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Introduction to Test Facility for Iodine Retention in Filtered Containment Venting System

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1. Introduction

The containment pressure can increase substantially and the containment may be threatened during the severe accidents because lots of steam, hydrogen, and non-condensable gases with the radioactive aerosols and gases are generated. A filtered containment venting systems (FCVS) is one of the strategies maintaining the containment pressure by releasing the high temperature and pressurized gas from inside the containment to the environment. During the releasing process, fission products are filtered simultaneously by FCVS to reduce the leakage of radioactive materials to the environment. So, in many countries the implementation of FCVS's is under discussion to mitigate fission product release not only in the short-term but also in the long-term view.

To verify the performance of FCVS, the large-scaled tests [1, 2, 3] have been performed such as advanced containment experiments (ACE), the iodine and aerosol retention rate test facility (JAVA), etc. The elemental and organic iodides are the main gaseous iodine species in the containment atmosphere. For the iodine retention, experimental programs have confirmed the existence of gaseous organic iodine in some cases in higher concentrations than for gaseous molecular iodine (I_2) [4]. The Reaction of Methyl iodide (CH_3I) with surfaces and the removal by containment filters and scrubbers is less efficient in comparison to molecular iodine. In the recent years, an experimental and analytical work has been conducted at the Paul Scherrer Institute (PSI) to develop a process leading to a fast, comprehensive and reliable retention of volatile iodine species in aqueous solutions [5, 6].

New FCVS test facility to verify the performance of FCVS is designed and under construction. The iodine retention tests are planned with elemental iodine or with organic iodide loaded carrier gas consisting of pure non-condensable gas, pure steam and of typical mixtures of non-condensable gas/steam. This paper introduces the iodine generation and measurement system for the iodine retention test of FCVS.

2. Experiment Apparatus

2.1 Capacity of test facility

The most of the FCVSs has a pool scrubbing chamber, droplet separator, and dry aerosol filtration system to eliminate the aerosol, and iodine. During the severe accident, if the pressure inside the containment is reached to specific opening value, the vent pipe will be opened by the operator or the operation of the rupture disk. Because of the high pressure inside the containment, the radioactive gas releases to the filtration tank through the vent pipe. In the first stage of FCVS, most of the radioactive aerosol and iodine are removed in the pool scrubbing process. However, there are still the radioactive gas passing the pool includes tiny aerosol and entrained water droplets. To eliminate the water droplet, several kinds of the droplet separators are applied. In next stage, the dry filtration system removes very tiny aerosols and droplets. The key components of the FCVSs are a pool scrubbing chamber, droplet separator, and dry aerosol filtration system [7].

Table I: Systems of FCVS test facility

Part	System	Main Equipment
Test Vessel	Performance Test Components	FCVS Pressure Vessel
		Scrubber Nozzle
		Droplet Separator
		Dry aerosol filter
Thermal-hydraulic	Gas Supply System	Steam Boiler Unit
		LN2 Storage Tank & LN2 Evaporator Unit
		Air Compressor Unit
		Air & N2 Heater
		Air & N2 Reservoir
		Steam Ejector
	Storage & Drain System	Suppression Tank
	Cooling System	Steam Condenser
		Circulation Pump
		Cooling Tower
		Strainer
Aerosol/Iodine Generation & Measurement	Aerosol/ Iodine generation & Measuring System	Aerosol/Iodine Injector
		Sampling Bottle
		Suction Chamber
		Suction Pump

The large-scaled performance tests have been performed such as ACE, JAVA, etc. New FCVS test facility is designed and under construction. The FCVS test facility consists of a test vessel, thermal-hydraulic, and aerosol/iodine generation and measurement parts as shown in Table I. The containment pressure can be reached up to 9 bar at severe accident without venting [9]. The target capacity of the FCVS test facility is summarized in Table II. The maximum operation pressure in front of the inlet nozzle is 10 bars and the temperature is 200 °C. The test section can be operated from ambient pressure up to 10 bars by a pressure control system. The steam generation capacity is up to 5000 kg/hr, in order to simulate the high stream mass fraction. Nitrogen and air can be supplied up to 1800kg/hr.

The fluid, gas and wall temperatures, the absolute, gauge and differential pressures along the test section and the flow rates at the inlet and outlet of the test section will be measured. The water level swell and the pH of the scrubber solution will be monitored online during the test by a special guided radar probe and a pH electrode device, respectively. The whole test section can be trace heated to compensate for heat losses, to prevent steam condensation and to reduce iodine losses at cold walls.

