Regulatory Issue in the NuScale SMR ECCS Valve with Focus on the Application of Single Failure Criteria to the Closure Function of the Inadvertent Actuation Block Valve

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1. Introduction

There is many ongoing research into small modular reactors (SMR) around the world, with NuScale SMR being a prominent example. The NuScale SMR is the first light-water reactor SMR to achieve design certification by U.S. Nuclear Regulatory Commission (NRC), incorporating several innovative designs. However, during the design certification review process, the NuScale SMR encountered several licensing challenges, some of which is related to the Emergency Core Cooling System (ECCS) valves [1]. Among these, the most critical issue was whether to apply the single failure criterion (SFC) to the closing function of the Inadvertent Actuation Block (IAB) valve which is a key component of the ECCS valve [2]. A similar issue is expected in the Design Certification of i-SMR, which is expected to include an ECCS design similar to that of NuScale.

So in this paper, we review the role of the IAB valve and the associated regulatory issue to prepare for future challenges.

2. NuScale ECCS Design

In conventional large nuclear power plants, safety injection tank, pumps, and refueling water storage tank are employed to cool the core during and after anticipated operational occurrences (AOOs) and postulated accidents, including loss-of-coolant accidents (LOCAs). In contrast, the NuScale SMR utilizes a simpler, passive system consisting of three reactor vent valves (RVVs) mounted on the upper head of the reactor pressure vessel (RPV), two reactor recirculation valves (RRVs) mounted on the side of the RPV to achieve core cooling. The coolant is vaporized in the core leaves as steam through the reactor vent valves, is condensed and collected in the containment vessel (CNV), and is then returned to the downcomer region inside the reactor vessel through the reactor recirculation valves [3].

The RRVs and RVVs each consist of four components as shown in Fig. 1: a main valve, a lAB valve, a reset valve, and a trip valve. Positioned between trip valve and the main valve pathway, the IAB valve integrates to prevent the unintended opening of the main valve [4]. If the pressure differential between the RPV and the CNV exceeds a predetermined threshold of 1300 psi regardless of any reason, IAB valve inhibits the main valve from opening.

When differential pressure to approximately 950 psi ± 50 psi, the IAB valve reopens, thereby permitting the main valve to open. This function is crucial for avoiding ECCS valve malfunctions and prevents the premature opening of the main valve during accidents, ensuring system integrity and safety.

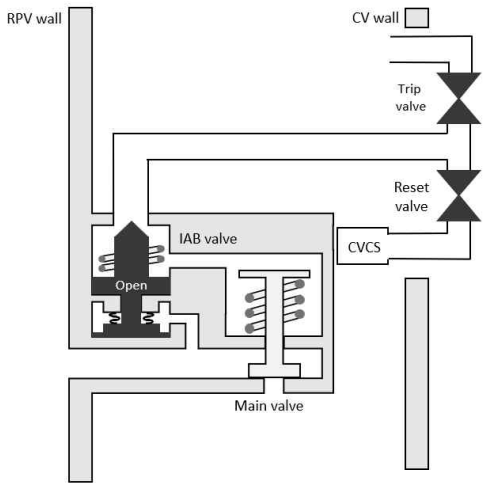

Fig. 1. NuScale ECCS valve.

3. Application of Single Failure Criteria to IAB Valve Closure Function

3.1 Single failure regulatory requirement to ECCS

The NRC applies the single failure criterion to the ECCS and its subsystems to ensure their critical safety functions. In 10CFR50 Appendix K, it states the following regarding the application of the SFC: "An analysis of possible failure modes of ECCS equipment and their effects on ECCS performance must be made. In carrying out the accident evaluation, the combination of ECCS subsystems assumed to be operative shall be those available after the most damaging single failure of ECCS equipment has taken place."

Additionally, there are notable Secretary (SECY) reports that provide guidance for applying the single failure criterion to the IAB valve. The SECY-77-439 report states, "In a fluid system, the inability of a simple check valve to transition to its designated position constitutes a passive failure." Meanwhile, the SECY-94-084 report indicates that "In passive systems, the

failure of a check valve is considered as an active component subject to the SFC. However, this does not apply if the valve exhibits reliability comparable to that of passive components." these two reports provide guidance on the application of the SFC [4,5].

