

Development of Conceptual Design for the ATOM Safety System

Gwang Hyeok Seo^a, Minwook Na^a, Doyoung Shin^a, Hong Hyun Son^a,
Yonghee Kim^c, Jeong Ik Lee^c, Sung Joong Kim^{a, b*}

^a Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu,
Seoul 04763, Republic of Korea

^b Institute of Nano Science and Technology, Hanyang University, 222 Wangsimni-ro, Seongdong-gu,
Seoul 04763, Republic of Korea

^c Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology,
291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea

* Corresponding author: sungjkim@hanyang.ac.kr

1. Introduction

Recently, an effort to develop a further advanced SMR, called Autonomous Transportable On-demand reactor Module (ATOM), has been made by a new research team in Korea. It has been pursued that not only a naturally-safe and autonomous operation but also more flexible siting, which include where there is little cooling water, were set as a major development direction. In this study, following the previous study of the ATOM system [1], major design goals with its backgrounds and simple numerical simulation are discussed.

2. Motivations of a New SMR

There are several motivations and design goals for development of a new SMR, the ATOM system. First, autonomous load-following operation is pursued as an important design feature without managing control rods movement and boron concentration. A previous study from our research group reported that reactor power could follow the power demand in a soluble-boron-free (SBF) system [2]. They used a simple lumped PWR model, and with varying the power demand calculation results showed good feasibility of daily load-following operation. This concept was entitled ‘passive daily load-following operation (FDLPO)’. Figure 1 shows variation of power demand and following reactor power changes in 3-day PDLFO while the heat transfer capacity of a steam generator (Γ) changes without any active reactivity control.

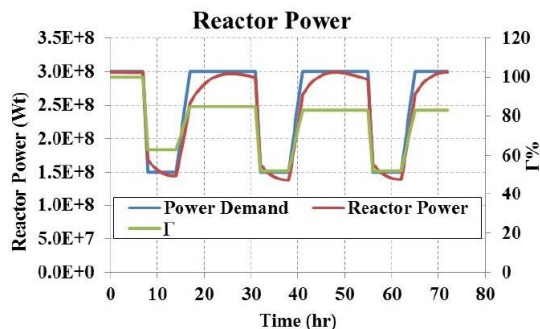


Fig. 1. Reactor and demand powers in the 3-day PDLFO [2].

Consequently, this implies that autonomous operation of a well-established SBF SMR could be achieved and eventually provide an advantage of electrical grid stability.

Moreover, other innovations in reactor systems is required to fulfil a SMR with the PDLFO mode. All the system design have to be examined and developed newly because the autonomous SMR does not demand any boron insertion to the primary system. To improve reactor safety even in various accident scenarios, development of the safety systems is essentially expected. Also, it should be noted that the research project consists of two phase. In the first phase, general PWR conditions are preferentially considered, and thus primary and secondary systems adopt water as a coolant. After developing a prototype system, the air-cooled SCO₂ power conversion cycle will be adopted in the second phase.

In the following section, a brief description of the ATOM safety system currently considered is discussed. In addition, for investigating feasibility of the safety systems, the MARS code, a thermal hydraulic safety code developed in KAERI (Korea), is employed to investigate ranges of the major design parameters of the safety systems.

3. Safety Systems of ATOM

At the first research phase, general PWR conditions are currently considered. Although major design parameters of ATOM are currently open, the target reactor power and primary system pressure were set to 300 MW_{th} and 15 MPa, respectively, to develop the autonomous small PWR system. Table 1 summaries target design parameters of the ATOM primary system.

Table 1: Target Design Parameters of the ATOM System

	Value
Thermal power (MW _{th})	300
System pressure (MPa)	15
Core inlet temperature (K)	564
Core outlet temperature (K)	585
Fuel temperature (K)	900
Fuel material	UO ₂

3.1 Description of ATOM Safety System

The ATOM system pursues passive safety systems and indefinite grace time during an accident. Figure 2 shows an overall view of ATOM system, and passive residual heat removal system (PRHRS), passive containment cooling system (PCCS), and dry/wet cooling system (DWCS) as an ultimate heat sink with an air cooling process are suggested. In the previous study, conceptual features and its directions were briefly discussed [1].

