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Accident Environment Assessment for the Development of a Flammability Risk Monitoring System

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1. Introduction

In the event of severe core damage, radioactive material may leak into the outside environment through cracks and breaks in the containment building. The dynamic and thermal loads generated by the combustion of flammable gases such as hydrogen and carbon monoxide can threaten the integrity of the containment building.

In March 2011, a hydrogen explosion occurred at the Fukushima accident, but there was no reliable measurement of hydrogen concentrations in the reactor building. In 2014, the OECD Nuclear Energy Agency (NEA) surveyed that most countries have established an instrumentation system that can measure hydrogen concentration by inhaling the atmosphere in the containment building. Previous hydrogen measurement systems installed in domestic plants have functional limitations in that they only sample the atmosphere inside the containment building at a few locations and provide a simple display of hydrogen concentration. In addition, carbon monoxide can extend the flammability limit of hydrogen, but there was no information on carbon monoxide concentration measurement.

The concentration of flammable gases is an important decision criterion for accident management. Even if other accident management strategies are being implemented, hydrogen control should be switched to when there is a combustion risk. The development of adequate countermeasures and accident management strategies to maintain the integrity of the containment building requires a flammability risk monitoring system.

2. Methods and Results

2.1 Research Project

From April 2022 to December 2026, we plan to develop a Flammability Risk Monitoring System for Severe Accidents as a technology for accident mitigation under a new task of the Development of Core Technologies to Improve Safety of Operating Nuclear Power Plants promoted by the Ministry of Science and ICT. This R&D project consists of the following tasks. (1) Develop a system to measure the concentration of combustible gases by sampling the atmosphere of the containment building, (2) Develop a hydrogen concentration evaluation model based on the operation of the Passive Autocatalytic Recombiner (PAR) using a non-sampling method, and (3) Develop an algorithm to

