EXPERIMENTS FOR POST ACCIDENT HYDROGEN DISPERSION IN F.M.VAULT USING HELIUM

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ABSTRACT

Under certain postulated accident scenarios involving a Loss of Coolant Accident (LOCA) simultaneous with impairment of Emergency Core Cooling (ECC), generation of hydrogen due to reaction between the zirconium clad and coolant is predicted in the coolant channel. The hydrogen generated in the coolant channels would eventually get released either in Fuelling Machine (FM) vault or in the pump room atmosphere depending on the location of the break. Analytical studies carried out so far to estimate the time dependent hydrogen concentration in the accident FM vault consider the entire vault as a single volume. Tests were, therefore, planned to assess the mixing within the FM vault atmosphere with and without the availability of cooling fan units by releasing a known quantity of helium (instead of hydrogen) at selected locations and monitoring the relative concentration of helium in air at various locations. Test was conducted by releasing about 360 l helium over a period of 3 to 4 minutes at preselected locations and by measuring the relative concentration (leak rates indicated by helium leak detectors) at various locations in the FM vault. The results of cases with fans operating indicate repeatable and consistent trends of good mixing in the vault. For other cases (non turbulent, still condition) the results are sensitive to various factors including orientation of release. The former set of cases (turbulent, fans operating) are more relevant for postulated accident conditions.

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1. INTRODUCTION

Under certain postulated accident scenarios involving loss of coolant simultaneous with impairment of Emergency Core Cooling System (ECCS), generation of hydrogen due to reaction between the zirconium clad and water is predicted in the coolant channels. The hydrogen generated in the coolant channels would eventually get released either in the Fuelling Machine (FM) vault or in the pump room atmosphere depending on the location of the break in the primary heat transport system boundary. A vertical section of the Reactor Building is shown in Fig-1. In the event of release of hydrogen in the Fuelling Machine (FM) vault,the concentration of hydrogen in FM vault during the initial period would be high. However,during this period, the steam concentration would also be high, so as to inhibit the combustion.

Analytical studies carried out so far to estimate the time dependent hydrogen concentration in the accident FM vault consider the entire vault as a single uniform volume. Tests were, therefore, planned mainly to assess the mixing in the FM vault atmosphere with and without the availability of cooling fan units by releasing a known quantity of helium in air at various location.

2. OBJECTIVE OF THE TESTS

The tests were planned with three major objectives.

2.1 Assessment of FM vault cooler adequacy in mixing the vault atmosphere following the release of known quantity of helium gas (instead of hydrogen). Specifically the purpose was to assess the dispersion of the released gas in the vault atmosphere. The assessment was planned to take into account the following effects.

a) Elevation of release: Three elevations (See Fig-2) were selected for releasing the gas.

b) Orientation of release : In different trials,the helium gas was discharged in upward, downward and horizontal (away from the calandria) direction.

c) Operation of the vault cooler fans : Tests were conducted with the following states of the vault cooler fans.

i. 100% of vault cooler fans on
ii. 50% of vault cooler fans on
ii. 0% of vault cooler fans on

2.2 Study on formation of high concentration pockets, especially between beams or other areas in upper part of the FM vault.

2.3 Study on stratification of gas following release

3. DISPERSANT GAS

While the postulated accident conditions will involve a mixture of hydrogen and steam, the tests were done with helium as dispersant gas. Equipment dealing with helium gas, like Helium Leak Detectors (HLD), cylinders containing helium etc were all readily available with the Quality Assurance Group at the Kakrapar project site (where the test was conducted) offering a safe and convenient choice of dispersant gas.

During the tests, helium gas was discharged using a pressure reducing valve and a flow meter so as to have a total discharge of 360 litre over a period of 4 minutes. The quantity of gas was determined on the basis that the HLD used for determining the gas concentration near the release location should not get saturated and the HLD located in the pressure relief chamber should register significant change in gas concentration during the test.

4. MONITORING OF GAS CONCENTRATION

4.1 Detectors

Standard Helium Leak Detectors (HLD) readily available with the Quality Assurance Group were employed to monitor the relative concentration of gas at various locations in the test FM vault. Out of five HLDs available at Site four were employed for the tests. However, for studying the dispersion of the gas and stratification if any following the release a minimum of five monitoring points were identified in the test schematic. This necessitated splitting of each test into two runs.

This also provided an opportunity to establish the repeatability of the tests by comparing the concentrations at the monitoring points common to the two runs. Before conducting the tests, each HLD was calibrated using a standard leak and their sniffers adjusted to read approximately equal background reading. Similarly the delay involved in sniffer, tubing and the machines were determined to ensure that variations and delays are minimum. Each HLD was connected to a recorder for verification of observed data which were recorded manually during the tests.

4.2 Monitoring locations

Based on the layout of PHT system piping and other equipment in the FM vault, the expected distribution of the dispersant gas and the constraints with regard to the availability of the HLDs, five locations (See Figure-2) were selected for monitoring the gas concentration.

Location A : Near point of release, approximately at 1 m distance from the release location.

Location B : Above FM vault coolers between FM 11 and 13 (This sniffer was shifted to FM vault ceiling between the structural steel beam during one of the tests).

Location C : In line with channel A-10 approximately 4.5 m from the end fitting face (approximately at the centre of FM vault).

Location D : At the base of stair way no.4 at 101 m elevation (i.e. one metre above the FM vault floor).

Location E : At top of the Pressure Relief Chamber (PRC) in the opening between PRC and Pump Room (PR).

As mentioned earlier, in order to conduct the test with 4 HLDs each run was conducted first with probes at A, B,C, D and repeated with probes at A, E, C, D. This also helped in establishing the repeatability of each run by comparing the gas concentrations at A,C & D.

5. RELEASE LOCATIONS

In order to ascertain the effect of gas release viz. its dispersion and distribution, three release location were selected (See Figure-2).

Location 1 : At the end fitting of channel R-18, about 2.5 m above floor.
Location 2 : At the end fitting of channel C-4, about 5.3 m above floor.
Location 3 : Between the reactor headers inside the insulation cabinet. (Approx. 1.0 m below ceiling).

These locations were decided based on the layout of PHT system piping, mainly to cover the various elevations at which the breaks in piping are possible.

6. TEST

6.1 Test Set-up

The tests were conducted in the South FM vault of Kakrapar Atomic Power Project Unit-1. At the time of conducting the test the FM vault doors were not fully commissioned. Plastic sheets and adhesive tapes were, therefore, used for installation of atmospheric barrier between the FM vault and the accessible areas at 100 m floor. Through the South wall, FM vault was in communication with the South pressure relief chamber and the pump room as it would be during normal operation or a postulated accident condition.

Of the four HLDs, three were located in the FM vault itself while the fourth one was located in the pump room area with its tube running through a floor opening upto the probe location `B'. This probe was shifted to the opening between PRC and PR during the repeat trials of each test.

6.2 Data Acquisition

The test data were acquired by manual recording of the relative gas concentration (i.e. the leakage rate reading indicated by the HLD) at various locations by experienced HLD operators of quality assurance group. Based on a pilot study conducted earlier, frequency of manual recording of data was decided to be 30 secs. from beginning of the test upto 10 minutes, at an interval of 1 minute between 10 and 20 minutes period and subsequently 2 minutes for the remaining duration of the test. This was backed up by automatic recording of the data in a multichannel recorder connected to the HLDs.

