3.2 HYDROGEN COMBUSTION MANAGEMENT DURING A SEVERE ACCIDENT AT THE PLANT WITH THE ICE CONDENSER TYPE CONTAINMENT

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Abstract

In Japan, hydrogen mitigation measures inside the containment vessel during a severe accident are taken against the plant with the ice condenser type containment. Ohi Power Station Unit #1&2, which Kansai Electric Power Co.,Inc. owns, are the only plants of this kind in Japan.

Kansai has investigated the hydrogen mitigation measures in collaboration with Mitsubishi Heavy Industry Co.,Ltd.

As a result of extensive experiments and analyses, the glow plug type igniter was selected as a hydrogen mitigation device. Environmental conditions were investigated for the purpose of selection of the device. To decide the location of installation, Kansai performed analysis of mixing behavior of hydrogen focusing on the results of small scale combustion testing conducted by Nupec (Nuclear Power Engineering Corporation).

This paper will introduce the detailed results of Kansai's investigation of hydrogen mitigation measures for Ohi Power Station Unit #1&2

I. Introduction

It has been also investigated in Japan if a large amount of hydrogen generated during severe core damage would affect the containment integrity.

The hydrogen management described in this paper is based on the intensive studies initiated in July 1992 when the Ministry of International Trade and Industry (MITI) decided to request accident management (AM) for commercial reactors in response to the policy statement of the Nuclear Safety Commission (NSC) in May 1992.

AM for nuclear power plants in Japan is defined as a voluntary safety enhancement activity and not as a regulatory obligation.

The strategies of AM were presented in detail by the utilities to MITI in the form of "AM report" for each plant at the end of March 1994. MITI judged that utilities' AM strategies were effective for prevention and mitigation of a severe accident through reviewing all the reports , and submitted a report to NSC which included this conclusion on all the Japanese plants at the end of October 1994. NSC also published a report in December 1995 which concluded that utilities' AM strategies were adequate for prevention and mitigation of severe accident.

II. Criteria of flammable gases in Japanese nuclear facilities

The generation of flammable gases in a design basis accident is limited as "the concentration of either oxygen or hydrogen shall not exceed 5% or 4% respectively in the atmosphere inside the reactor containment vessel at least for 30 days after the occurrence of an accident" as described in the NSC's "safety evaluation criteria for light water reactor facilities for power generation"

Although there is no NSC's guidelines clearly defined for the beyond-design basis accident in Japan,

MITI determined that utilities' assumptions were adequate for the hydrogen generation and its consequence as one of severe accident phenomena;

- an assumption of the 75%Zr-water reaction during the core damage was sufficient for the calculation of the amount of generated hydrogen.
- there is little possibility of rapid failure of the containment by detonation if the hydrogen concentration inside the containment was less than 15%.

It is recognized that the hydrogen concentration will not reach the flammable limit even during a severe accident because the atmosphere inside the containment is purged of oxygen with nitrogen in Japanese BWRs.

As a result, hydrogen management is necessary only for Ohi unit-1 and 2 (1175MWe Westinghouse PWR plant), which are accommodated with the ice condenser type containment.

III. Hydrogen Management

The following five subjects are to be considered for the hydrogen management during a severe accident;

1. Select a type of the device which is expected to actuate in an assured manner , considering the containment atmosphere such as temperature , pressure and other chemical conditions during a severe accident.
2. Specify the severest scenario of hydrogen generation to study the effectiveness of the device in mitigating the effects of hydrogen.
3. Understand exactly the mixing behavior of hydrogen in the containment based on the above scenario.
4. Locate the equipment (igniter) inside the containment in consideration of characteristics of mixing behavior of hydrogen and combustion phenomena
5. Verify that containment pressure will not exceed the threshold proof pressure after burning of hydrogen

In this paper, we discuss the hydrogen management for the plants with the ice-condenser type containment from the viewpoints listed above.

III-1. Selection of hydrogen control device

It is necessary to install some kind of the device for the exclusive use of hydrogen control because the existing electric hydrogen recombiner for the design basis accident is hardly able to control a large amount of hydrogen generated rapidly during a severe accident.

The desirable devices include the glow plug type igniter, catalytic igniter, catalytic recombiner and spark type igniter.