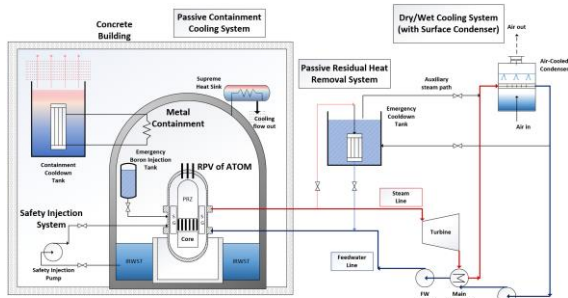


Fig. 2. Schematic of the overall ATOM system.

Currently, we consider a concept of an air cooling tower as the containment system for passive heat removal in PRV and metal containment cooling processes. Figure 3 shows that the ATOM and metal containment is placed below the ground level, and the natural draft cooling tower is built surrounding the metal containment.

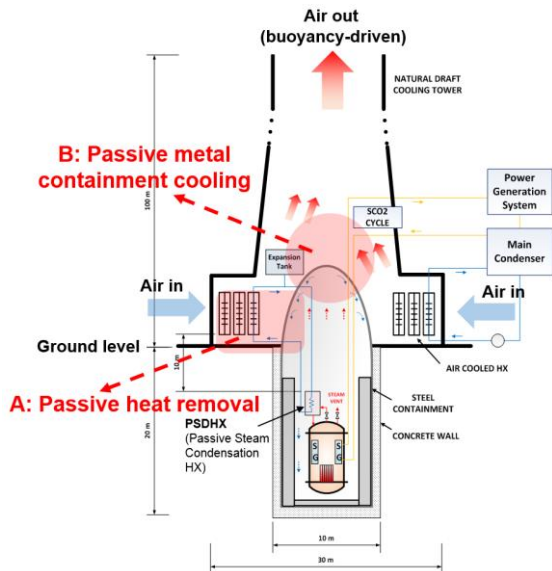


Fig. 3. Schematic of the ATOM system with the cooling tower for the air flow and heat removal process.

During an accident, cold air flows to the inside of the cooling tower, and heated air escapes from the top of the tower. Since the air flow is driven by buoyancy force, passive natural circulation is expected and indefinite grace time could be achieved by the heat

removal process, especially during a SBO accident. As shown in Fig. 3, shows the passive heat removal process (Process A in Fig. 3) with the heat exchangers installed in the tower. Hot steam is condensed by the heat exchanger connected to RPV inside the metal containment, and the heat exchanger in the cooling tower removes the transferred heat. Moreover, the passive containment cooling process (Process B in Fig. 3) can be achieved by cooling the metal containment surface as shown in Fig. 3. The hot steam generated inside the metal containment is condensed at the upper region of the containment by the air flow in the tower. Consequently, introduction of the natural draft cooling tower is expected to assist the safety systems of PRHRS and PCCS, and it could eventually provide the indefinite or further enhanced grace time during an accident.

3.2 Investigation of Design Parameter Ranges

It is an essential process to assess feasibility of suggested safety systems. For a quantitative assessment, ranges of the major design parameters of the safety systems are needed to determine with the MARS code. Since natural circulation is expected to occur in several systems proposed, as a starting step a simple input model was developed with a closed primary loop and a secondary pipe system. Figure 4 shows a schematic of the input model for the natural circulation. In the primary loop, lower heating core and upper heat exchange parts are connected with a pressurizer. The heat exchange volumes is thermally linked to the secondary system.

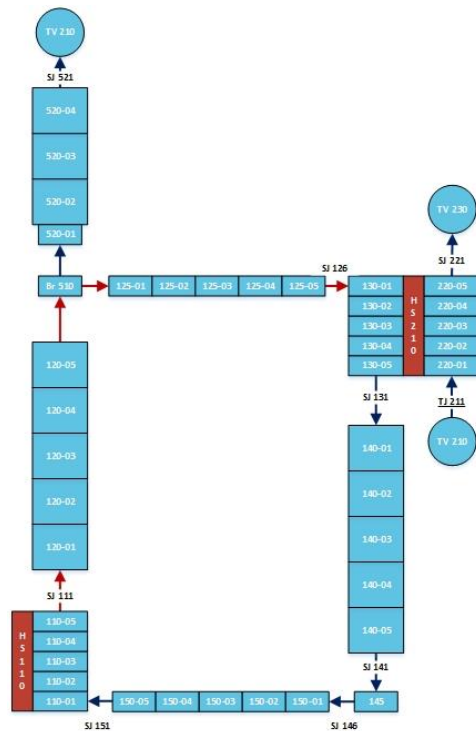


Fig. 4. MARS model of natural circulation loop for ATOM.