6.3 Test Run

As mentioned earlier, due to the constraints in availability of HLDs each experiment was conducted in two stages viz. Case-A (monitoring done at locations A, B, C and D) and Case-B (monitoring done at location A, E, C & D). Based on the criteria that readings of all HLDs remain practically constant for about 6 minutes the test duration with vault cooler fans operating was about 60 mins. whereas the tests without vault cooler fan operating ran for about 90 minutes. Following each trial, FM vault was purged till the HLD readings returned to the background. Tests were conducted for various combinations of release locations, release orientations and number of FM vault cooler fans operating. The details of various combination studied are given in Table-1.

7. TEST RESULTS

Figures 3 to 18 give the test results showing measured concentration Vs. time at various locations. The concentration is indicated in terms of helium leakage rate (cc/sec) as seen by HLDs.

Following observations emerge from these results:-

i) General trend : There is peaking in the concentration following the release in approximately 5-8 minutes followed by rapid decrease in the peak. Apart from the overall reduction of concentration in the vault (which results from escape of gas from the vault to other regions), the progressive reduction in relative concentration among various locations is indicative of the degree of mixing within the vault. The concentrations fall to near final steady state values in about 40-80 minutes, the lower end of this range being represented by cases in which vault fans are operating.

ii) Repeatability : In cases with fans operating (Case 1,4,7), excellent repeatability was established, as seen from results from pairs of tests with probes at locations, A, C and D unchanged. However, in cases without fans, except in Case 2 (where repeatability was again excellent), the repeatability was not good. Cases of poor repeatability are also characterised by low concentrations of helium (order of magnitude lower) in the bulk of the vault volume.

iii) Mixing behaviour when no fans are operating : Among the cases of no fan operating (Cases 2,3,5,6), in some runs, (3A, 3AR, 5A, 6A, 6B), the helium appears to escape (perhaps as a plume) upward and out of the vault, with very little dispersion in bulk of the vault. This can only happen in still conditions in the vault atmosphere, which are not expected for postulated accident conditions.

In the remaining runs of cases representing no fans operating (2A, 2B, 3B, 5B, 5AR), there was mixing in the vault.

Above behaviour indicates that the results for no fan operating may be getting strongly influenced by presence or otherwise of small air currents in the vault (particularly near release location) at the time of release. Also, the direction of release appears to play a role as can be seen that for downward release (Case 2) there is good mixing.

iv) Concentration gradients/stratification : Irrespective of location of release and whether or not the fans were operating it was observed that concentrations at top of the vault tends to be higher than that at the bottom of the vault (test 1 is an exception). When fans are operating (in case of tests 1, 4, 7) the concentration at the middle is highest. Also the concentration gradient along the height flattens out with time. This process was observed to be faster with 6 fans operating than with 3 fans (tests 4 Vs. 1&7).

For cases with fans operating, the final stratification factor between top and middle elevation (i.e. ratio of concentration at location B and C) is 1.2 or lower. The factor between top and bottom is 2 or lower.

For cases with no fans operating, barring situations in which little or no helium reaches lower elevations (as discusses in (iii) above, the final stratification factor between top and bottom is 2.5 or less.

v) With more turbulence (more fans operating) less helium seems to escape up and out (as seen from lower concentration at location E), and more of it mixes with the vault atmosphere. At the other extreme, as noted before, when there is no turbulence, and release orientation is horizontal or vertically upwards, most of the dispersant (helium) escapes up and out of vault, with very little going to lower elevations.

vi) High concentration pockets near ceiling : To detect any formation of high concentration pockets between the structural steel beams near FM vault ceiling, in one test (Case 6A) (See Fig-15), the probe B was shifted at 60 min into the run, from its usual location near the ceiling, to inside of a representative pocket close to the ceiling. The jump in the concentration by a factor of 1.7, gives an idea of the effect.

8. CONCLUSION

The tests were helpful in understanding the possible behaviour of hydrogen in the actual FM vault in the plant for a range of possible release location and FM vault cooler operation.

The results for cases with turbulent conditions in vault atmosphere (cases with fans operating) show consistent and repeatable behaviour from which relatively coherent picture can be drawn. On the other hand, the results for cases with no fans operating tend to be more sensitive to various factors (e.g. orientation of release and presence of air currents); general conclusions for these cases are less easy to draw. In postulated accident conditions, the former (turbulent conditions) will be more representative, not only because the fans will be operating, but also because of turbulence caused by condensing steam conditions.

TABLE-1

EXPERIMENTS FOR HYDROGEN DISPERSION IN FM VAULT USING HELIUM
TEST CONFIGURATIONS

Test No./ Designation	Release Location	Release Orientation	Number of FM vault cooler fans operates	Remarks
1 (1 ↓ 3F)	1	downwards	3	To assess the effect of 50% fan operation. See Fig 3&4
2 (1 ↓ 0F)	1	downwards	0	See Fig 5&6
3 (1 ↑ 0F)	1	upwards	0	See Fig 7,8 &9 (See Note-1)
4 (1 ↓ 6F)	1	downwards	6	To assess the effect of 100% fan operation. See Fig 10&11.
5 (2 → 0F)	2	horizontal away from calandria	0	See Fig 12,13 14 (See Note-1)
6 (3 ↑ 0F)	3	upwards	0	See Fig-15,16
7 (2 ↑ 3F)	3	upwards	3	See Fig 17&18

Locations : (See Fig 2)

1. At the channel R-18 (about 2.5 m above floor).
2. At channel C-4 (about 5.3 m above floor).
3. Inside insulation cabinet (about 1 m below ceiling)

Note-1 : For these cases, three runs (A, B & AR) Were taken instead of the usual two. (Run AR is repeat of Run A).

