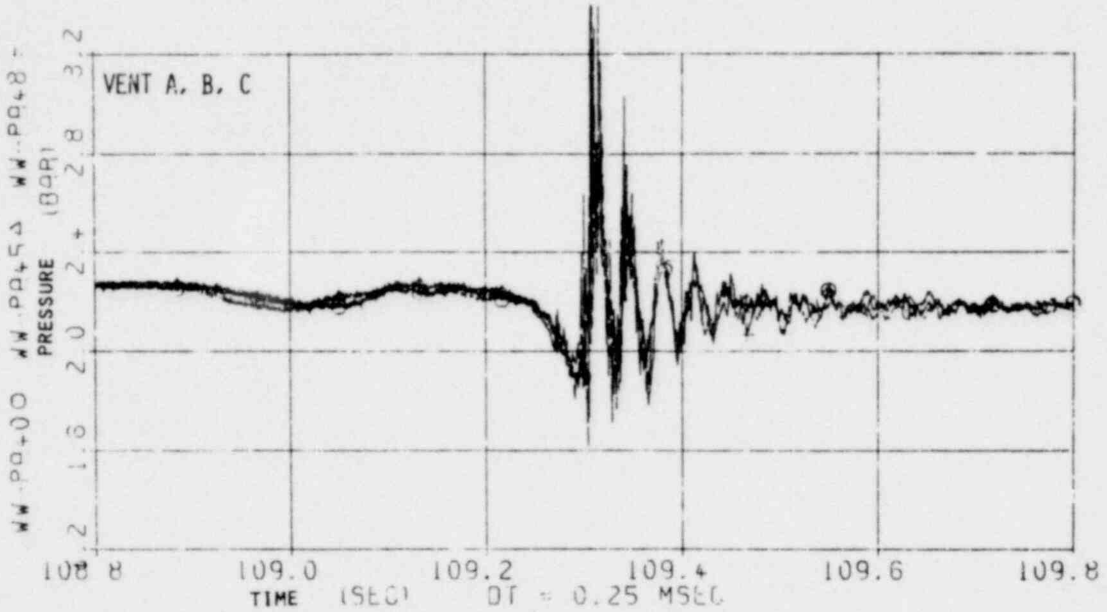

PSS-TEST /M 02

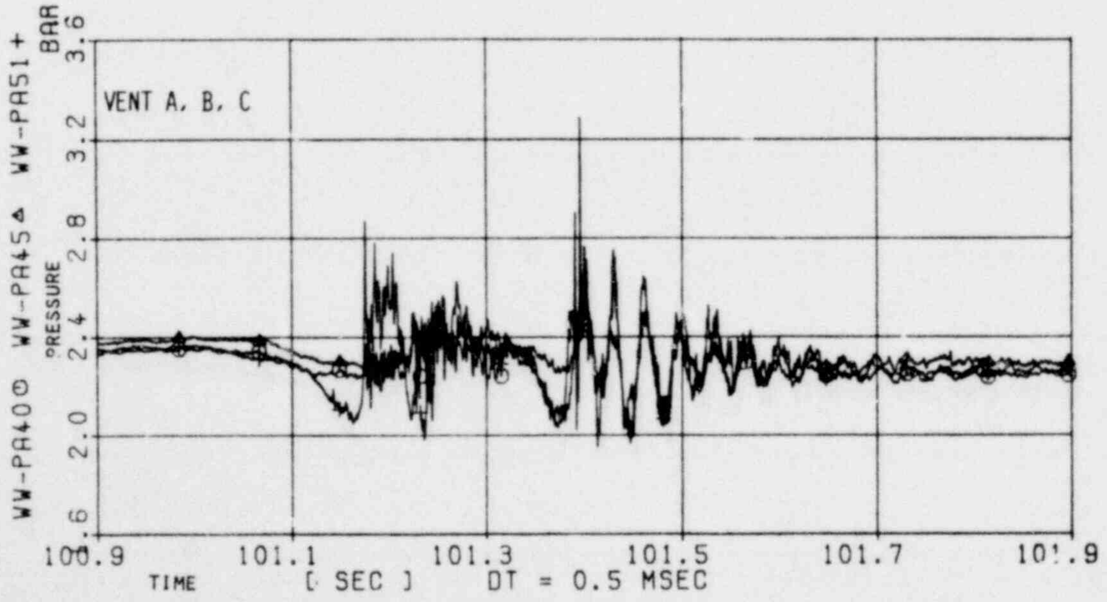

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