Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Preliminary Concept Development for Malfunction-Prevention Valve in ECCS

Jong Hui Lee [a*], Seek Kim [a]
[a]*Korea Atomic Energy Research Institute, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057*

[*]*Corresponding author: jonghuilee@kaeri.re.kr*

Keywords : malfunction prevention, ECCS, small modular reactor, steel containment vessel

1. Introduction

Small modular reactors (SMRs) are increasingly regarded as promising energy systems that can operate in harmony with renewable resources such as solar, wind, or hydro power. Their potential to replace conventional fossil-fueled plants has drawn significant attention in the context of the global climate crisis [1, 2].

A notable milestone was reached in 2012, when the Korea Atomic Energy Research Institute (KAERI) developed the System-integrated Modular Advanced Reactor (SMART), which became the first SMR worldwide to obtain standard design approval (SDA) [3]. Following this achievement, KAERI advanced the concept to SMART100, a design that adopts fully passive engineered safety features (ESFs) as lessons learned from the Fukushima accident, and SMART100 was granted SDA in 2024. Recently, "Team Korea," under the leadership of Korea Hydro & Nuclear Power (KHNP), initiated the development of the innovative SMR (i-SMR) with the ambition of positioning Korea as a leading player in the future nuclear market.

The i-SMR (Fig. 1) integrates major primary system components—including the reactor coolant pump (RCP), steam generator (SG), and pressurizer—directly within the reactor vessel. This configuration inherently eliminates the possibility of a large-break loss-of-coolant accident (LBLOCA). In addition, the introduction of a steel containment vessel combined with containment-mounted double isolation valves enables passive reactor cooling driven solely by natural forces under accident conditions. For instance, in the event of an accident, the release valve at the top of the reactor and the recirculation valve near the lower vessel side are open. Steam is vented upward, while the condensate generated in the passive containment cooling system (PCCS) accumulates in the annular space between the reactor vessel and containment. Once the water level in the annular space exceeds that in the reactor vessel, the condensate flows back into the core through the recirculation valve, thereby completing a natural circulation loop within the emergency core cooling system (ECCS).

However, unintended actuation of the release or recirculation valves—whether caused by mechanical malfunction or operator error—could unnecessarily activate the ECCS. Therefore, a malfunction-prevention valve is considered essential. This study investigates preliminary design mechanisms to realize such functionality.

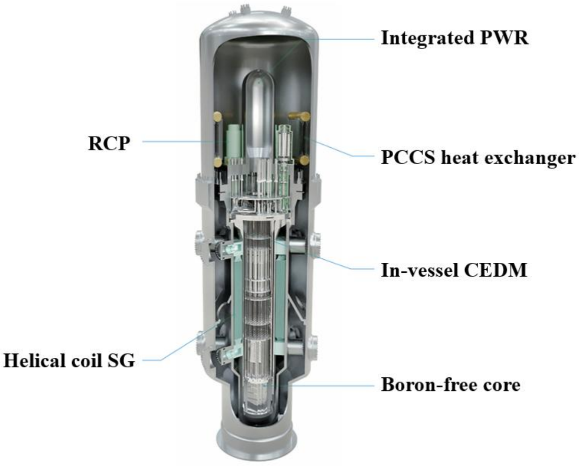

Fig. 1. Concept of i-SMR [4].

2. Methods and Results

Here, a brief overview of various mechanisms will be provided to prevent malfunction for ECCS, while the detailed mechanisms will be discussed at the conference. Fig. 2 shows an example of ECCS valve [5].

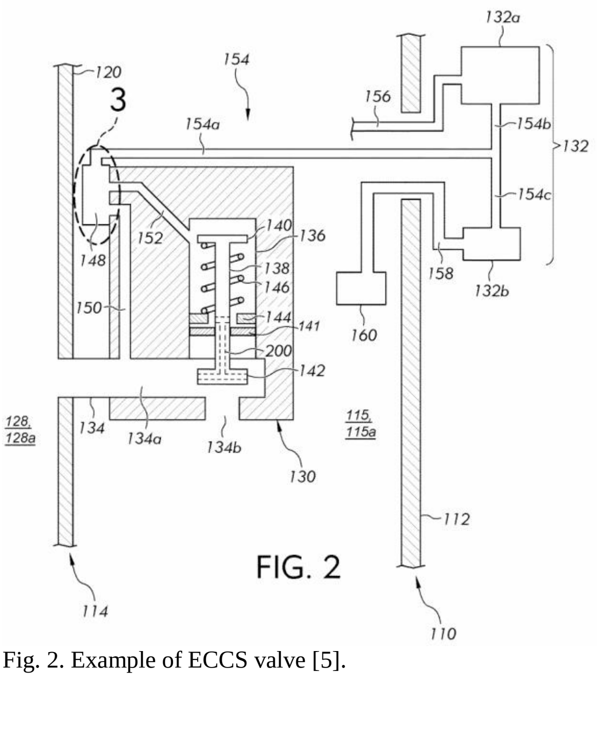

Fig. 2. Example of ECCS valve [5].