3.2 Regulatory Issue

NuScale and NRC staff have encountered differing perspectives on the application of the Single Failure Criterion to the closure function of the IAB valve, and have not reached a satisfactory compromise. NuScale referenced SECY-77-439, aiming to avoid the application of the Single Failure Criterion, whereas NRC staff argued, based on SECY-94-084, that the IAB valve is not reliable enough to be considered a passive component and thus should be subject to the Single Failure Criterion. The main arguments from each party are presented in Table I.

Table I: NuScale, NRC staff main argument [6,7].

	main argument
NuScale	The guidance document for applying the SFC to the IAB valve is SECY-77-439, which provides guidelines for high-pressure, passive safety systems. According to this document, considering the design and function of the component, a qualitative assessment alone, comparing it to the precedent of the simple check valve which was not subject to the Single Failure Criterion, is sufficient to deem a valve's failure to close as a passive failure. So, closing function of IAB valve should not be subject to SFC
NRC staff	Its design is more complex and operates under more challenging conditions compared to traditional simple spring-actuated differential pressure valves. Therefore, it is untenable to exempt it from the SFC based on a comparison with previous cases. Additionally, the IAB valve closure function is a critical safety role by needing to close swiftly during certain transient and accident conditions to prevent premature main valve opening and malfunction. A failure of this valve could significantly challenge the NuScale safety analysis, potentially affecting fuel acceptance limits and peak containment pressure during certain licensing basis events. Hence, the closure function of the IAB valve must be designed to meet the SFC

Due to these differences in opinion, NuScale and the NRC have been unable to reach a consensus. To resolve the issue, the NRC staff has proposed three options to the Commission. Table II below shows the proposed options.

Table II: Options proposed by the NRC staff to the Commission for resolving the issue. [7].

	Main content
Option 1	If NuScale can demonstrate the inherent reliability of the IAB valve by reducing scenarios that would necessitate its closure, such as malfunctions of the trip valve or DC power losses, the NRC would consider not applying the SFC.
Option 2	Under the SFC, NuScale should re-perform the accident analysis, modify the design, or provide technical and legal justification to apply for an exemption from the SFC.
Option 3	Exemption from the SFC at the discretion of the committee

The committee conducted a vote to resolve this issue, and three out of four members, including the chairman, opposed applying the SFC to the IAB valve closure function. The main arguments are outlined in Table III.

Table III: Committee's Decision [8].

Comm-ission	When determining the application of the SFC, the focus should not individual components but the overall safety of the integrated system. Traditionally, the application of the SFC has utilized risk-informed approaches. The Probabilistic Risk Assessment (PRA) results demonstrated that the failure of the IAB valve to close still met the target Core Damage Frequency (CDF) and Large Release Frequency (LRF) objectives. Therefore, the SFC is not applied.

4. Application of the SFC to the i-SMR IAB Valve Closure Function

According to open literature on the design of the ECCS for the i-SMR, a valve is expected to be installed to prevent malfunctions of the ECCS, similar to the approach taken by NuScale. In Korea, Article 44 of the Regulation on Technical Standards for Reactor Facilities mandates that Structures, Systems, and Components (SSCs) performing safety functions must be designed to account for single failures to ensure and maintain a sufficiently high level of reliability. Additionally, Regulatory Guidance 7.12 on the Design

of Passive Safety Systems provides guidance on the application of the SFC to check valve, stating that "In the design of passive safety systems, the application of the SFC is required for check valves, except in cases where the operability of the check valve can be guaranteed through comprehensive evaluation of test data or operational experience under similar system conditions."

However, the currently disclosed design data does not appear to take this criterion into account enough. Extensive discussions are expected to be necessary to address this issue, and it will be important to review the precedent set by the NuScale licensing case.

5. Conclusions

In this paper, the role of the IAB valve within the NuScale SMR's ECCS and the regulatory challenge associated with the application of the SFC is reviewed. The IAB valve, designed to prevent malfunctions and premature opening of the ECCS main valve, is an innovative feature in the NuScale SMR. There was a divergence of views between NuScale and the NRC regarding the application of the SFC to this essential safety component. Finally, it was determined that the SFC would not be applied, as the safety objectives for CDF and LRF is satisfied, consistent with the NRC's established methodology for assessing the necessity of the SFC. In Korea, the i-SMR design, which incorporates a valve similar to NuScale SMR, is currently under development. This review provides insights for addressing similar licensing challenges and assists in the exploration of effective solutions.

Acknowledgement

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