Lessons Learned for Design of ECCS Valve obtained from NRC's Design Review results

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***Keywords : Small Modular Reactor, Design of Emergency Core Cooling System Valve, Regulatory Audit**

1. Introduction

NuScale Small Modular Reactor (SMR) has been developed that adopted passive Emergency Core Cooling System (ECCS) with a different concept from ECCS applied to existing large nuclear power plants and obtained design certification from United State Nuclear Regulatory Commission (USNRC). NuScale's passive ECCS adopted a method of recirculating the reactor coolant inside Reactor Pressure Vessel (RPV) and Containment Vessel (CNV), instead of the traditional ECCS injecting the additional reactor coolant from outside of reactor to mitigate the accidents such as Loss of Coolant Accident (LOCA).

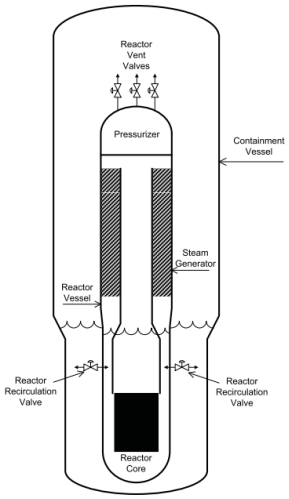

Fig. 1. ECCS operation in NuScale [1].

Two ECCS valves were developed to implement the new concept of passive ECCS in NuScale, as shown in Fig. 1. The Reactor Vent Valve (RVV) is installed on the top of RPV to vent the reactor coolant steam into the CNV, and the steam is condensed by heat transfer through the CNV wall to the reactor pool. The condensed reactor coolant is accumulated in lower part of the CNV and moved into the downcomer of the RPV through the Reactor Recirculation Valve (RRV) installed on the side of the RPV. The ECCS valve plays a key role in NuScale's accident mitigation by opening the main valve to provide the water into the core at the appropriate time. However, if the ECCS valve can be inadvertently opened during normal operation, it can cause the LOCA itself. Therefore, prevention of inadvertent actuation is the important feature of ECCS valve. To prevent inadvertent actuation of ECCS valve, an Inadvertent Actuation Block (IAB) valve was applied to the ECCS main valve of NuScale. Thus, NuScale's ECCS valve is a valve system consisting of main valve, IAB valve, trip valve, and reset valve, as shown in Fig. 2 [1].

During the regulatory audit for Design Certification Application (DCA) of NuScale, the USNRC evaluated whether the design of the ECCS valve could keep the reactor safety and mitigate the postulated accidents. During the USNRC's regulatory audit, numerous Requests of Additional Information (RAI) from USNRC and the response to RAI by the NuScale were conducted in various fields of ECCS valve, such as valve design data, operability evaluation and validation results, application of the single failure criterion to IAB valve, and Failure Mode and Effect Analysis (FMEA) results. Based on the regulatory audit, NuScale updated the ECCS valve design by reflecting of audit result.

In this study, the results of regulatory audit for NuScale ECCS valve were reviewed. The audit results of existing design to be considered important in developing new ECCS valve, which can reduce trial and error in the design process and increase design completeness. Therefore, the results of this study can be helpful to establish the key considerations of the ECCS valve design for the new SMR.

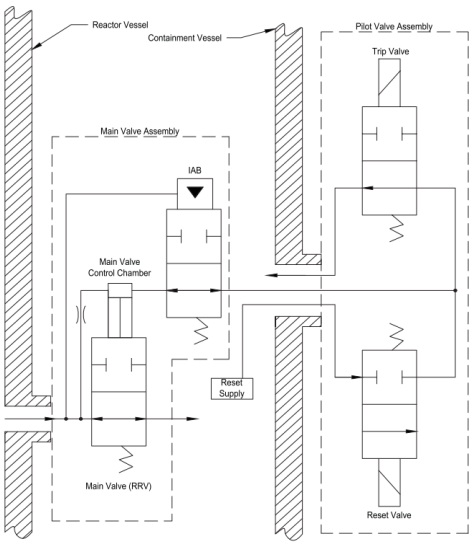

Fig. 2. Conceptual diagram of NuScale ECCS valve [1].

