Introduction to Large-sized Test Facility for validating Containment Integrity under Severe Accidents

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1. Introduction

Containment integrity has become a more important issue of nuclear safety since the Fukushima Daiichi accident where a reactor building failed by a hydrogen explosion. The environment and humans are seriously affected by radioactive materials released from a damaged reactor building under a accident. To mitigate severe accidents, it is fairly significant to retain the integrity of the containment building.

An overall assessment of containment integrity can be conducted properly by examining the hydrogen behavior in the containment building. Under severe accidents, an amount of hydrogen gases can be generated by metal oxidation and corium-concrete interaction. Hydrogen behavior in the containment building strongly depends on complicated thermal hydraulic conditions with mixed gases and steam. If hydrogen is locally accumulated over a deflagration to detonation limit, the containment integrity can be threatened. Passive Auto-catalytic Recombiners (PARs) were developed and installed to consume hydrogen [1]. The performance of a PAR can be directly affected by the thermal hydraulic conditions, steam contents, gas mixture behavior and aerosol characteristics, as well as the operation of other engineering safety systems such as a spray.

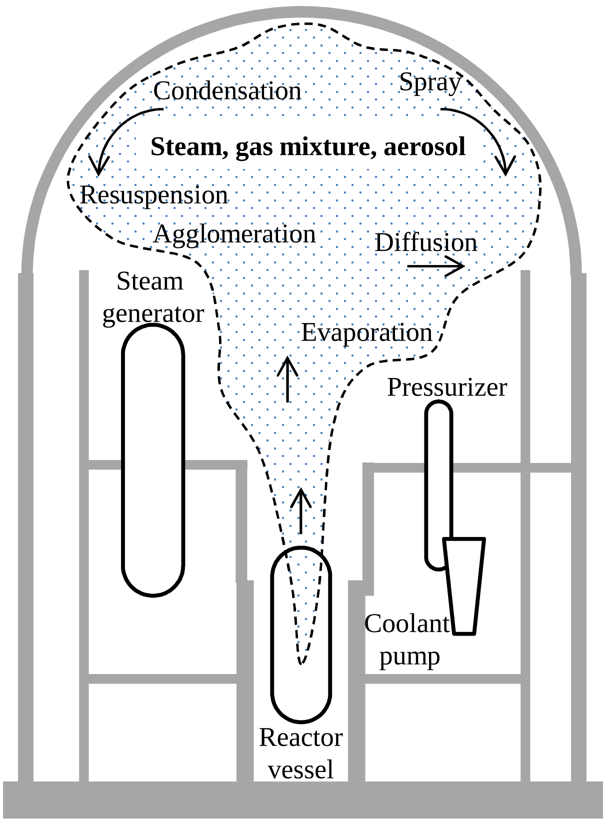

Fig. 1. Complicated phenomena in containment building under a severe accident

A large-sized test facility is required to simulate complicated behavior of gases, steam, and aerosol in the containment building under severe accidents (Fig. 1), because it is difficult to examine integrated physical phenomena of heat and mass transfer and chemical reaction in a laboratory scale test. In addition, the models in computer codes for a severe accident assessment can be validated based on the experiment results in a large-sized test facility. The Korea Atomic Energy Research Institute (KAERI) is now preparing a large-sized test facility to examine in detail the safety issues related with hydrogen including the performance of safety devices such as a PAR in various severe accident situations. This paper introduces the KAERI test facility (Fig. 2) for validating the containment integrity under severe accidents.

2. Test facility

The test facility for validating containment integrity consists of several systems as described below:

(1) Large-sized pressure vessel to simulate the containment building, and to install a structure and PAR within a vessel

(2) Control systems for temperature and pressure in a vessel

(3) Supply systems for steam, gases, and aerosol released into a vessel

(4) Measurement systems for gas concentration and aerosol characteristic

Design of the KAERI test facility was based on previous large-sized facilities to apply their advantages, and to overcome their limitations. Experiments on hydrogen and iodine are highly dangerous, and it is difficult to measure in real time individual gas concentrations of a mixture including steam.

2.1 THAI test facility

The THAI (Thermal-hydraulic, Hydrogen, Aerosol and Iodine) test facility operated by Becker Technologies GmbH in Germany from 2000 was chosen as a basic model, because its experimental safety and measurement reliability were officially confirmed in several national projects and international collaborative research projects [2].

