LOCA-75-127-NP

Post LOCA
Boric Acid Mixing Experiment

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COMBUSTION
ENGINEERING

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To: J. Longo, Jr.

Post LOCA
Boric Acid Mixing
Experiment

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LOCA-75-127

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Purpose

At the request of Nuclear Safety, the Nuclear Labs have completed a post LOCA boric acid concentration experiment (see attached report).

This memo reviews the experiment and indicates the application of the experimental results to a PWR.

Summary

1) Credit can be taken for mixing between the core liquid and the liquid in the vessel lower plenum. This lowers the boric acid concentration (compared to just using core liquid) and lengthens the time to reach the limiting concentration.

2) The initial buildup of boric acid precipitate occurred at the coldest place in the region of concentration (core and lower plenum). This is the inside surface of the vessel lower head. This precipitate occurred before the concentration in that region reached the 1 atm solubility limit. This is a result of the colder water in the bottom head.

   A PWR is expected to have hotter fluid in that region. Thus, the start of precipitation should agree more closely with the solubility limit for boiling liquid.

3) Upon disassembly, the heater elements were mostly free of boric acid. This indicates that the core can be adequately cooled for some time after the onset of boric acid precipitation.

Discussion

An experiment was run to investigate the post LOCA boric acid buildup in a model reactor vessel. Details of the experimental setup and results are given in Reference 1. The model simulated the core, lower plenum and annulus regions of a PWR. Dilute boric acid solution [ ]^{a} was added to the annulus and electrical heaters caused water to boil in the core. Thus, the boric acid concentration increased with time. This is representative of a large [ ]^{a} cold leg break in a PWR with ECCS injection into the cold legs.

Liquid Mixing

The principle reason for running this experiment was to determine if the liquid in the core region mixes with that in the lower plenum. The mixing of these solutions was confirmed both by visual observation of the flow patterns and by hourly measurements of the boric acid concentration at five locations throughout the simulated vessel. The consequence of this experiment is that the post LOCA boric acid concentration is now known to increase at a significantly slower rate than if the concentrated solution in the core did not mix with other liquid in the vessel.

> This experiment did not simulate a condition in which a large amount of post LOCA liquid would be present in the upper plenum (e.g. many hours after a large break or a small break with steam generator depressurization). For such a condition, additional mixing may occur between the liquid masses in the core and upper plenum.

The boric acid concentration results are given in Figure 1. The actual concentrations were sampled twice (usually) at each time and location up until the solubility limit was reached. The information shown in Figure 1 represents the mean values of the data given in Table 3 of Reference 1.

These measurements were taken hourly at five locations in the simulated vessel. These are:

1) upper part of annulus
2) lower part of annulus
3) simulated core region
4) between the two plates of the lower support structure
5) below the lower support structure and inside the region bounded by the flow skirt.

These measurements are valid up until the occurrence of the solubility limit at 1 atm (29.3 w/o). Beyond this time the sampling pippette picked up solids which yielded erroneous results for concentrations (see Reference 1).

It is seen from Figure 1 that the boric acid concentrations in the core and lower plenum (Regions 3, 4 and 5) increased at fairly similar rates (except for a single anonymous data point measured between the lower support plates at 12 hours). These results provide the bases for assuming uniform mixing between the liquid masses in the core and lower plenum regions of a PWR. It is also seen from Figure 1 that the transient boric acid concentrations in the upper and lower portions of the annulus fluctuated with time and generally were higher in value than the inlet concentration [ ]. Thus, the annulus is seen to participate in the backmixing process to a small degree.

An analytical prediction has been made of the transient boric acid concentration in the core and lower plenum. This transient concentration is based on the power history to the heater rods reported in Reference 1 (P.2). The analytical prediction is also shown on Figure 1. This prediction follows the trend of the measured data, with a slight conservatism, up to about 8 hours. Beyond 8 hours the slope of the measured data decreases and the difference between this data and the prediction is significant. The reasons for this behavior are as follows:

a) Between 3 and 8 hours there is a substantial (and temporary) rise in the boric acid concentration in the upper and lower annulus regions. Thus, the effective mixing volume is larger than that of the core and lower plenum. For this reason, the predicted concentration, which is based on just the core and lower plenum mixing volumes, is an overprediction in this time span.

b) Beyond 8 hours a buildup of precipitate was noted on the inside surface of the vessel lower heat (Reference 1-P.3). This accumulation of solid boric acid slowed down the rate of increase in the solution concentration for the core and lower plenum. This is why the measured and predicted results diverged so significantly beyond 8 hours. The reason for the occurrence of a precipitate on the inside lower vessel head after 8 hours is that the relatively low temperature in this region (see Figure 2) established a low boric acid solubility limit. This lower than saturation temperature is due to heat losses out through the uninsulated sides and bottom of the simulated vessel.*

The temperatures of the various regions in the simulated vessel were recorded hourly. This data is shown in Figures 2 and 3. It is seen, from Figure 2, that at 8 hours the temperature in the lower plenum (inside the flowskirt) is [ ]^{a}. The inside surface of the lower head should be somewhat colder than the measured value inside the flowskirt.

The boric acid solubility is highly temperature dependent. This can be seen from Figure 4, which is reproduced from Reference 2. At a temperature of [ ]^{a} the maximum solubility of boric acid is seen to be equal to [ ]^{a}. Figure 1 shows that, at 8 hours, the existing boric acid concentration in the lower plenum liquid is about [ ]^{a}. Thus, there is good agreement between the measured boric acid concentration in the lower plenum and the solubility limit which is based on the measured temperature.

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*This heat loss was enhanced by the presence of a fan which blew air over the experiment for a portion of the run time. The purpose of this fan was to clear out the evolving steam to aid visibility.

Beyond 8 hours the measured lower plenum temperature (Figure 2) is seen to rise to the saturation value at about 18 hours. The cause of this slow temperature rise is not firmly established, although I suspect that the buildup of the boric acid thickness in the lower head served to insulate this region and thereby reduce heat losses. Also, beyond 8 hours the measured boric acid concentration in the core and lower plenum rose slowly and reached the one atmosphere solubility limit (29.3 w/o) at between 15 and 16 hours. This is in general agreement with the temperature dependent solubility limits obtained from Figures 2 and 4.

For a CE-PWR there is insulation around the sides of the reactor vessel and on the bottom and sides of the reactor cavity (see References 3 and 4 for Calvert Cliffs). This insulation plus the vessel thickness will limit heat loss and will cause the lower plenum temperature to be closer to that in the core than was observed in the uninsulated and thin walled experimental setup. These qualitative considerations for a PWR indicate that the maximum boric acid solubility in the lower plenum liquid should be fairly close to that in the core. Thus, the analytical predictions of boric acid concentration should be more valid for a PWR than for this experiment. When precipitation does start in a PWR, it should proceed from the coldest place in the core or lower plenum.

Post Precipitation Conditions

An important observation made during this test is that the lower support plates, with their small size holes [ ]^{a} did not fill up with solid boric acid until the precipitate first filled the lower head and then rose to the level of the plates. In fact, even after the lower head filled with precipitate some water managed to get to the heater section via flow channels that appeared in various parts of the boric acid plug (see Figures 16, 17 and 18 of Reference 1). The liquid level inside the barrel could not be observed late in the test as precipitate collected on the inside surface of the simulated barrel (see below).

It is also seen from the test results (Figure 14A, Reference 1) that a certain amount of boric acid was thrown upwards from the boiling region when the concentration got close to the 1 atm solubility limit. This reduced the boric acid mass in the liquid filled portion of the vessel. This effect was also noted in the smaller scale experiment reported in Reference 2.

For a PWR, the above results show that there is no catastrophic effect associated with the post LOCA initiation of boric acid precipitation. Rather, it is a time dependent effect throughout the upper and lower portions of the vessel with the buildup proceeding gradually.

Post Test Examination

The disassembly of the test setup was recorded in Figures 5, 6 and 7 (all attached). Figure 5 shows the test section minus the simulated vessel. This figure shows the plug of boric acid in the lower plenum. Some of the precipitate inside the simulated core barrel developed after the heaters were turned off and the temperature dependent solubility limit dropped below the existing concentration.

Figure 6 shows the simulated core barrel with the lower head plug of boric acid cut off. It is seen that the lower support plate region is filled with precipitate, although observations during the test indicated that the heaters were receiving some liquid.

Figure 7 shows that the precipitate in the heater region was building up from the inside wall of the simulated barrel (coldest location). At the time of test termination the lower 3/4 of the heater rods were generally free of precipitate. There is some precipitate visible on the upper 1/4 of the heaters. This indicates that the upper portion of these rods were in contact with less liquid than the lower region. This condition existed prior to the occurrence of precipitate and is a result of the axial void distribution in the heater section (see Figure 12, Reference 1). Hence, it is not clear whether the upper part of the heaters was or was not drying out at the end of the test (38 hours).

References

1) [ ]^{a,c}

2) D. J. Morgan, ECCS-Boric Acid Concentration (Generic) Physical Data, Results of Preliminary Testing", NLM-74-479, November 25, 1974.

3) Bechtel Spec. No. 6750-M-339, Spec. for Reactor Cavity Insulation, Calvert Cliffs Nuclear Power Plant, January 6, 1970.

4) Drawings from Universal Fabricated Products, DWG. Nos. 3836-1 to -12.

