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Preliminary Study of Conceptual Design of the ATOM Safety System

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1. Introduction

The Small Modular Reactor (SMR) has received attention over the world for potential advantages, such as outstanding flexibility for siting, lower capital investment, or advanced safety [1]. Recently, a new research project has begun in Korea for the conceptual development of a further advanced SMR that pursues a naturally-safe and autonomous operation called Autonomous Transportable On-demand reactor Module (ATOM). Major design goals of the ATOM system are focused on the boron-free primary coolant system that enables the automatic load follow operation. For the secondary system, the air-cooled SCO_2 power conversion cycle is considered [2], and the air-cooled condensate system is selected as an ultimate heat sink. This air cooling system is expected to well response to extreme environmental conditions, such as a desert where a lack of cooling water is certainly expected. Moreover, indefinite grace time for accident mitigation is considered with advanced safety systems. In this study, features of the conceptual ATOM safety system are preliminarily discussed as a first step.

2. Literature Reports of Safety Systems of SMRs

Nuclear power plants including SMRs employ various safety systems to prevent any damages to the reactor system during postulated accidents and to reduce any consequences to the public and environments as much as possible. Although there are many different types of reactors and safety systems, four groups of the systems can be considered: the reactor trip system, residual heat removal system (RHRS), safety injection (SI) system, and containment system [3]. For the development of ATOM, safety designs of several SMRs currently developed over the world is discussed in the following.

mPower (Babcock & Wilcox, USA) has an electrical output of 180 MWe for each module, and two modules are designed to deploy [4]. The mPower design implements in-vessel control rod drive mechanism (CRDM) as the trip system. The passive containment cooling system (PCCS) is considered with a large volume metal containment cooled by water or air spray. The in-vessel corium retention strategy is also adopted for a severe accident mitigation measure. Under the station blackout (SBO), 72 hr grace time for the accident mitigation is expected with DC batteries [5]. The Westinghouse SMR (Westinghouse, USA) with an electrical power of 225 MWe utilizes improved components of the AP1000 (Westinghouse) [4]. The in-vessel CRDM and emergency boron injection system are adopted as the trip system. The SI system is passively driven by gravity, and the metal containment is usually submerged in a water pool for the purpose of passive cooling. DC batteries can allow 72 hr grace time for the accident during SBO [5]. NuScale (NuScale Power, USA) has an electrical output of 45 MWe for each module, and up to 12 modules are designed to deploy [1]. Different from other SMRs, NuScale pursues entire passive safety system with no electrical driven pump. The inside of the metal containment is in a vacuum, and the outside is submerged in a water pool for passive cooling. The NuScale design implements decay heat removal system (DHRS) and a passive condenser in the water pool for the residual heat removal. The passive SI is activated with an open of the recirculation valve. The in-vessel corium retention strategy is also adopted to mitigate a severe accident. Furthermore, a long term grace time of 30 days is a noticeable design feature of NuScale including 3days water cooling. Even, the indefinite grace time could be achievable with proper air cooling available [1, 5]. As similar to the mPower design, SMART (KAERI, South Korea) with an electrical capacity of 100 MWe adopts the boron injection system for the reactor trip and the passive residual heat removal system (PRHRS) for the emergency core cooling [4]. The concrete containment with the spray system is used. As similar to mPower and NuScale, the bottom part of the reactor vessel is passively cooled by the in-vessel retention strategy.

Moreover, different from the SMRs mentioned, SmAHTR is a kind of fluoride-salt-cooled high-temperature reactor (FHR) with an electrical power of 125 MWt [6]. To remove the core decay heat, SmAHTR is designed to adopt natural draft air coolers as an ultimate heat sink. Since the ATOM system employs an air cooling system for an ultimate heat sink, this approach indicates noticeable information.

As discussed, the SMRs pursue an improved level of safety and reliability, especially adopting passive features as compared to current commercial reactors. Thus, the suggested safety systems are carefully considered in development of the ATOM safety system.

3. Conceptual Development of the ATOM System

3.1 Design Features of the ATOM System

To enhance the passive features, the passive RHRS and PCCS are mainly dealt with. Figure 1 shows schematic view of overall ATOM system including PRHRS, PCCS, and the ultimate heat sink part in the air cooling system. The reactor pressure vessel (RPV) of ATOM and emergency injection system are covered by the metal containment that is involved by the outer concrete building.

