Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Aerosol Retention Test in Water-Filled Tank for Bypass Accident Mitigation System

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1. Introduction

A containment bypass accident refers the accident in which fission products are released to the environment bypassing the containment barrier. The steam generator tube rupture (SGTR) with fuel damage is the representative containment bypass accident. In this accident, the fission products produced by fuel damage are transferred to the secondary side of the steam generator (SG), and then are released to the environment via main steam safety valves (MSSVs) or atmospheric dump valves (ADVs).

A system mitigating the radiological consequences by the SGTR bypass accident was suggested and the conceptual design was made. The system is composed of the piping connected from the 2nd side of SG to the water-filled tank for the depressurization and the decontamination of the fission-product laden steam. When the SGTR occurs with the fuel failure, the steam ejected from the broken SG tube is transferred into the mitigation system instead of the environment, and the fission product in the steam is contained in the tank and the containment.

In this article, the aerosol removal in the water-filled tank was investigated experimentally, to examine the performance of the bypass accident mitigation system. The scaled-down model of the suppression tank was built, and the aerosol removal tests were performed with the it. The results from the tests are utilized to validate the applicability of the system in the actual nuclear power plants.

2. Bypass Accident Mitigation System

Figure 1 shows the schematic of the containment bypass accident by SGTR. In the accident, the fission product generated from the damaged fuel is released to the primary coolant, and ejected to the 2nd side of SG through the broken tube. The 2nd side of SG is pressurized by the heat delivered by the tubes and the ejected steam through the break, and therefore the MSSVs or the ADVs are open to reduce the pressure. Because the MSSVs and the ADVs are connected to the environment directly, the fission product can be released to the environment penetrating the containment barrier. Those kind of bypass accidents are unlikely to occur, however, the accident results in a large release of fission product to the environment without the containment barrier. Therefore, researches were performed for these SGTR to examine the consequences by the accident [1-5].

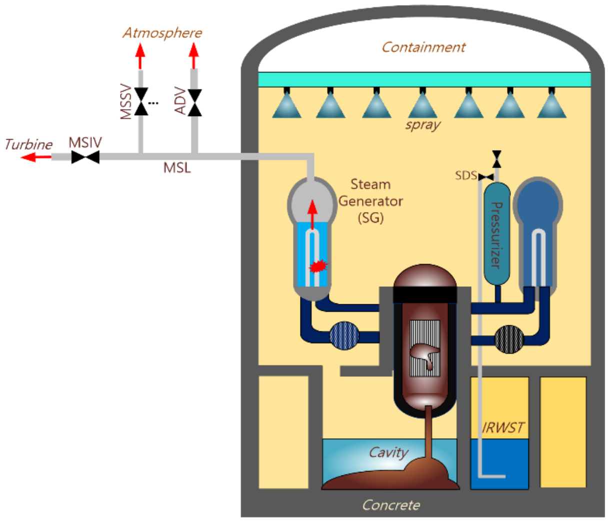


Fig. 1 Schematic of Bypass Accident by SGTR

Figure 2 shows the schematic of the mitigation system for the containment bypass accident. The system is composed of the piping connected from the SG or from the main steam line (MSL) and the water-filled suppression tank for the depressurization and the aerosol retention. When a SGTR occurs with the fuel damage, the valve (V1) is open and the primary coolant ejected from the broken SG tube is flows into the suppression tank. The suppression tank is designed sufficiently large that the water inside the tank can condense the entering steam by the accident.

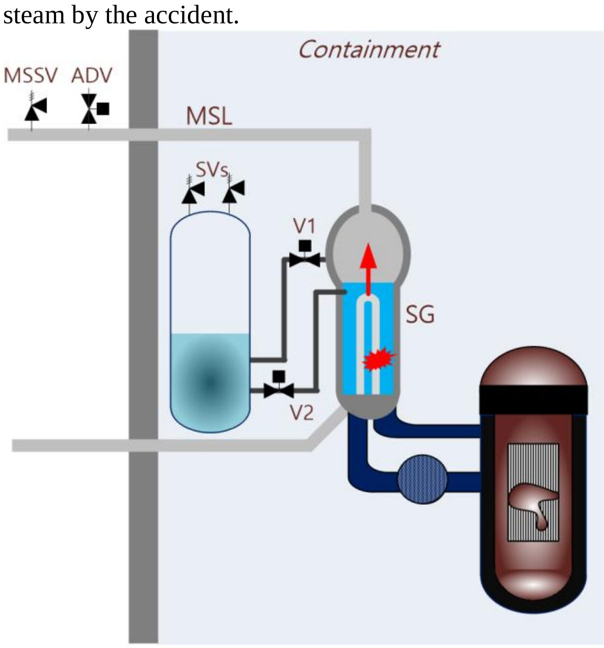


Fig. 2 Aerosol deposition on tube bundle (top) and deposited mass on single tube versus distance

The suppression tank has safety valves connected to the containment, and therefore the fission products in the primary coolant is ejected to the containment environment. Since the radioactive material is confined in the containment, small amount of the fission products are released to environment through the containment leakage. Therefore, the radiological consequences to the environment is minimized even in the SGTR with fuel damage.