2.1 Differential pressure type [6]

Malfunction-prevention can be achieved by utilizing the pressure difference between the reactor and containment vessels [5]. A spring-loaded differential pressure valve opens only when the pressure differential falls below the setpoint. For example, under normal operating conditions, the reactor pressure is higher while the containment pressure is lower, resulting in a differential pressure greater than the spring setpoint; thus, the malfunction-prevention valve remains closed and inadvertent actuation is avoided. However, in the event of an accident, when coolant is released and the pressure difference between the reactor and containment vessels decreases, the valve opens accordingly.

2.2 Electronic type [7]

The electronic type determines whether the malfunction-prevention valve should open or close based on decision algorithms that utilize sensor information. For instance, under normal operating conditions, such as adequate differential pressure, the valve remains closed. In the event of an accident, however, the valve is designed with a fail-safe feature to open when the differential pressure decreases or when power is lost.

2.3 Temperature-dependent type [8]

During an accident, coolant release causes a rapid decrease in both pressure and temperature inside the reactor. The temperature-dependent type operates the valve through a sealed temperature-sensing element and a connected tube. Under normal conditions, when the reactor temperature is high, the valve remains closed, thereby preventing inadvertent actuation. In contrast, when the temperature decreases during an accident, the valve opens accordingly.

2.4 Check valve type [9]

If the malfunction-prevention valve is applied only to the recirculation valve, a simple approach is to use a check valve. Even if the main valve is opened, the check valve prevents the release of coolant, thereby realizing the malfunction-prevention function. Conversely, in the event of an accident, when condensate accumulates in the annular space, the check valve allows flow from the containment back into the reactor vessel.

2.5 Bi-directional valve type [10]

Malfunction-prevention functionality can also be achieved by employing a bi-directional check valve that permits flow in one direction while blocking flow in the opposite direction, together with auxiliary devices. However, the valve configuration including auxiliary devices becomes highly complex. Therefore, a detailed description is omitted.

3. Conclusions

This study outlined several preliminary mechanisms for malfunction-prevention valves, including differential pressure, electronic, temperature-dependent, check, and bi-directional types. These concepts demonstrated potential to enhance the reliability of ECCS, while further detailed design and validation will be necessary for real-world application.

ACKNOWLEDGEMENT

This work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20228540000010, Concept Development of Highly Reliable Valves for Emergency Core Cooling System in Innovative SMR)

REFERENCES

[1] J. H. Lee and I. S. Park, Robust technique using magnetohydrodynamics for safety improvement in sodium-cooled fast reactor, Nuclear Engineering and Technology, Vol.54, p. 565, 2022.

[2] J. H. Lee and I. S. Park, Magnetohydrodynamic stabilizer suppressing gas entrainment for safety improvement in a sodium-cooled fast reactor, International Journal of Energy Research, Vol. 46, p. 23595, 2022.

[3] K. K. Kim, W. Lee, S. Choi, H. R. Kim, and J. Ha, SMART: The First Licensed Advanced Integral Reactor, Journal of Energy and Power Engineering, Vol. 8, p. 94, 2014

[4] Innovative Small Modular Reactor Development Agency, i-SMR leflet (Korean), KHNP.

[5] O'Brien et al., Inadvertent actuation block valve for small modular nuclear reactor, Dec. 6, 2022, United States Patent, US11,521,757 B2.

[6] J. H. Lee, S. Kim, C. B. Chang, and H. Cho, Safety lock valve and Nuclear Facility including the Same, Apr. 23, 2025, Korea Patent, 10-2025-0054667.

[7] J. H. Lee, S. Kim, C. B. Chang, and H. Cho, Safety lock valve and Nuclear Facility including the Same, Apr. 11, 2025, Korea Patent, 10-2025-0049045.

[8] J. H. Lee, S. Kim, C. B. Chang, and H. Cho, improper operation prevention valve and Nuclear Facility including the Same, Sep. 24, 2024, Korea Patent, 10-2024-0139957.

[9] J. H. Lee, S. Kim, C. B. Chang, and H. Cho, Nuclear Facility, Mar. 17, 2025, Korea Patent, 10-2025-0037289.

[10] J. H. Lee, S. Kim, C. B. Chang, and H. Cho, improper operation prevention valve and Nuclear Facility including the Same, May. 7, 2025, Korea Patent, 10-2025-0059823.