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Revisiting Application Purpose of Single-Failure Criterion for Determining the Applicability to Passive Safety System

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1. Introduction

i-SMR has an innovative design with a passive safety system that differs from conventional large light water reactors [1]. However, gaps exist between the design characteristics and the current safety standards. In particular, the exemption application of single failure criterion for inadvertent actuation block valves used in passive emergency core cooling systems is under discussion.

In this study, the purpose and application of the single failure criterion, its limitations, and cases where it cannot be applied were reviewed as the cornerstone for a feasibility review of exemption.

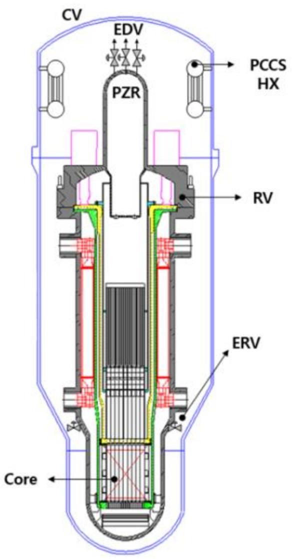

Fig. 1 The passive safety system of the i-SMR related to the single failure criterion [2].

2. Consideration related to single failure criterion

2.1 Purpose and application method of single failure criterion

A single failure is a failure in which a system or component loses its ability to perform its intended safety function, including any consequential failures that may result [3]. Article 44 of the Korean nuclear reactor rules requires that the structures, systems, components that perform the safety function must be able to demonstrate that it can achieve the safety function even in the event of a single power failure and single failure, depending on the importance of the safety function [4].

These regulations are intended to satisfy the defense-in-depth principle, which is the basic principle of nuclear facilities. Defense-in-depth is a concept that applies multiple layers of regulations that overlap with safety activities to ensure that even if a failure occurs, it would be compensated for or corrected without causing harm to individuals or the public at large [5]. The general objective of defense in depth is to ensure that a single failure, whether equipment failure or human failure, at one level of defense, would not propagate to jeopardize defense in depth at subsequent levels [6]. This objective is also effectively achieved by applying a single failure criterion that improves the reliability of the system performing the safety function [5].

As a principle for ensuring safety, redundancy, which is the deployment of multiple independent systems that perform the same function so that a single system failure does not affect the entire function, and diversity, which is the application of different technologies or principles when performing the same function to prevent common cause failures, and independence, which is the maintenance of physical and functional separability so that the failure of one system does not affect another system, play important roles [3].

2.2 Limitations of application and conditions of non-application of single failure criterion

However, the IAEA recommended that a literal interpretation of the single failure criterion based simply on the redundancy of safety functions may not be valid in all situations [7]. For example, in cases where the frequency of postulated initiating event (PIEs) is relatively high, a design that exceeds the redundancy required by the single failure criterion may be necessary. On the contrary, if the frequency of a postulated initiating event is extremely low, there is less need to maximize the reliability of the safety group, and the basic redundancy requirement can be waived.

According to Design Code 335, there is justification for non-compliance with the single failure criterion: (1) very rare PIEs, (2) very improbable consequences of PIEs [8]. In other words, depending on the correlation between the frequency limit for a plant damage state, the frequency of an initiating event and the reliability of all the systems, if the frequency limit for a plant damage state, an initiating event are similar to or lower than the pre-established allowable frequency limit, it is not necessary to additionally equip a safety system with high reliability [7].

2.3 Cases of non-application of the single failure criterion

NuScale's inadvertent actuation block valve is a notable example of a component that does not apply a single failure criterion by very improbable consequences. This demonstrates that in order to determine whether safety goals (i.e. core damage and large release frequency) are met, evaluating the overall system functionality rather than focusing solely on individual component failures is a more appropriate method for protecting public health and safety than strictly applying the single failure criterion [9]. Furthermore, if policy precedents and probabilistic risk assessments are not adequately utilized, unnecessary time and resources may be wasted on issues with extremely low risk. Consequently, considering the low risk level of this case, the inadvertent actuation block valve is not applied the single failure criterion.

3. Conclusion

This study reviewed the purpose and application of the single failure criterion, its limitations and cases of non-application. The single failure criterion is a key element of safety functions and defense-in-depth. The IAEA recommended that a literal interpretation of the single failure criterion based simply on the redundancy of safety functions may not be valid in all situations. Frequency limit for a plant damage state, the frequency of an initiating event and the reliability of all the systems should be considered when deciding whether to apply the single failure criterion. In the NuScale case, the applicability of the single failure criterion was determined based on whether the intended safety targets were met, rather than solely focusing on individual component failures. Based on this review, additional review is required to determine whether the application of the single failure criterion exemption for passive emergency core cooling system is (1) whether it does not conflict with other regulation criteria and guidelines, (2) whether the fundamental purpose of the technical standards can be achieved, and (3) whether it can guarantee safety at a level equivalent to or better than the current technical standards, as the conditions for the exemption and the proposed exemption handling regulations are currently being changed [10].

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