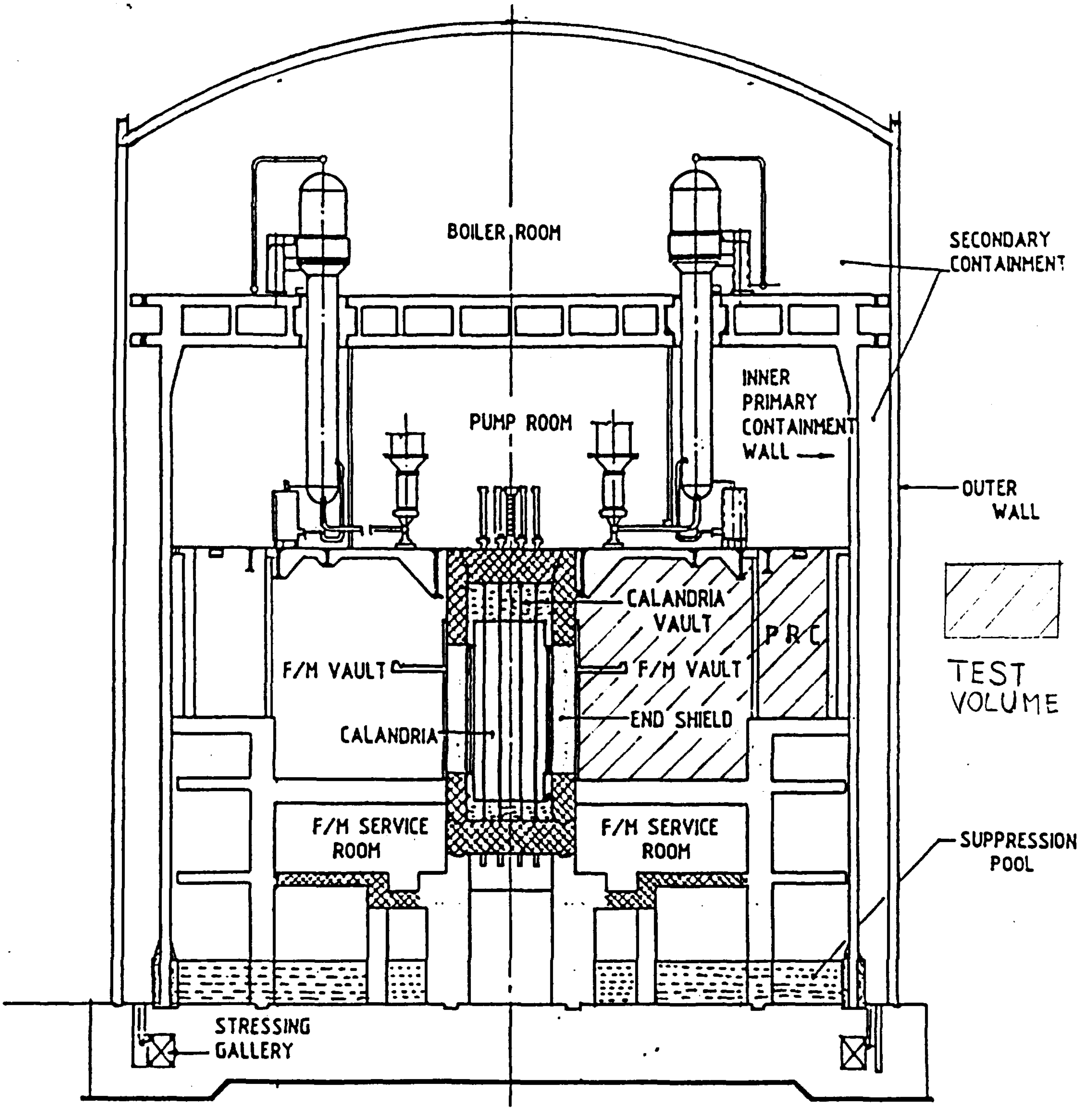
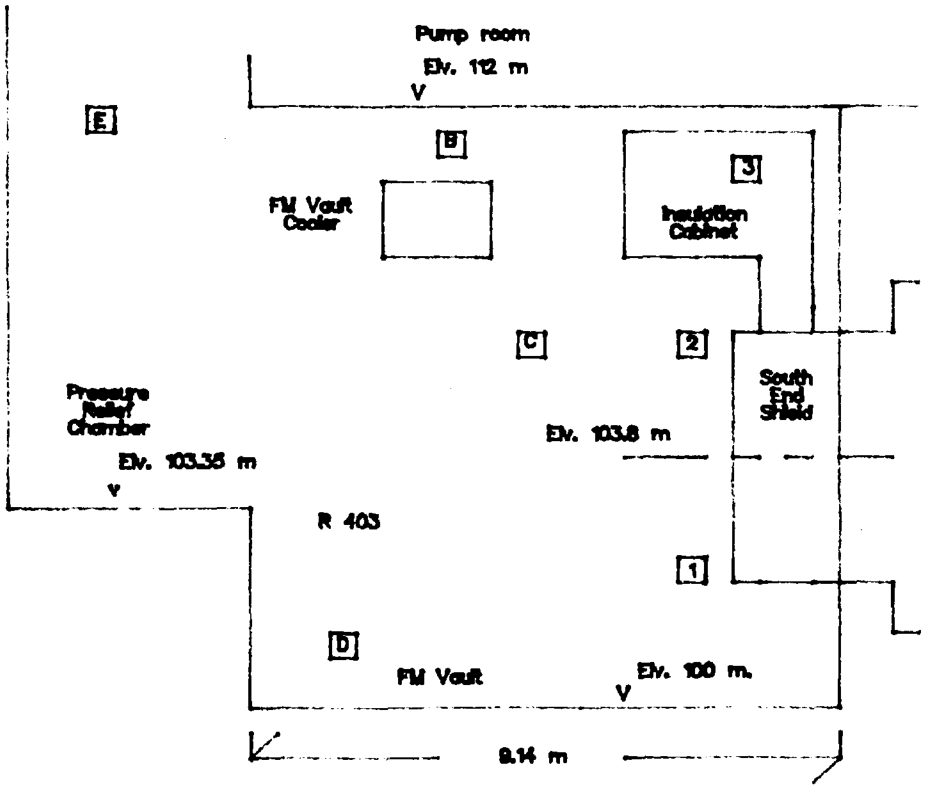


FIG. 1 — KAPP REACTOR BUILDING

Fig.—2 KAPP FM Vault Hydrogen Mixing Studies Release And Measurement Points.



1 at R–18 (about 2.5 m above FMV floor)

2 at C–4 (about 5.3 m above FMV floor)

3 Inside insulation cabinet,near headers

A 1m away from release location.

B Above FM Vault coolers at about 110.5 m elv.

C In line of A–10, about 4.5m from the endfilling face.

D At the base of Stairway no.4 at 101m elv.

E At top of PRC in the opening between PRC & PR.

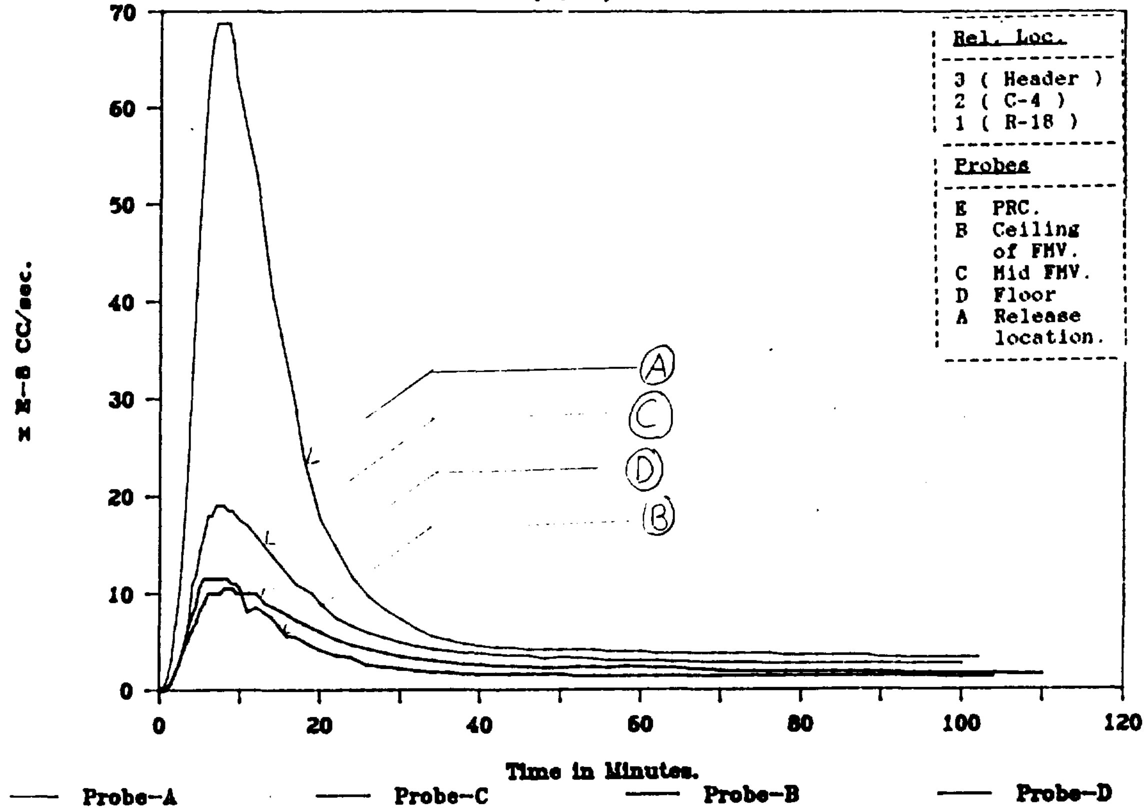
Notes:

