

Feasibility Test of Hydrodynamic-driven Salt Drain System for Cartridge-Type Molten Salt Reactor

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1. Introduction

Molten Salt Reactors (MSRs) are promising Generation IV concepts because of their high temperature, low-pressure operation and potential advantages associated with liquid fuel. Exchangeable cartridge-type concepts provide additional design flexibility by enabling periodic replacement of salt exposed components and integration of major reactor functions within a compact module.

For liquid-fueled MSRs, reliable relocation of the fuel salt from the active core to a drain region is an important safety function. Several liquid-fueled MSR concepts, including the Molten Salt Reactor Experiment (MSRE), used freeze-valves to isolate the primary system from drain tanks and initiate gravity-driven fuel-salt drainage on demand [1–3].

Freeze-valves must satisfy conflicting requirements, together with associated auxiliary systems. Its reliability should therefore be evaluated at the system level.

Previous studies have primarily addressed freeze valve geometry and phase-change behavior to improve its functional reliability. Alternatively, cartridge-type reactor concepts incorporating drainage mechanisms independent of freeze-valve actuation have also been proposed [4–5]. Such concepts avoid direct dependence on the freezing and thawing functions of a freeze valve. However, the hydraulic feasibility of the associated hydrodynamic-driven salt drain concept has not been sufficiently demonstrated.

This study investigates the hydrodynamic-driven salt drainage concept of cartridge-type MSR using the MARS-KS system code. The analysis evaluates gravity driven drainage following a pump trip as a preliminary hydraulic assessment for a cartridge-type MSR system.

2. Proposed System and Methodology

2.1 Configuration of Cartridge-type MSR with Hydrodynamic-driven Salt Drain Concept

The proposed system employs a hydrodynamic-driven drainage mechanism without a separate freeze-valve actuation process. The system adopts concentric geometry with an upper double-pipe section and a lower

triple-pipe section, as shown in Fig. 1. The upper section contains the core and annular circulation channel. The lower section contains the downcomer, annular channel, and drain region. Forced circulation maintains the core inventory and minimizes the liquid inventory in the drain region. After pump shutdown, the loss of pump-induced hydraulic head allows gravity-driven drainage.

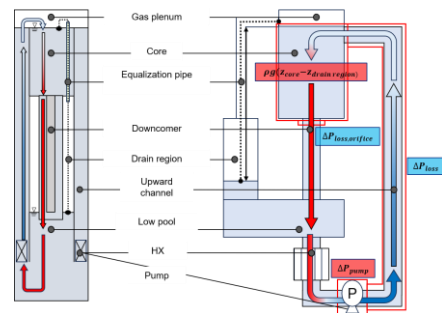


Fig. 1. Schematics of hydrodynamic-driven drain system for cartridge-type MSR

2.2 MARS-KS Nodalization

The system was modeled using MARS-KS V1.5, as shown in Fig. 2. Table 1 summarizes the main geometric parameters. The core–downcomer flow area was reduced to approximately 7% of the adjacent downcomer area to provide the hydraulic resistance required for core formation. A pump was applied to the circulation path.

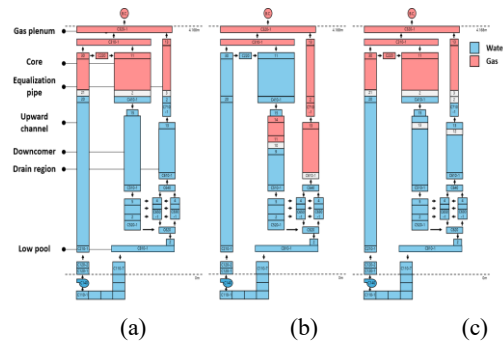


Fig. 2. Schematic nodalization of the demonstration facility depicted with (a) initial, (b) steady-state, and (c) post-drain

Table. 1. Summary of key design parameters of MARS-KS nodalization

Component	Area (m ²)	Height (m)	D _h (m)
Gas plenum	0.05	0.168	0.68
Upward channel	0.117	3.8	0.12
Core	0.209	1.14	0.52
Downcomer	0.0123	2.1	0.06
Drain region	0.181	1.82	0.32
Low pool	0.212	0.1	0.52
Equalization pipe	3.22e-3	1.248	0.032

The MARS-KS model also used water and air as working fluids. The initial condition contained 0.85 m³ of water, which corresponds to approximately 65% of the total volume. Air occupied the remaining volume. Both phases were initially stationary. The pump flow rate increased to approximately 1.13 m³/s over 180 s and remained constant until 2000 s. The pump velocity was then reduced to simulate a pump trip.

