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Development of Core Heat Removal Objective Provision Trees for Sodium-Cooled Fast Reactor Defense-in-Depth Evaluation

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1. Introduction

Based on the definition of Defense-in-Depth levels and safety functions for KALIMER sodium-cooled fast reactor, suggested in the reference [1] and [2], OPTs for level 1, 2, and 3 defense-in-depth and core heat removal safety function, were developed and suggested in this paper.

The purpose of this OPT is first to assure the defense-in-depth design during the licensing of Sodium-Cooled Fast Reactors (SFR), but it will also contribute in evaluating the completeness of regulatory requirements under development by Korea Institute of Nuclear Safety (KINS). The challenges and mechanisms and provisions were briefly explained in this paper. Comparing the mechanisms and provisions with the requirements will contribute in identifying the missing requirements. Since the design of PGSFR (Prototype Gen-IV SFR) is not mature yet, the OPT is developed for KALIMER design.

2. Core Heat removal – Level 1 Defense-in-Depth

The objective of level 1 defense-in-depth (DiD) is the prevention of deviations from normal operation and failure. For the core heat removal safety function, acceptance criteria can be to transfer the power generated in the core to the ultimate heat sink respecting allowed temperature ranges on fuels and structures during normal operation.

2.1 Challenges

Identified challenges in this research for this safety function were as following;

- Coolant flow blockages in the core,
- degradation of heat removal through PHTS/IHTS/SGS/SFP,
- anomalous temperature distribution in the core, and
- excessive power levels,

For the completeness, system boundaries became the starting points of challenge identification. This approach has the advantage in that the consideration of system characteristics of existing design can be possible. In other words, the difference design conditions and characteristics of systems which contain different materials and pressures such as KALIMER.

2.2 Mechanisms

As mechanisms of the safety function degradation or failure, followings were identified;

- Debris,
- fuel element cracking or vessel internals failure,
- degraded or disrupted flow paths,
- loss of coolant inventory,
- loss of forced convection,
- loss of ultimate heat sink,
- loss of vital powers,
- loss of instrumentation and control,
- sodium-water reaction,
- Xenon oscillations or instabilities,
- uncertain power measurements, and
- cover gas incursion to coolant

These mechanisms were identified based on the following points of view;

- Cooling paths,
- coolant inventory,
- capability of cooling by forced convection,
- ultimate heat sinks, and
- other supporting functions such as vital electric powers, instrumentation and control.

The basis of mechanism identification was prepared separately from the OPTs as a technical basis for the development.

2.3 Provisions

Provisions for the identified mechanisms to the safety function degradation, were listed. Detailed design features in KALIMER design will be identified and findings and insights will be derived using developed OPTs as a next step of this research.

Mechanisms and provisions for the challenge “degradation of heat removal for SFP” were not included in the scope of this paper considering the design status of KALIMER reactor.

For level 2 DiD of core heat removal safety function, following provisions were selected for the mechanisms of debris and fuel element cracking or vessel internals failure;

- Reactor core is continuously monitored,
- Automatic shutdown is available all times,
- Monitoring of activity in the primary circuit,
- Margin in fuel thermal performance,
- Pool-type PHTS and large vessel,
- Natural circulation and heat transfer within the pool (high thermal conductivity of coolant),
- High heat capacity negative reactivity coefficient, and
- LCO for core cooling capability.

2.4 Objective Provision Trees

Among developed OPTs for level 1 and 2 DiD and core heat removal safety function, several samples were illustrated in Figure 1 to 4 as examples. OPTs for level 3 DiD core heat removal safety functions were suggested in the reference [1].

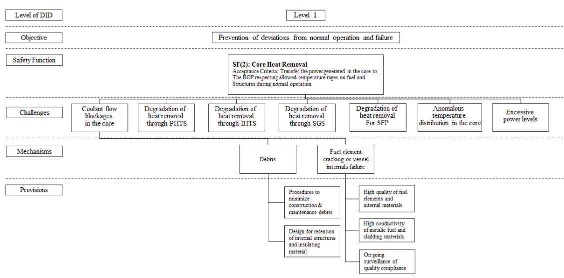

Figure 1 Level 1 DiD - Core Heat Removal (1/2)

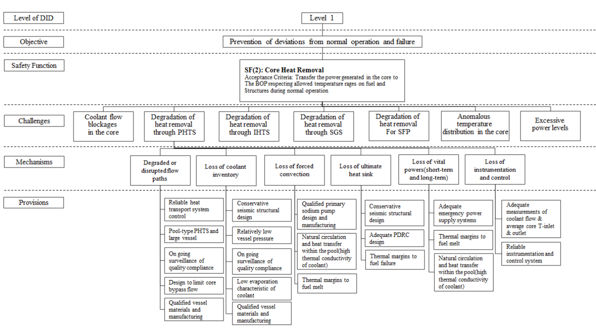

Figure 2 Level 1 DiD - Core Heat Removal (2/2)

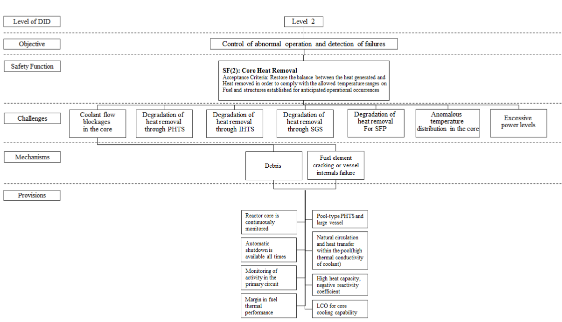

Figure 3 Level 2 DiD - Core Heat Removal (1/2)

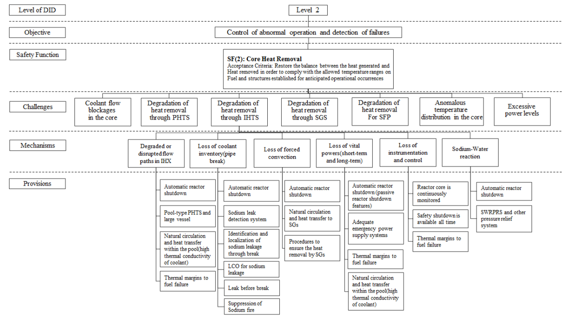

Figure 4 2 DiD - Core Heat Removal (2/2)

3. Conclusions

Developed OPTs in this study can be used for the identification of potential design vulnerabilities. When detailed identification of provisions in terms of design features were achieved through the next step of this study, it can contribute to the establishment of defense-in-depth evaluation frame for the regulatory reviews for the licensing process.

At this moment, the identified provisions have both aspects as requirements and design features already adopted in KALIMER design. In the next stage of this study, derived provisions to be adopted will be compared with the actual design features and findings can be suggested as recommendations for the safety improvement.

ACRONYM

PHTS: Primary Heat Transfer System,
IHTS: Intermediate Heat Transfer System.
SGS: Steam Generator System, and
SFP: Spent Fuel Pool.

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