Application of Passive Autocatalytic Recombiner (PAR) for BWR Plants in Japan

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INTRODUCTION

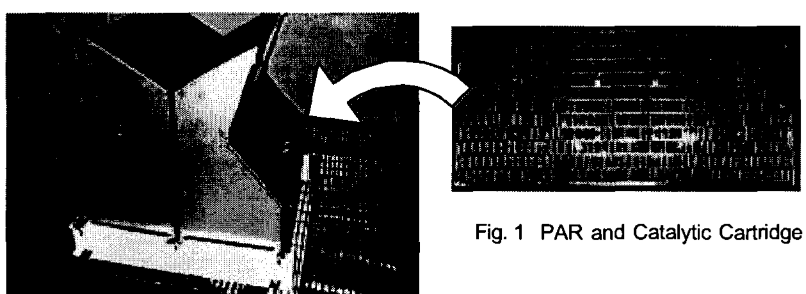

Fig. 1 PAR and Catalytic Cartridge

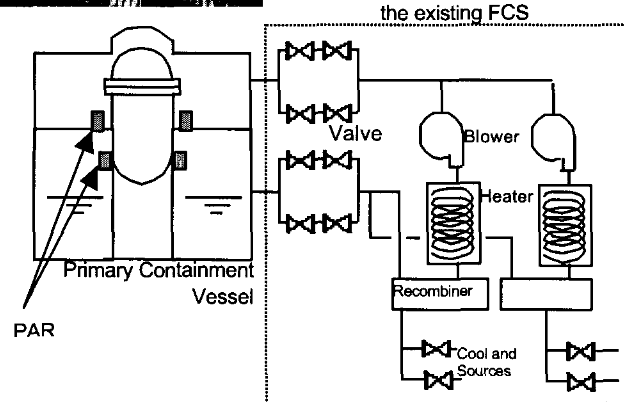

Fig. 2 Outline of PAR and Forced Circulation/Heating FCS

The passive autocatalytic recombiner (PAR) (Fig.1), which can recombine flammable gases such as hydrogen and oxygen with each other to avoid an explosion in case of a loss-of-coolant accident (LOCA), installed in the primary containment vessel does not require a power supply or dynamic equipment, while the existing flammability gas control system (FCS) of most BWRs as an outer loop of the primary containment vessel needs them to make flammable gases circulate through blowers and heaters in the system (Fig.2). PAR offers a number of advantages over existing FCS, such as high reliability, low cost due to much smaller amount of materials needed, good maintainability, good operability in case of a LOCA, and smaller space for installation. An experimental study has been carried out for the purpose of solving the problems of applying PAR to Japanese BWR plants instead of existing FCS, in which we grasped the basic characteristics of PAR.

OBJECTIVE OF THIS STUDY

Some utilities with nuclear power plants in the United States have been studying the application of PAR to reduce maintenance costs, and some have already applied PAR to their plants. In Europe, PARs have been set up in several nuclear power plants to cope with severe accidents (SA).

Design requirements for PAR include terms relating to pressure, steam partial pressure, hydrogen concentration, oxygen concentration, ambient air temperature, effect of the concentration of reaction inhibitors, such as iodine for recombining hydrogen and oxygen, and design life. Since PAR manufacturers carried out tests on conditions for PWR, a study must be carried out to confirm the performance of PAR under specific conditions of a BWR, and on the condition of licensing in Japan, on which we have to consider the influence of very severe reaction inhibitors.

DETAILS OF THIS STUDY

Current findings and the details of this study

Current findings on PAR and problems to be solved for the application of PAR to BWRs in Japan are summarized below.

-Self-starting characteristic

It is necessary to obtain self-starting characteristic data under the conditions of BWR-LOCA (operation of the emergency containment spray system, low hydrogen/oxygen concentration, existence of reaction inhibitors, etc.).

-Hydrogen removal speed

The performance evaluation method established by catalyst manufacturers under the PWR conditions include hydrogen concentration, oxygen concentration, and pressure as parameters. The effects of other parameters are considered as the correction factor. We have carried out in-vessel tests on condition that hydrogen and oxygen concentration are low, and the emergency containment spray system is activated. And we have confirmed quantitative effect of reaction inhibitors, such as iodine compound by single catalyst element tests.