The expected functions for the hydrogen mitigation device are as follows;

- ignition : able to ignite in an assured manner when the hydrogen concentration within the installed compartment is 8 % or less.
- mission time : operable 1 week after the occurrence of an accident
- actuation: automatically actuates immediately after the occurrence of an accident
- environmental condition : able to withstand the atmospheric conditions during an accident (spray, steam, iodine, aerosol)

Kansai Electric Power Co., Inc. has carried out experiments on the available devices.

Experimental results are summarized on Table 1. After comprehensive review of these experimental results, we have decided to adopt the glow plug type igniter.

The reasons why we employed the glow plug type igniter are described in detail as follows.

Kansai Electric carried out experiments of three types/four kinds of hydrogen combustion devices manufactured by three different companies. We examined six parameters to evaluate their performance. The significance of these six parameters and their experimental condition are explained at first and then the results are described.

III-1(1). Lower limit of hydrogen concentration for ignition

It is necessary to confirm that the hydrogen mixture gas is ignited at low hydrogen concentration. In this regard, we carried out experiments on the minimum hydrogen concentration for ignition considering the reliability of ignition and the influence of steam. The criteria is that the hydrogen mixture gas shall be ignited under 8vol% ,which might avoid large scale combustion inside the containment. In addition, the steam concentration ranged below 55vol% which can make the atmosphere inert.

III-1(2) Lower limit of temperature for ignition

In case of LOCA, temperature inside the containment of ice-condenser type plant Ohi unit #1&2 is lower than that of dry type containment plant. Therefore, it is necessary to confirm that hydrogen is ignited at the lower temperature in an assured manner before it accumulates to higher concentration. The experimental condition was set at 283K (10℃, 50° F) at the minimum to envelop the lower limit of temperature inside the containment assumed for accident scenarios of the Safety Analysis Report.

III-1(3) Delay of Ignition

A large amount of hydrogen would be generated relatively in a short period of time in a severe accident scenario. Accordingly, even if the hydrogen concentration reaches to the flammable level in the compartment with a igniter installed, the delayed ignition may cause a large scale of combustion followed by the failure of the containment when the concentration exceeds 8vol% in a wide area with delay of ignition.

Consequently, we measured the time delay of ignition through experiments for each device.

Allowable time delay for ignition was assumed to range from 4 through 36 seconds considering the rate of hydrogen generation and the free volume of compartment.

III-1(4) Resistance against poison

It is also necessary to take into account the fact that a lot of iodine and aerosol inside the containment may adhere to the surface of igniter in a severe accident. For the catalytic igniter, it is necessary to check the possibility if the iodine degrades the activity of catalyst and if the aerosol attached to the surface of catalyst prevents contact with hydrogen gas.

And it is necessary to check if degradation of insulation caused by aerosol stuck to the surface prevents spark generation because the spark type igniter generates spark by the potential difference between electrodes.

III-1(5) Gas velocity

The gas velocity around the hydrogen combustion device has an influence on the ignition.

For the catalytic igniter, the lower gas velocity generally makes the amount of hydrogen supply less, which may lead to inflammability. Accordingly, the gas velocity varied from 0.3 to 5 m/s in the experiments and successful ignition was required in this range.

III-1(6) Countermeasures against spray water

There are two trains of containment spray system inside the containment of Ohi unit #1&2. It is necessary to verify that the spray water onto the hydrogen combustion device may not cause degradation of its performance.

III-1(7) Experimental results and evaluation

The candidate devices were investigated through experiments and studies regard above six items.

As a result, it has been proved that the igniters are designed so that spray water during an accident may not cause any trouble and all the devices meet the requirement on the gas velocity.

As summarized in Table 1, the catalytic igniter showed low reliability in four items; lower limit of hydrogen concentration, ambient temperature for ignition, delay of ignition, and resistance against poison. Meanwhile, the spark type igniter did not meet three criteria except for the lower limit of hydrogen concentration for ignition.

The reason why the spark type igniter was determined not to be accepted because of lower limit of temperature for ignition and delay of ignition depends on the fact that the temperature switch doesn't properly operate under the atmosphere at low temperature rather than the performance of the igniter itself.

On the other hand, it was confirmed that the glow plug type igniter met all the criteria.

In conclusion, we have decided to employ the glow plug type igniter as a hydrogen mitigation device in a severe accident for Ohi unit #1&2.

III-2. *Selection of analysis scenario*

We have investigated to determine the severest scenario with a large amount of hydrogen generated.