1) Sketch not to scale

2) Dimensions shown are approximate.

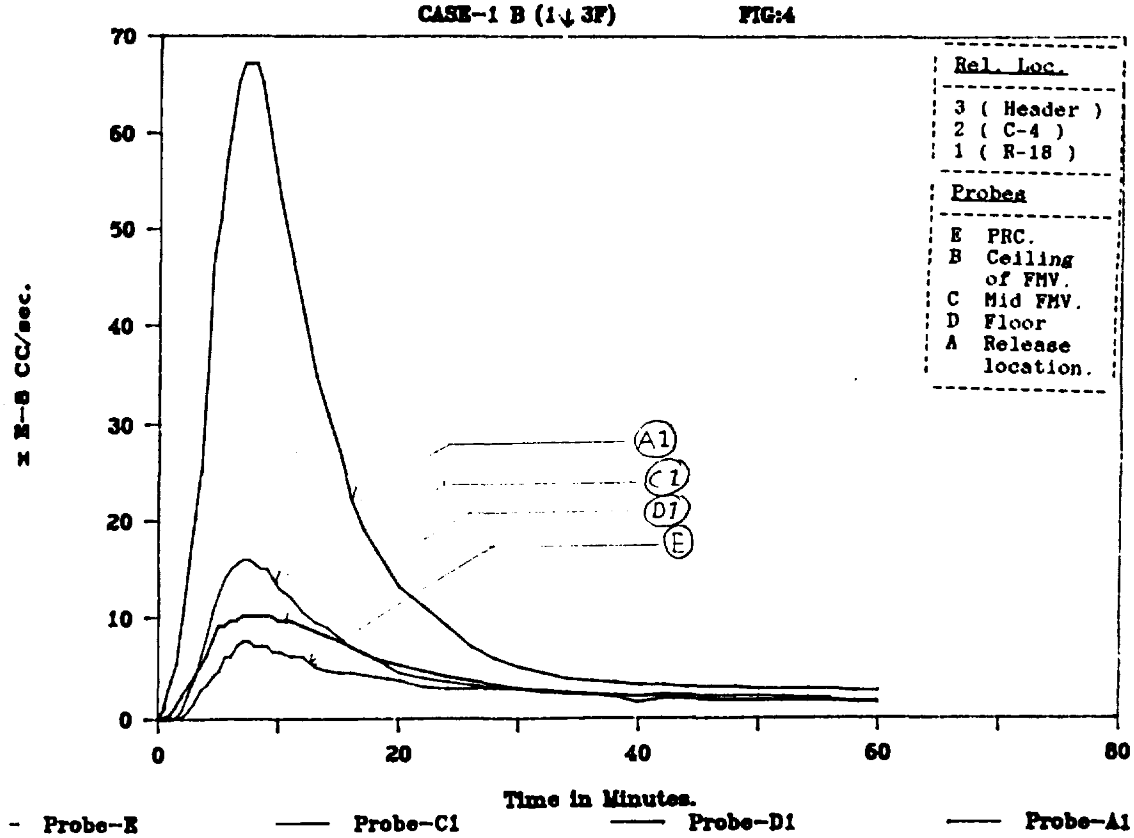
HYDROGEN MIXING EXPT.

CASE-I A (1↓3F) FIG:3



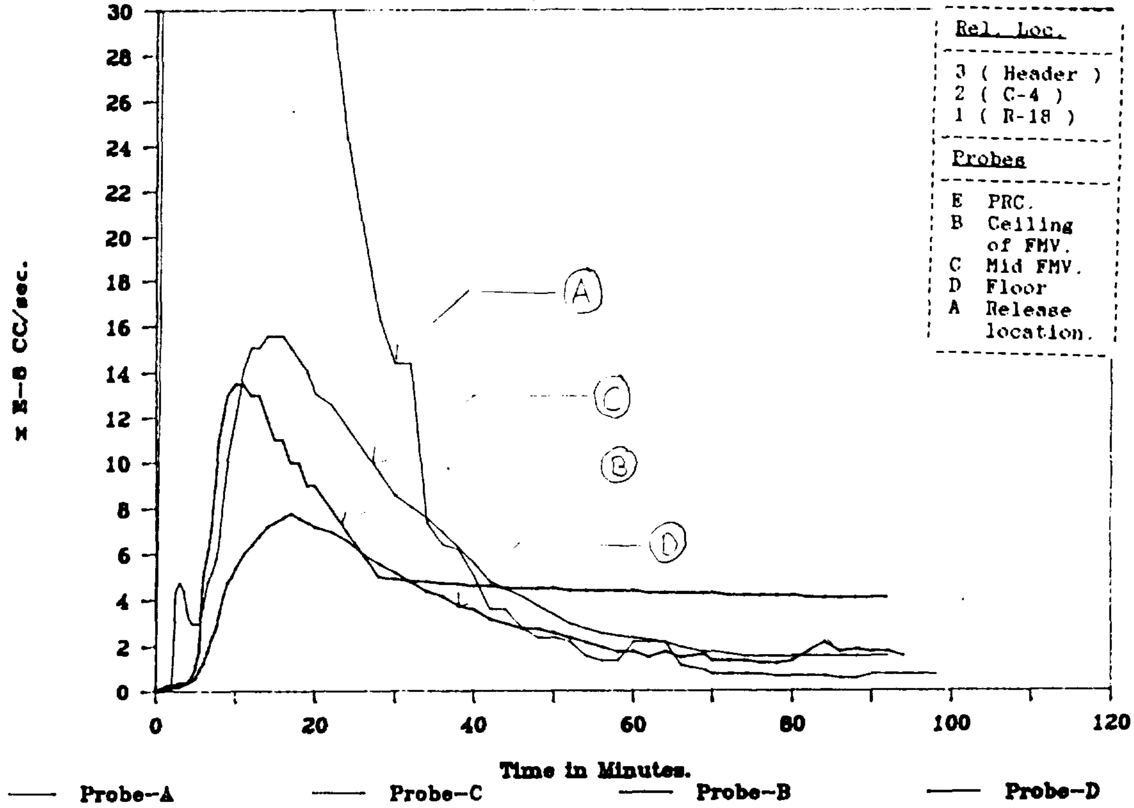
HYDROGEN MIXING EXPT.