Fig. 1

BORIC ACID MIXING EXPERIMENT
BORIC ACID CONCENTRATION vs. TIME

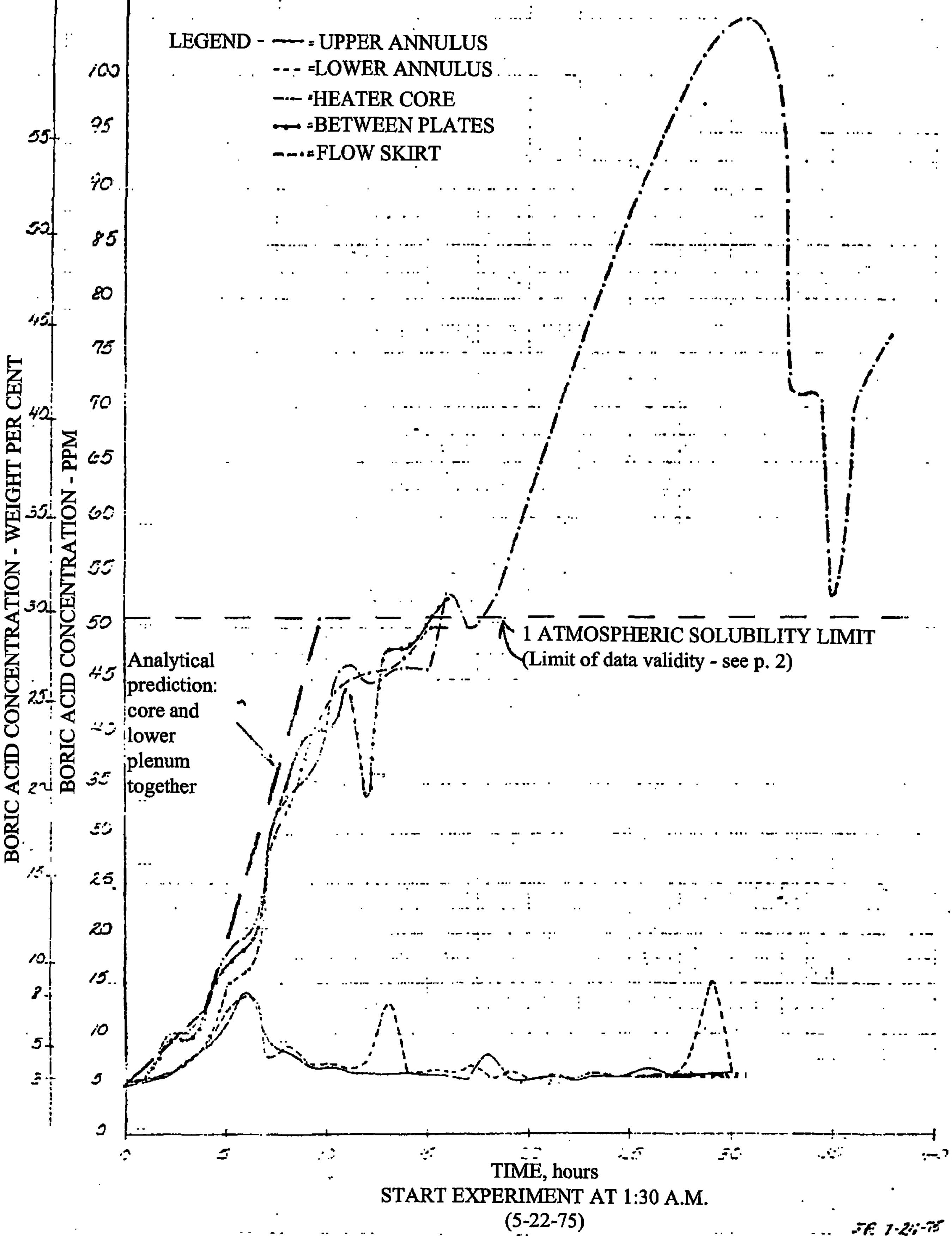

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Figure 2 **Boric Acid Mixing Experiment**

