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Considerations and Potential Issues in Licensing Isolation Valve Design of Metal Containment for NuScale-type SMR

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1. Introduction

Small modular reactors (SMRs), defined as nuclear reactors with an electrical output capacity of 300 MWe or less, are being actively developed due to their enhanced safety features and flexible modular design. These reactors incorporate several innovative design elements that distinguish them from traditional large-scale nuclear power plants. Given the rigorous regulatory review required for these innovative reactors, a deep understanding of regulations is essential alongside development. To this end, we have studied the regulatory aspects of SMRs through NuScale Power's standard design certification process for the US600. NuScale sought exemptions for 17 regulatory requirements during the licensing of its US600 reactor. [1] One such exemption was for the CIV, for which NuScale presented valid arguments and evidence to the NRC regarding the General Design Criteria, resulting in approval. As South Korea is also developing its own SMR with various innovative designs, regulatory issues are likely to arise during the licensing process. One such issue is the containment isolation valve. However, the existing regulatory framework in Korea faces challenges in effectively licensing reactors featuring novel designs, particularly given the absence of previous licensing precedents. The containment isolation valve serves as a prime example of such complexities. This review aims to conduct a comparative analysis of the NuScale US600 reactor's standard design certification process and South Korea's domestic regulatory requirements. Furthermore, the outcome from this review is expected to contribute to the identification of CIV-related issues during the licensing of i-SMR in Korea.

2. Review of the NuScale US600 Licensing Process with Focus on CIV

2.1 Design of the Containment Isolation Valve in the NuScale US600 Reactor

NuScale's containment isolation system features a single-body, dual-valve design with two ball-type valves located outside the containment building. These hydraulically operated Primary System Containment Isolation Valves (PSCIVs) are remotely controlled from the main control room and equipped with position indicators. Designed to automatically close in response to accident conditions requiring containment isolation, each valve has its independent actuator. Fig.1 shows the conceptual design of PSCIVs. NuScale claimed this design eliminates piping between valves and the vessel, minimizing welds outside containment and preventing pipe breaks or leakage between these components. By positioning the hydraulically operated containment isolation valve outside the containment, the valve is kept out of the post-accident atmosphere within a Containment Vessel (CNV) [2]

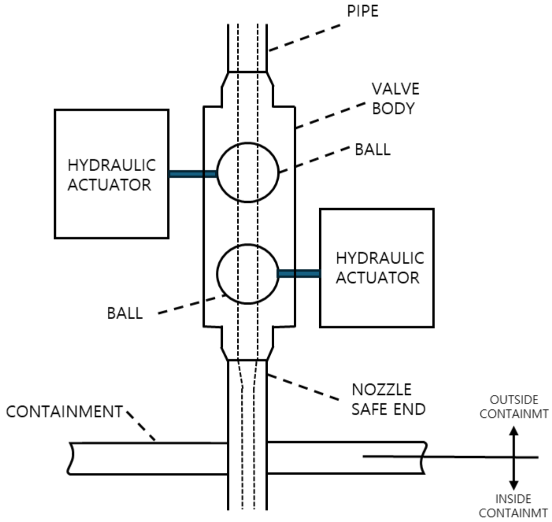

Fig. 1 Conceptual Diagram of Primary System Containment Isolation Valves

2.2 Regulatory Requirement of Containment Isolation Valve in the US

General Design Criteria (GDC) is minimum requirements for the principal design criteria of water-cooled nuclear power plants that are similar in design and location to plants for which the Commission has issued construction permits.
Containment isolation valves are addressed in 10CFR50 Appendix A. The specific provisions of this guideline are as follows.

GDC 55 — Reactor coolant pressure boundary penetrating containment.

Each line that is a part of the reactor coolant pressure boundary and penetrates primary reactor containment shall be provided with containment isolation valves one inside and one outside unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis.

Isolation valves outside containment shall be located as close to containment as practical and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety. [3]

GDC 56 — Primary containment isolation.

GDC 56 requires the same valve requirements as GDC 55 for lines that connect directly to the containment atmosphere and penetrate the primary reactor containment. [3]

GDC 57 — Closed system isolation valves.