We have re-evaluated the performance evaluation method for BWR plants by these test results.

-Aged degradation by reaction inhibitors
We have confirmed and evaluated the degradation of PAR due to exposure to reaction inhibitors quantitatively by single catalyst element tests.

-Required number and arrangement of units
The evaluation method of the hydrogen removal performance of catalyst manufacturers is established on the assumption that ambient gases in the dry well and the wet well are completely mixed up. The validity of the assumption and the effects of the operation of the emergency containment spray system on catalytic performance in view of arrangement are unclear. We have found the number of PAR required for keeping an allowable level of flammable gases and effective arrangement of PAR units using the above two experimental data set and analytical approach.

-Thermal degradation
There are few adequate data available on a drop in catalytic efficiency due to thermal degradation. So in order to gain sufficient data, we have carried out single catalyst element tests and evaluated the effects of thermal degradation during LOCA.

Therefore this study has been conducted with the aim of quantitatively clarifying the above effects by carrying out single catalyst element tests and in-vessel spray tests.

Single catalyst element tests
In order to make clear the effects of reaction inhibitors attached on the surface of a catalyst, single catalyst element tests have been carried out on the following two items:

¥Clarification of the effects of reaction inhibitors on hydrogen removal speed
¥Quantitative evaluation of aged degradation by reaction inhibitors during BWR-LOCA

Regarding the hydrogen removal speed of PAR system under review, tests should be conducted to check the validity of the method proposed by catalyst manufacturer.

It seems that the catalytic performance is affected by the amount of reaction inhibitors attached on the catalyst. Not only the reaction inhibitor concentration but also the catalyst surface temperature are considered to affect the attachment. Therefore, tests should be carried out in consideration of these three parameters. In addition, the amount of reaction inhibitors attached on the catalyst should also be checked. Thus, the effects of I_2 (gas), CsI (aerosol), CH_3I (gas), which are the chemical forms of iodine compounds, on catalytic performance is checked. In line with the results, plans are to carry out tests using iodine as a reaction inhibitor, so that the three parameters of iodine concentration, inlet flow rate, and hydrogen concentration are examined.

-Testing system

Fig. 3 shows a schematic diagram of the testing system. The system is made up of a reaction vessel housing a catalyst cartridge, a gas supply, a reaction inhibitor generator, a condenser, a flue gas processor, and various measuring instruments. The efficiency of reaction in the catalytic layer can be measured by the hydrogen/oxygen densimeter, installed at the inlet of the reactor. Regarding conditions in the reaction vessel, temperature distribution in the catalytic layer can be measured by the thermocouples fitted on the reaction vessel.

-Testing procedure

¥Nitrogen is substituted for the air in the reaction vessel, simulating the atmosphere inside the primary containment vessel.

¥Temperature and gas flow rate are set.

¥Reaction inhibitor is put into the reaction vessel.

¥Then gas composition, the amount of reaction inhibitor injected, temperatures, pressure, and gas flow rate are measured at fixed intervals.

¥Catalytic efficiency is quantitatively evaluated from the difference in hydrogen concentration between the catalyst inlet and outlet.

-Test parameters

The iodine concentration was set to 32 mg/m^3, conforming to Japanese licensing conditions. But because of the restriction of the test duration, tests condition was accelerated by increasing iodine concentration.