Legend
——— = 4 core
—·—·— = 5 between lower plates
- - - - = 6 inside flow skirt

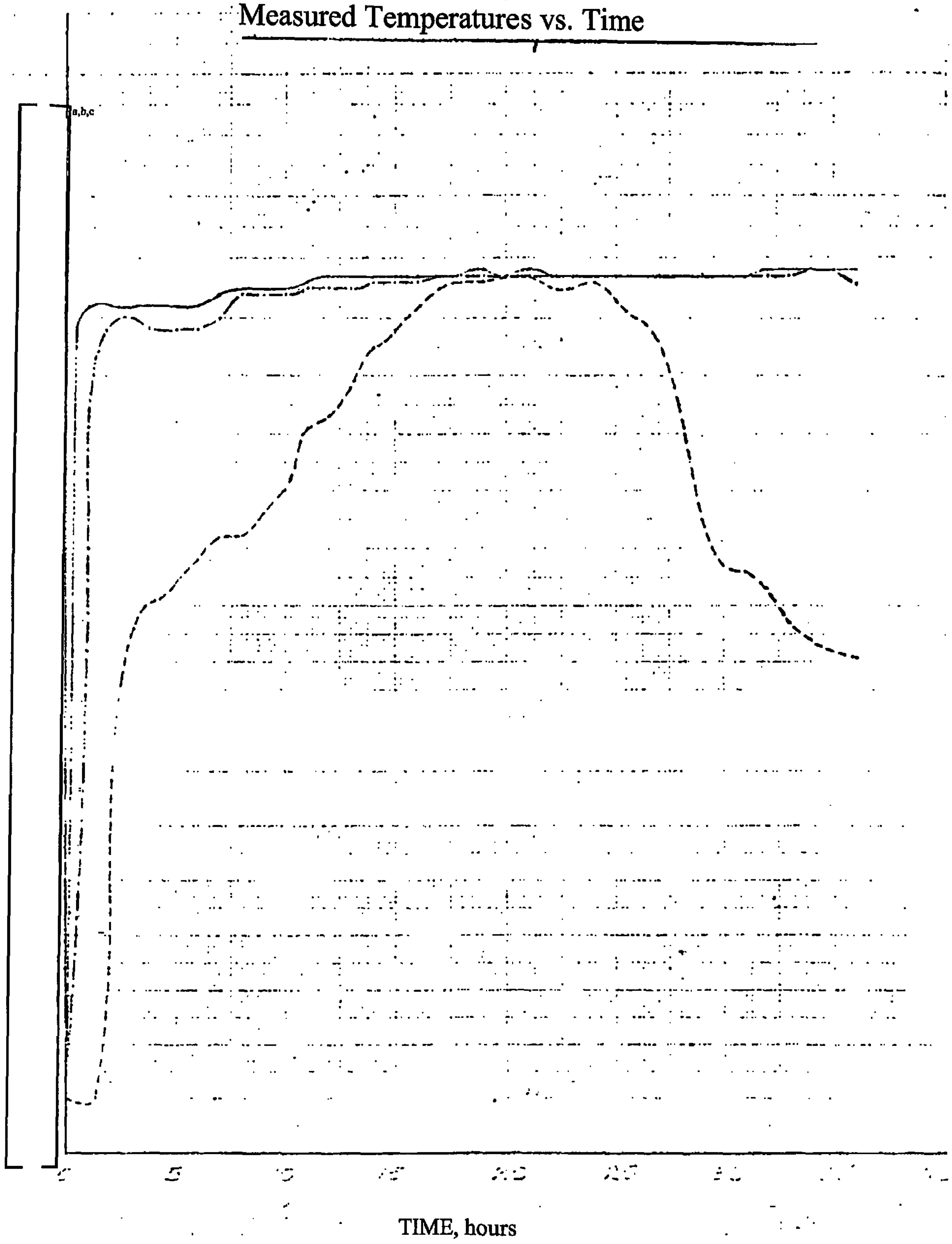


Figure 3 Boric Acid Mixing Experiment

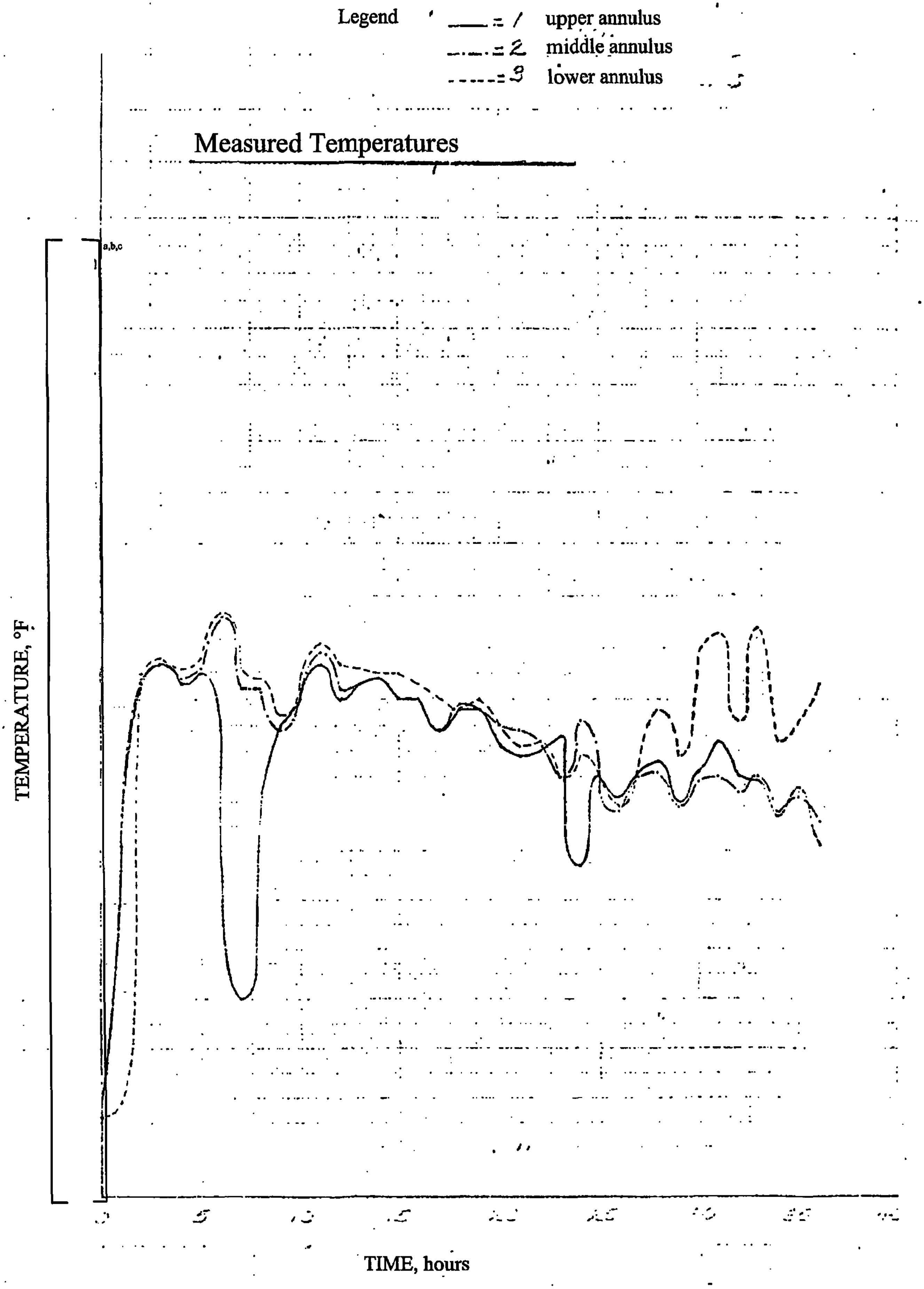
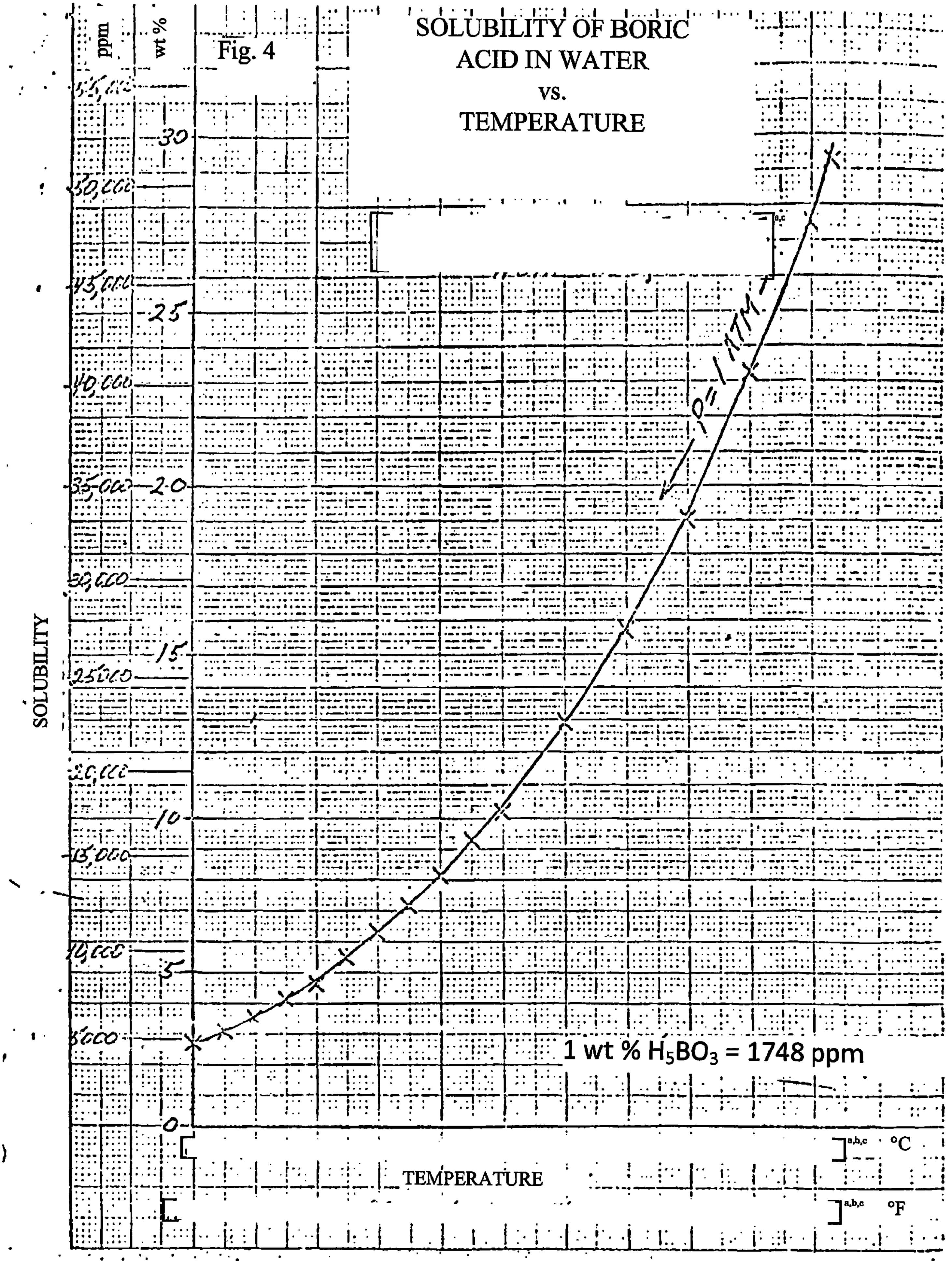


Fig. 4

SOLUBILITY OF BORIC ACID IN WATER vs. TEMPERATURE



1 wt % H_5BO_3 = 1748 ppm

FIG. 5

BORIC ACID MIXING TEST
POST TEST EXAMINATION
TEST SECTION MINUS SIMULATED VESSEL

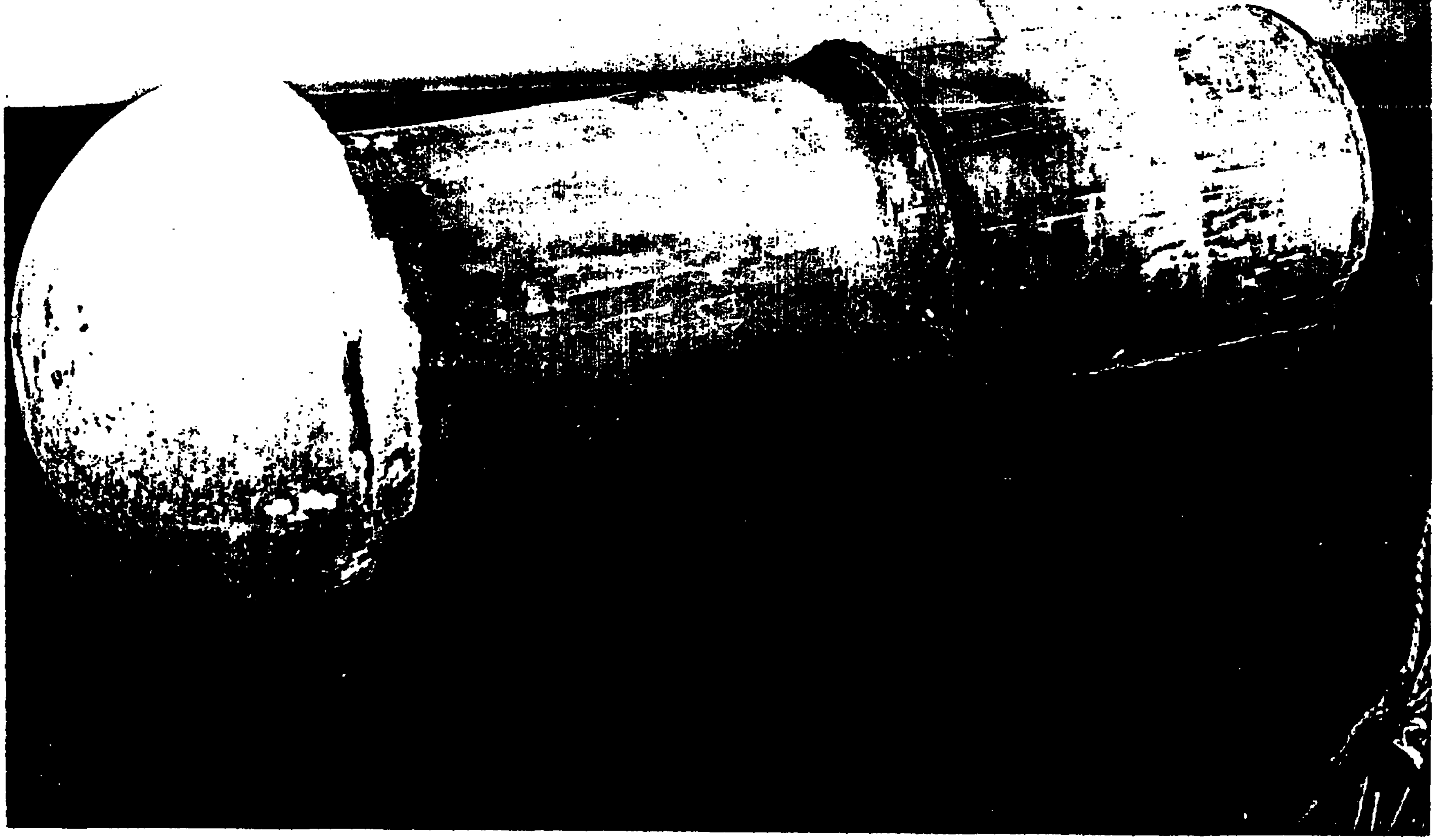
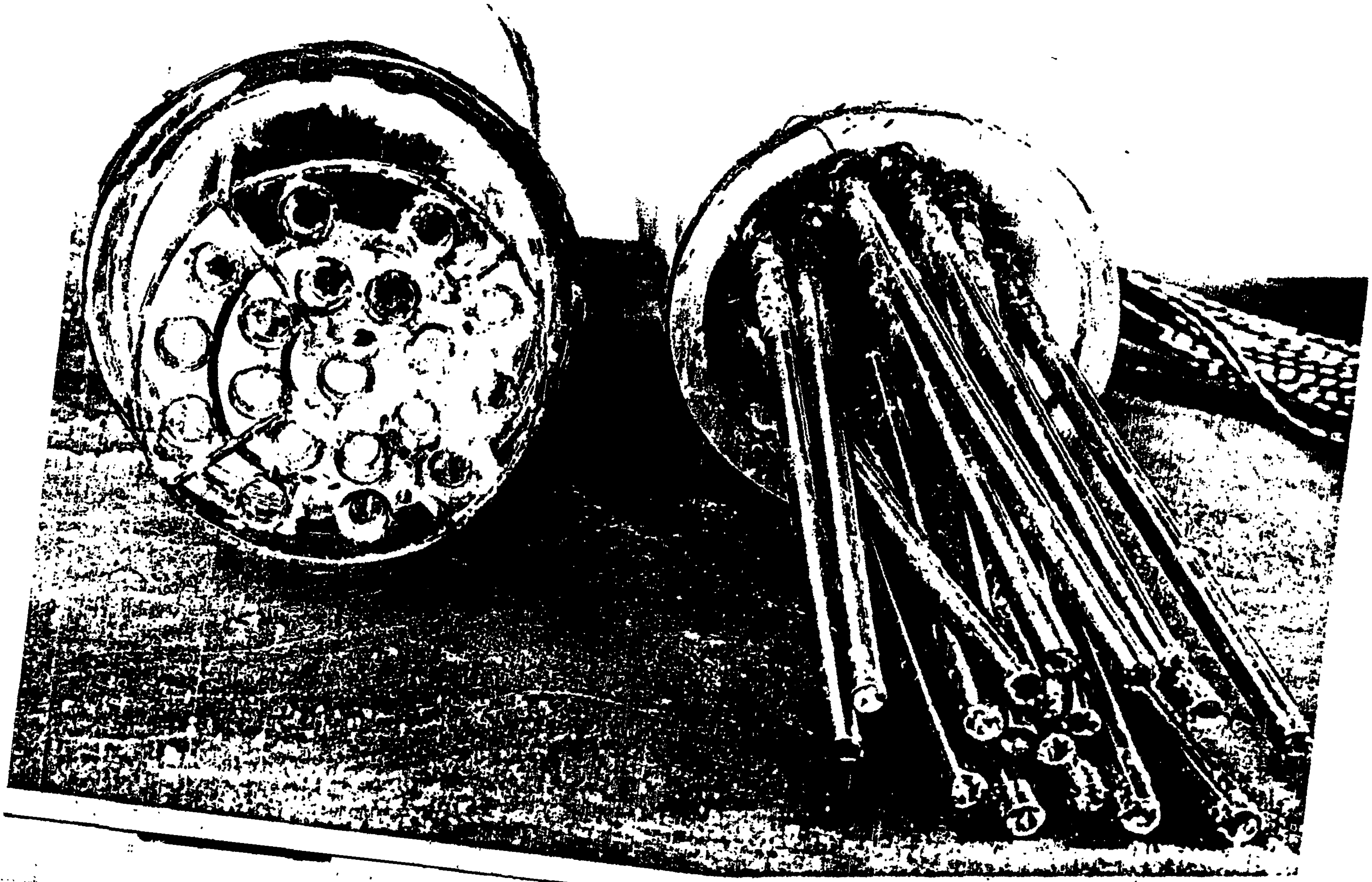