3. Results and Discussions

Fig. 3 shows the liquid levels during startup and steady-state operation. The core level increased with pump flow and reached the active-core height of 1.14 m at approximately 180 s. The level remained nearly constant until pump shutdown. The drain-region level decreased to nearly zero and remained gas-filled. These results show that the pump-induced hydraulic head redistributed the initial liquid inventory and established a stable operating core.

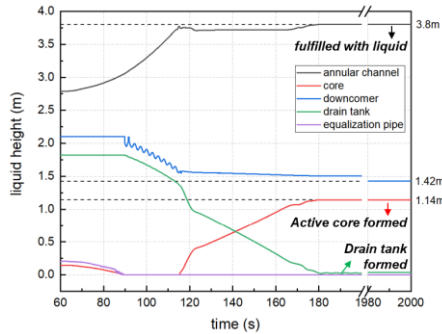


Fig. 3. Level variation during startup and steady state

Some gas remained in the upper core region at steady state, as shown in Fig. 2. (b). The strong area contraction at the core–downcomer connection is expected to produce high local velocities and complex gas–liquid interfacial behavior. The current nodalization may not adequately resolve these local phenomena. Experimental observations and modeling sensitivity studies are therefore required to assess this behavior.

After the pump trip at 2000 s, the core level decreased and the drain-region level increased, as shown in Fig. 4. Both liquid levels eventually approached their initial values. This result demonstrates gravity-driven

redistribution of the core inventory to the lower drain region.

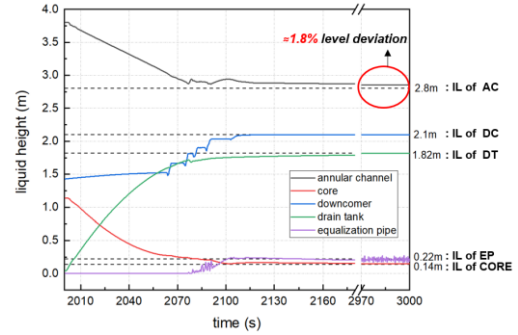


Fig. 4. Level variation during gravity driven drainage after pump trip

4. Conclusions

The hydrodynamic-driven drainage mechanism applied to a cartridge-type MSR configuration was preliminarily assessed using MARS-KS. The calculation demonstrates pump-driven core formation, stable steady state operation, and gravity drain without relying on a freeze-valve. The present results provide a preliminary feasibility assessment of the hydrodynamic-driven salt drainage concept. Based on these results, the experimental facility will be constructed to experimentally evaluate hydraulic behavior and further define the design conditions required for implementation of the proposed drainage concept.

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REFERENCES

- [1] R. H. Guymon, *MSRE Systems and Components Performance*, Oak Ridge National Laboratory, ORNL-TM-3039, 1973.
- [2] B. M. Chisholm, G. F. Flanagan, S. L. Krahn, and G. T. Mays, *A New Look at Licensing Basis Events for the Molten Salt Reactor Experiment*, Oak Ridge National Laboratory, ORNL/TM-2018/788, 2018.
- [3] B. M. Chisholm, S. L. Krahn, and A. G. Sowder, "A Unique Molten Salt Reactor Feature – The Freeze Valve System: Design, Operating Experience, and Reliability," *Nuclear Engineering and Design*, Vol. 368, 110803, 2020.
- [4] International Atomic Energy Agency, *Small Modular Reactor Technology Catalogue, 2024 Edition*, ARIS Supplement, IAEA, Vienna, 2024.
- [5] S. de Groot, A. Claisse, and Thorizon Technical Team, "THORIZON ONE: A Cartridge Core Molten Salt Reactor," International Conference on Fast Reactors and Related Fuel Cycles (FR26), Beijing, China, 2026.