For the analysis with use of MAAP3.0, the following scenarios were considered:

S2D (small break LOCA + failure in ECCS injection)
S2H (small break LOCA + failure in ECCS recirculation)
TMLB' (loss of main feed water + failure in auxiliary feed water system)
S1H (intermediate break LOCA + failure in ECCS recirculation)

As shown in Table 2, the analytical result indicated that the maximum amount of hydrogen generated was equivalent to about 45% Zr-water reaction amount and the maximum hydrogen generation rate was equivalent to 1.1 kg/sec. Considering these analytical results and scenarios, it is indicated that the deeper the core is exposed and the larger the amount of water vapor supplied to the core, the larger the amount and generation rate of hydrogen are.

Table 2:Hydrogen Generation in a Severe Accident

Scenario	Amount of hydrogen generated(*)	Maximaum hydrogen generation rate	Initiation of core melt
S2D	41%	~1.1kg/sec	1.3hr
S2H	39%	~1.0kg/sec	7.4hr
TMLB'	40%	~0.5kg/sec	1.6hr
S1H	30%	~0.5kg/sec	2.0hr

(*)Zr-water reaction equivalence

The large amount of hydrogen generated results in a severe effect in view of the increase in the containment internal pressure when hydrogen is burnt, while the high generation rate results in a severe effect in view of the efficiency in hydrogen control

In addition, when considering the initiation of hydrogen generation, 1 week of the mission time is sufficient for the hydrogen burning device since the occurrence of the core damage would be less than eight hours in all sequences shown in Table 2.

Based on the above considerations, the scenario S2D (small break LOCA + failure in ECCS injection) was selected as the severest one, and investigation was conducted as follows assuming the amount of hydrogen generated as equivalent to 75% Zr-water reaction amount.

III-3. Investigation of hydrogen mixing behavior inside containment vessel

Next, we analyzed hydrogen mixing behavior inside the containment vessel. The scenario to be analyzed was S2D with the assumed amount of generated hydrogen equivalent to 75% Zr-water reaction amount as mentioned in the previous section. The Fig.1 shows the time transient of the release rate of hydrogen generated.

We employed MAPHY-BURN code for the analysis. As shown in the Fig.2, the node-path model was established with the containment vessel divided into 23 compartments.

As shown in the Fig.3 , the analytical result indicated that the concentration of hydrogen at the bottom of the ice condenser inlet followed, with a constant time lag, the change of the hydrogen concentration within the compartment where hydrogen was generated. The peaks at the hydrogen concentration correspond to the increases of the amount of generated hydrogen.

This analytical result showed that hydrogen generated at the lower compartment went up to the upper part of the containment vessel through the ice condenser. This flow path of hydrogen is what expected in the design of the ice condenser type containment vessel.

III-4. Selection of location where igniter to be installed

Considering the hydrogen flow path shown in the analytical result as described in the above section, we have selected the location where igniters were to be installed.

Large scale hydrogen combustion in a broad space may challenge the containment vessel integrity. Accordingly, it is desirable to burn hydrogen locally at lower concentration. Therefore, it is designed that igniters should be located on the hydrogen mixing path and supplied power on actuation of the safety injection signal so that they can get igniting condition prior to hydrogen generation. It has been confirmed that sufficient power capacity is assured though it is supplied from the emergency power source.

The Fig.4 shows the locations of igniters.

On the other hand, the result of the small scale hydrogen combustion test conducted by Nupec under the contract with MITI showed that the way in which flame propagates depends on the hydrogen concentration[1]. As shown in the experimental result of the Fig.5, the flame propagates only to the limited area with the hydrogen concentration at 4 % while the flame gradually propagates upward at 6 % and then rapidly spreads over upward and downward at 8 %. As can be seen from these results, it is important to burn hydrogen at its low concentration for mitigation of the effect on the containment vessel integrity.

We are also investigating the locations of igniters to be installed at the plant site, and details will be soon revealed.

It is planned to install a simple cover on the glow plug for protection against spray water injected during an accident and for protection during the annual inspection.

III-5. Analysis of Containment vessel internal pressure

Finally, it is necessary to verify that the containment vessel internal pressure will not exceed the limit when the installed igniter actuates. The design pressure of the containment vessel at Ohi unit 1 and 2 is equivalent to 0.84 kg/cm2G, while it is expected that the containment vessel can withstand up to about 3 times the design pressure.