CASE-1 B (1↓3F) FIG:4



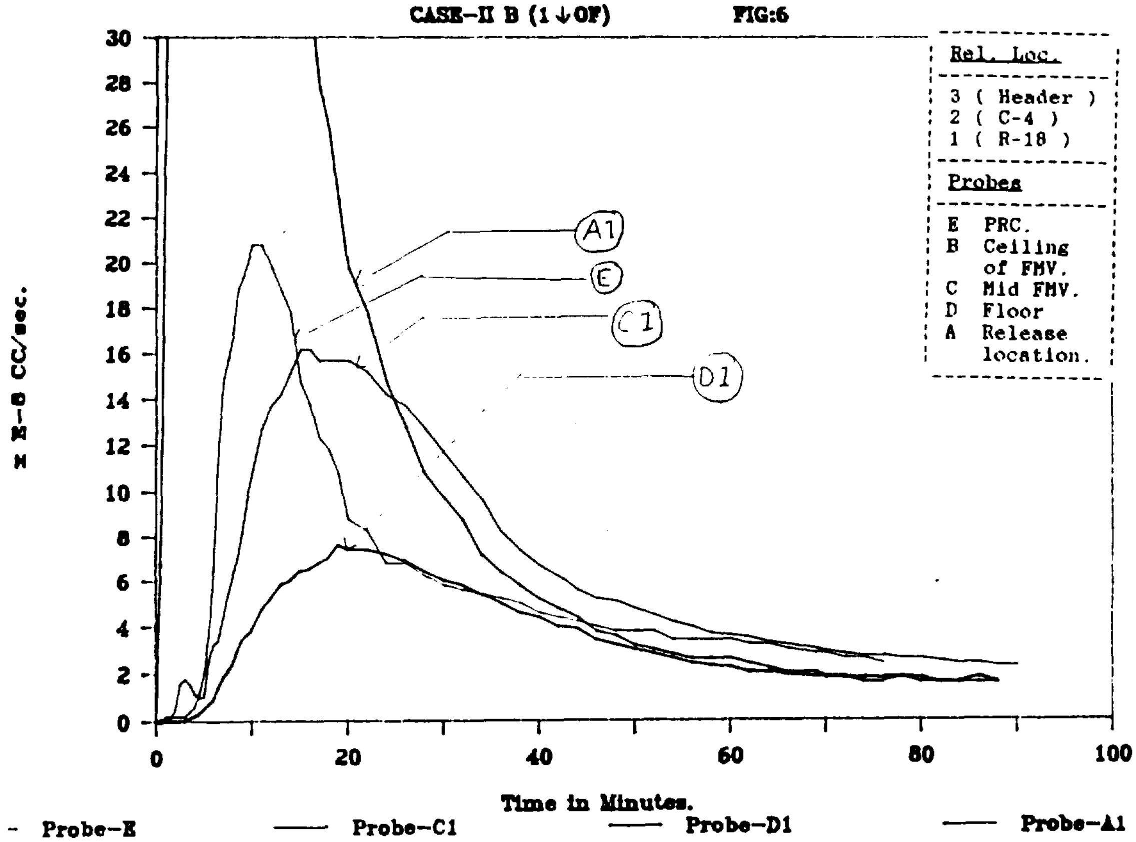
HYDROGEN MIXING EXPT.

CASE-II A (1↓OF) FIG:5



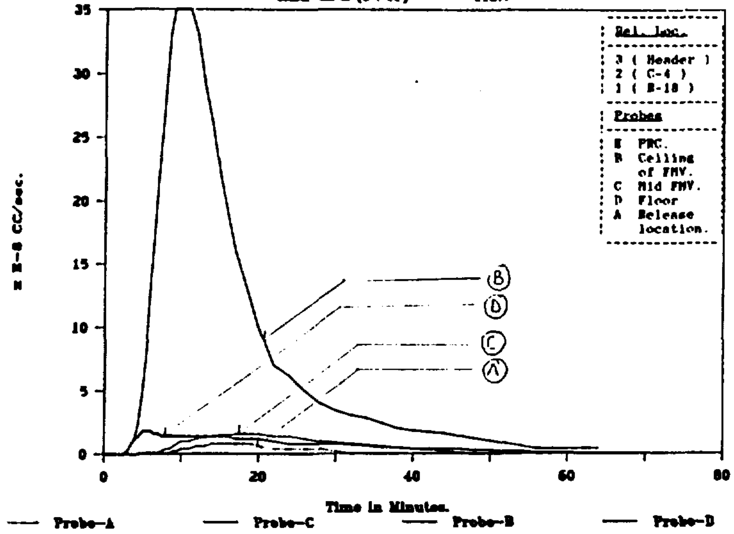
HYDROGEN MIXING EXPT.

CASE-II B (1↓OF) FIG:6



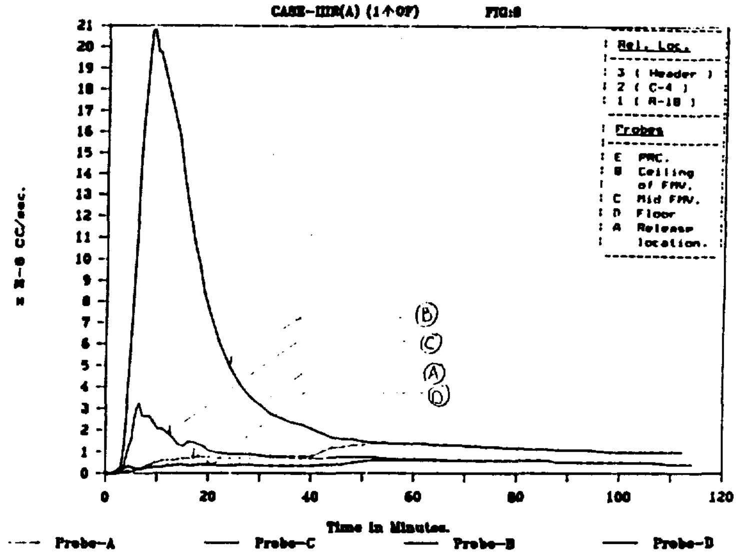
HYDROGEN MIXING EXPT.

CASE-III A (1↑OF) FIG:7



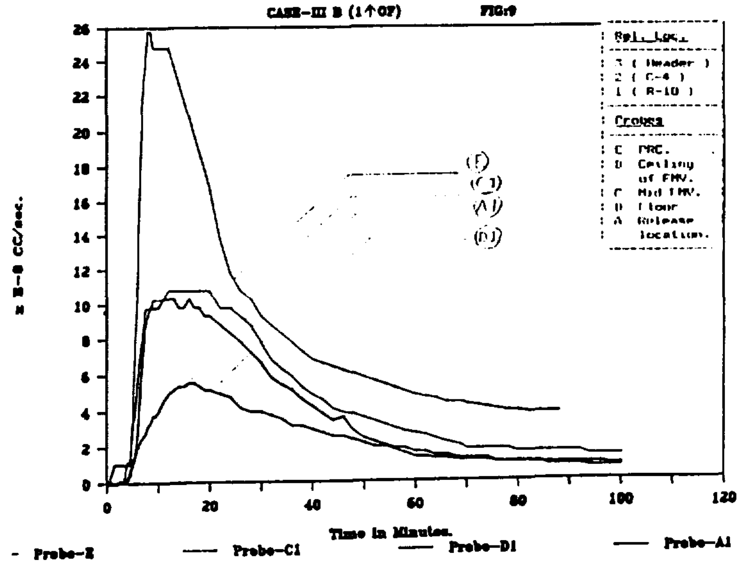
HYDROGEN MIXING EXPT.