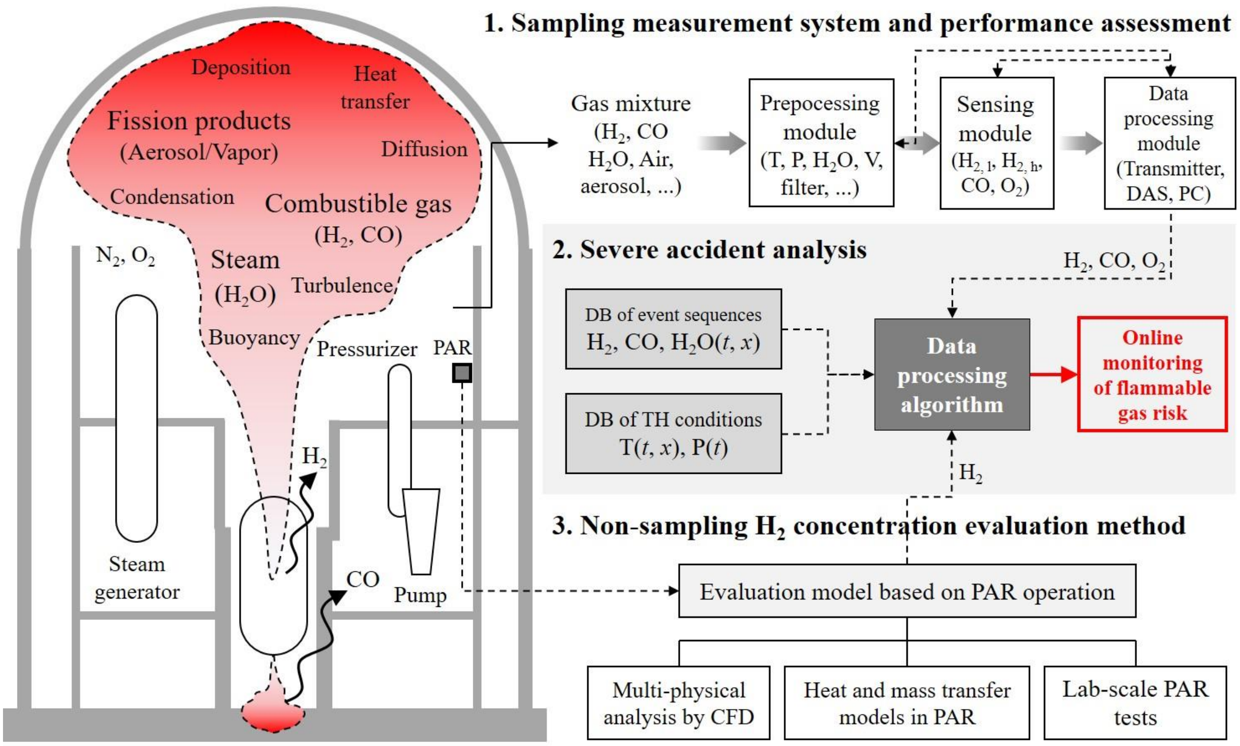

Fig. 1. Research project overview concept map

comprehensively analyze the measurement data, non-sampling hydrogen concentration evaluation model, and accident environment database, as shown in Fig. 1 [1].

While the sampling method can protect key components such as sensors and signal processors and ensure measurement reliability in accident environments, the risk of fission products leaking through the sampling piping limits the number of piping penetrates through the containment building. The non-sampling method will use temperature information from dozens of PARs to evaluate hydrogen concentrations that cannot be obtained at limited sampling locations.

2.2 Accident Environment Assessment

The accident environment such as pressure, temperature, gas compositions, and fission product concentrations influences the technical specifications of the measurement system that monitor the risk of combustible gases by inhaling the containment building atmosphere. The MELCOR code was used to calculate the sequence for a Small Break Loss of Coolant Accident (SBLOCA) in OPR1000. This study assumed a 2-inch break in a cold leg, and all safety systems were assumed to be inoperative except for the Safety Injection Tank (SIT). Steam, combustible gases, and fission products generated during a severe accident can be released into the containment building's upper atmosphere through a flow path and control volume. Inside the containment building, the free volume was divided into the reactor cavity, inner shell, outer annulus, and the dome area on top of the containment building.

During the progress of the accident, the atmospheric pressure was continuously increased by the steam released into the containment building atmosphere from the 2-inch rupture of a cold leg. In this study, the maximum atmospheric pressure in the upper part of the containment is set to 500 kPa based on the OPR1000 containment design pressure. When the pressure in the upper part of the containment building reached 500 kPa, the atmospheric temperature increased to 409 K. The saturation pressure of the steam at 409 K is 321 kPa, which is 64.2% of the atmospheric pressure. Under the atmospheric pressure and temperature ranges, the hydrogen concentration increased to 4.0 vol%. During the process of sampling the containment building atmosphere, the steam condenses, so the hydrogen concentration in the measurement system can be as high as 11.6 vol%. Under the same pressure and temperature conditions as that for hydrogen, the carbon monoxide concentration increased to 4.0 vol%. At this point, the steam, oxygen, and hydrogen concentrations are 65.6 vol.%, 5.5 vol.%, and 4.0 vol.%, respectively. As with the case of hydrogen, the concentration of carbon monoxide in the measurement system can be relatively high, up to 11.7 vol.%, when the steam is removed during the process of sampling.

The initial release of fission products from the cladding failure resulted in an increase in aerosol concentrations in the containment building atmosphere. The aerosol concentration in the upper part of the containment building was calculated by dividing the total mass of the radioactive aerosol by the volume of the control volume. The aerosol and vapor fission products concentrations increased up to 4.5 g/m^3 and 3.8 g/m^3, respectively. The mass median diameter of the dry aerosol size distribution presented from 1 to 5 μm.

2.3 Conceptual Design of Monitoring System

The monitoring system consists of a concentration sensing module for hydrogen, carbon monoxide, and oxygen, and a preprocessing module for accident environment sampling, and a data processing module. The intake piping allows fluid to be drawn from the atmosphere inside the containment building and vented back into the containment building.

The temperature and pressure of the gas being inhaled through the piping at a specific location inside the containment building during a severe accident, the sampling flow rate, aerosol-type fission products, and saturated vapors can affect the measurement uncertainty. To ensure the measurement reliability of the gas concentration sensors, a preprocessing module for accident environment sampling is required to control the temperature, pressure, and flow rate of the mixed gas sampled from the containment building, and to remove dust and moisture contained in the gas.

3. Conclusions

To derive the operating environment for the flammability risk monitoring system, the atmospheric temperature, pressure, concentrations of steam, combustible gases, and fission products were evaluated for the SBLOCA scenario in OPR1000 using MELCOR code. In the future, we plan to design the monitoring system that protects concentration sensors from accident environments and ensure measurement reliability when sampling the atmosphere in a containment building.

ACKNOWLEDGMENTS

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