Based on the above scenarios, an analysis was conducted for the severest condition in view of the containment pressure increase, assuming that hydrogen begins to burn at the concentration of 8 % within the compartment where the igniter is installed and then hydrogen thoroughly burn out. The result showed that the containment pressure would not exceed the containment design pressure and that the containment integrity was maintained (Fig.6).

It was assumed to install 17 igniters in this analysis. Actually, the number of igniters to be installed will be doubled to 34 to allow for some margin.

IV. Considerations on installation of igniter

Igniters shall be supplied with power from the emergency bus through the breaker to prevent adverse effects on the existing safety systems due to failure of the igniter. In this power distribution scheme, the breaker will be automatically opened to protect the emergency bus when ground fault occurs on the power cable to the igniter.

In addition, cables shall be in accordance with the LOCA specification, considering the characteristics against the environmental condition.

V. Future subject

It is planned to install the equipment for countermeasures against hydrogen combustion as one of the facility improvements required for the accident management strategies. We intend to complete the facility improvements by 2000 and to prepare the guideline for the accident management strategies.

VI. Conclusion

In Japan, countermeasures against hydrogen combustion during a severe accident are taken for the plant with the ice condenser type containment vessel.

We adopted the glow plug type igniter as a hydrogen burning device considering the environmental condition.

We also investigated the hydrogen mixing behavior and increase in the containment vessel internal pressure, assuming the amount of hydrogen generated equivalent to the Zr-water reaction amount at 75 %, based on the S2D scenario.

Igniters are to be installed at the lower part of the compartment, considering the result of experiment conducted by Nupec.

It is planned to install 34 igniters which are equivalent to the double of what required.

Installation of igniters, which is planned as part of the facility improvements required for the accident management strategies, will be completed at latest by 2000.

References

[1] "Current Status of the Reliability Demonstration Test of Nuclear Power Generation Facilities" p.152, Nuclear Power Engineering Corporation, 1993

Table 1: Experimental Results of Hydrogen Igniters in condition of Severe Accident

item	criteria	catalytic igniter(M)			catalytic igniter(S)			Spark type Igniter (S)			Glow plug type Igniter (T)		
		results	grade	note	results	grade	note	results	grade	note	results	grade	note
Lower Limit of Hydrogen Concentration for Ignition	H2≦8 vol% at Steam Conc. ≦55 vol%	～6%H2 at 20%Steam 6～7%H2 at 40%Steam	×	ignited at 5.4% in good condition (ex. dry). Low reliability of initial ignition	～9%H2 at 20%Steam No Ignition at ～10%H2 at ≧40%Steam	×	ignited at 6-7% in dry condition. Low reliability of initial ignition	～7%H2	○		≦6%H2	○	
Lower Limit of Temperature for Ignition	≦10℃	Successful ignition at 10 ℃	×	Low reliability of initial ignition	Successful ignition at 10 ℃	×	Low reliability of initial ignition (little initial activity at low temperature)	≧40℃ without poison	×	Ignitable even at 0 ℃ in the Working Report	No Problem because of extremely high temp. (～1000℃) on the *surface of igniter*	○	Iginition temp. =730℃ →margin=270℃
Delay of Iginition	4～36sec	5-30sec in good condition (ex. dry)	×	Strongly affected by humidity and *the number of* times of ignition	5-30sec in good condition (ex. dry)	×	Strongly affected by humidity and *the number of* times of ignition	CsOH makes delay longer up to 276 sec *as the experiment goes on.*	×	7 sec in the Working Report	Automatic Actuation by Safety Injection signal or CV Isolation signal	○	
Resistance against Poison	I2, CsOH	Poisoned in the condition of I2 0.05g/m3 ×24h or CsOH 10g/m2	×		Poisoned in the condition of I2 0.05g/m3 ×24h or CsOH 10g/m2	×		Temperature Switch; failure even over 10%H2 in case of I2=0.05g/m3 × 1h Electrode; *Spark rate decreases as experiment goes on in case* of CsOH=3.6g/m3 × 14h	×	It is assumed that CsOH 3.6g/m3 × 14h should be equivalent to CsOH *10g/m3* × 5h	Not affected Poisons evaporate from the surface of glow plug because of its high temperature.	○	Zirconia stuck to the surface of plug is simulated by use of crystal glass cover around the plug
Gas Velocity	*0.3～5 m/s*	Successful ignition in the range *of 0.3～5m/s*	○		Successful ignition in the range *of 0.3～5m/s*	○	Another *experiment* was carried out between 0.1&4.1m/s	ignited at 0.3m/s	○	6m/s in the Working Report. (the lower gas velocity is, the harder ignition occurs)	Surface temperature is *higher than ignition* temperature even if 5m/s flow	○	Surface Temp. *=780℃*
Counter-measures against Spray Water		*Protected Structurally*	○		Protected Structurally (ignited at just below 6%H2)	○		Protected Structurally (ignited at just below 8%H2)	○		*Protected Structurally*	○	
SUMMARY		Some items don't meet requirements	×		Some items don't meet requirements	×		Some items don't meet requirements	×		All the items meet requirements	○	Endurance has been proven by TVA and our test.