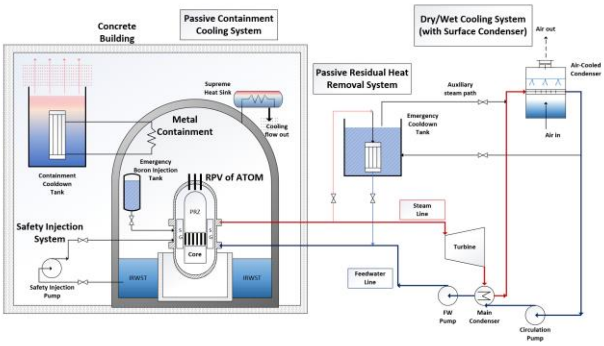

Fig. 1. Schematic of the overall ATOM system

As mentioned, ATOM employs PRHRS for the emergency core cooling with the emergency cooldown tank (ECT) connecting to the primary or secondary system. Figure 2 describes the ATOM PRHRS. The hot steam generated in the RPV is condensed through the heat exchanger submerged in the ECT, and the condensed coolant flows to the secondary side.

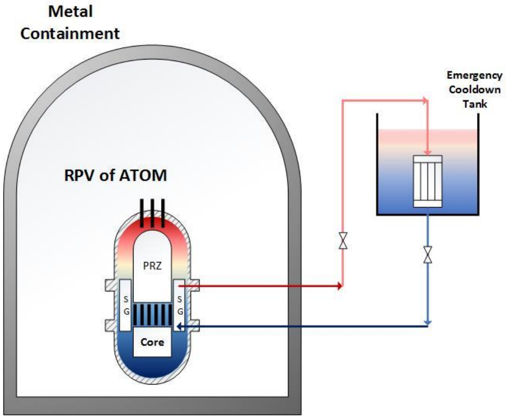

Fig. 2. Schematic of the ATOM PRHRS

The dry/wet cooling system (DWCS) of ATOM with the air-cooled condenser works as an auxiliary system that augments working time of the passive safety system and grace time for the operators. Figure 3 shows the DWCS of ATOM. The heat from the PRHRS is transferred to the ultimate heat sink or DWCS, and finally the generated heat is removed.

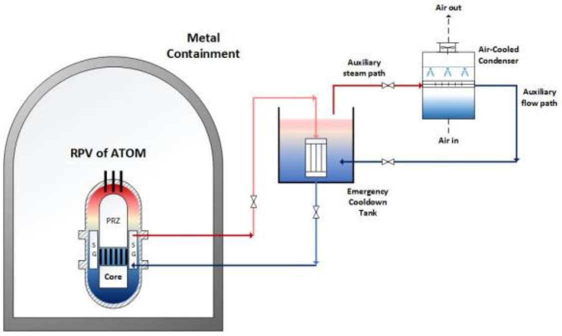

Fig. 3. Schematic of the ATOM DWCS

The heat transfer at the metal containment surface is facilitated by the containment cooldown tank (CCT) and supreme heat sink for the PCCS. Figure 4 shows the PCCS of ATOM and concrete building structure. The generated heat can be removed through mainly two paths: one with the CCT and the other at the metal containment surface. An auxiliary component of supreme heat sink is also utilized to improve the heat removal at the surface. As the heat transferred from containment increases, an auxiliary boron safety could be activated to mitigate the pressure inside the supreme heat sink developed. This could eventually improve the grace time for the operators.

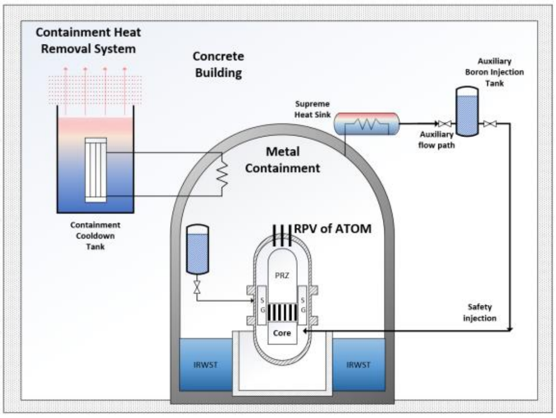

Fig. 4. Schematic of the ATOM PCCS

Note that, since the in-vessel CRDM is adopted as a main trip system at the initial stage of the project, the trip system is not mainly considered at the current study.

3.2 Modeling of ATOM System using the MARS Code

The feasibility assessment of the ATOM safety system is carried out using the MARS code, the 1D system analysis code. Since the design parameters and system components are currently open, a quantitative assessment can be achieved with the code calculation. At the current stage, a simple calculation with the primary and secondary system of ATOM for the steady state is presented in Figs. 5 and 6. The coolant temperatures before and after the reactor core are evaluated as 540 K and 580 K, respectively, as shown in Figure 5(a). Thus, the temperature difference for the steady state is ~40 K. Figure 5(b) shows that the feed water temperature is 457 K at the steam generator (SG) inlet, and the steam temperature is 547 K at the SG outlet. Moreover, the steady state result indicates that the generated heat of ~264 MWt is transferred through SG as shown in Fig. 6.