3. Test Facility

Figure 3 shows the schematic of the suppression tank of the bypass accident mitigation system and the scaled-down test facility of it. The system was designed for the OPR1000 type plant, and the capacity of the tank was designed based on the calculation results of the consequential-SGTR (C-SGTR). The C-SGTR scenario started from the station black out (SBO) and the SG tube was broken by creep failure due to the hot steam circulating in the tubes. The tank was designed to be horizontal to be accommodated in the containment of the actual power plant, and the total 36 nozzles are installed in the bottom of the tank.

Figure 4 shows the test facility built to examine the aerosol removal capability in the tank. The test facility is the scaled-down model of the suppression tank, such that the length of the tank is reduced whereas the diameter is kept the same as the original. 4 nozzles were installed in the bottom of the test facility tank. The aerosol generation system was installed at the upstream of the facility to supply the aerosol-laden gas into the tank, and the aerosol sampling systems were installed at the inlet and at the outlet of the tank to sample the aerosols at each position. The aerosols were sampled under isokinetic condition and then the aerosol concentration were calculated using the aerosol mass accumulated on the filter and the sampled air volume during the sampling. Then, the decontamination factor (DF) was calculated by comparing the aerosol concentrations such that

$$DF = \frac{C_{in}}{C_{out}}$$

where C is the aerosol concentration.

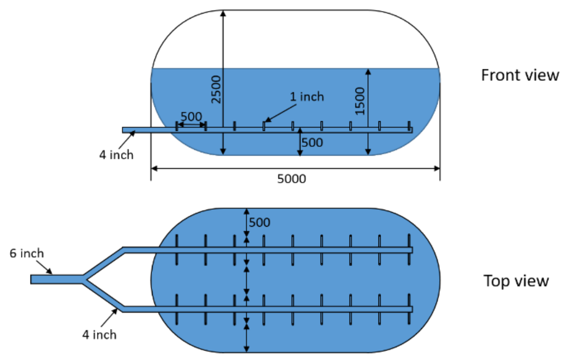


Fig. 3 Suppression tank of bypass accident mitigation system

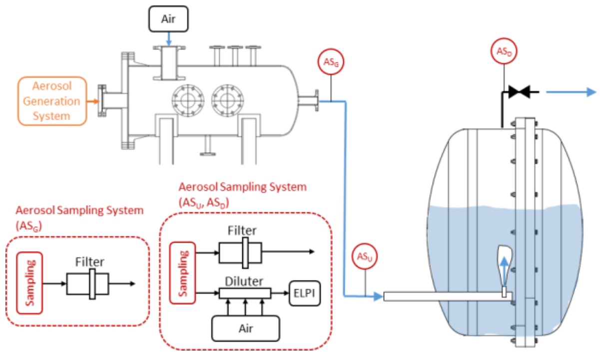


Fig. 4 Scaled-down test facility of the suppression tank

4. Test Conditions

Table 1 shows the conditions of the aerosol retention test using the facility. The working fluid was air to get a conservative results excluding the effect of steam condensation. The mass flow rate of 0.13 kg/s was determined from the average steam mass flow rate ejected through the broken tube from the calculation of C-SGTR scenario, and the high flow rate condition of 0.20 kg/s were also tested to check the effect of mass flow rate on the aerosol retention. The inlet gas temperature was set sufficiently higher than the saturation temperature at the upstream pressure of the tests, and the pool temperature was set between the room temperature and the saturation temperature in the tank. The pool pressure raised little higher than the atmospheric pressure, 2 bar, for ease of aerosol sampling.

Table 1 Test Condition

Variable	Value
Working fluid	Air
Mass flow rate (kg/s)	0.13, 0.20
Inlet gas temperature (°C)	~170
Pool pressure (bar abs)	2.0
Pool water temperature (°C)	60
Aerosol Particle	SiO_2 (AMMD 1 μm)
Nozzle type	Single circular, Multi-hole

Table 2 Test Matrix

Test No.	Mas flow rate (kg/s)	Submergence (m)	Nozzle
A-01	0.13	1.0	Simple Circular
A-02	0.13	0.5	
A-03	0.20	0.5	
A-04	0.13	-0.1(Dry)	
A-06	0.13	-0.1(Dry)	Multi - hole
A-07	0.13	0.5	
A-08	0.13	1.0	

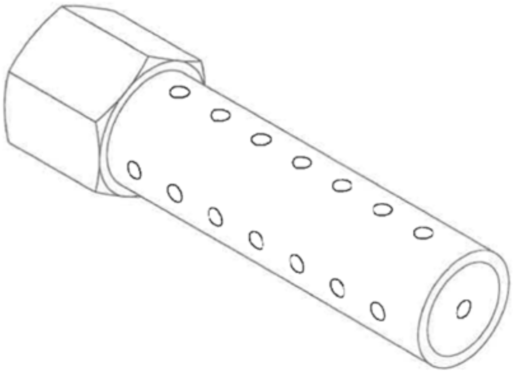


Fig. 5 Multi-hole nozzle used for tests.