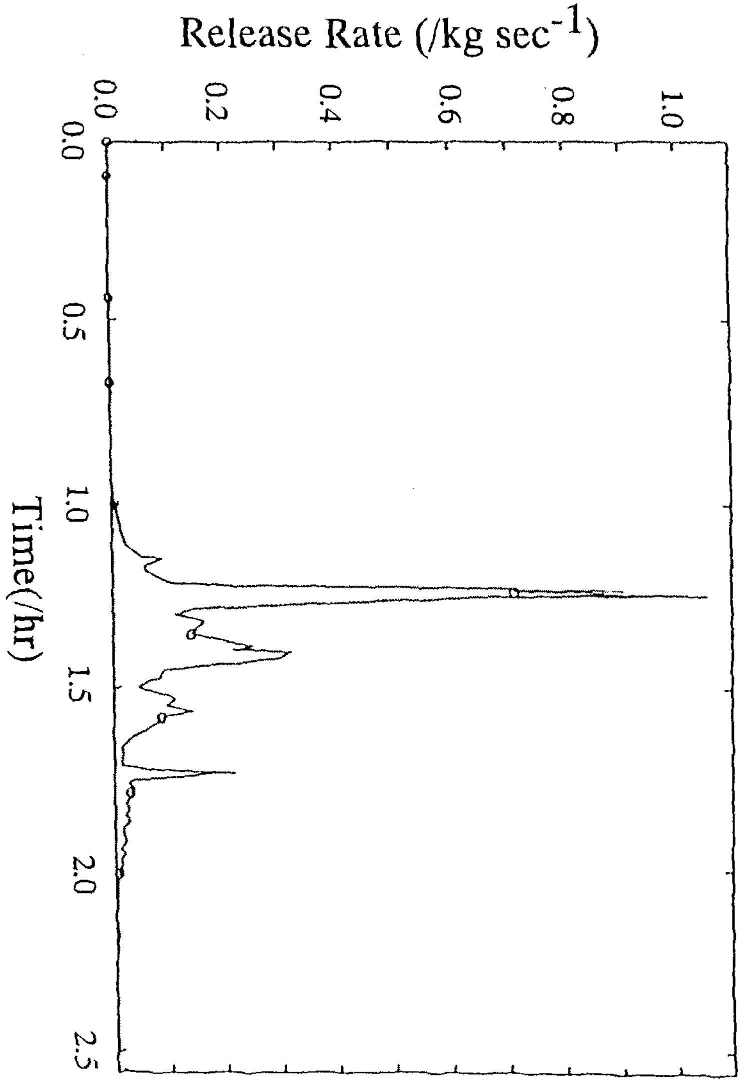


Fig.1: Hydrogen Release Rate in case of S2D

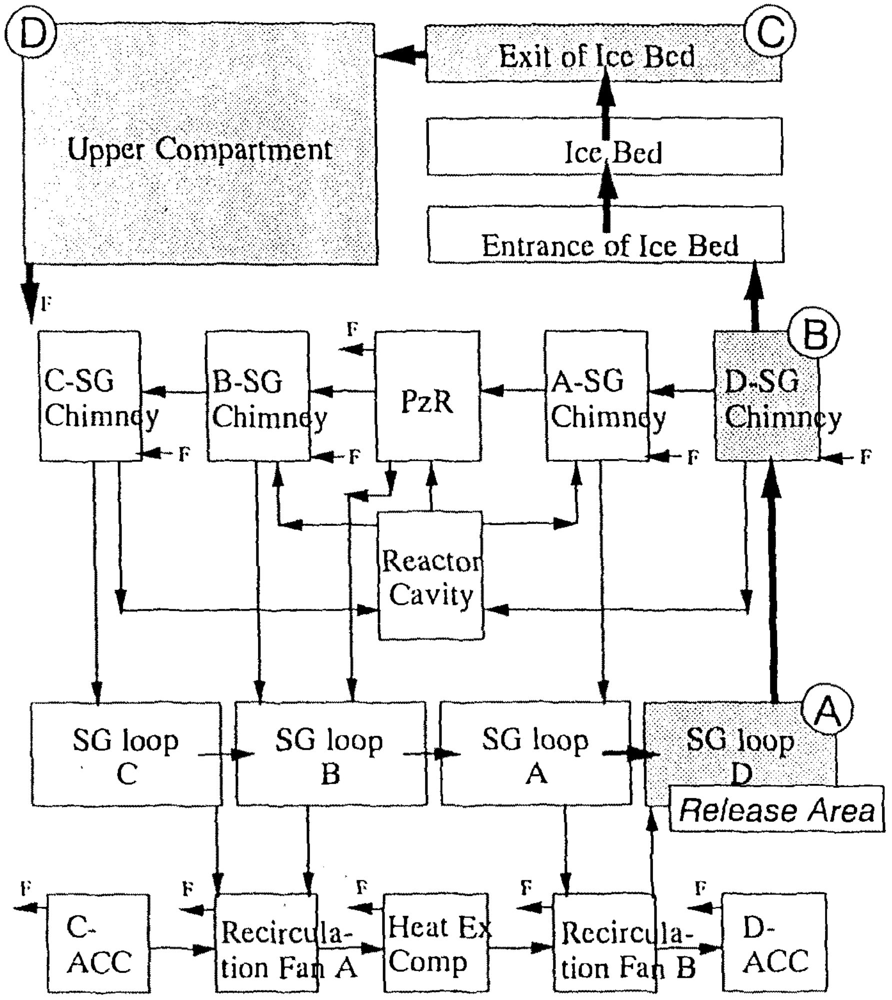


Fig.2: Node-path model of Ohi #1&2 for MAPHY-BURN

Results of H2 Conc. change for shaded areas are on the graph.
Thickness of arrows implies the flow rate of gas.
"F" means the flow by the air return fan.