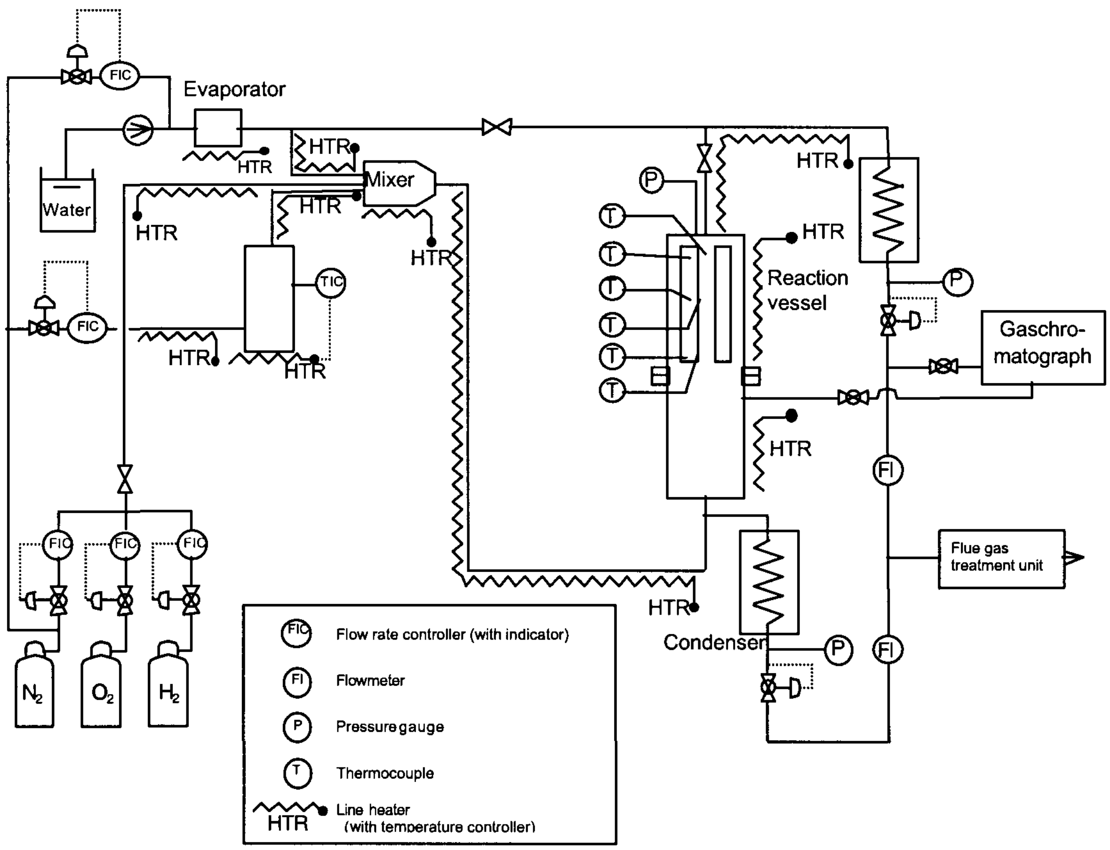

Fig. 3 A Schematic Diagram of the Single Catalyst Element Testing System

-Results of tests

The basic activity of the catalyst has been confirmed to be satisfactory as the hydrogen removal efficiency exceeded 90%. Fig. 4 shows the results of immersion tests. Among the iodine compounds, I_2 is found to be the most effective inhibitor on catalytic performance. Fig. 5 shows the results of high concentration acceleration tests conducted in order to check the effects of I_2.The results of these tests indicate that although the hydrogen removal efficiency declines slowly over time, a certain level of activity is remained. Thus, hydrogen removal performance in the continuous presence of iodine and the validity of the hydrogen removal performance evaluation method was confirmed.

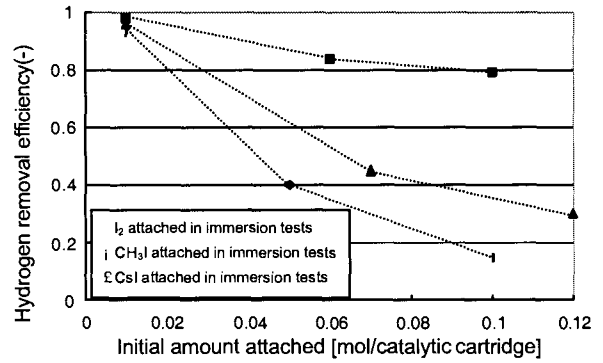

Fig. 4 Percentage of Drop in Hydrogen Removal Efficiency on Account of Reaction Inhibitors

