

Preliminary Test of Spatial Aerosol Removal for SMR Fission Product Mitigation System

Jae-hoon Jung^{a*}, and Jeongyun Oh^a

^aIntelligent Accident Mitigation Research Division, KAERI, Daeduk-daero 989-111, Daejeon, Korea

*Corresponding author: jhjung@kaeri.re.kr

1. Introduction

Small Modular Reactors (SMRs) and advanced reactors feature enhanced inherent and passive safety, resulting in very low probabilities of severe accidents[1]. Nevertheless, additional engineered measures can further reduce potential radioactive releases under beyond design basis conditions.

A radioactive material reduction system (RMRS) has been developed as a closed-loop, fan-driven filtration system. The system draws contaminated gas from the reactor protection building, removes droplets and aerosol particles through multi-stage filtration, and returns the treated gas to the building. Previous work established the system concept and verified HEPA-level aerosol filtration using metal-fiber media at the component scale [2–5]. The next requirement is system-scale verification because the effective removal rate in a large space is governed not only by intrinsic filter efficiency but also by transport, mixing, deposition, leakage, and sampling representativeness.

This study describes the construction and preliminary testing of an engineering-scale thermal-hydraulic and aerosol performance verification facility. The objectives are to confirm integrated operability, demonstrate the feasibility of aerosol generation and sampling, and obtain initial filter and space-removal data before systematic performance qualification under accident-relevant gas, temperature, and humidity conditions.

2. Experimental Facility

2.1 Experimental setup

The facility consists of a test vessel, gas supply and conditioning systems, an aerosol generation/mixing chamber, the RMRS test article, sampling lines, and an off-gas treatment system. Air, and steam can be supplied independently and conditioned before entering the vessel. Simulated aerosol is introduced upstream of the mixing chamber. The RMRS recirculates vessel gas through its filter train, while the off-gas line includes a heat exchanger and final filter.

The main vessel was fabricated from ASTM A240 Type 316L stainless steel with an internal diameter of 1.58 m, a height of 2.1 m, and an internal volume of 3.5 m³. Its design pressure and temperature are 9.9 kg/cm²G and 200 °C, respectively. Mineral-insulated heaters on the vessel and heating tapes on piping provide thermal conditioning. Vortex flowmeters measure vessel inlet and outlet flow, and a pneumatic globe valve controls the outlet area. Pressure and temperature are measured at the

RMRS inlet and outlet, and differential pressure is measured across the filter.

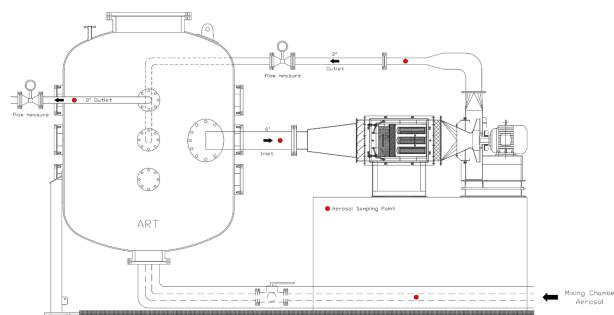


Figure 1. Test vessel, RMRS, and flow path

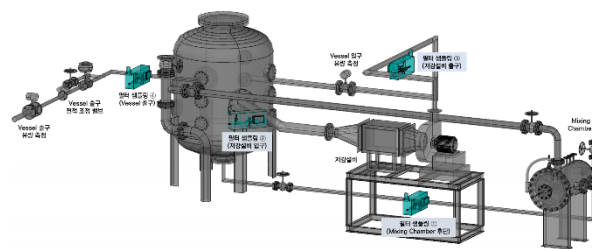


Figure 2. Aerosol sampling points.