CASE-IIIB(A) (1↑OF) FIG:8



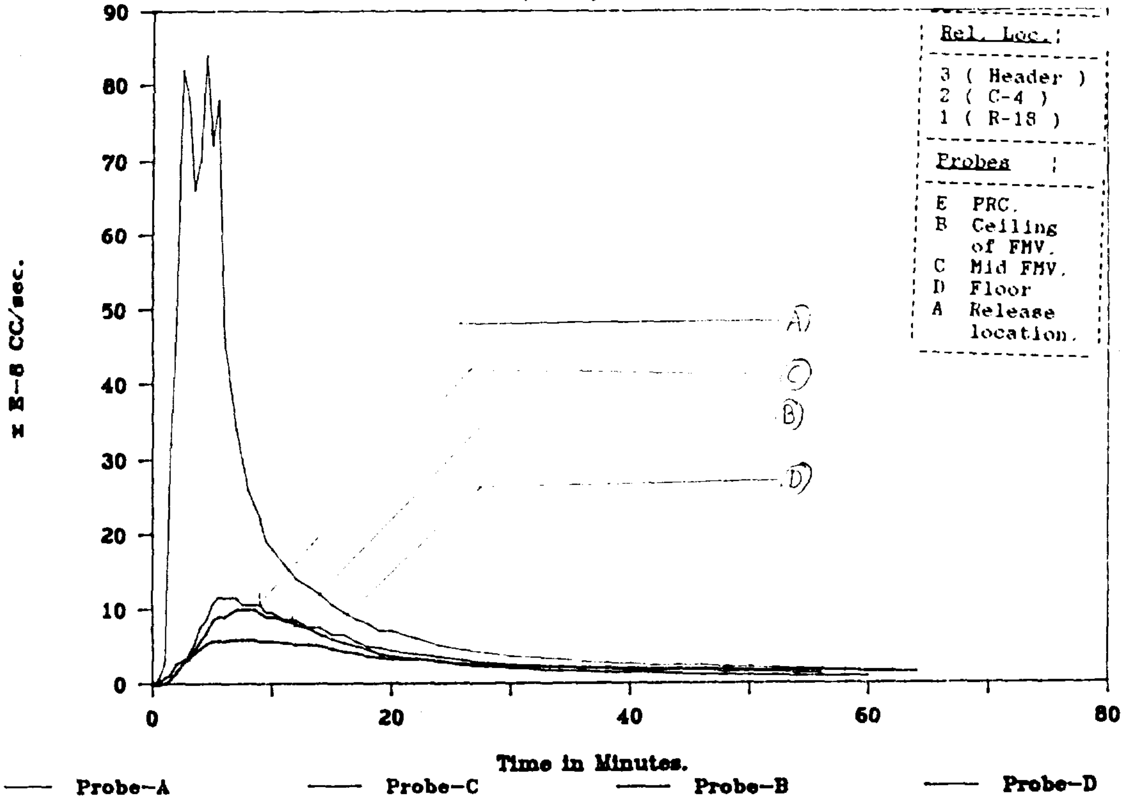
HYDROGEN MIXING EXPT.

CASE-III B (1↑OF) FIG:9



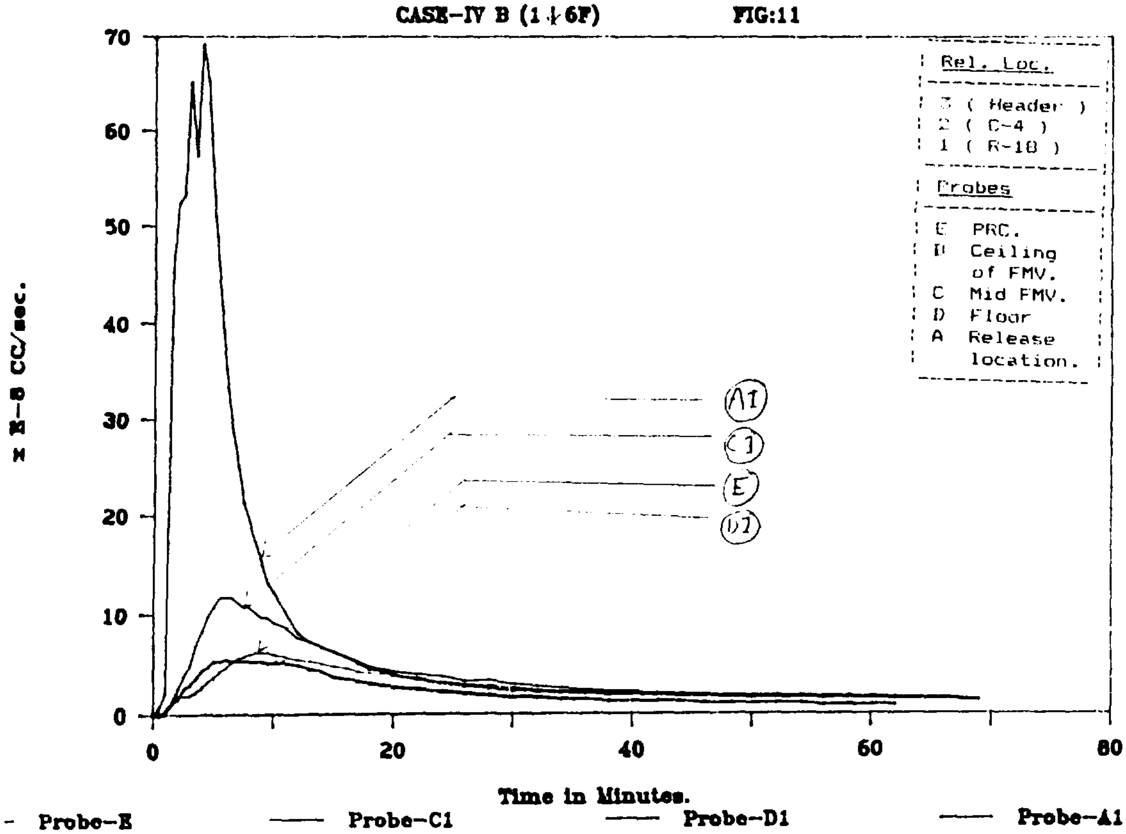
HYDROGEN MIXING EXPT.