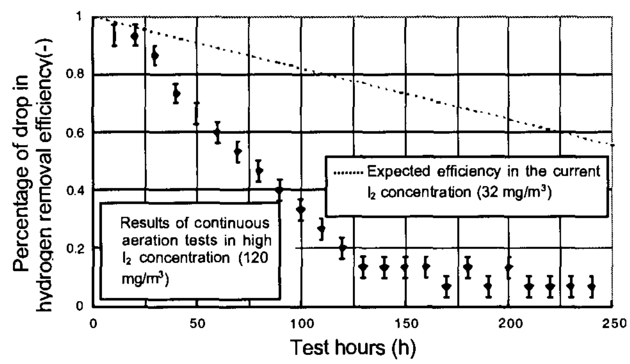

Fig. 5 Percentage of Drop in Hydrogen Removal Efficiency

In-vessel spray tests

In order to obtain data on hydrogen removal performance under low hydrogen and oxygen concentration, and under containment spray activating conditions, in-vessel spray tests have been carried out to confirm:

¥The validity of the hydrogen removal performance evaluation method of catalyst manufacturers (including the low-oxygen degradation factor) under BWR conditions

¥The spray flow behavior, the self-starting characteristic of a catalyst due to the effects of water attached, and the amount of processed hydrogen.

¥The effects of flue gas (high-temperature gas) from the outlet of PAR on the containment vessel wall and other internals

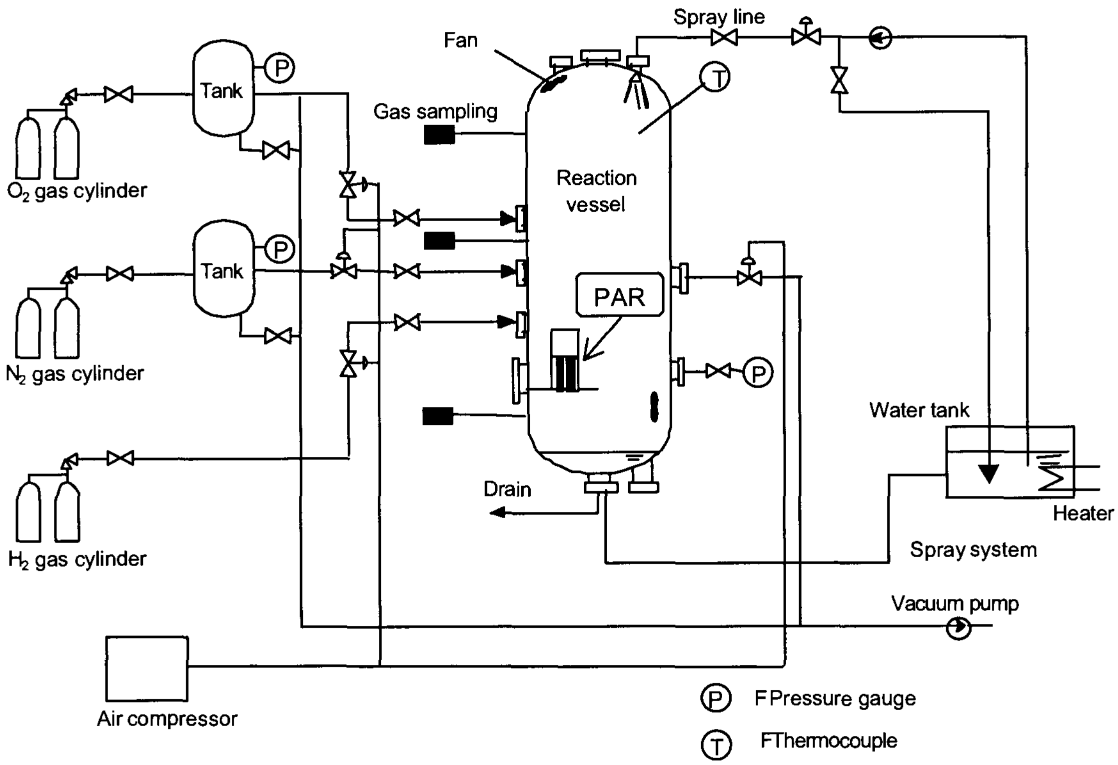

Fig. 6 A Schematic Diagram of the In-the-Vessel Spray Testing System

-Testing system

The testing system is composed of a cylindrical vessel, which is 1.5 meters in bore, 3.5 meters in height, and 5.8 m^3 in internal volume, a gas injector/feeder, a water sprayer, a gas analyzer, and a vacuum pump. Fig. 6 shows a schematic diagram of this testing system.