Each line that penetrates primary reactor containment and is neither part of the reactor coolant pressure boundary nor connected directly to the containment atmosphere shall have at least one containment isolation valve which shall be either automatic, or locked closed, or capable of remote manual operation. This valve shall be outside containment and located as close to the containment as practical. A simple check valve may not be used as the automatic isolation valve. [3]

Table 1 lists the provisions and the corresponding valve required to meet those provisions. GDC 55 and 56 have same requirement about containment isolation valve.

2.3 A Summary of NuScale and NRC Arguments in the Containment Isolation Valve Licensing Process

In the licensing process, the applicant explains how their design achieves the fundamental objectives of the regulations in the Safety Analysis Report and requests exemptions in the Exemption Report. The NRC evaluates these analyses and exemption requests and provides a response. The following section summarizes the applicant's and regulator's opinions on each provision.

2.3.1 GDC 55 and 56

NuScale's Justifications
(1) The two sets of PSCIVs share a single valve body, a design that prevents pipe breaks between the two valves. The valve directly welded to the end of the CNV nozzle outside the CNV is preventing pipe breaks or leaks between the CNV and PSCIVs.
(2) The bolted connections forming the pressure boundary of the valve and the valve stem packing include dual seals and means to detect, measure, and seal any leakage through the seals.
(3) Both valves are located outside the isolation valve to avoid exposure to the harsh post-accident containment environment.
(4) The isolation valves are designed and certified as Seismic Category 1, ASME Code Class 1 components, ensuring the integrity of the valves themselves. [2]

NRC's Evaluation
(1) The NRC staff determines that locating the isolation valve on the safe side of the containment nozzle is equivalent to placing the valve as close to the containment as possible, given that the safe side is welded directly to the containment nozzle. This assessment eliminates the consideration of pipe breaks between the valve and the CNV.
(2) The two valves are located outside the containment, with the piping between the containment nozzle and the isolation valve installation point ensuring the integrity of the piping. The valves meet the criteria in SRP

Table.1 Valve classifications applicable to penetrations and related regulations

Regulatory Reference	Description/ Containment Penetration	Isolation Valve Needed.	Compliance
GDC55	RCS Injection (CNV6), RCS Pressurizer Spray (CNV7), RPV Discharge (CNV13), RPV High Point Degasification (CNV14)	PSCIV(Single body dual valve welded)	Meets the intent of GDC 55 Exemption justified.
GDC56	CRDS Return (CNV5), Containment Evacuation System (CNV10), Containment Flood and Drain System (CNV11), CRDS Supply (CNV12)	PSCIV(Single body dual valve welded)	Meets the intent of GDC 55 Exemption justified.
GDC57	Feedwater Line1,2(CNV1,2), Main Steam Line 1,2(CNV3,4), Decay Heat Removal 1,2 (CNV22,23)	SSCIV: Feedwater Isolation Valve: Feedwater Line1,2(CNV1,2) Main Steam Isolation Valve: Main Steam Line 1,2(CNV3,4) No Valve: Decay Heat Removal 1,2 (CNV22,23)	Meets GDC 57: Feedwater Line1,2(CNV1,2) Meets the intent of GDC 57 Exemption justified: Main Steam Line 1,2(CNV3,4), Decay Heat Removal 1,2 (CNV22,23)

Section 3.6.2, "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping," and associated BTP 3-4, thus demonstrating the integrity of the equipment itself.
(3) While GDC 55 and 56-related lines are not essential for preventing or mitigating a LOCA, placing the isolation valves in the closed position upon receipt of a closure signal or loss of operating power provides an added layer of safety.
(4) Locating the containment isolation valve externally prevents a single valve inside from being exposed to the severe post-accident environment.
(5) The design meets appropriate quality standards, including ASME Code, Section III, Class 1, Subsection NB, "Class 1 Components," and seismic Category 1 criteria. [6]

2.3.2 GDC 57

NuScale's Justifications for Decay Heat Removal System
(1) The Decay Heat Removal System (DHRS) satisfies the intent of GDC 57 with the exception that it uses closed-loop piping to create an isolation barrier outside of containment instead of an isolation valve. The DHRS piping external to containment serves as the isolation barrier, establishing the containment boundary outside of containment without requiring valve actuation. [2]

NRC's Evaluation
(1) NRC's staff approves the applicant's justification for the first isolation barrier, finding that the closed system within containment adequately meets the provisions of NuScale DSRS Section 6.2.4, Acceptance Criterion 15. [6]

3. A Review of Containment Isolation Valve Regulations in Korea

In this section, we identify the regulatory provisions for containment isolation valves in South Korea and explain the differences in regulatory requirements between the US. This comparative analysis can help us anticipate and address potential licensing challenges in Korea similar to those encountered by NuScale in its previous licensing processes.