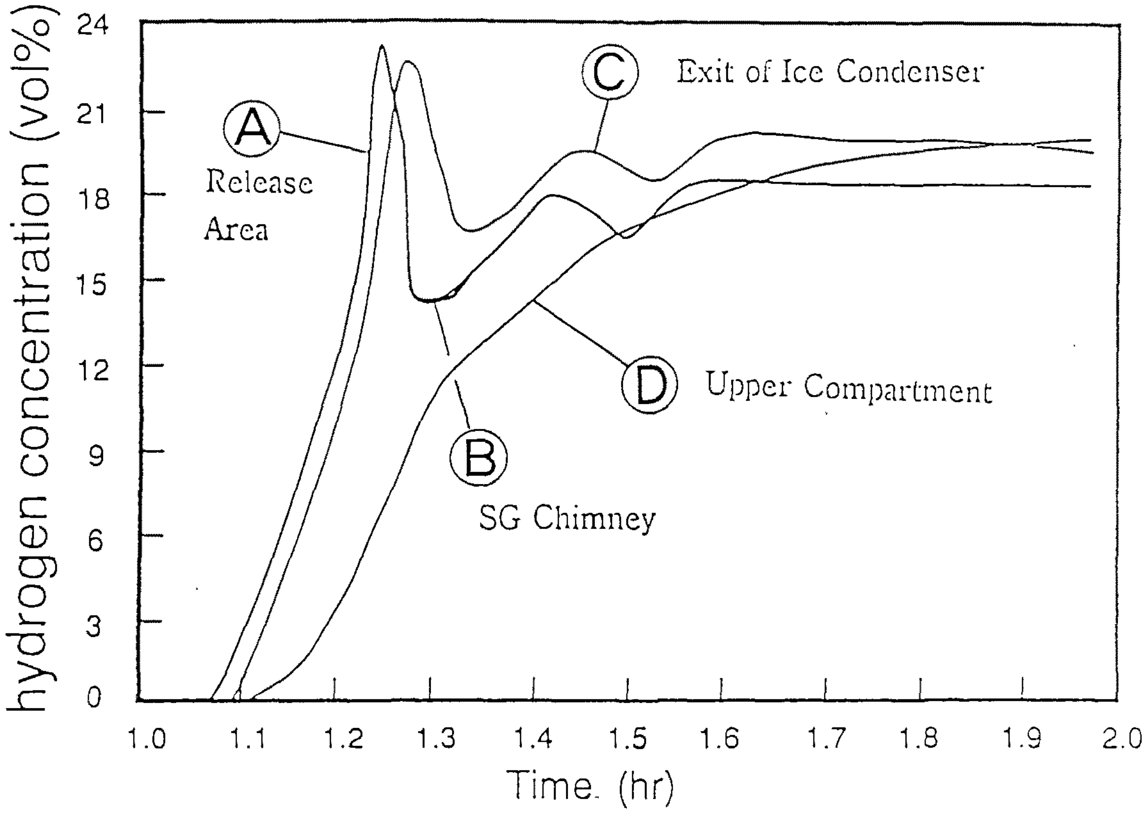


Fig.3 : Mixture of Hydrogen in the Containment