Table 2 shows the test matrix with varying the conditions of mass flow rate, submergence, and the nozzle type. The submergence was varied from 0 (dry condition) to as high as 1.0 m from the nozzle exit. A simple circular pipe and a multi-hole nozzle was used for the test to compare the effect of end nozzle on the aerosol retention. Figure 5 shows the multi-hole nozzle having 29 holes used in the tests.

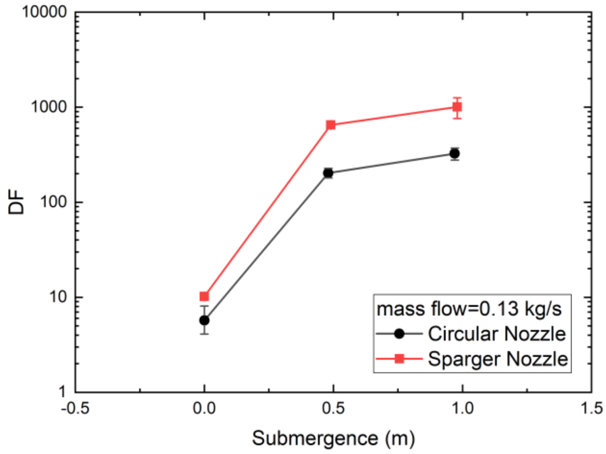
5. Results of Tests

Table 3 shows the summary of the test results, with the range of DF and the average DF of them. The range of the DF was from the sample-to-sample variation for each tests. Generally, the DF is higher with higher mass flow rate, with higher submergence, and with the multi-hole nozzle than the simple circular nozzle. The range of DF varies from about 5 in the dry tests, upto more than 1000 under some flooded tests.

Figure 6 shows the DFs versus the variables of the tests, the submergence and the mass flow rate. The DF increases as the submergence increases, because the more aerosols are removed as the residence time of rising bubbles increases. When comparing the circular nozzle and the sparger nozzle (multi-hole nozzle), the sparger nozzle shows higher DF because the total surface area of the jet ejected from the multiple hole is larger comparing to the single circular nozzle, enhancing the aerosol removal at the interface. The jet velocity ejected from the nozzle are set almost the same for both nozzles.

Table 3 Decontamination Factors of Tests

Test No.	Nozzle	DF	Avg. DF
A-01	Simple Circular	278~372	325
A-02		180~227	203
A-03		1469~1126	1297
A-04		4.1~8.4	5.7
A-06	Multi-hole	9.8~10.5	10.2
A-07		616~685	651
A-08		760~1254	1007



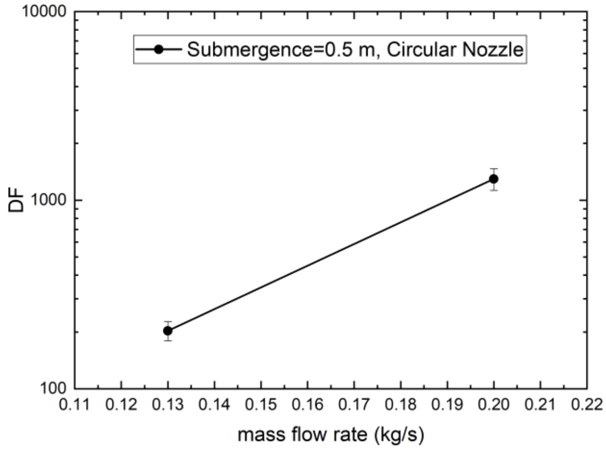


Fig. 6 DFs with respect to submergence (upper) and mass flow rate (lower)

The DF increases as the mass flow rate increases, because the impaction of the aerosol particle is enhanced at high mass flow condition.

Overall, the DF were sufficiently high, more than 100 under the flooded test conditions. The suppression tank of the bypass accident mitigation system is designed to be water-filled with submergence of 1.0 m, therefore more than 99% of the radioactive aerosols are expected to be removed in the tank. The remaining aerosols are ejected to the containment atmosphere, therefore the radiological consequences to the public will be minimized even with the bypass accident by SGTR.

6. Summary

The mitigation system for the containment bypass accident by SGTR was designed to reduce the radiological consequence to public. The conceptual design is composed of the piping and the suppression tank and is designed to be operated under the fuel-damaged SGTR condition. The operation of the mitigation system collects the fission-product laden steam ejected from the broken SG tube, and remove the radioactive aerosol in them.

The scaled down-model of the suppression tank was built as the test facility to validate the aerosol removal capability of the tank. The aerosol removal tests were conducted for the different mass flow rate, submergence, and nozzles. The test results show the increasing DF trends versus submergence and mass flow rate. Also, the DF was higher with the multi-hole nozzle than with the simple circular nozzle. The DF was more than hundreds under the submerged tests, therefore the mitigation system seems effective to remove the radioactive aerosol when a SGTR with fuel failure occurs.

Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (Ministry of Trade, Industry and Energy) (No.KETEP-20181510102400).

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