Fig. 6

Boric Acid Mixing Test
Post Test Examination
Boric Acid Plug Removed from
Barrel Bottom

FIG. 7
BORIC ACID MIXING TEST
POST TEST EXAMINATION



Heater Section of
Simulated Core Barrel

DISTRIBUTION

COMBUSTION ENGINEERING
DEVELOPMENT DEPARTMENT

TEST REPORT

REACTOR MODEL
ECCS BORIC ACID CONCENTRATION TEST

591951

Prepared by: G. P. Norton
Reviewed by: G. D. Rogers

Reviewed by: N. R. Stolzenberg
Approved by: Laboratory Manager

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Date of Issue: 7/7/75

Ref. Test Request No. 398

1.0 INTRODUCTION

Current CE ECCS designs utilize a boric acid solution injected into the core region via a safety injection system. It has been postulated that this system may result in unacceptably high concentrations of boric acid in certain core regions during a long term post LOCA cooling operation. High concentrations of boric acid could result from the continuous evaporation of a coolant solution due to boil off in the core region when core flushing and mixing does not exist to the necessary degree.

The test described in this report was undertaken to demonstrate the effects of adding boric acid solution and boiling at atmospheric pressure in a model reactor assembly. By geometric simulation of the various zones in a reactor assembly, boric acid precipitation was examined to evaluate its effect upon core cooling.

The intent of this test was to simulate ECCS design for a long term operation following a cold leg break when core flushing is unavailable and core decay heat is removed by boil off of a borated solution.

2.0 SUMMARY

A visual model built reasonably to scale and incorporating the separate flow regimes of interest, has shown that mixing does occur between the zones in question. Both qualitative and quantitative results support this conclusion. Visually observed convection patterns were noted early in the test and increased with increasing concentration, and samples taken from the various regimes show general mixing occurring.

3.0 OBJECTIVE

Through application of a model assembly, the test will illustrate to a reasonable degree:

1. How and where boric acid precipitation develops in a reactor assembly.
2. Whether precipitation forms quickly or is delayed by the inherent mixing action of the core region through fluid reflux (back mixing).
3. If flow through the lower support plates eventually ceases when precipitation increases in these regions.
4. How carryover of boric acid solution may eventually effect the plugging of the steam venting pathway above the core region.

4.0 DISCUSSION

4.1 Test Setup

A large reservoir tank was employed to supply boric acid solution to a glass model reactor assembly. Thermocouples were installed in the model and temperatures monitored on a digital indicator. A powerstat connected via a junction box to heater rods within the model allowed variable power inputs to these rods. A 1 ml lab pipette was utilized to withdraw coolant samples from the model (see Figure 8).

The model fabricated for this test simulates to a reasonable degree the various zones of a reactor assembly. To enable construction of a model in a minimum amount of time, primarily with available equipment, restrictions were imposed upon the ability to adhere to a constant model scale. Therefore, model dimensions varied from those of a true scale and are tabulated in Tables 1 & 2. The model geometry demonstrates to a reasonable degree: an outer vessel and annulus region, a lower plenum with flow skirt and support plates, and a heated core region with upper plenum.

The model reactor assembly was constructed of glass and plexiglas material with stainless steel support plates, flow skirt and heater rod support.^{a,c} A balanced arrangement of [,] heater rods comprised the core region, [ ] total. See Fig. 6.

Concentration sampling and thermocouple locations are shown in Figure 7.

4.2 Procedure

The model was initially filled with a [ ]^{a} boric acid solution from the reservoir tank at room temperature. Solution level within the model was maintained initially and throughout the test, at the top of heater rods (core region). Upon completion of initial data recording, the powerstat was set to [ ]^{a,b} of full power to stabilize temperature variations throughout the model. Inlet flow of preheated boric acid solution from the reservoir tank to the model upper annulus region was adjusted to maintain a constant level in the core. Following completion of the first hour of the test, the powerstat was set to [ ]^{a,b} and maintained through the fourth hour at which time the final setting of [ ]^{a,b} full power was achieved. Power settings above [ ]^{a,b} produced boiling at the top of upper plenum and spillage out of the vessel and therefore the upper [ ]^{a,b} power limit was selected. On an hourly basis, three concentration samples were withdrawn from each of five locations with temperatures recorded for eight locations (See Tables 3&4)* The level of solution in the reservoir tank was recorded hourly to provide a record of the coolant makeup per unit time (Figure 5).

Photographs were taken at periodic intervals throughout the test. (See Figs. 12-23).

The concentration samples were placed in plastic vials of 2.5 ml volume and capped for chemical analysis. Three samples were taken to alleviate large sampling errors. Some errors in measurement are likely, due to an inability to maintain placement of the pipette at the same level in each of these regions through repeated samplings, and the possibility that insertion of the pipette into the small volumes of the lower core region and the size of the samples could disturb the concentrations in these regions.

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*All available samples were not analyzed.

4.3 Results

Figs. 1 & 3 exhibit curves for the time rate to precipitate boric acid in the five regions of the reactor model. Shown are the initial 18 hours of operation after which uniform sampling of the core region could not be continued due to precipitation buildup in the lower regions. Attempts at taking liquid samples were unsuccessful due to rapid solidification in the pipette. High concentration samples were obtained by removing glass tubes with solid precipitate and analyzing a uniform length.

Caution: The curves presented serve only to illustrate and provide the basis for an evaluation of the trend that presented itself during performance of the model test. The actual injection concentration, flow rate and boil off rate for the actual reactor are different, therefore an extrapolation to the reactor system operation based upon these results is not attempted in this report. The results do show that thermal mixing does occur between the various regimes producing a general solution concentration mechanism. Mixing and flow rates were very slow and it is not known if other flow rates would produce more or less concentrating. Table 3 is a tabulation of samples analyzed. Erratic data such as that between the support plates during the twelfth hour are not indicative of the overall trend but probably due to faulty placement of the sampling probe or improper labeling of the sample container.

Figures 1 & 4 show that good agreement did exist for time to concentrate between the various regions of the core barrel and that back mixing of higher density solutions between these regions did take place. Theoretically, without back mixing the time to reach bulk precipitation (50,000 ppm) in the heater core region of this model would have occurred within approximately 14 hours, as compared to the observed localized precipitation in greater than 16 hours during the test.

Observed during the test and fundamental to back mixing were the presence of thermal convection currents in the lower core regions. These formed at the outset of the test immediately below the core support plate; convection currents progressed through the lower support plate to eventually encompass the entire flow skirt region by three hours into the test. Movies taken of the model during the test, on file with the ED&S Photography Department (Bldg. 5), display these thermal currents. Still photos did not show the patterns.

The initial appearance of boric acid precipitation occurred about eight hours into the test. Formation began as a thin layer on the bottom of the outer glass vessel (See Figure 9) at a level below the rim of the support stand.

Observations made include:

At 14 hours into the test, deposits had grown to two inches above level of support stand and began to increase in thickness. By approximately 16 1/2 hours, precipitation enclosed 2/3 the flow skirt region and appeared on the lower support plate. One-half hour later, the flow skirt region was completely enveloped and 1/4 the region between the plates. At 18 hours, buildup in the liquid-vapor region above the heaters began to appear and two-thirds of the region between the plates was now enclosed. The initial appearance of precipitate in the core region on the core support plate began 19 hours into the test. Rapid buildup of precipitation continued throughout the model from this time to test termination, 38 hours from startup. Boron precipitation had completely enclosed the lower annulus, flow skirt and support plate regions and two-thirds of the heater core region. Buildup did occur in the steam venting pathway but at no time was venting impaired. (See Figures 10 & 11)

Observed late into the test were the continual appearance of flow channels between the support plates and flow skirt regions. Eventually, following close-off, these channels would reappear a short time later in other locations.

At completion of the test, it was apparent that at no time was the operation of heater rods of the core region impaired by the accumulation of boric acid precipitation in the model assembly. A reasonably constant boil off rate, see Figure 2 , the result of unabated heater rod output rates indicates a continuous flow of coolant through the region.

TABLE 1

TABULATION DIMENSIONS (approx.)

