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Analysis of Regulatory Practices and Development of Regulatory Focuses on Passive Safety System

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1. Introduction

The advanced reactors and Small Modular Reactors (SMRs) such as SMART100, iSMR, and NuScale, which are recently being developed domestically or abroad, are widely adopting the passive safety system as their safety feature in order to improve the reactor safety than ever compared to the conventional reactors using the active safety system. Passive safety systems rely on the natural driving forces such as the gravity, the pressure difference or the density differences in the fluid system. Therefore, the passive safety system is considered to be highly reliable compared to the active safety system which depends on a pump for circulating the fluid.

Regarding the passive safety system, Korea Institute of Nuclear Safety (KINS) developed the regulatory guidelines based on what had been discussed in the course of licensing the past passive reactors such as AP600 and AP1000 [1]. The regulatory guidelines provide the definition of passive component and system, the endorsed technical standards, and the regulatory positions to the safe shutdown, single failure criteria, and in-service test. However, the developed guidelines need to be improved to embrace up-to-date global regulatory focuses or discussions on newly emerging advanced reactors and SMRs with a wide variety of passive safety systems.

In light of these circumstances regarding the passive safety system, studies on the development of performance/reliability evaluation method and the technical standards for the passive safety system are being carried out through the long-term research project titled as “Study on Validation of the Consolidated Safety Analysis Platform for Applications of Enhanced Safety Criteria and New Nuclear Fuels”. In the present study, therefore, as a part of the research on “the technical standards for the passive safety system”, regulatory focuses applicable to domestic safety review on the passive safety system are identified based on through analyses on up-to-date international regulatory practices.

2. Analysis on Regulatory Practices

To understand global regulatory practices on the passive safety system well, it is necessary to review individual country’s regulatory practice. However, it is pretty much formidable job to do so, therefore, we choose two recently published reports from international organizations to analyze the international regulatory practices instead. The one from Working Group on Regulations of New Reactors at Organization for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA-WGRNR) [2] and the other one from Reactor Harmonization Working Group at Western European Nuclear Regulators Association (WENRA-RHWG) [3] are referred to in the present study considering that these two reports were elaborated by safety experts from nuclear regulatory bodies of major foreign countries. In the present study, OECD/NEA-WGRNR and WENRA-RHWG reports were reviewed separately and highlights from these two reports were compared each other including the contents from the existing KINS regulatory guidelines [1] on the passive safety system.

2.1 OECD/NEA-WGRNR Report

The WGRNR recently surveyed the regulatory practices of nine participating member states for the safety assessment of the passive safety system and published a report [2]. The WGRNR sought to identify the trends in regulation of each country by selecting five chapters that show the characteristics of the passive safety system in comparison with the active safety system and prepared the question list to identify the regulatory trends of the passive safety system in each country. The five chapters are as follows:

1. Requirements for passive safety systems;
2. Testing and analyses of passive safety systems;
3. Regulatory review of passive safety systems;
4. Commissioning and periodic verification testing;
5. Experience with passive safety systems.

We reviewed the report carefully and compiled seven regulatory practices needed to get our attention for the passive safety system over the active safety system. The summary of seven regulatory practices identified are shown below:

A. Use of Single Failure Criteria;

Many countries apply the single failure criteria to the passive safety system in accordance with IAEA Safety Standard SSR-2/1, “The design shall take due account of the failure of passive component unless it has been justified in the single failure analysis with a high level of confidence…”. They have a regulatory position that the single failure criteria should be applied if a sufficient level of reliability of the passive safety system cannot be demonstrated.

B. The Validation of Computer Codes and The Conduct of Testing Used to Demonstrate Safety Performance;

In many countries, it has been confirmed that there are no additional requirements for the validation of passive safety system performance, but some countries prefer experiments for performance validation to analytical methods using computer programs. This is believed to be taken into account the level of difficulty and uncertainty in numerical analysis of the passive safety system due to the inherent complexity.

C. Concurrent Operation of Several Different Passive Safety Systems (Trains);

Many countries considered that the effect of simultaneous operation of multiple (or multiple train) passive safety systems should be evaluated by analytical methods or physical experiments considering that the overall performance of the passive safety system may be negatively affected.

D. Concurrent Operation of Passive and Active safety systems;

Many countries are concerned that the performance of the overall safety system may be negatively affected by mutual interferences if the passive and active safety systems are operating simultaneously, and this effect should be evaluated by analytical methods or physical experiments.

E. Quantitative and Qualitative Analysis Results for Passive Safety Systems Reliability;

Many countries apply similar reliability methods (e.g., Quality Control, Environmental Qualifications, etc.) to the passive safety system as well as the active safety system. However, driving forces for the passive safety system such as gravity are normally smaller than those of the active safety systems that use forced circulation such as pumps, so the uncertainty included in the best estimate analysis code calculation may be equivalent to the driving force size, and there are a possibility that accident scenarios, that are predicted not to lead to core damage by calculating the best estimate analysis codes, may actually lead to core damage. The US recommended the use of an appropriate reliability model taking the characteristics of the passive safety system into account.