Table 1. Main test-vessel specifications

Parameter	Specification
Material	ASTM A240-316L SS
Design pressure	9.9 kg/cm ² G
Design temperature	200 °C
Inner diameter / height	1.58 m / 2.1 m
Wall thickness / volume	10 mm / 3.5 m ³

2.2 Aerosol generation and sampling

SiO₂ was selected as a non-radioactive surrogate aerosol. The aerosol was injected into the mixing chamber and transported to the vessel before RMRS operation. Four filter-sampling locations were installed: downstream of the mixing chamber, at the RMRS inlet, at the RMRS outlet, and at the vessel outlet. This arrangement permits comparison of the supplied aerosol, filter inlet/outlet concentrations, and spatially averaged vessel response. The test duration was 1,800–2,400 s depending on the run.

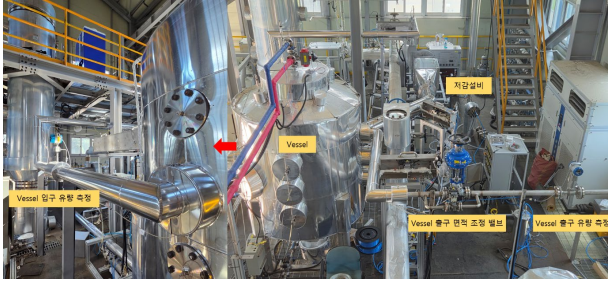


Figure 3. Constructed vessel, RMRS, flowmeters, and control valve.

3. Results and Discussion

3.1 Test method and data reduction

After establishing the prescribed gas flow, the aerosol was injected and mixed in the vessel. Filter samples were collected at the four locations during each test. The captured SiO_2 mass was determined from the sampled filters and converted to a mass concentration using the sampled gas volume. For the filter performance test, the RMRS decontamination factor was calculated from the inlet and outlet concentrations as “ $\text{DF} = C_{\text{in}} / C_{\text{out}}$,” where C_{in} and C_{out} are the aerosol mass concentrations measured upstream and downstream of the RMRS, respectively. Space-removal performance was evaluated separately using the fraction of injected aerosol discharged outside the test space, $f_{\text{out}} = m_{\text{out}}/m_{\text{in}}$. The external-release suppression performance was defined as $\eta_s = (1 - f_{\text{out}}) \times 100$. This system-level metric includes the integrated effects of RMRS circulation, mixing, transport, and deposition and is therefore distinct from the intrinsic filter DF.

3.2 Facility operability

The integrated tests confirmed operation of the air/steam supply, aerosol injection, vessel mixing, sampling, concentration measurement, and RMRS circulation functions. Flow could be measured at both vessel connections and adjusted with the outlet control valve. Differential-pressure and temperature measurements were available across the RMRS filter train. No functional limitation preventing aerosol removal tests was observed during the preliminary tests.

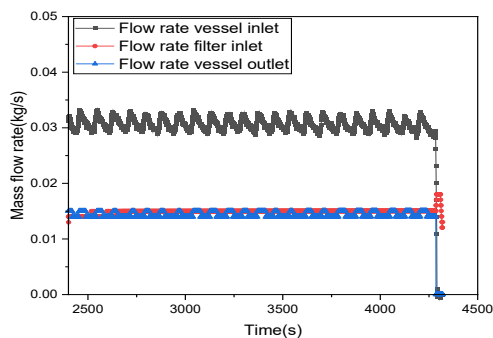


Figure 4. Flow rate test results

3.3 Preliminary aerosol removal results

A representative filter test conducted at 1 bar with a SiO_2 suspension, an injected SiO_2 mass of 0.002368 kg, and a test duration of 1,800 s produced filter inlet and outlet aerosol concentrations of 44.20 and 0.234 mg/kg, respectively. The resulting DF was 188.7, confirming the basic aerosol capture function of the RMRS filter train. Because this test was intended as a preliminary functional check, the DF is reported here descriptively rather than used as the principal system-scale performance indicator.

3.4 Discussion

The five preliminary space-removal tests produced removal efficiencies between 71 and 93%. The differences among cases reflect the integrated response of RMRS circulation, vessel mixing, transport, deposition, and sampling, rather than variation in filter efficiency. Accordingly, the results are used to demonstrate facility operability and the feasibility of the proposed evaluation method; a pathway-specific mass balance is required before formal performance qualification.