Item	Reactor (Calvert Cliffs I) [a,b,c]	Scale	Model [a,b,c]
ID of Vessel		1/18	
Height of Vessel		1/16	
ID of Core Barrel		1/24	
Height of Core Barrel		1/16	
OD of Core Barrel		1/23	
Width of Annulus		1/7	
Opening from Vessel (Hot & Cold Legs)		1/16	
Height from Lower Plate to Bottom of Vessel		1/16	
Height from Core Support Plate to Lower Plate		1/16	
Height of Flow Skirt		1/16	
Length of Heater Rods (Active Core)		1/11	
Flow Area Through Support Plates		1/24	
Flow Area Through Flow Skirt		1/24	
Upper Plenum Flow Area		1/20	

Scaling Ratios

[a,b,c]

TABLE 2

STEAM RATE COMPARISONS

Item	Reactor (post LOCA 10^4 sec) [a,b,c]	Model [a,b,c]
Power (K.W.)		
Q_{core} (btu/sec)		
W_{core} (lbm/sec)		
G_{steam} (lb/sec-ft^2)		

TABLE 3

CONCENTRATION (ppm Boron)

	C_1 Upper Annulus			C_2 Lower Annulus			C_3 Heater Core			C_4 Between Plates			C_5 Flow Skirt		
Time	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
5/22/75															
0130	4723	5009	4893	5004	5146	6111	5425	5197	5151	5295	5234	5244	5016	5209	5323
0230	5278	5238	5327	5285	5683	5257	5879	5924	5969	5638	5940	5654	5483	5423	5802
0330	5814	5679	5638	5792	5811		9911	9527		9033	9448		6349	6001	
0430	6830	7394		7302	7339		10302	10096		10074	8815		7013	6791	
0530	8664			8620	8780		13208	13104		12346	13104		9454	9127	
0630	11622	9944		13701	10768		17913	17519		17013	16437		14196	14688	
0730	13915	14112		13860	13663	13944	19570	19841	19444	18559	18574	18948	16313	16200	
0830	9499	9871	9691	9603	9771	3853	27074	28137		26769	28326		26860	26264	
0930	8336	8345		9313	8315	8494	32019	34514	33700	34834	33102	37296	32211	32555	
1030	7152	7016		7306	7090		35409	35912		39896	39484		39670	36685	
1130	6684	6972		7562	6797	6999	39781	40566		40507	40118		38489	41003	48577
1230	6450	6234		6700	6323		45817	47000		43560	44969		45996	43431	
1330	6157	6184		7321			45096	44850		33867					
1430	6060	6134		13337	18265	6579	46037	44980		49895	45943		46923	46124	45490
1530	6167	6093		6113	6115		46264	46400		47614	48662				
1630	5814	5967	6133	6365	6100	6207	41043	48062	48934	49085	51470	1973	48488	50294	50000
1730	6049	5731	6092	6423	6081	6003	50000	56218		51568	53734		50404	49461	
1830	5367	5742		6455	5791	7920	50000								
1930	7966			5635											
2030	5534	5665		5859	7228	5732									
2130	5449			5438											
2230	5607			5720											
2330	5404			5575											

TABLE 3
CONCENTRATION (ppm Boron)
(Continued)

	C_1 Upper Annulus			C_2 Lower Annulus			C_3 Heater Core			C_4 Between Plates			C_5 Flow Skirt		
Time	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
5/23/75															
0030	5619			5703	6344										
0130	5704			5822											
0230	5966			5642											
0330	6655			5862											
0430	5974	5988		5987											
0530	5813			8494											
0630	6038			15215											
0730	6298			6165											
0830							102586	108480							
0930															
1030							71700								
1130							71440								
1230							53191								
1330							69021								
1430															
1530							76783								
End of Test															

RESERVOIR TANK CONCENTRATION

Before Test	Mid Test
5083	5251
4993	5613
4960	5590

TABLE 4

TEMPERATURE (°F)

TIME	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	TANK LEVE
0130	81	80	76	81	78	70	—	—	38 5/8 (INCHE
0230	131	126	79	212	175	69	—	—	38 1/16
0330	162	163	165	212	209	106	—	—	38 3/8
0430	167	167	168	212	210	156	—	—	37 7/8
0530	163	164	166	212	208	161	—	—	37 1/4
0630	165	166	168	212	208	164	—	—	36 7/8
0730	124	176	177	212	208	168	—	—	36 1/8
0830	100	162	166	214	210	172	—	—	35 1/4
0930	142	162	164	215	214	172	—	—	34 1/4
1030	155	154	157	215	214	176	162	161	34
1130	160	161	163	215	214	180	155	154	33 3/4
1230	167	169	171	216	215	191	162	161	32 3/4
1330	160	162	167	217	215	193	168	168	32
1430	163	163	166	217	215	198	162	161	31 1/2
1530	164	164	165	217	216	205	164	163	31
1630	160	160	165	217	216	208	163	162	30
1730	160	159	163	217	216	212	162	160	29 1/2
1830	154	153	154	217	217	215	160	160	28 1/2
1930	158	159	158	217	217	216	154	152	27 1/2
2030	158	158	160	218	217	216	166	157	27 1/4
2130	151	155	155	217	217	217	159	159	26 1/2
2230	149	154	151	218	217	217	157	155	26
2330	150	152	152	217	217	215	156	153	25 1/2
0030	148	145	145	217	217	215	152	150	24 1/2
0130	127	156	149	217	217	216	147	145	23 3/4
0230	145	142	145	217	217	213	158	155	23
0330	141	138	139	217	217	210	143	143	22 1/4
0430	146	145	146	217	217	206	140	138	21 1/2
0530	148	146	158	217	217	194	146	144	21
0630	140	139	139	217	217	175	147	146	20
0730	146	144	168	217	217	167	145	145	19 1/2
0830	152	150	173	217	217	166	151	150	18 5/8
0930	145	142	156	218	217	163	144	142	17 3/8
1030	144	145	174	218	217	157	146	145	17 1/4
1130	137	138	152	218	218	154	137	138	16 1/4
1230	143	141	142	218	218	152	142	140	15 1/4
1330	131	136	163	218	216	151	136	135	14 3/4
1430	144	146	158	218	218	151	147	146	14 5/8
1530	106	148	153	218	218	152	151	148	13 3/4

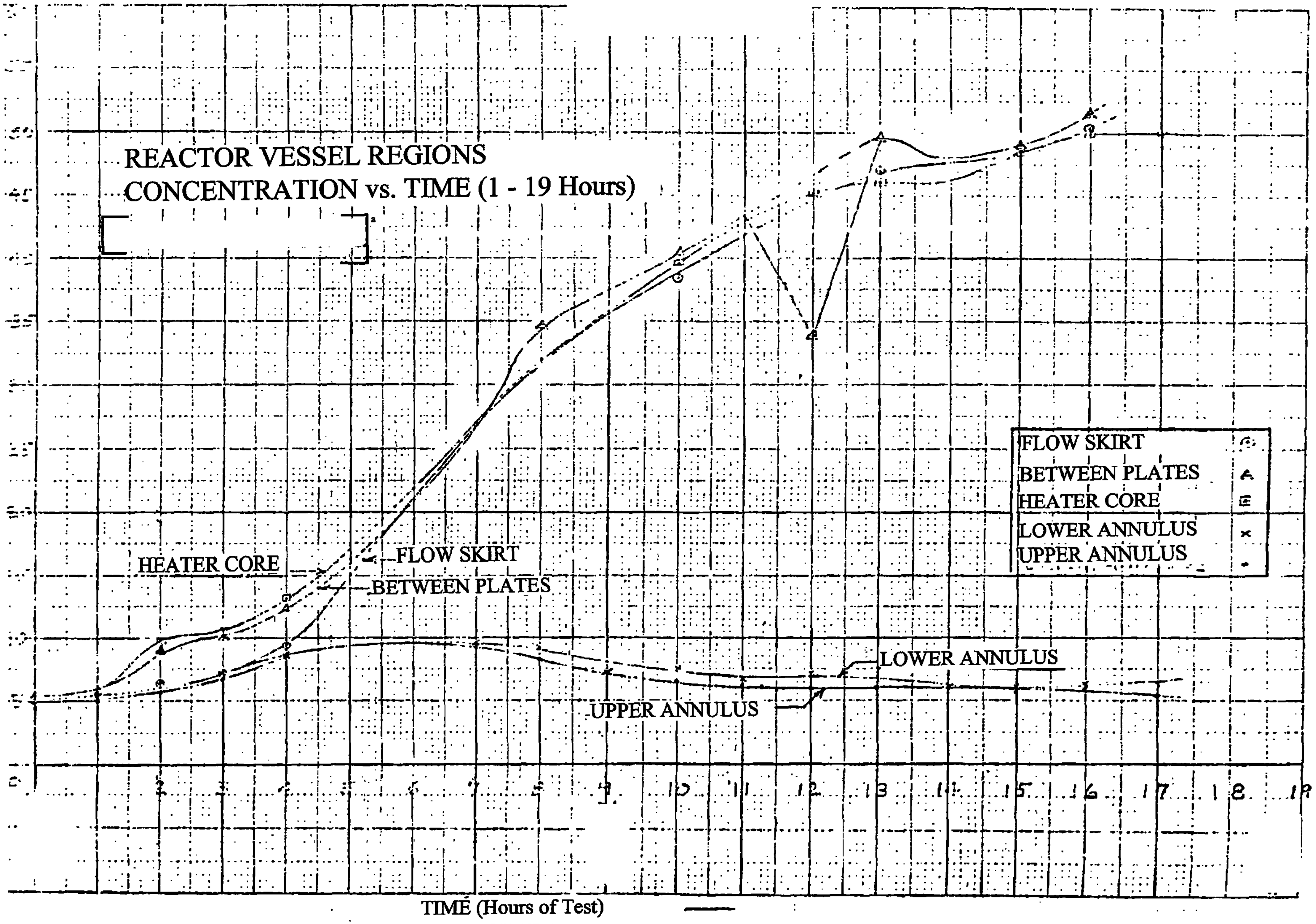

REACTOR VESSEL REGIONS
CONCENTRATION vs. TIME (1 - 19 Hours)
HEATER CORE
FLOW SKIRT
BETWEEN PLATES
LOWER ANNULUS
UPPER ANNULUS
FLOW SKIRT
BETWEEN PLATES
HEATER CORE
LOWER ANNULUS
UPPER ANNULUS
0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
TIME (Hours of Test)