Table II: Capacity of the Test Facility

Parameter	Value
Maximum operating pressure	10 bar
Maximum operation temperature	200 °C
Steam generator capacity	5000 kg/hr
Nitrogen generator capacity	1800 kg/hr
Air supply capacity	1800 kg/hr

2.2 Test Plan

It will be performed the thermal hydraulic test without iodine feeding at the selected test conditions to use for detailed test planning. The iodine removal test will be performed in the high inlet pressure with high and low steam mass fraction using the steam/nitrogen to observe the non-condensable gas effect in decontamination factor (DF) of the test facility. In order to simulate the most severe case, the test will be performed at the maximum iodine concentration condition. The higher concentration is also required at the test section inlet in order to detect high DFs using the measurement techniques presented in the next section. The elemental and organic iodine tests will be performed separately due to the limitation of the measurement. All tests are planned lasting 4-5 hours to collect an appropriate number of I_2 and CH_3I samples at the inlet and especially at the outlet, respectively. During the test, the temperature of pool, the mixture level swell, the pressure, and the pH will be measured.

2.3 Iodine generation

Gaseous elemental iodine is easily generated by heating solid iodine crystal, but it will be needed another chamber or system to control the iodine generation rate. Gaseous molecular iodine will be generated by dissolving solid iodine crystal in a certain amount of ethanol. The solid iodine is easily melted in the ethanol. The chamber which has the liquid solution is pressurized to inject into the main flow in the inlet piping of the test facility. The liquid solution is fed by an electronic controlled dosing pump or gear pump to a two-fluid spray nozzle attached to a heated evaporation chamber where the solution is atomized by a pressurized hot nitrogen flow into extremely fine droplets. In the evaporation chamber, the liquid ethanol evaporates and gaseous elemental iodine is formed. The generated elemental iodine is injected into the main flow in the inlet piping of the test facility. The spray system can be operated at pressures up to 10bars and temperatures of 200°C.

The same two-fluid spraying system will be used to generate gaseous organic iodide, but the pure liquid CH_3I is used and is directly injected by the dosing pump or gear pump to a two-fluid spray nozzle. The generated organic iodine with pressurized hot nitrogen is injected into the main flow. Gaseous elemental iodine and organic iodine concentrations in the range of about 5 to 200 ppm may be reached but it is depending on the experimental conditions.

2.4 Iodine measurement

Due to the experimental environment, the radioactive iodine such as ^{131}I labeled iodine or methyl iodide won't be used in this facility. To measure the elemental and organic iodine concentration and to determine DF of the test facility, different measurements based on non-active samples will be. Gas samples are taken simultaneously from the inlet and outlet piping of the test section during the test. The gas sample flow rates can be controlled by mass flow controller easily. It also can be controlled by the calibrated critical orifices which are operated at critical flow conditions by controlling the downstream sampling pressure.

Elemental iodine will be sampled to liquid gas scrubber columns with a coolant jacket as shown in Fig. 1. The temperature of the operation gas can reach to near the saturation temperature, the coolant jacket is required. It will be analyzed by iodide ion selective electrodes (ISE). To use ISE, the scrubber water is doped with ascorbic acid to reduce I2 to I^- ions. Although this system can be used like on-line measurement with ISE, the data indicates the trend of the inlet and outlet concentration, it is not the precise result because ISE is very sensitive to temperature change. For the precise result, the calibration work should be performed for the ISEs before the test under well controlled conditions such as temperature, and samples are analyzed under same conditions. Two or three scrubber columns will be operated in parallel and in series during the test to get the multiple sample date. In addition, a spectrophotometer is going to be used to analyze the iodide concentration in same samples based on UV light absorption in order to increase data reliability.