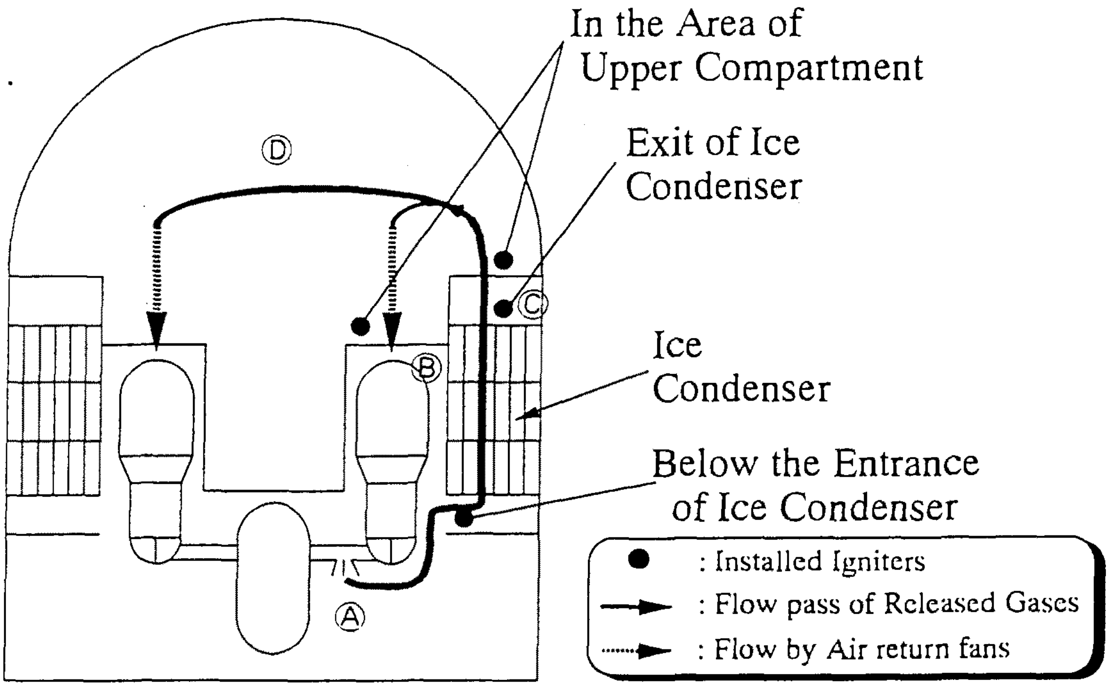
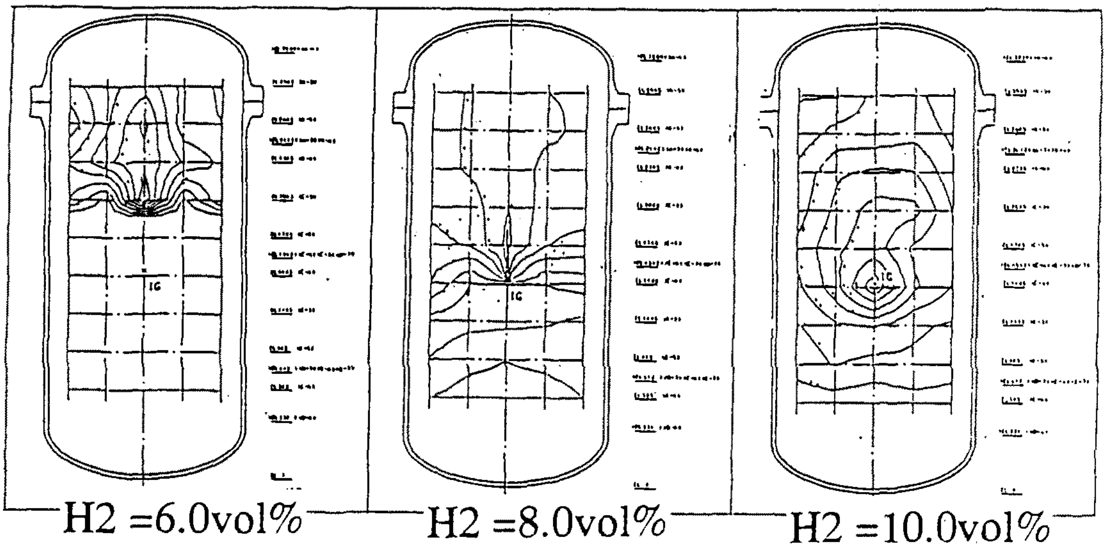