A pressure vessel of THAI is 9.2 m in height and 3.2 m in diameter, and the total free volume is 60 m^3. The design pressure of a vessel is 1.4 MPa at 450 K, which is enough to withstand a typical hydrogen detonation. To control the atmosphere temperature in a pressure vessel, heat transfer fluid circulates through a double wall of the outer wall of a vessel. There are three separated double walls in the cylindrical part, and electrical resistance wires make contact on the top and bottom heads. Steam, aerosol, and gases such as hydrogen, oxygen, nitrogen and air are supplied through flanges installed at various elevations and orientations. The THAI test facility includes a gas analyzer system with an accuracy of 0.2 vol% for hydrogen.

2.2 KAERI test facility

A pressure vessel of the KAERI test facility is 9.5 m in height and 3.4 m in diameter, and the total free volume is 80 m^3. The aspect ratio of height to diameter is 2.8, which is similar with the THAI test facility and is adequate for scaling the containment building down to examine the gas behavior under a severe accident. A larger free volume compared with the THAI test facility can generously offer a wide range of scaling. The design pressure of a vessel is 1.5 MPa at 450 K, and six legs of a vessel support by maximum 130 tons, i.e., a vessel could be entirely filled with water as a scrubbing solution. From these specifications, a vessel can also be used to validate the performance of the Containment

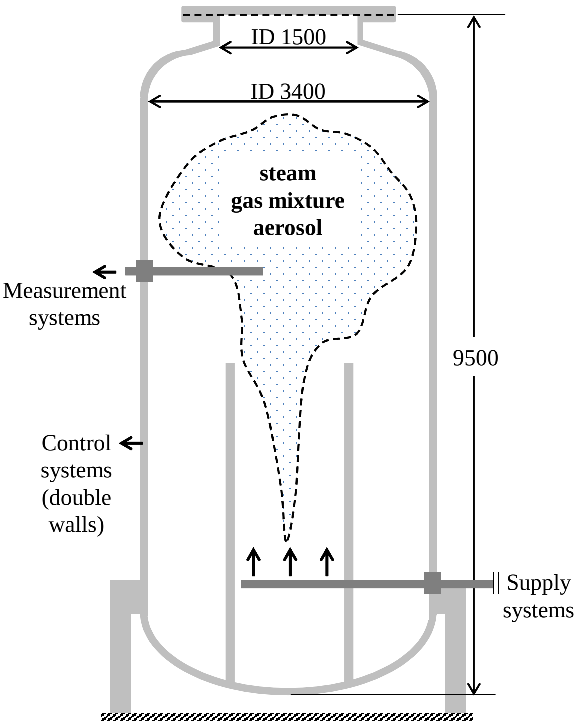

Fig. 2. Schematic of KAERI test facility

Filtered Venting System (CFVS) for containment integrity [3], where the CFVS consisting of nozzles submerged into scrubbing solution and filters in a pressure vessel mitigates overpressure in the containment building, and it decontaminates the fission products as well. A pressure vessel includes five separated double walls from a bottom head to a top head to independently control wall temperature in various elevations, and to reduce the heat loss from a vessel to the environment. 51 flanges with different sizes are installed on the wall in various elevations and orientations for supply systems of steam, gases and aerosol, and for measurement systems of gas distribution and aerosol characteristic.

Stainless steel 316L as a vessel material for a long operating time was chosen by considering the corrosion resistance. Experimental conditions under steam and fission products can corrode a vessel material. Stainless steel iron-based alloy is a good choice for this environment because it has a high corrosion resistance. Stainless steel is categorized by various types that are determined by the element composition such as chromium(Cr), nickel(Ni), molybdenum(Mo), titanium(Ti) and so on. Corrosion resistance of stainless steel strongly depends on these elements. Corrosion of stainless steel can occurred through a reaction of iron in steel with steam as a corrosive agent, where, chromium in steel reacts with oxide and then makes a chromium-oxide layer, called a passive film. This passive film on the surface of stainless steel prevents the corrosive agent from penetrating through stainless steel and reacting with iron. Therefore, stainless steel with a passive film on its surface has high corrosion resistance for chemicals in a general environment.

Table 1 Types of stainless steel

Types	Element composition (%)
304L	Cr(18), Ni(9), low carbon
321	Cr(18), Ni(9), Ti(0.3)
316L	Cr(18), Ni(12), Mo(2), low carbon

The main corrosion issues for a large-sized pressure vessel made by stainless steel under experimental conditions are as follows [4-5]:

(1) Intergranular corrosion: 51 flanges for the supply and measurement system should be welded on a vessel surface. A welding temperature of over 500℃ makes chromium in steel react with carbon in steel, i.e. $Cr_{23}C_6$ is generated and chromium in steel is depleted. A passive film made by remaining chromium in steel would be inadequate to protect from corrosive agents. This means the corrosion resistance becomes partially weak near the welding parts. A small corroded area induced by high welding temperature can be gradually expanded throughout a vessel. To prevent intergranular corrosion, molybdenum and titanium as element composition are added to stainless steel. They make a

uniform passive film near a high welding temperature. In table 1, the low carbon composition is good for high welding temperature because the amount of chromium reacting with carbon decreases, and the remaining chromium can make a passive film on a steel surface. Stainless steel 316L consisting of molybdenum and low carbon have a higher resistance on intergranular corrosion compared with 304L and 321.