-Testing procedure

The testing vessel is evacuated. Nitrogen and oxygen gases are put into the vessel at given partial pressure respectively. Then spray water is injected and temperature is set at the condition of LOCA. After spray flow rate is adjusted, hydrogen gas is injected and reaction conditions in the vessel are measured. Temperature and gas composition at the inlet and outlet of the catalytic layer, and flow rate at the inlet of the catalytic layer are measured.

-Results of tests

To check the effects of spray water, tests have been conducted at varying spray flow rate. As shown in Fig. 7, it is found that because the flow rate of gas passing through PAR rises with an increase of spray flow rate, hydrogen removal speed tends to increase. When the spray is activated right over PAR, drops of water are protected by the hood, not to affect catalytic efficiency.

Under low-oxygen conditions, hydrogen removal performance tends to decrease with a drop in oxygen concentration as shown in Fig. 8. Thus, it is found that recombination reaction in the catalytic part takes place by oxygen diffusion rate control. Accordingly, a rational evaluation method can be obtained by revising the low-oxygen evaluation method proposed by the equipment manufacturers.

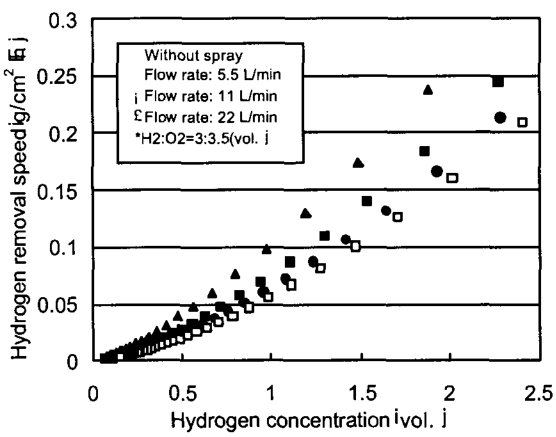

Fig.7 Containment Vessel Spray Performance Retention Tests

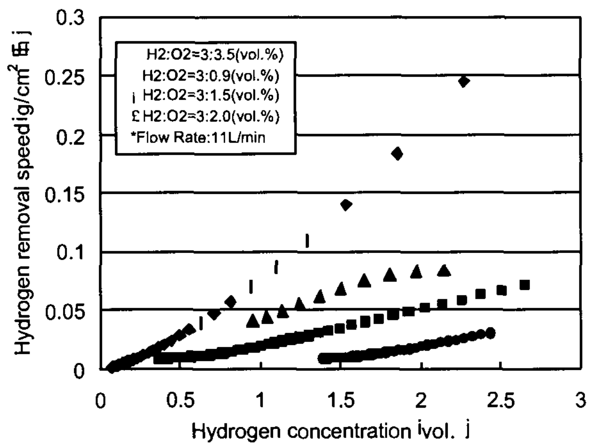

Fig.8 Low Oxygen Concentration Performance Retention Tests

Study on required number and arrangement of units

Based on the data derived from the above test results, the evaluation method of hydrogen removal performance has been determined. Moreover, judging from the relation to the amount of reaction inhibitors released in the containment vessel, the required number and arrangement of units have been examined.

A reaction inhibitor, which is released in the containment vessel, is presumed to be iodine that accounts for 50% of the core inventory. Based on the test results, a chemical form of iodine is conservatively determined as 100% iodine (I_2). Under these conditions, the required number of PAR units has been analyzed in order to maintain the containment vessel atmosphere below the flammability limit during a LOCA for 30 days.