CASE-IV A (1↓6F) FIG:10



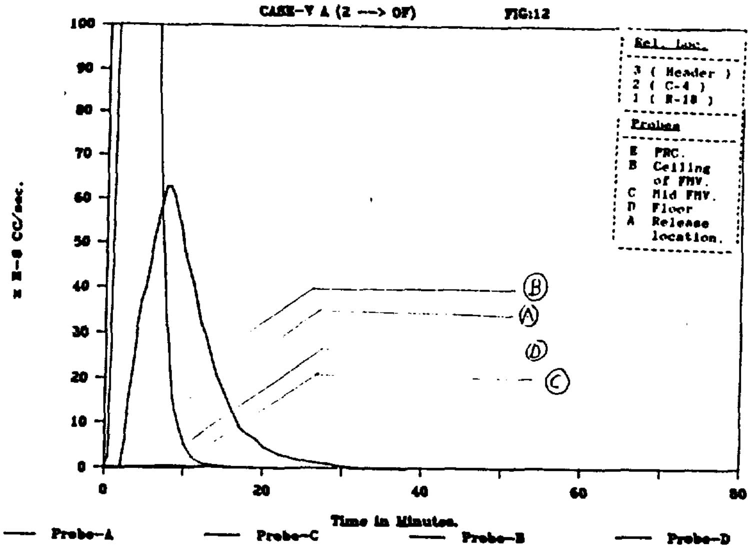
HYDROGEN MIXING EXPT.

CASE-IV B (1↓6F) FIG:11



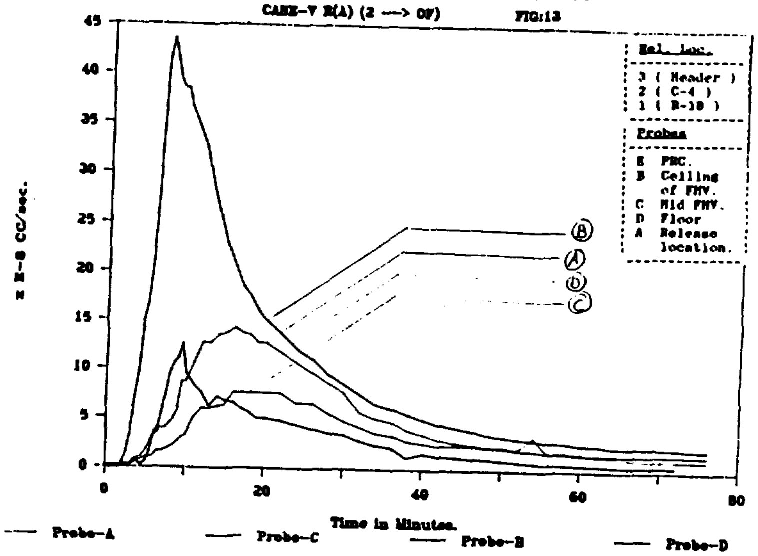
HYDROGEN MIXING EXPT.

CASE-V A (2 ---> OF) FIG:12



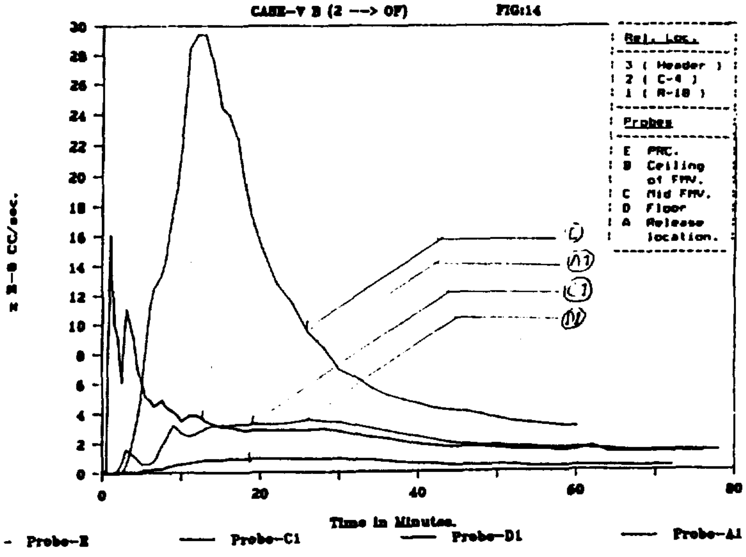
HYDROGEN MIXING EXPT.