In order to investigate ranges of the design parameters, mass flow rate of the natural circulation loop was evaluated. First, for validity of the input model, a simple comparison was carried out with code and theoretical calculations. Since the primary system is a closed loop for natural circulation, a summation of friction and form losses for pressure drop can be expressed by Eqs. (1 – 3) [3]. Note that, in this stage, a single-phase flow condition was applied in the code simulation.

$$\sum \left(f_i \frac{L_i}{D_{e,i}} + K_i \right) \frac{\dot{m}^2}{2\rho_i A_i^2} = (\rho_C - \rho_H) g L_{TC} \quad (1)$$

$$K_{SC} = 0.42(1 - d^2 / D^2) \quad (2)$$

$$K_{SE} = \left[1 - (d / D)^2 \right]^2 \quad (3)$$

Where, \dot{m} and L_{TC} are mass flow rate and the length of thermal center between the lower heating core and upper heat exchanger parts, respectively. Sudden contraction (K_{SC}) occurred at the outlets of the lower heating core and the upper heat exchanger parts, and sudden expansion (K_{SE}) was expected at both of the inlets parts. The code result with L_{TC} of 6.5 m shows a good agreement with the analytical calculation, as shown in Fig. (5).

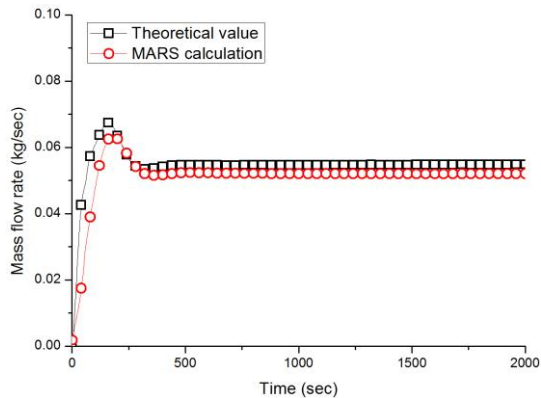


Fig. 5. Mass flow rates of the theoretical and MARS calculations.

Figure 6 shows a variation of mass flow rates with changing L_{TC} . As described in Eq. (1), the mass flow rate of natural circulation in the primary loop is proportional to the length of thermal center L_{TC} . The applied power at the lower heating part was 5 kW, and L_{TC} was changed from 4.5 m to 6.5 m. The code results show that the mass flow rates increase slightly with L_{TC} .

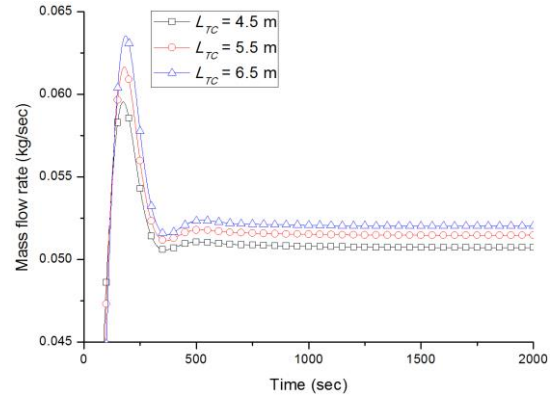


Fig. 6. Variation of mass flow rates with changing L_{TC} .

4. Concluding Remarks

In this study, conceptual design of the ATOM safety system was discussed. The passive heat removal processes were expected in the PRV and metal containment during an accident. Moreover, the MARS code was employed for quantitative assessment and ranges of design parameters. At the current stage, a simple comparison work was carried out with the natural circulation loop. The calculation results showed that the mass flow rate increases slightly with L_{TC} . In the next step, more extensive simulations are essentially required for feasibility assessment of the safety system. The MARS simulations will investigate not only the natural circulation but also boiling and condensation to capture significant phenomena and the design parameters.

Acknowledgement

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REFERENCES

- [1] G. H. Seo, D. Shin, H. H. Son, S. J. Kim, Preliminary Study of Conceptual Design of the ATOM Safety System, Transactions of the Korean Nuclear Society (KNS) Spring Meeting, May 18 – 19, Jeju, Korea, 2017.
- [2] A. A. E. Abdelhameed, H. ur Rehman, Y. Kim, Y., A Physics Study for Passively-Autonomous Daily Load-Follow Operation in Soluble-Boron-Free SMR, Proceedings of the International Congress on Advances in Nuclear Power Plants 2017 (ICAPP 2017), April 24 – 28, Fukui and Kyoto, Japan, 2017.
- [3] F. M. White, Fluid Mechanics, 7th ed., McGraw-Hill, New York, NY, USA, 2011.