(2) Corrosion induced by heat transfer fluids: To control the temperature in a pressure vessel, heat transfer oil flows through double walls of a vessel, where the temperature of oil will be managed by electric resistance heaters. Oil makes a thin film on a steel surface, which protects stainless steel from corrosion; however, a passive film on a steel surface would be melted by contact with oil for a long operating time. In the maintenance of the temperature control system, oil should be carefully exchanged without contacting air with a surface of the double wall.

(3) Corrosion induced by iodine: Iodine is the most hazardous fission product and affects the corrosion of stainless steel. Halogens gases such as iodine, bromine, chlorine and so on pass through a passive film on a steel surface, and react with iron, i.e., FeI_2 is generated. Although all types of stainless steel are corroded by iodine, the concentration of iodine will be too small to affect the corrosion of the overall pressure vessel. The regular cleaning of an inner vessel mitigates corrosion, and prolongs the operating life. Corrosion induced by iodine will also occur in a sampling pipe line to measure the concentration of gases because iodine easily deposits on a surface. Deposition of iodine makes high iodine concentrations in a steel sampling pipe, which affects the measurement accuracy. The maintenance of the sampling pipe lines and the calibration test for the gas concentration should be regularly checked.

A pressure vessel with the specifications mentioned above was made, and was installed at the KAERI site in March 2014. The constructions of the additional facilities and systems for operating the KAERI test facility are ongoing processes. The commissioning tests for controlling the thermal hydraulic conditions and gas concentration at the KAERI test facility will be conducted by this year.

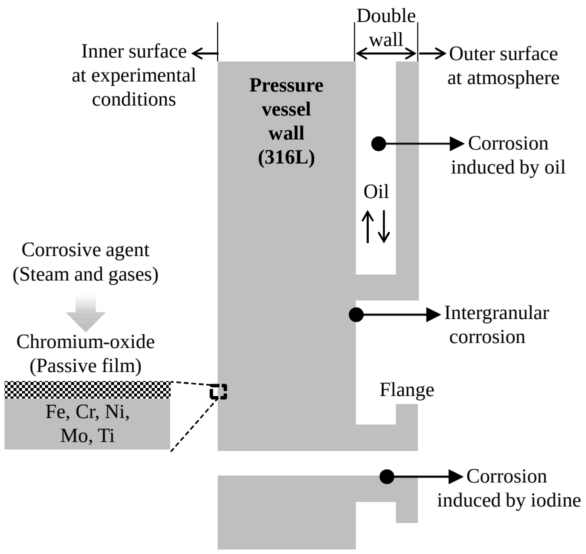

Fig. 3. Corrosion in large-sized pressure vessel

3. Conclusions

To validate the containment integrity, a large-sized test facility is necessary for simulating complicated phenomena induced by an amount of steam and gases, especially hydrogen released into the containment building under severe accidents.

A pressure vessel 9.5 m in height and 3.4 m in diameter was designed at the KAERI test facility for the validating containment integrity, which was based on the THAI test facility with the experimental safety and the reliable measurement systems certified for a long time. This large-sized pressure vessel operated in steam and iodine as a corrosive agent was made by stainless steel 316L because of corrosion resistance for a long operating time, and a vessel was installed in at KAERI in March 2014. In the future, the control systems for temperature and pressure in a vessel will be constructed, and the measurement system for hydrogen concentration in a gas mixture including steam will be installed to complete the KAERI test facility. The commissioning test of the thermal hydraulic conditions and gas distribution in a vessel will be conducted to confirm the experimental safety and reliable measurement systems by this year.

Hydrogen behavior and the performance of PAR in various thermal hydraulic conditions similar to severe accidents in the containment building will be carried out. Another application of the KAERI test facility is for validating the performance of the CFVS consisting of nozzles submerged into scrubbing water and filters in a pressure vessel. It is expected that the experimental data generated from the KAERI test facility will contribute to an enhancement of the containment integrity and to validate the models in a computer code for a severe accident.

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