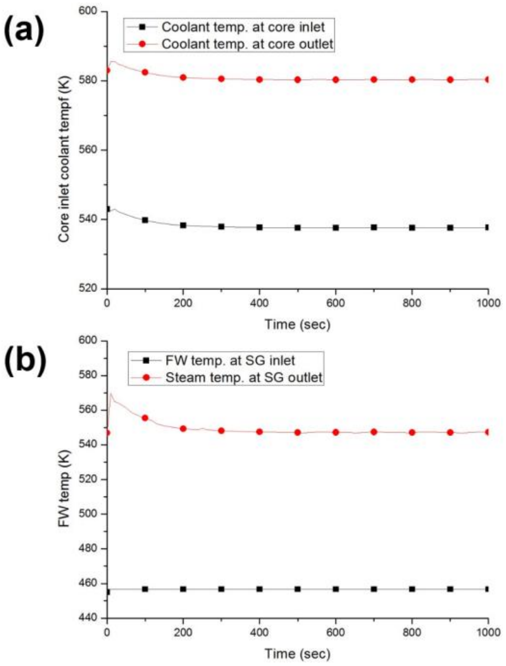

Fig. 5. Coolant and steam temperatures: (a) Coolant temperatures at the core inlet and outlet (b) Feed water and steam temperatures at SG inlet and outlet

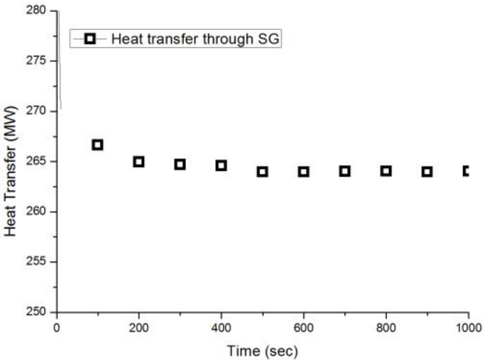

Fig. 6. The amount of heat transfer through SG

Furthermore, this preliminary calculation indicates a simple case of steady state of ATOM. For the feasibility assessment of the reactor system, further evaluations are needed with various ranges of design parameters, especially under various accident scenario.

4. Concluding Remarks

In this study, the conceptual development of ATOM safety system was preliminarily discussed. To design and select the safety system, the design features of currently developed SMRs were reviewed. Major outcomes of this study are summarized as follows:

(1) Most SMRs employ passive safety systems to enhance the safety and reliability. The NuScale design adopts entire passive features, but the reactor power is limited relatively lower. In This regard, one of major design goals of the ATOM system is to set the optimum passive systems.

(2) Several safety systems are currently considered for ATOM including PRHRS, PCCS, and DWCS. The air cooling part as the ultimate heat sink in DWCS is important because it eventually could response to extreme regions lacking enough cooling water.

(3) At the current stage, the MARS modeling is prepared for the steady state calculations. For further study, in order to assess the feasibility of the suggested safety systems and cycle analysis, quantitative evaluations are essentially required, especially including accident scenarios.

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REFERENCES

[1] D. T. Ingersoll, Z. J. Houghton, R. Bromm, and C. Desportes, NuScale small modular reactor for Co-generation of electricity and water, Desalination, Vol. 340, pp. 84-93, 2014.

[2] J. Lee, J. I. Lee, H. J. Yoon, and J. E. Cha, Supercritical carbon dioxide turbomachinery design for water-cooled small modular reactor application. Nuclear Engineering and Design, Vol. 270, pp. 76-89, 2014.

[3] International Atomic Energy Agency, “Design Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident”, Report No. IAEA-TECDOC-1785, International Atomic Energy Agency (IAEA), Vienna, Austria, 2016.

[4] International Atomic Energy Agency, “Advances in Small Modular Reactor Technology Developments, A Supplement to: IAEA Advanced Reactors Information System (ARIS)”, International Atomic Energy Agency (IAEA), Vienna, Austria, 2014.

[5] Z. Liu and J. Fan, Technology readiness assessment of small modular reactor (SMR) designs, Progress in Nuclear Energy, Vol. 70, pp. 20-28, 2014.

[6] S. R. Greene et al., “Pre-Conceptual Design of a Fluoride-Salt-Cooled Small Modular Advanced High-Temperature Reactor (SmAHTR)”, Report No. ORNL/TM-2010/199, Oak Ridge National Laboratory, Oak Ridge, TN, USA, 2010.