FIGURE 1

K&E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1240

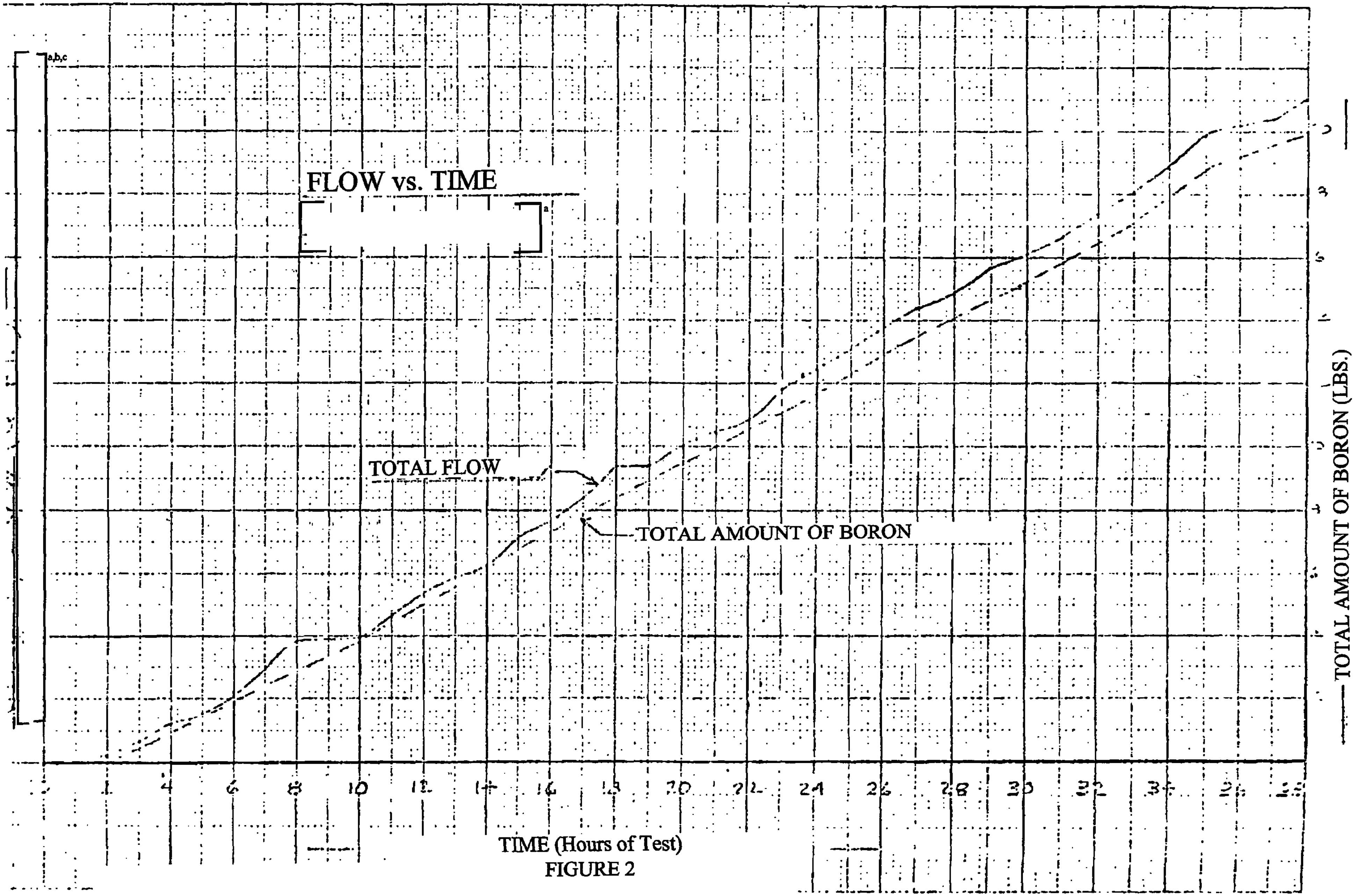
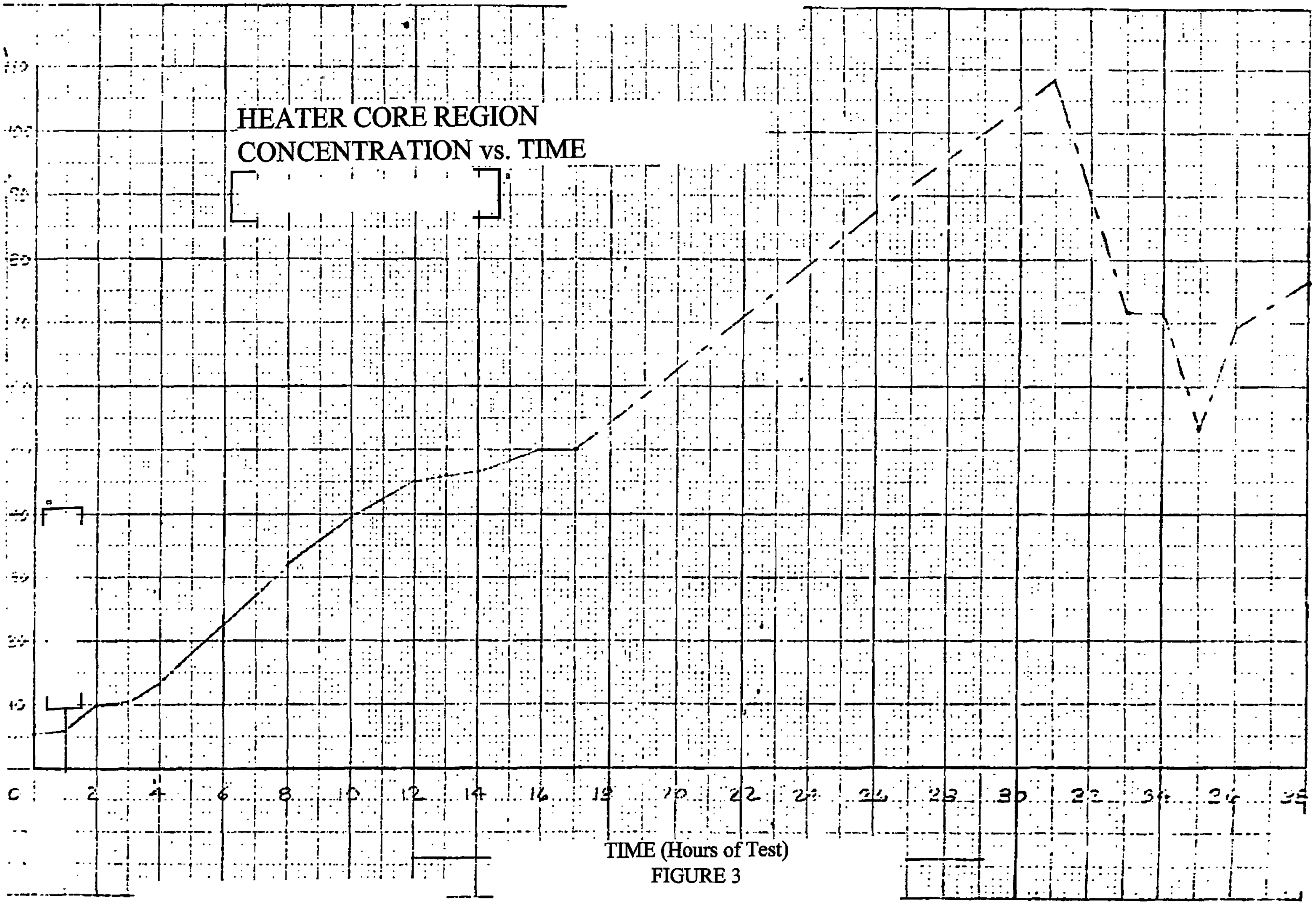


FIGURE 2

K+E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1240



TIME (Hours of Test)

FIGURE 3

K+E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1240

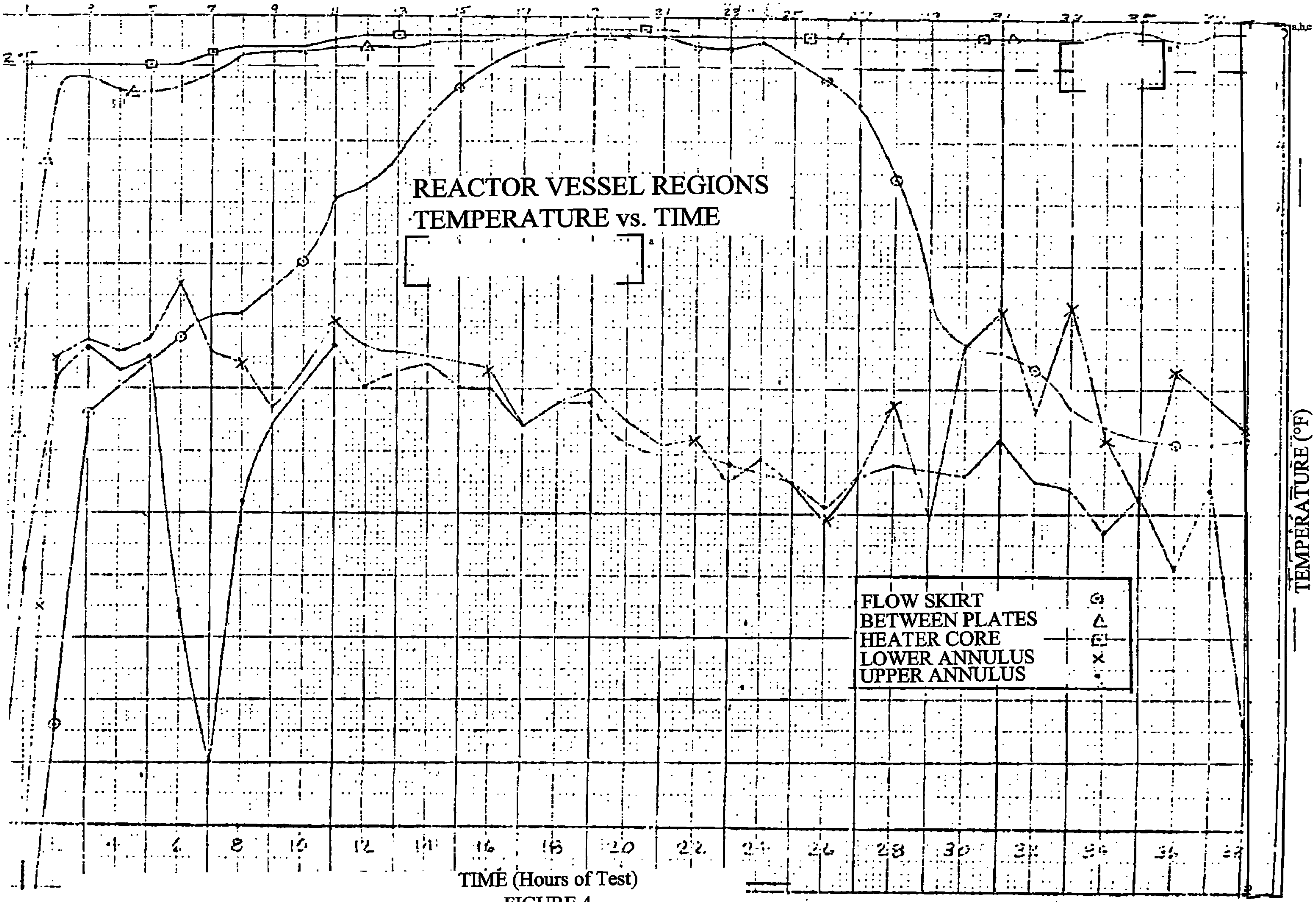


FIGURE 4

FLOW RATES

(flow in = boil off)