F. The Evaluation of The Impact of False Actuation (Starting) of Passive Safety System;

Many countries did not separate the passive or active systems in the evaluation of the effect of malfunctions in the safety system, and some countries took specific positions on the evaluation of the impact of malfunctions in the passive safety system. In Korea, the malfunction effect of the passive auxiliary feedwater system (PAFS) was evaluated in the past APR+ design certification review, and it was stated that the effect of the malfunction of the passive safety system should be considered in the design requirements. In the US, it has been stated that the evaluation of malfunction and inadvertent actuation of passive safety systems should be included in licensing documents to the same extent as Anticipated Operational Occurrences (AOOs). Finland and Russia also shared their position that, in the case of safety systems (without distinction of passive or active type), the effect of malfunction should be considered as an initiating event and evaluated.

G. Commissioning and Periodic Verification Testing of The Passive Safety System.

It was confirmed that many countries apply the same standards as the active safety system for the test of the passive safety system. Finland and Russia have the position that the test should be carried out for the passive safety system as far as possible, especially for active components included in the passive safety systems.

2.2 WENRA-RHWG Report

Recently, the WENRA-RHWG published a report reflecting the characteristics of the passive safety systems, which summarizes what needs to be considered in the safety review on the passive safety system [3]. The report was mainly prepared by experts from eighteen WENRA member states to supplement the safety reference levels applied to existing reactors for use in reviewing new reactors with wide application of the passive safety systems.

The WENRA–RHWG report consists largely of three safety assessment areas for the passive safety system review, which can be further divided into several smaller topics as shown in Table 1.

Table 1: WENRA–RHWG report contents

Area 1. Actuation of a passive system
Topic 1. Assessment of actuation of passive safety system
Topic 2. Inadvertent actuation of passive safety system
Area 2. Performance of safety function
Topic 1. Specific range of conditions and consequences on safety analysis
Topic 2. Performance demonstration
Topic 3. Internal and external hazards consideration for passive system
Topic 4. Consideration of human actions
Topic 5. Probabilistic Safety Assessment
Area 3. Operating experience feedback
Topic 1. Implementation of operating experience feedback

We have summarized the regulatory positions of the report into the eight major regulatory focuses as follows:

A. Assessment of Actuation of Passive Safety System;

The possibility of low operation failure of the passive safety system should be verified by comprehensive analysis and guaranteed by verification of operational availability of the equipment used for operation initiation and operability of the relevant I&C and support systems.

B. Inadvertent Actuation of Passive Safety System;

The effect of inadvertent actuation of the passive safety system should be evaluated because the pressure on the primary side may be reduced or the isolation function of the containment may be lost due to inadvertent actuation of some passive safety systems.

C. Specific Range of Conditions and Consequences on Safety Analysis;

With respect to the weak driving force of the passive safety system, the followings should be considered:

- Parameters that can affect performance or failure of the passive safety system
- Effects of environmental conditions
- The amount of margin to prevent cliff-edge effects
- Dynamic behavior of the passive safety system performance
- The effect of the passive safety system opened to the reactor coolant system on the isolation of the containment.

D. Performance Demonstration of Passive Safety System;

The effect of non-safety system, the operating range in the computer code analysis, the definition and the achievement of Final Safety State, and the commissioning and periodic test plan should be considered in the course of performance demonstration.

E. Internal and external hazards consideration for passive systems;

Even if the environmental condition of the passive safety system for operation changes due to internal and external events, the passive safety system should be able to perform its original safety functions.

F. Consideration of Human Actions;

When an accident occurs, the operation of the passive safety system may not require operator's operation, but the potential gain or necessity of operator intervention should be considered. In this regard, a device should be provided to verify the performance of the passive safety system.

G. Probabilistic Safety Assessment;

When assessing the reliability of the passive safety system, diverse root causes should be derived and reflected in the reliability model of the system, considering the phenomena that cause functional failure of the passive safety system.

H. Operating Experience Feedback.

Since there is not much experience in operation of the passive safety system, consideration should be given to using the results of preservice test and in-service test related to passive safety systems as a substitute for the operation experience.

3. Identification of Additional Regulatory Focuses and Their Evaluations

From the analysis of regulatory practices in OECD/NEA and WENRA reports, we have drawn largely ten different areas of requiring additional regulatory focuses including specific items as follows in Table 2. While identifying these findings, we compared the contents of the KINS regulatory guide [1] with the summary of the reports [2, 3] as well so that we can leave out something duplicated among them. Since most of area and item depicted in Table 2 can be considered as "performance and reliability issues of the passive safety system", the result can be fed back to the research on the development of the methodology for evaluating performance/reliability of the passive safety system. Table 3 shows how to evaluate the part of the additional regulatory focuses identified in Table 2 from the safety analysis perspective.