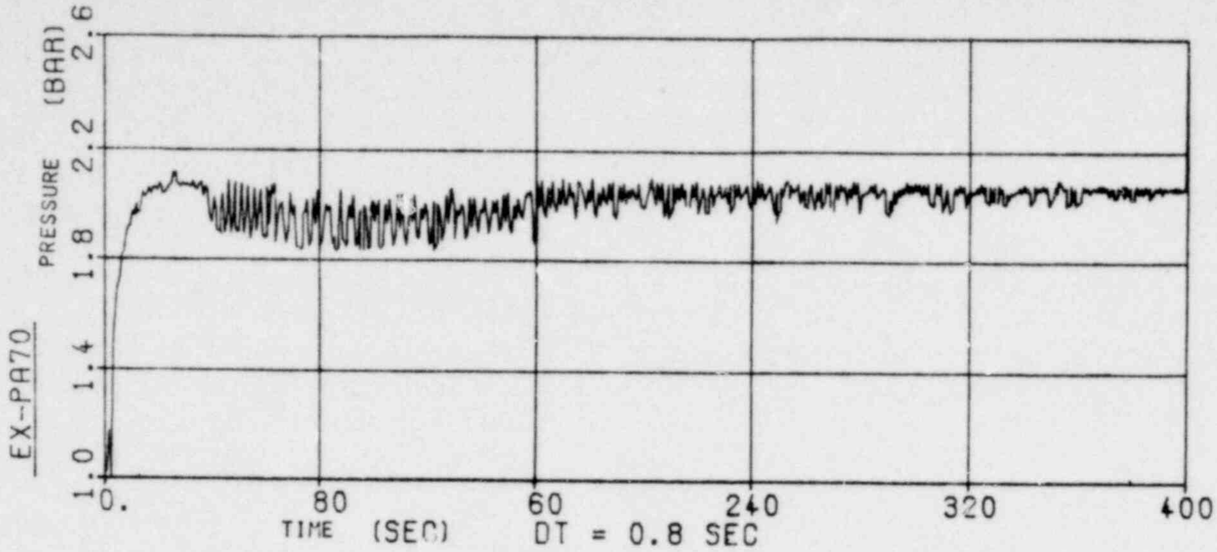
FIG. 14

CHUG EVENT DETAIL



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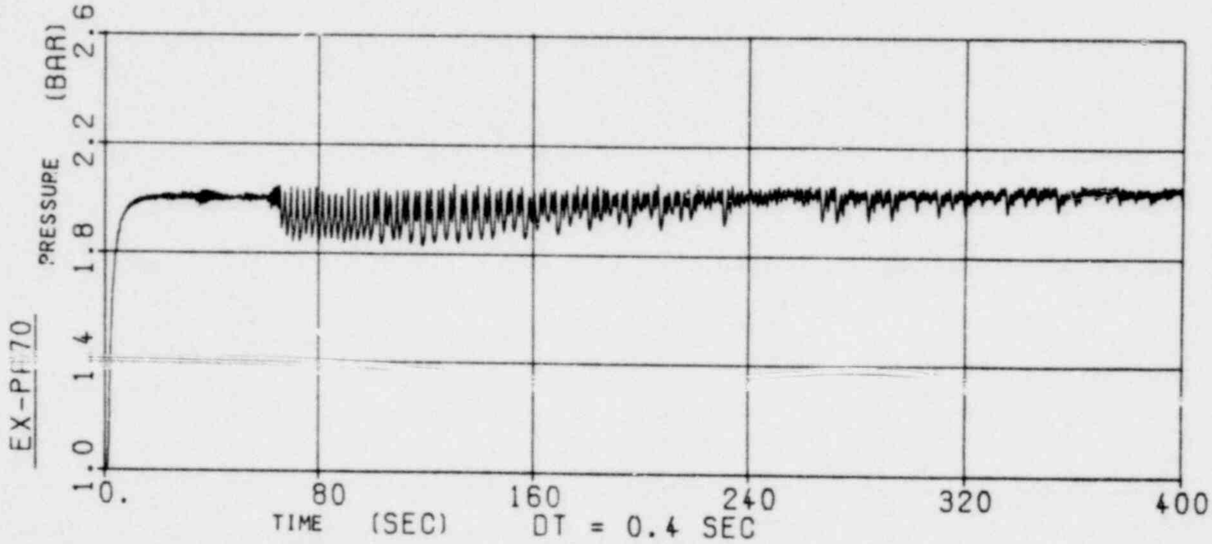