3.1 Regulatory Requirement of Containment Isolation Valve in Korea

The Nuclear Safety and Security Commission (NSSC) is the nuclear regulatory body in Korea, and it provides Regulatory Guidance for the licensing process of nuclear power plants. Containment isolation valves are addressed in Chapter 7, Engineering Safety Systems and Containment Systems, of the Regulatory Guide for Light Water Reactors. The specific provisions of this guideline are as follows.

KINS/RG-N07.07,Rev.3—Design of Reactor Containment Isolation Systems [5]

A. Containment Isolation System

1) Piping penetrates the containment building and connects it to the reactor coolant pressure boundary and the containment building atmosphere.

Piping penetrating the reactor containment building and directly connected to the reactor coolant pressure boundary or the containment atmosphere shall be provided with isolation valves one inside and one outside, unless alternative containment isolation provisions can be demonstrated for specific piping categories such as instrument lines.

2) Engineered Safety Features and Power Plant Safety Shutdown System Piping Penetrating the Containment Building

Piping for engineered safety features typically has one isolation valve installed inside and outside the containment building. However, if the system reliability is sufficient, forms a closed loop outside the containment building, and meets the single failure criterion, a single isolation valve may be permitted.

3) Installation of two isolation valves outside the containment building

Typically, piping systems described in items 1) and 2) are equipped with isolation valves one inside and one outside the containment building. However, if internal valve installation is challenging, a dual isolation valve configuration outside containment may be adopted. In such cases, the valve and piping adjacent to containment must have leakage mitigation features. Alternatively, the piping and valves can be designed to meet pipe rupture criteria and include leakage detection and prevention for stem and bonnet seals.

A comparison of regulatory provisions between Korea and the United States will be discussed in the following section.

4. Identification of differences between the Korea and US and the results

In the U.S., if a GDC cannot be met, an exemption must be requested. For the NuScale US600, exemptions have been sought for isolation valves that do not comply with applicable provisions. In contrast, KINS/RG-N07.07, Rev.3 that is Korean regulation guide about containment allows for the installation of two isolation valves outside the containment building in cases where installation of a isolation valve is infeasible.[5]

We can identify a difference in regulatory requirements between the US and Korea regarding the common design of installing two containment isolation valves externally. Table.2 provides Summary of differences about regulation between the Korea and Us about CIVs While the NuScale has passed the review by adopting an approach of exempting provisions related to CIVs, Korea might be able to obtain approval by utilizing existing provisions (KINS/RG-N07.07, Rev.3).

Table.2 Summary of differences about regulation between the Korea and Us about CIVs

Country	Regulatory bases of CIVs	The installation of two external valves
United States	10CFR50 Appendix A. GDC 55, 56 and 57	Not Allowed (Exemption Required)
Korea	KINS/RG-N07.07, Rev.3	Allowed

5. Conclusion

A review of the NuScale US600 licensing process and domestic regulations revealed that when two external containment isolation valves are installed in a nuclear power plant, regulatory bodies assess whether the valves meet appropriate quality standards. They also evaluate if the valves are equipped with leak sealing and control facilities to ensure safety. Unlike US regulations, regulations in South Korea explicitly allow the installation of two external valves, suggesting that new regulations or amendments may not be necessary. However, due to the lack of precedents for applying and reviewing additional requirements, regulators may need to provide appropriate examples for this regulation. Additionally, a safety assessment is necessary to compare the risks and accident severity inside and outside the containment vessel, and to analyze scenarios where both external containment isolation valves fail or are damaged.

Acknowledgement

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