Table 2: Items of Additional Regulatory Focuses

A1. Considerations for validation of performance I1. Check whether the application range of the computer program used to prove the performance of the passive safety system is appropriate, and conduct a validation test if necessary (consideration on the effects of reciprocal influence and scaling during validation tests).
A2. Weak driving force I1. Evaluation of phenomena and parameters affecting the performance or failure from the driving force perspective (non-condensable gas, leakage of the system) I2. Environmental condition assessment (atmospheric temperature) I3. Application of margin concept to prevent Cliff-Edge Effect (consideration of aging effect) I4. Performance demonstration considering dynamic behavior I5. Evaluation of the effect of system arrangement on the isolation function of containment
A3. Operability I1. Operability should be guaranteed through comprehensive analysis and operability evaluation of related components (i.e. check valve)
A4. Internal and external hazards I1. The original safety function should be able to be performed even if the environmental conditions operated by internal and external accidents (atmospheric heat sink, fire, and earthquake) change.
A5. Reliability I1. Functional failure should be considered in the reliability assessment and the root causes derived are reflected in the reliability model
A6. Simultaneous operation of multiple systems I1. The effect of simultaneous operation of multiple (multiple) passive systems on the performance of safety functions by analytical method or demonstration test
A7. Simultaneous operation of active & passive systems I1. Evaluation of the effects of simultaneous operation of the passive safety system and the active system(non-safety system) on the performance of the passive safety system

by analytical method or demonstration test
A8. Evaluation of the effect of malfunction
I1. The effects of malfunction and inadvertent actuation of the passive safety system should be evaluated.
A9. Considerations for human actions
I1. Evaluation of the potential benefits or needs of operator intervention and the installation of the performance verification device for the passive safety system I2. Consideration on the sensitivity of the passive safety system to human error from the design, construction, and operation stage of the system
A10. Reflection of operating experience
I1. Reflection of the operating experience by utilizing the results of Preservice & In-Service tests

※ A: Area, I: Items of Additional Regulatory Focuses

Table 3: Evaluation Plan for the Regulatory Focuses

A1. Considerations for validation of performance
E1. Are the coverage of the models and correlations included in the thermal-hydraulic system code appropriate for analyzing the target passive safety system? (Has the PIRT been prepared and used to evaluate the code?)
A2. Weak driving force
E1. Has the safety analysis been performed, including the effects of non-condensable gas and system leakage? E2. Has the safety analysis been performed considering the effects of atmospheric heat sink (temperature)? E3. Has the safety analysis been performed considering the effects of the aging, such as reducing the diameter of pipes due to contamination? E4. Considering that the performance degradation of the passive safety system over time, has the safety analysis been conducted for a sufficiently long time to draw conclusions on the passive safety system performance? E5. Has the safety analysis been demonstrated that there is sufficient margin to avoid cliff- edge effects that may be caused by uncertainties included in the performance evaluation of the passive safety system? (The safety analysis should reflect the uncertainty in the factors that are expected to change in relation to performance and the potential causes of the change in that factor.)
A3. Operability
E1. Considering the weak driving force of the passive safety system, is the appropriate check valve model used for the safety analysis?
A4. Internal and external hazards
E1. Has the safety analysis been performed assuming the worst atmospheric heat sink conditions (temperature, humidity and particle concentration) after the accident? E2. Has the safety analysis been performed assuming that the temperature distribution of circulation loop of the passive safety system became the weakest condition to impede natural circulation due to fire? E3. Has the safety analysis been performed assuming that the piping shape of the passive safety system was deformed due to the earthquake and became the weakest condition to impede natural circulation?
A5. Reliability
E1. Has the reliability model of the passive safety system been reflected assuming the root causes in consideration of functional failure?
A6. Simultaneous operation of multiple systems
E1. Has the safety analysis been performed considering the effect of simultaneous operation of multiple (or multiple train) passive safety systems?
A7. Simultaneous operation of active & passive systems
E1. Has the safety analysis been performed considering the simultaneous operation of the passive safety system and the active system (non-safety system)?
A8. Evaluation of the effect of malfunction
E1. Has the safety analysis been performed considering the effects of malfunction and inadvertent actuation of the passive safety system?
A9. Considerations for human actions
E1 Has the safety analysis been performed considering the effects of operator intervention and measures?

※ A: Area, E: Evaluation Plan for the Regulatory Focuses

4. Summary

The advanced reactor and SMR, which are recently being developed domestically or abroad, are widely adopting the passive safety system. In addition to the existing regulatory guidelines, regulatory focuses applicable to the passive safety system are identified over the through analyses on up-to-date regulatory practices of foreign countries, which are the reports of OECD/NEA-WGRNR and WENRA-RHWG.

We think that the drawn regulatory focuses need to be referred to the development of the regulatory positions and the domestic safety review on the design of the passive safety system in conjunction with the existing regulatory guidelines.

The results of this study will be also used to resolve the performance and reliability issues of the passive safety system from the safety analysis perspective.

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