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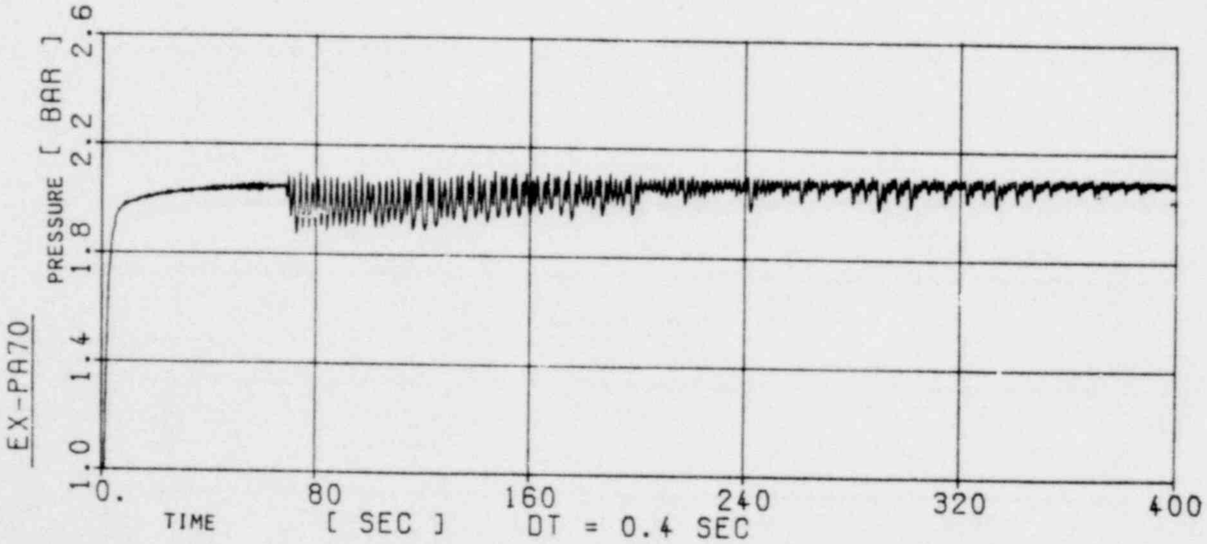

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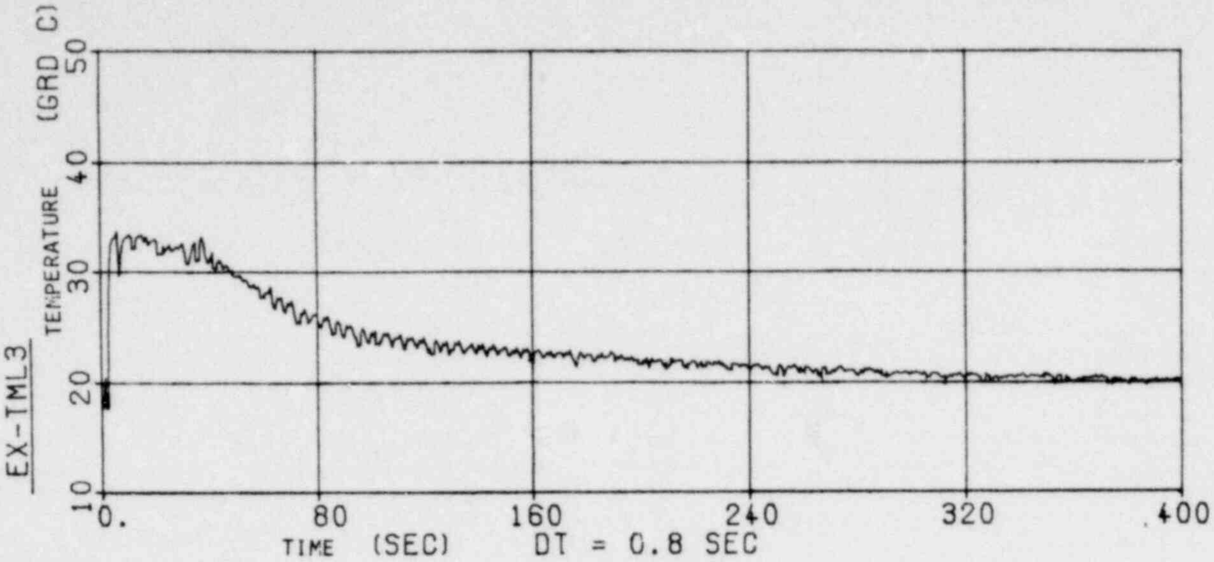
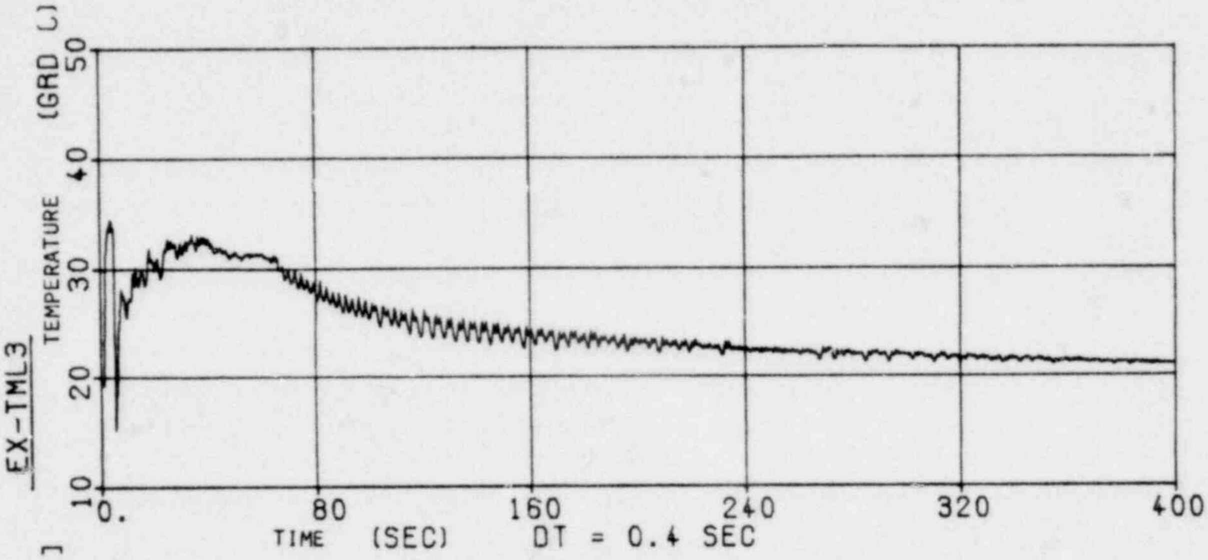
FIG. 15