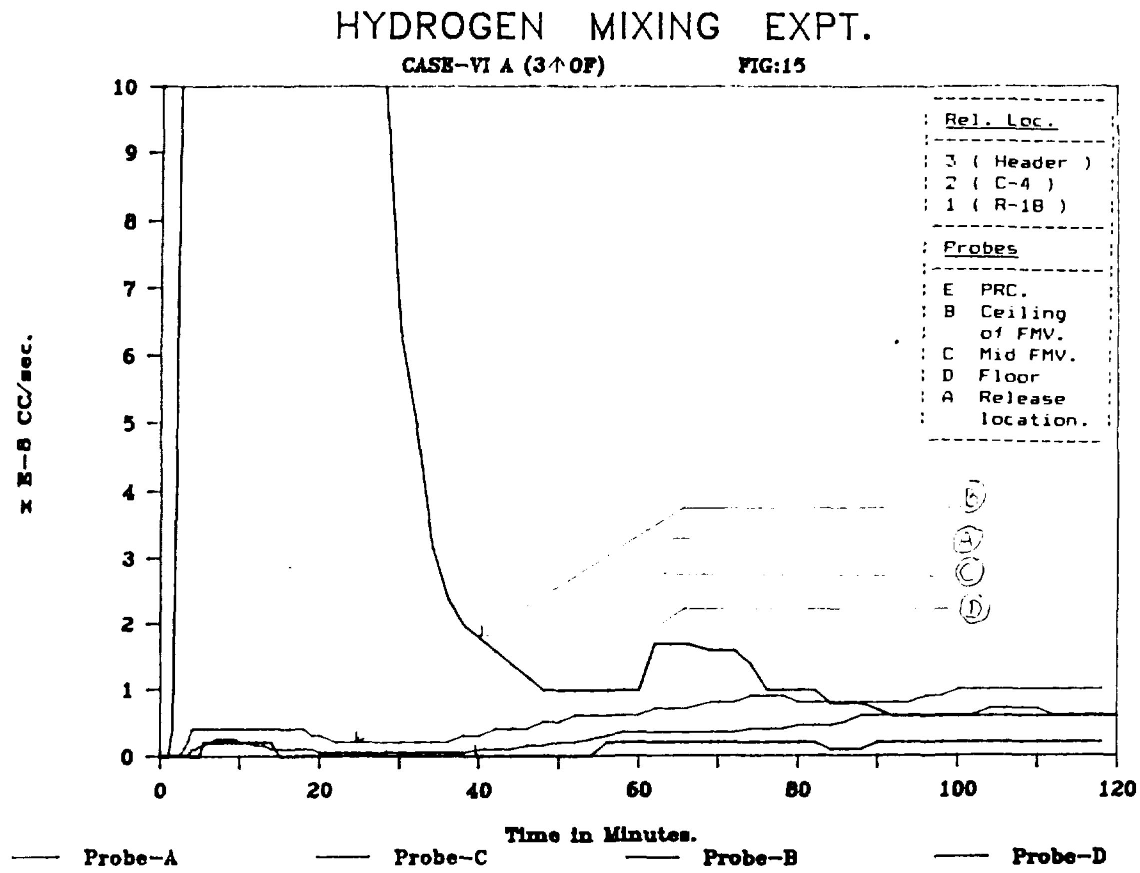
CASE-V B(A) (2 ---> OF) FIG:13

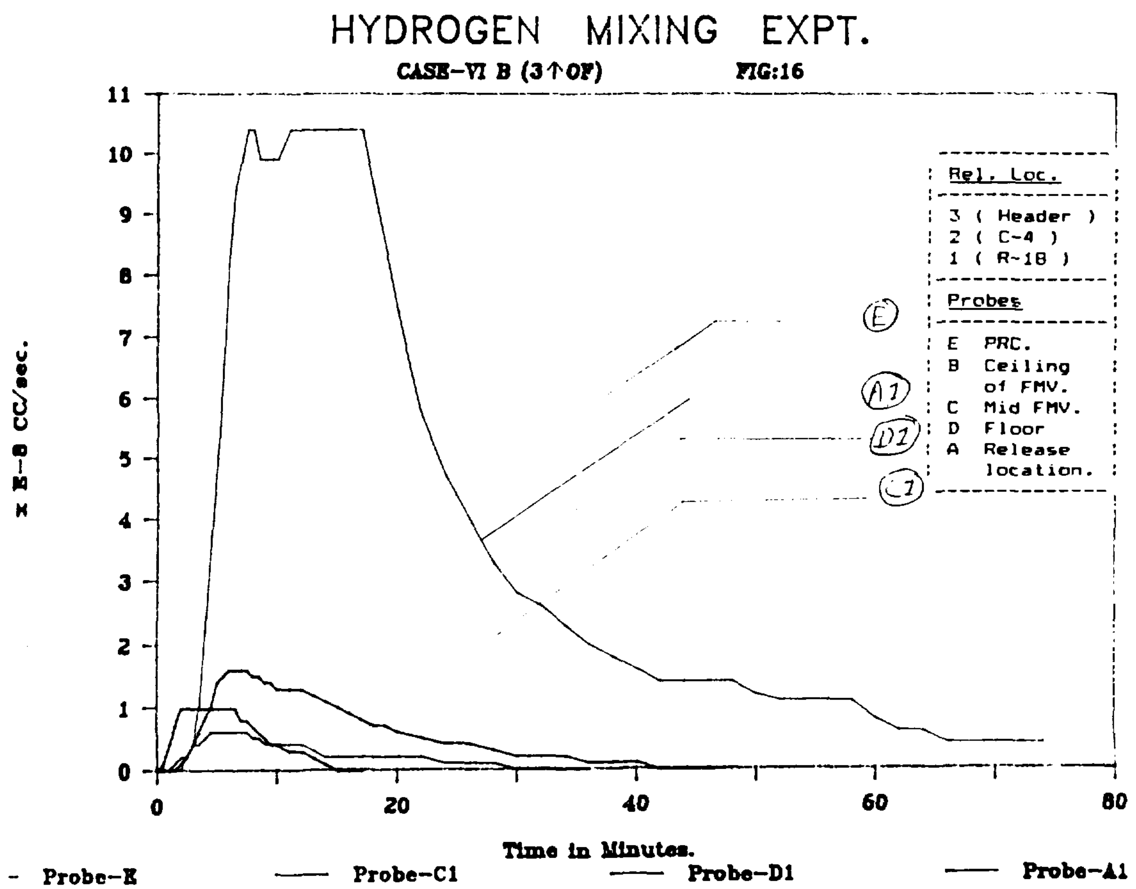


HYDROGEN MIXING EXPT.

CASE-V B (2 ---> OF) FIG:14

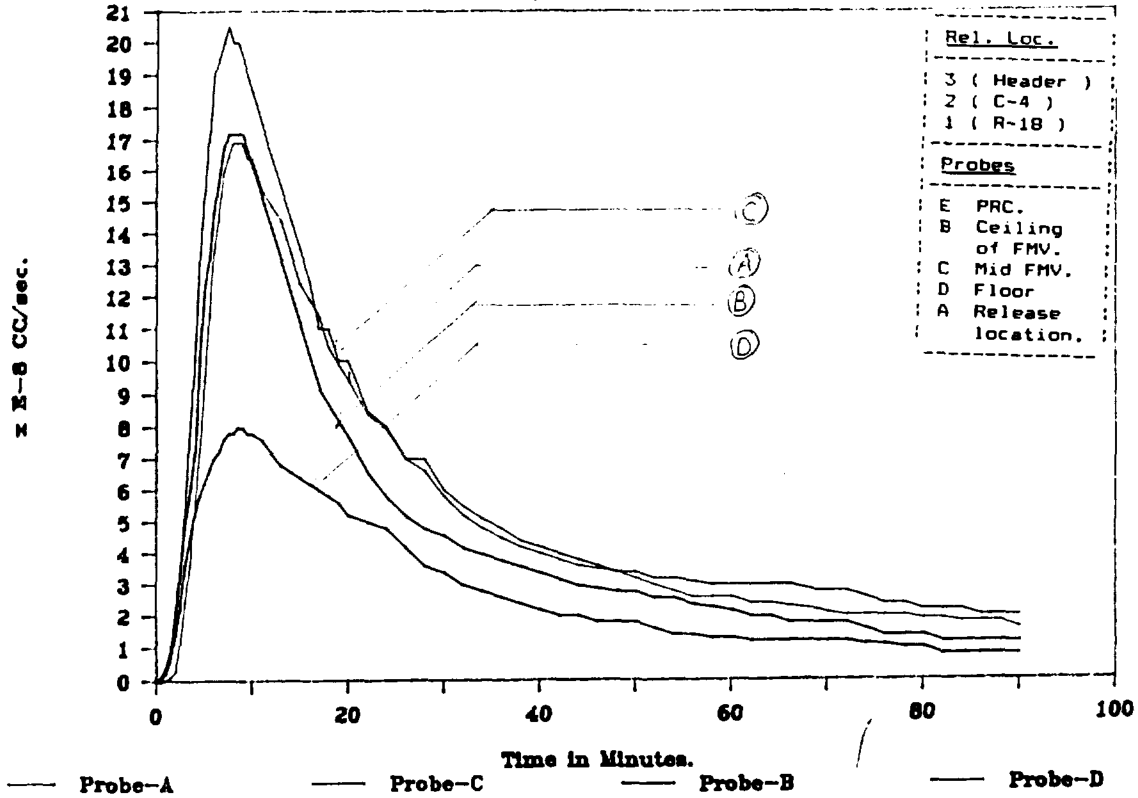



HYDROGEN MIXING EXPT.
CASE-VI A (3↑OF)
FIG:15
10
9
8
7
6
5
4
3
2
1
0
x E-8 CC/sec.
0
20
40
60
80
100
120
Time in Minutes.
Probe-A
Probe-C
Probe-B
Probe-D
Rel. Loc.
3 (Header)
2 (C-4)
1 (R-18)
Probes
E PRC.
B Ceiling of FMV.
C Mid FMV.
D Floor
A Release location.
B
A
C
D


HYDROGEN MIXING EXPT.
CASE-VI B (3↑OF)
FIG:16
11
10
9
8
7
6
5
4
3
2
1
0
x E-8 CC/sec.
0
20
40
60
80
Time in Minutes.
Probe-E
Probe-C1
Probe-D1
Probe-A1
Rel. Loc.
3 (Header)
2 (C-4)
1 (R-18)
Probes
E PRC.
B Ceiling of FMV.
C Mid FMV.
D Floor
A Release location.
E
A1
D1
C1

HYDROGEN MIXING EXPT.

CASE-VII A (3↑3F) **FIG:17**



HYDROGEN MIXING EXPT.

CASE-VII B (3↑3F) **FIG:18**