Table 1 The Required Number of PAR Units

Evaluation cases	Required number	
	D/W	W/W
I_2 gas-liquid partition coefficient = 100	4 ‘ 7	1
Realistic I_2 gas-liquid partition coefficient = 400	1	1

Table 1 shows the results of evaluation made on the 1300MW class ABWR. When reaction inhibitor conditions are evaluated according to the current conservative Japanese licensing requirements, 4 to 7 units are required in the dry well and one unit is needed in the wet well. In addition, when these conditions are evaluated according to the realistic iodine gas-liquid partition coefficient[1], one unit is required in the dry well and one unit in the wet well.

Based on this evaluation, a study has been conducted on how to arrange PAR units in the containment vessel. The ABWR containment vessel is divided by grating into three sections. When maintainability and ascending gas flow in the containment vessel[2,3] are taken into consideration, it is desirable to install the units on the uppermost grating as shown in Fig. 9. The number of the PAR units in the dry well, 4-7, can be reduced to three by increasing catalytic cartridges to be inserted into one unit. In this case, it is found that these units can properly be arranged even if consideration is given to interference with other devices in the containment vessel, as well as to the effects of high-temperature gas released from PAR unit.

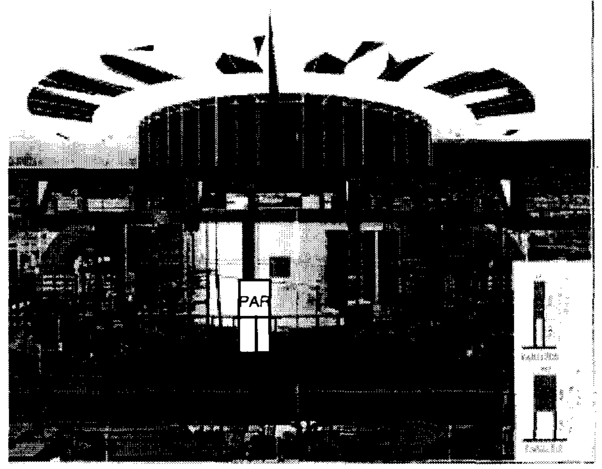

Fig.9 An Example of Arrangement in the ABWR Containment Vessel

Economical evaluation

PAR requires a smaller initial investment than the conventional FCS system. In addition, annual inspections cost less (see Table 2). Thus, PAR can be introduced in construction plants and also can replace conventional FCS units installed in existing plants.

Table 2 Cost Comparison Between PAR and the Conventional FCS

		Conventional	PAR	Remarks
Initial costs	Equipment	11.2	0.8	PAR11; 4 units
	Pipes and valves	4.5	0	
Testing system		0	0.1	For checking performance
Maintenance expense		2.8	0.1	In terms of initial cost
Total		18.5	1	

The total costs for PAR are given as 1.

CONCLUSIONS

- The performance of PAR under ABWR accident conditions has been judged, according to test results, to satisfy the Japanese licensing requirements.
- Although reaction inhibitors have a large effect, it is possible to set a reasonable number of PAR units and meet licensing requirements.
- By adopting PAR in a ABWR plant, economic efficiency and operability can be improved substantially in comparison with the conventional FCS unit.

REFERENCE

1)C.F.Weber, E.C.Beahm and T.S.Kress, “Iodine Chemical Forms in LWR Severe Accidents”, JAERI-M 92-012, p415(1992)

2)T. Fujii, K. Fujimoto, S. Yamanari and Y. Yoshinari, "A Thermal Analysis Model for Catalytic Hydrogen Recombiners in Containment Vessel of a BWR", Proceedings of the 7th Internatinal Conference on Nuclear Engineering, Tokyo, Japan, April 19-23, 1999.

3)M.Tahara, H.Oikawa, K.Arai, ”A Catalytic Recombiner Performance Analysis Considering Fluid Dynamics in a Containment” Second Japan-Korea Symposium on Nuclear Thermal Hydraulics and Safety, Fukuoka, Japan, October 15-18,2000