EXPANSION ROOM PRESSURE HISTORY



GKSS PSS-TEST NR. VM 01



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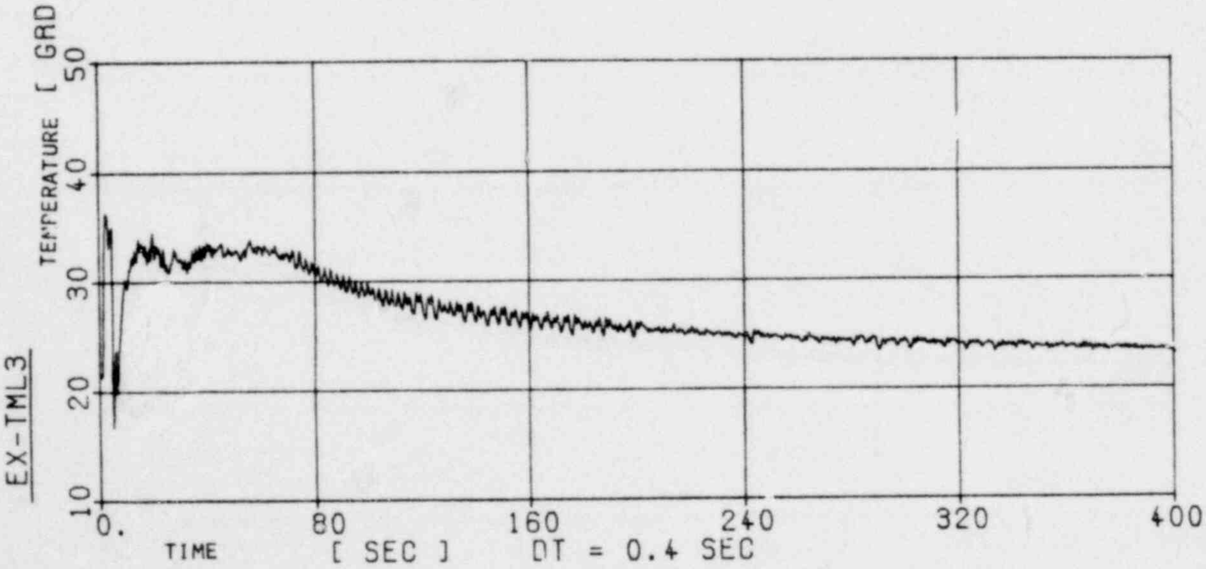

GKSS PSS-TEST VM 03 FIG. 16

EXPANSIONROOM TEMPARATURE HISTORY