Table I: Representative follow-up items and resolution during three audit phase

Audit phase	Representative follow-up items	Resolution of follow-up items
Initial audit	ECCS valve calculations and analyses review at the valve supplier facility	Resolved by review of calculations and documentation for the ECCS valves. Audit item was closed by QA documents.
	FMEA review to evaluate potential failure modes of the ECCS valve (including its four valve subcomponents)	Resolved by review and resolution of RAI for FMEA which provided by NuScale.
	Review of final design of the IAB valve for consistency with the description in the RAI response	Resolved by FMEA audit during second and third audit.
	Review of design tests and analyses to justify the IAB valve as a passive component with Commission policy related with single failure criterion	In commission paper SECY-19-0036, USNRC staff requested that commission provide guidance of single failure criterion for IAB valve. Commission issued a Staff Requirements Memorandum (SRM) for SECY-19-0036 that directed NuScale DCA without assuming a single active failure of the IAB valve.
Second audit	Plan to resolve the safety questions regarding the design demonstration testing of the ECCS valves	ECCS valve design demonstration testing was performed by NuScale. USNRC determine ECCS valve design demonstration testing satisfied 10CFR52.47(c)(2) and 50.43(e).
	Describe the plans to resolve the safety questions regarding the potential partial open failure mode for the main valve of the ECCS valves	USNRC performed the onsite review at Target Rock facility to discuss the calculation of ECCS valve. USNRC considered that NuScale has demonstrated that there is no credible potential of partial open failure mode of main valve in the ECCS valve system.
	Describe the capability of the IAB valve to meet its operating requirements and testing that is available to demonstrate IAB valve performance	Based on the ECCS valve design demonstration testing, the staff considered this follow-up item was resolved and closed.
Third audit	Lessons learned from the ECCS valve design demonstration testing to be addressed in developing the ASME QME-1 qualification program and the IST program for the ECCS valve system	A COL holder will address the ECCS valve design demonstration testing in developing the ASME QME-1 qualification program.

2. Results of ECCS valve Regulatory Audit

According to the 10CFR52.47(c) and 10CFR50.43(e), regulatory audit for NuScale ECCS valve was conducted by USNRC in three phases. The initial regulatory audit, conducted from November 2017 to January 2018, was aimed at (1) understanding the design of NuScale; (2) identifying the information in the Final Safety Analysis Report (FSAR); (3) identifying the information to support the basis for licensing and regulatory decisions; and (4) reviewing the docketing and non-listed information to evaluate conformance with regulatory guidance and compliance with USNRC regulation [2].

Through the initial regulatory audit, USNRC evaluated the eight perspectives including following important perspectives: (1) is the ECCS valve design suitable for performing the safety function?; (2) Is there no inadvertent opening?; (3) Has appropriate FMEA been performed to ensure the required safety functions and reliability?; (4) Can the IAB valve be considered as a passive device for single failure criterion?; (5) Can be reliably operated the ECCS valve? However, in the initial regulatory audit results, the USNRC pointed out that the NuScale ECCS valve did not demonstrate the performance and reliability to perform the safety functions. Therefore, USNRC required resolving the 18 follow-up items.

In the second regulatory audit conducted from March to May 2018, the USNRC focused on evaluating FMEA results to evaluate the design characteristics of ECCS valves and evaluated the follow-up items of the initial regulatory audit result [3]. In the second regulatory audit results, the USNRC pointed out again that the

performance and reliability of the NuScale ECCS valve were not sufficiently proven. Consequently, USNRC required a total of 121 detailed follow-up items. In particular, the USNRC pointed out that the results of the Proof of Concept (POC) test performed by NuScale were insufficient to demonstrate the performance of the ECCS valve. Also, USNRC required that the potential failure mode in which the main valve could be only partially opened under certain conditions be resolved. As a result, the USNRC concluded that it was necessary to resolve the follow-up items regarding the demonstration test of the ECCS valve design.

In the third regulatory audit conducted from March to October 2019, the results of the ECCS valve design demonstration test were evaluated, including whether the 121 detailed follow-up items were resolved [4]. Through the third regulatory audit, the USNRC evaluated that all 121 follow-up items were resolved. In particular, it was recommended not to apply the single failure criterion to IAB valve by commissioner's guideline. Furthermore, ASME QME-1 qualification program and the development of the IST (In-service testing) program should be included in the Combined License (COL).

3. Lessons Learned and Design Considerations

During the USNRC regulatory audit, it was pointed out that NuScale's ECCS valve design may not be sufficient to perform reliable safety functions. Based on the regulatory audit result, NuScale improved the design and set-point of the ECCS valve through the demonstration test.

Through the review of regulatory audit results, the main considerations for designing of ECCS valve are summarized as follows:

- Completeness of design documents and support data
- Ensuring performance and operational reliability through demonstration tests of ECCS valve and sub-components
- Appropriateness of FMEA results including sub-components of ECCS valve
- Application of single failure criteria for passive devices
- Implementation of ASME QME-1 qualification test and development of IST Program

4. Conclusions

Based on the review of regulatory audit results for the NuScale ECCS valve, major considerations were summarized for the designing of ECCS valve to the new SMR. The valve applied to the passive ECCS of SMR can have a very significant impact on accident occurrence or accident mitigation, depending on whether it is operated or not. Therefore, the ECCS valve should have sufficient operational reliability. The evaluation and demonstration test for validation of ECCS valve design should be carried out under appropriate range, and the impact on reactor safety should be minimized through the analysis of potential failure effect.

Acknowledgement

This study was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korean Government (Ministry of Science and ICT, MSIT) (No. RS-2023-00321928).

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