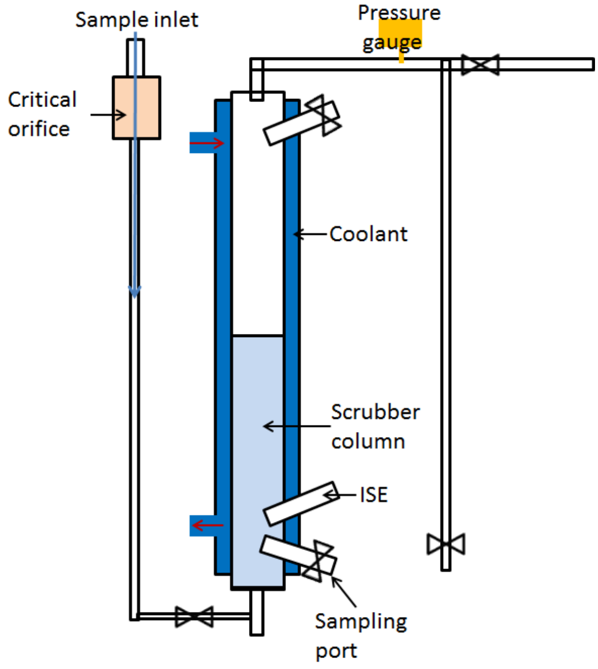

Figure 1. Elemental iodine sampling system

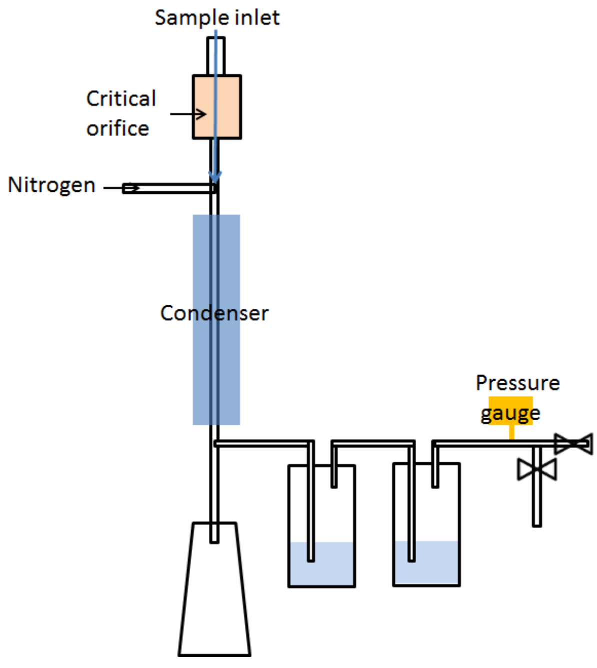

Figure 2. Organic iodine sampling system

Figure 2 shows the organic iodine sample system. The gas sample is mixed with nitrogen before going to the condenser where any steam present is condensed, because the residual gas with the contained CH_3I is needed after the condenser. It is into the two liquid gas scrubbers arranged in series and reacted with toluene. The condensed steam sample and the two samples from the toluene scrubbers are analyzed off-line using a gas chromatography/mass spectrometer (GC/MS). This method can detect low CH_3I concentrations. Organic iodine is characterized on-line measurement with UV photo ionization detectors (PID). PID is installed in special gas sampling trains because the maximum operating temperature of PID sensor is less than 50°C. The sample gas is mixed with nitrogen and directed to a condenser for cooling. The nitrogen is used to keep the partial pressure of CH_3I in the sample gas flow low enough to prevent the condensation of CH_3I at the given temperature. In addition, a continuous gas sample flow is directed from the inlet and outlet of the test section to a mass spectrometer.

3. Conclusions

In severe accidents elemental and organic iodides are the main gaseous iodine species in the containment atmosphere. Release of the gaseous species in sufficient quantities from containment to environment generates a risk for public health. The filtered containment venting systems (FCVS) can considerably reduce the leakage of radioactive materials to the environment.

New integral test facility is prepared to verify a performance of the FCVS. The test facility consists of a test vessel, thermal-hydraulic, and aerosol/iodine generation and measurement parts. For the iodine retention test, a thermal-hydraulic test, elemental iodine removal test, and organic iodine removal test will be performed. The elemental and organic iodine will be generated by the two-fluid spraying system, and the target concentration of iodine is in the range of about 5 to 200 ppm. The ISE and the spectrophotometer will be used to measure the elemental iodine, and both the PID and GC/MS will be used to measure the organic iodine.

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REFERENCES

[1] P. C. Pwczarski and K. W. Burk, PARC-90: A Code for Calculating Fission Product Capture in Suppression Pools, NUREG/CR-5765, Oct. 1991.
[2] M. E. Berzal, et al., State-of-the-art Review on Fission Products Aerosol Pool Scrubbing under Severe Accident Conditions, EUR Report 16241, 1995.
[3] Committee on the Safety of Nuclear Installations, Status-of-the-art Report on Nuclear Aerosols, NEA/CSNI/R(2009)5, Dec. 2009.
[4] B. Clément, N Hanniet-Girault, G Repetto, D Jacquemain, A.V Jones, M.P Kissane, and P von der Hardt., LWR severe accident simulation: synthesis of the results and interpretation of the first Phoebus FP experiment FPT0, Nuclear Engineering and Design, Vol. 226, p. 5-82, (2003).
[5] T. Lind, B. Jaeckel, and S. Güntay, A summary of the PSI Investigations on Iodine Chemistry in the Presence of

Impurities and Additives, OECD-NUGENIA/ SARNET workshop on "Progress in Iodine Behavior for NPP Accident Analysis and Management", Marseille, March 30 - April 1, (2015).

[6] D. Suckow, M. Furrer, J. Yang, B. Jäckel, and T. Lind, Investigation of iodine retention in a filtered system in the VEFITA test program, OECD-NUGENIA/ SARNET workshop on "Progress in Iodine Behavior for NPP Accident Analysis and Management", Marseille, March 30 - April 1, (2015).

[7] Committee on the Safety of Nuclear Installations, Status Report on Filtered Containment Venting, NEA/CSNI/R (2014)7, July 2014.

[8] OECD/NEA, Behavior of Iodine Project, NEA/CSNI/R(2011)11, January 2012.

[9] S.W. Lee, T. H. Hong, Y. J. Choi, M. R. Seo, and H. T. Kim, Containment Depressurization Capabilities of Filtered Venting System in 1000 MWe PWR with Large Dry Containment, Science and Technology of Nuclear Installations, Volume 2014 (2014).