Fig.4 : Location of Igniters in the Containment



H2 =6.0vol% H2 =8.0vol% H2 =10.0vol%

Fig.5: Flame Propagation Pattern
(Experimental result by NUPEC)

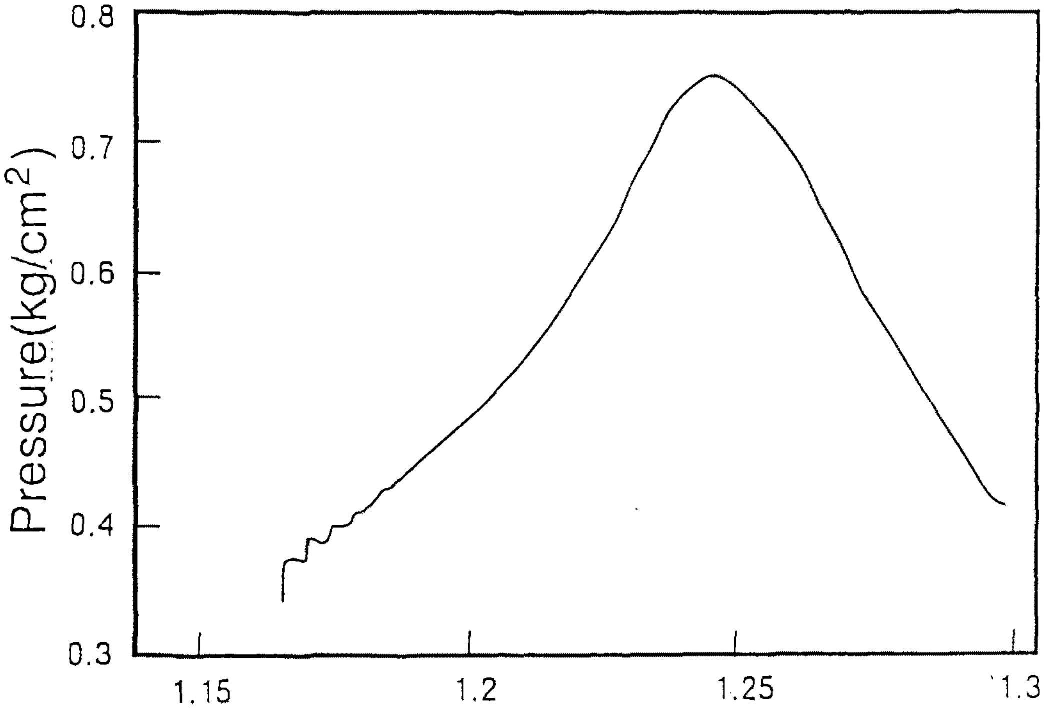


Fig.6: Pressure Rise in Hydrogen
Combustion by Igniters of Ohi #1&2
Combustion efficiency is assumed to be 100%