Start of Test	Time (Hrs.)	Boil Off (ft^3/hr)
0130 5/22/75	1	[a,b,c]
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	11	
	12	
	13	
	14	
	15	
	16	
	17	
	18	
	19	
	20	
	21	
	22	
	23	
	24	
	25	
	26	
	27	
	28	
	29	
	30	
	31	
	32	
	33	
	34	
End of Test	35	
	36	
1530	37	
5/23/75	38	
	Total Flow (Q)	

Avg. Mean Flow [a,b,c]

Figure 5

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER ________ CONT. NO. ________ MADE BY ________ DATE ________

LOCATION ________ DWG. NO. ________ CHK'D BY ________ DATE ________

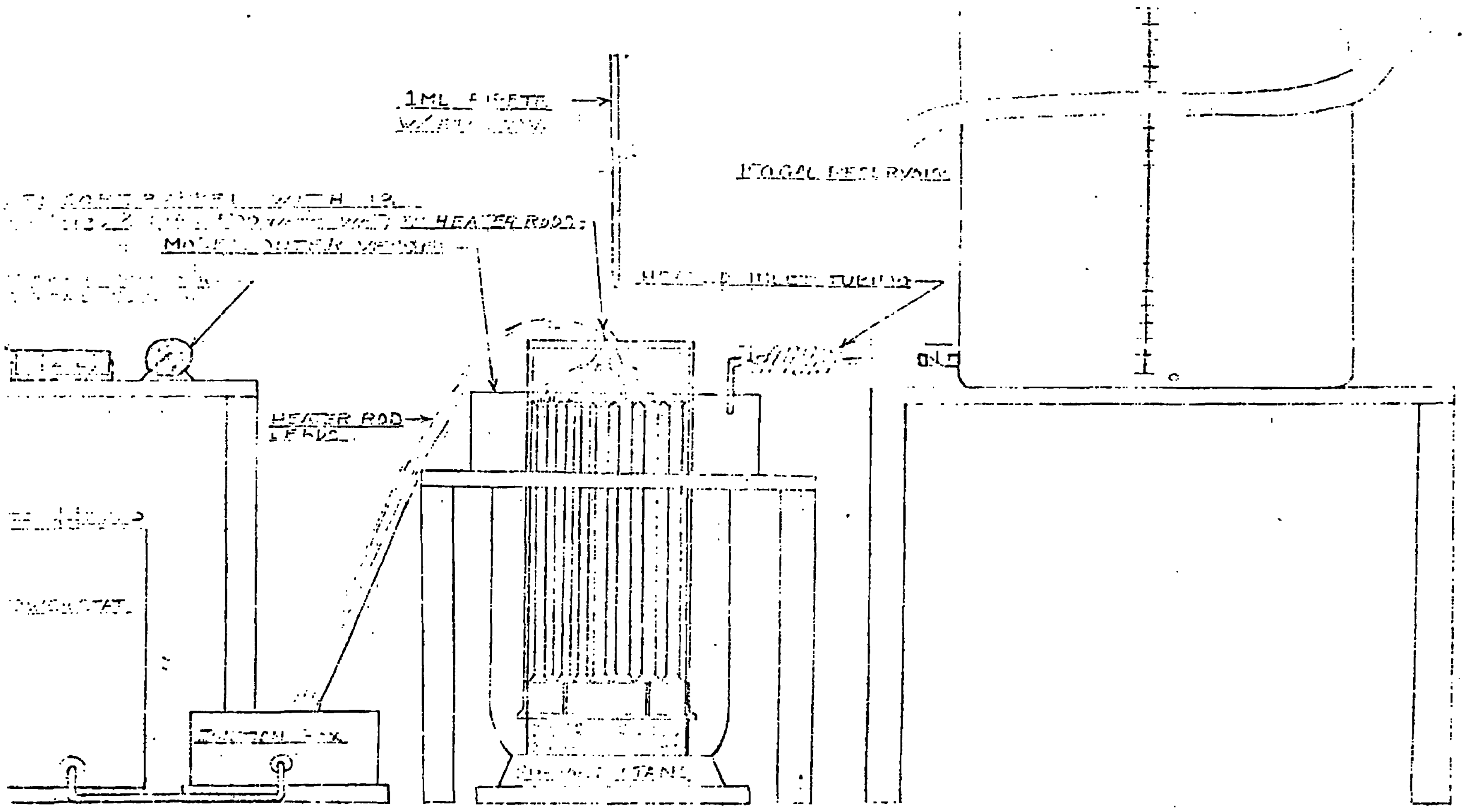
a,b,c

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER ____________ CONT. No. ____________ MADE BY ________ DATE ________

LOCATION ____________ DWG. No [illegible]

a,b,c



TEST APPARATUS

Figure 8

CUSTOMER ____________ CONT. No. ____________ MADE BY ________ DATE ________

LOCATION ____________ DWG. NO. ____________ CHK'D BY ________ DATE ________

a,b,c

COMBUSTION ENGINEERING, INC.

WINDSOR, CONN.

CUSTOMER ______ CONT. No. ______ MADE BY ______ DATE ______

LOCATION ______ DWG. No. ______ CHK'D BY ______ DATE ______

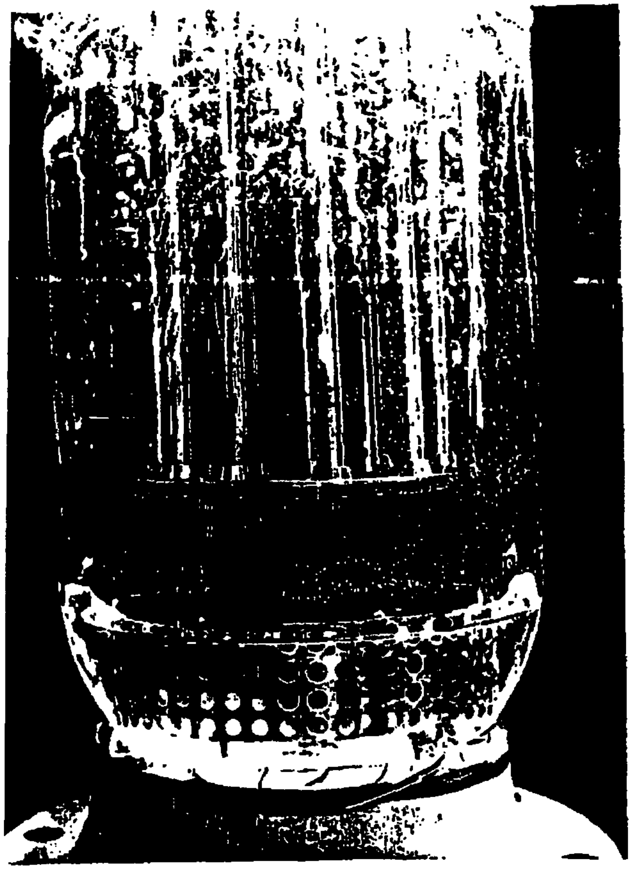
a,b,c

COMBUSTION ENGINEERING, INC.
WINDSOR, CONN.