시험조건	Unit & 비교						
압력	bar	1	1	1	1	1	1
주입 유량 (TH)	kg/s	0.03	0.031	0.03	0.494	0.0532	0.029
저감설비 OUT 유량	kg/s	0.017	0.015	0.011	0.238	0.011753	0.0169
Vessel 출구 유량	kg/s	0.015	0.014	0.015	0.129	0.0102	0.01597
메인 유량	kg/s	0.03	0.031	0.03	0.494	0.0532	0.0532
Vessel 입구 필터 샘플링 유량	lpm	4.108	4.203542	3.997	4.310172	4.304692	6.739766
저감설비 입구 샘플링 유량	lpm	4.376	4.385747	4.1756	4.481249	4.489795	6.90352
저감설비 출구 샘플링 유량	lpm	4.854	4.793759	4.559467	4.85454	4.795602	8.036724
Vessel 출구 샘플링 유량	lpm	4.188	4.155974	3.954581	4.227818	4.247068	6.907152
샘플링 시간	s	1800	1800	1800	1800	1800	1800
Vessel 입구 농도	mg/kg	47.06264	27.52693	18.31477	9.472214	13.24197	33.94179
Vessel 출구 농도	mg/kg	26.72827	5.788498	8.246087	4.950599	3.011654	19.77129
DF, 필터 (입구/출구)		188.6955	16.54485	11.10473	7.502433	37.12816	11.3359
외부로 나간 MASS		0.000728	0.000195	0.000263	0.002136	8.49E-05	0.000611
외부로 나간 비율		0.286453	0.127183	0.266122	0.253566	0.066957	0.187854

Table 2. Test conditions and space-removal efficiencies for all preliminary cases.

Because the present engineering-scale facility does not reproduce the full volume and flow characteristics of an actual reactor protection building, further testing should be performed at a scale that can represent the intended application. Such tests should preserve the relevant ratios of space volume, RMRS circulation flow rate, ventilation or leakage flow, and aerosol loading so that the space-removal performance measured in the experiment can be extended to an actual-size system.

4. Conclusions

A 3.5 m³ engineering-scale facility was constructed for performance verification of an SMR fission-product mitigation system, and preliminary SiO_2 aerosol tests were completed. The integrated gas supply, aerosol generation and mixing, RMRS circulation, sampling, and measurement systems operated as intended. Under a representative filter test condition of 1 bar, the measured

filter DF was 188.7. Five space-removal cases yielded efficiencies of between 71 and 93%, demonstrating the feasibility of engineering-scale testing under different operating conditions. The constructed facility and preliminary data provide the basis for subsequent tests that represent the volume and flow characteristics of the intended application. Because the present facility is smaller than the intended plant application, subsequent full-scale testing is required to confirm scalability and performance under actual-size conditions.

ACKNOWLEDGMENTS

This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government (MCCEE) (No. RS-2023-00257695).

REFERENCES

- [1] S. G. Lim, H. S. Nam, D. H. Lee, and S. W. Lee, "Design characteristics of nuclear steam supply system and passive safety system for Innovative Small Modular Reactor (i-SMR)," *Nuclear Engineering and Technology*, Vol. 57, 103697, 2025.
- [2] OECD/NEA, Filtered Containment Venting System (FCVS)—Status Report, 2024.
- [3] IAEA, Severe Accident Management Programmes for Nuclear Power Plants, Safety Reports Series No. 32, Vienna, 2012.
- [4] W. Y. Jung, J. H. Kang, K. W. Jang, J. Jung, and K. Yoo, "Performance evaluation of aerosol filtration for HEPA-level metal fiber filter," *Transactions of the Korean Nuclear Society*, Oct. 2025.
- [5] J. Jung, W. Y. Jung, J. Oh, and K. Yoo, "Development of an analytical framework for source term mitigation system in a small modular reactor," *NET*, 58, 2026, 104401.