CUSTOMER ________ CONT. No. ________ MADE BY ________ DATE ________

LOCATION ________ DWG. No. ________ CHK'D BY ________ DATE ________

a,b,c



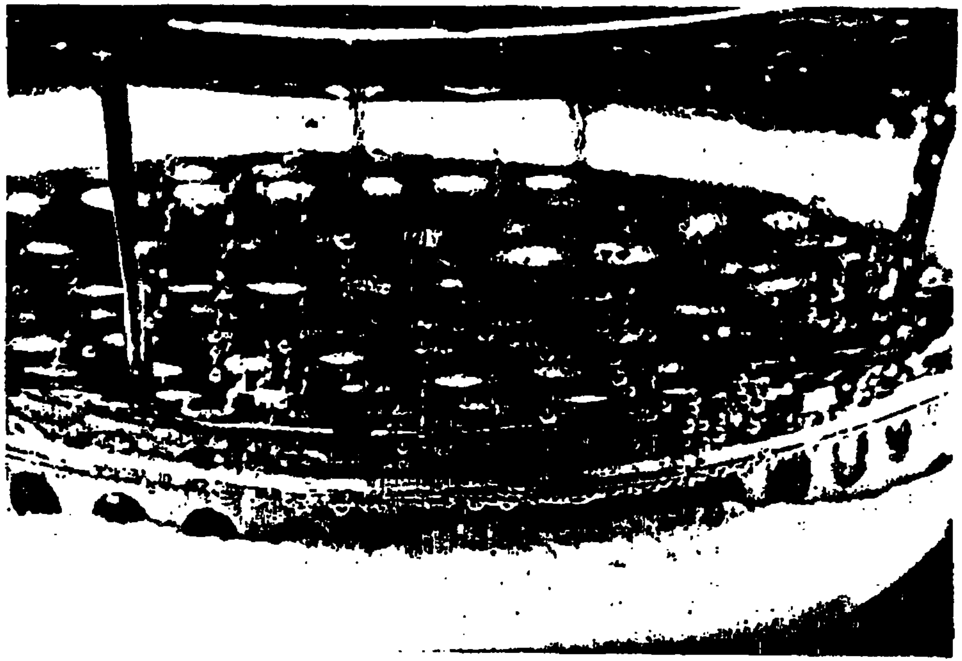
5:00 A.M. 5/22/75

VIEW SHOWING - FLOW SKIRT

SUPPORT PLATES, HEATER CORE

4 HOURS INTO TEST - NO PRECIPITATION

FIGURE 12



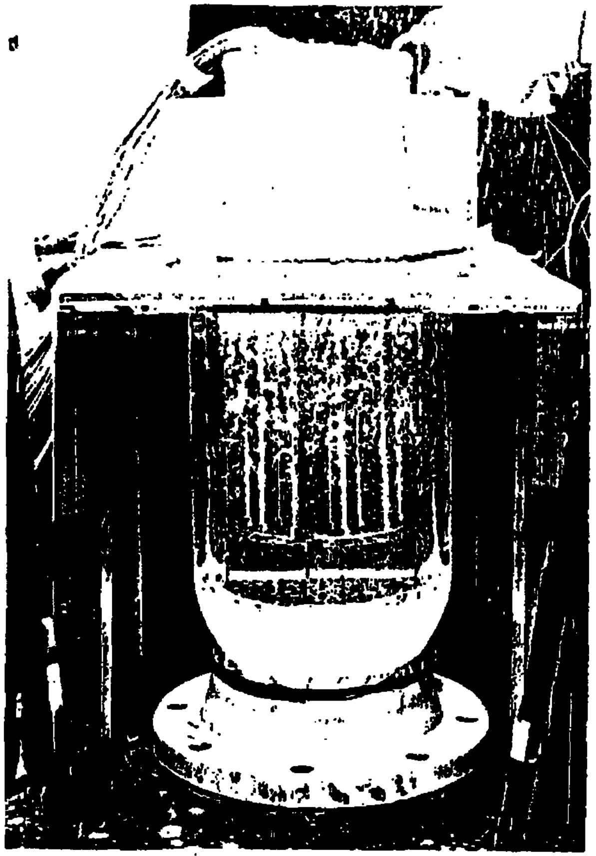
3:00 P.M. 5/22/75

14 HOURS INTO TEST - PRECIPITATION

BUILDUP IN OUTER ANNULUS AND LOWER

CORE REGION

FIGURE 13



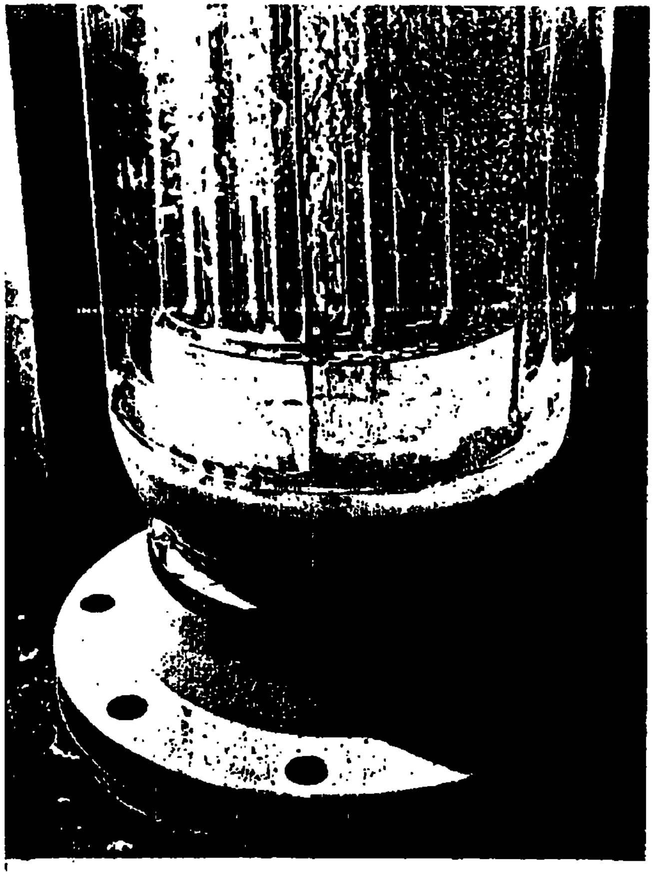
4:15 P.M. 5/22/75

FIGURE 14 A

4:15 P.M. 5/22/75

FIGURE 14 B

-- 15 HOURS INTO TEST --



6:30 P.M. 5/22/75

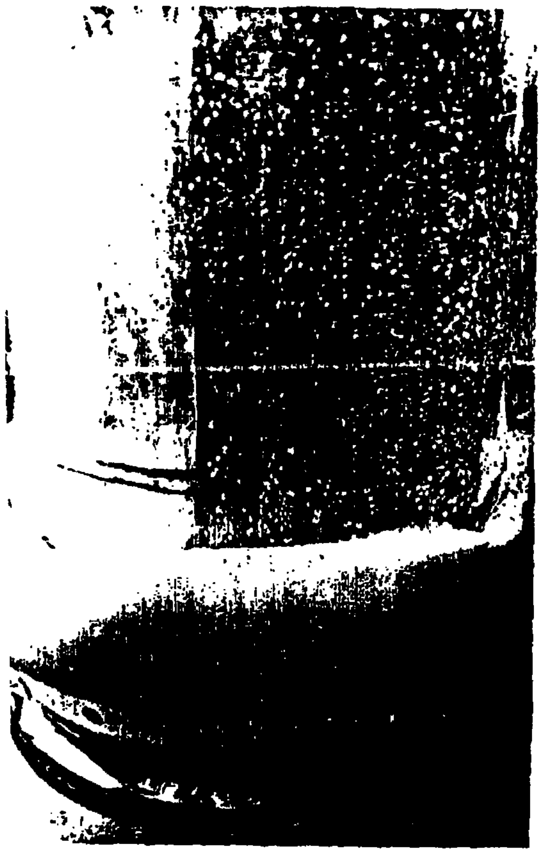
6:30 P.M. 5/22/75

15 1/2 HOURS INTO TEST - LOWER SUPPORT PLATE COVERED

BUILDUP BEGINNING TO FORM ON CORE SUPPORT PLATE

FIGURE 15A

FIGURE 15B



8:45 A.M. 5/23/75

31 HOURS INTO TEST

NOTE FLOW CHANNELS APPEARING

ER ANNULUS AND SUPPORT PLATE REGION

FIGURE 16

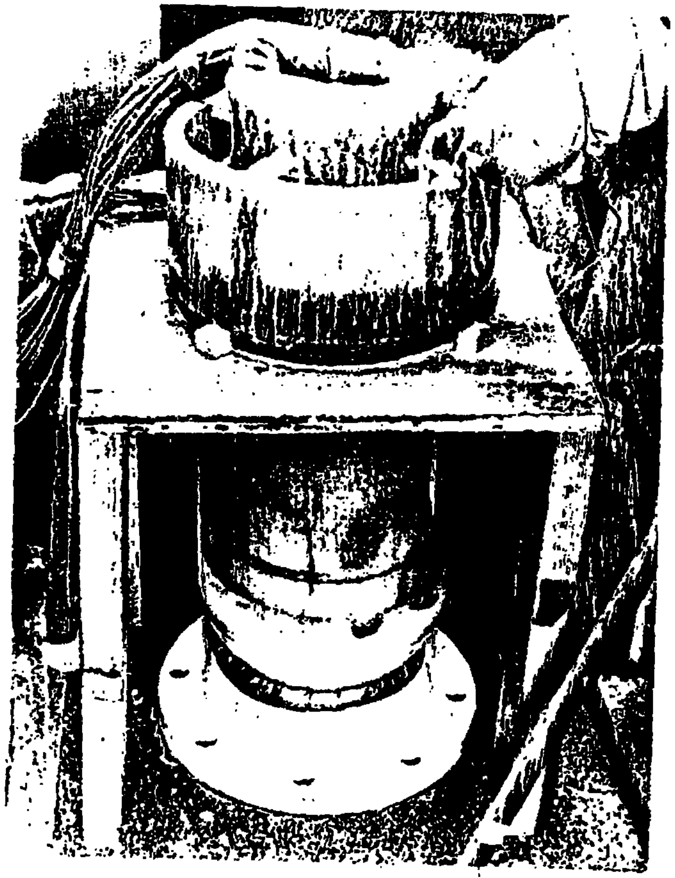
9:40 A.M. 5/23/75

32 HOURS INTO TEST

FLOW CHANNEL OPEN IN LOWER ANNULUS

CHANNEL CLOSING IN CORE SUPPORT REGION

FIGURE 17



10:30 A.M. 5/23/75

33 HOURS INTO TEST - FLOW CHANNELS CLOSED OFF

CHANNELS REAPPEARING IN OPPOSITE SIDE OF VESSEL

FIGURE 18

10:45 A.M. 5/23/75

UPPER PLENUM REGION WITH HEATER LEADS

FIGURE 19

4:00 P.M. 5/23/75

38 HOURS INTO TEST

UILDUP THROUGHOUT LOWER ANNULUS AND CORE BARREL REGION

FIGURE 20

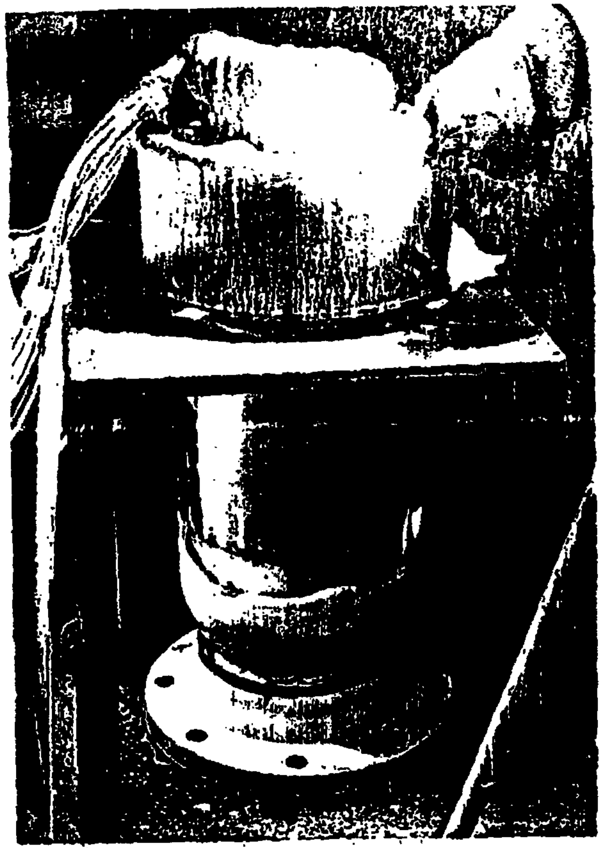
4:15 P.M. 5/23/75

38 HOURS INTO TEST

NOTE CLOSURE OF FLOW CHANNELS

AND BUILDUP ON UPPER PLENUM

FIGURE 21



4:15 P.M. 5/23/75

END OF TEST - 38 HOURS FROM STARTUP

RECIPITATION THROUGHOUT MODEL CORE BARREL

FIGURE 22

9:00 A.M. 5/27/75

VIEW SHOWING BUILDUP IN

UPPER PLENUM AND ON HEATER LEADS

FIGURE 23