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Preliminary comparison of mitigative effectiveness between WOG-based SAMG and PWROG-based SAMG in case of a severe accident initiated by TLOFW

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1. Introduction

1.1 Motivation of this work

Recently, the PWROG SAMG which is applicable to Babcock and Wilcox (B&W), Combustion Engineering (CE), and Westinghouse Pressurizer Water Reactor (PWR) Nuclear Steam Supply System (NSSS) designs was developed in February 2016 by incorporating the best features from the previous PWR generic SAMG, and PWROG recommended that its members apply the new SAMG. Accordingly, the study was started to improve the domestic SAMG framework based on WOG SAMG to PWROG SAMG [1]. It would be important to figure out the expected enhancement of the improved SAMG framework. This kind of evaluation can provide certain necessary insights for developing a realistically effective new SAMG framework.

1.2 Major Differences between the WOG and PWROG

In WOG-based SAMG [2], following the activation of the Technical Support Center (TSC), Severe Accident Guideline (SAG) is executed according to the sequence of DFC-SCST as shown in Fig. 1. Furthermore, within the WOG framework, there are dedicated steps evaluating the negative impacts before executing main steps in WOG SAGs and deciding whether to carry out the SAG mitigation actions according to the results of negative impact evaluation. Consequently, it can be depends on TSC decision maker and SAMG evaluator that the time spent for decision making and whether or not executing strategies within each SAG. On the other hand, in the PWROG-based SAMG, SAGs are executed based on the status of the DPG Worksheet as presented in Fig. 2. Moreover, within TSC SAGs of PWROG SAMG, mitigation strategies to alleviate negative impacts are assessed in-depth beforehand so that TSC can proceed the strategic actions based on relatively definite conditions. This can reduce uncertainties in consequential results which can be induced by different decisions and also in the length of time spent for executing steps of SAG.

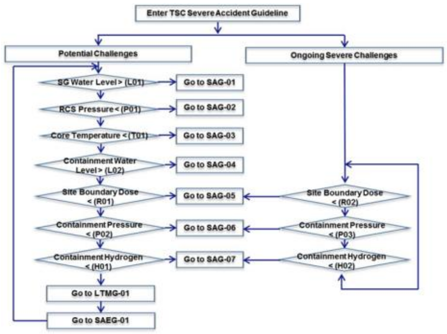

Fig. 1. DFC and SCST [3]

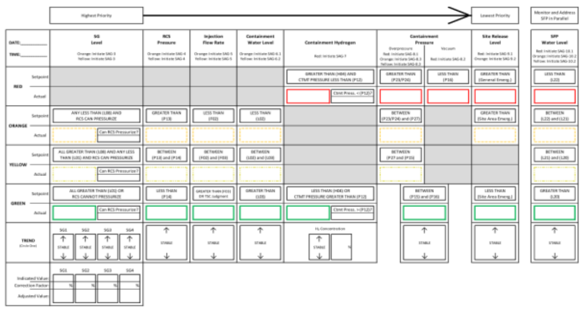

Fig. 2. DPG Worksheet

2. Methodology for comparison of SAMGs

The mitigative effectiveness of SAMGs are tried to be compared through simulations of the assumably expected situations when each SAMG is in progress. Modular Accident Analysis Program (MAAP) code is utilized for these SAMG simulations. The MAAP code is a comprehensive analysis tool capable of simulating the behavior of the reactor core, reactor coolant system, and reactor building in the event of a severe accident in a pressurized water reactor nuclear power plant. For this study, we utilized the latest version, MAAP5.06 [4], released in September 2021, and conducted analyses targeting the Westinghouse 3-loop plant. Fig. 3 shows the overall flowchart of this SAMG comparison study.

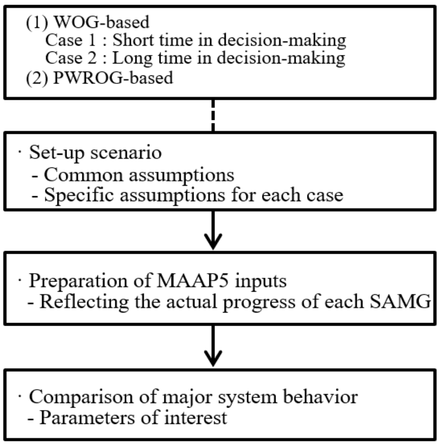

Fig. 3. Flowchart of the comparison process

2.1 Set-up scenario

For a preliminary study, a severe accident initiated by Total Loss of Feedwater (TLOFW) was set as the base scenario. In WOG-based SAMG, two cases are considered, which are for representing the uncertain range of time spent. Case 1 is for one with a shorter decision-making time and Case 2 is for one with a relatively longer decision-making time. For PWROG-based SAMG, it is assumed that only one case is considered, as it is unlikely to make significant differences in time spent for evaluation of negative impacts or in decision making for actions. By comparing these three cases, it is tried to figure out the enhanced effectiveness level in PWROG SAMG.

As a common assumption for each case, it was assumed that, within 30 minutes after the entry of a severe accident, depressurization successfully is achieved in SACRG-1 (Severe Accident Control Room Guideline) of the WOG-based SAMG and MCR SAG-1 of the PWROG-based SAMG. Additionally, at 1 hour after the severe accident, activation of TSC was assumed, and at 2 hours after the severe accident, the availability of portable equipment for the injection of primary and secondary systems was assumed. Additionally, the time required for executing each SAG was equally assumed to be 15 minutes for three cases in both SAMG.

Some specific assumptions for each case are needed to consider the time ranges resulted from the different processes of each SAMG structure. In WOG-based SAMG, two different times were assumed that entry into WOG SAG-1 after the ready for portable equipment. Because the time required is different in the elapsed time taken to re-enter WOG SAG-1 from the ongoing SAG since the portable equipment is available. And the time required for evaluating negative impacts was assumed to be 10 minutes for WOG-based Case 1 and 15 minutes for WOG-based Case 2. In the PWROG-based Case, no time is required for negative impacts assessment due to the characteristic of the PWROG SAMG. In this work, preliminary calculations were conducted partly considering a postulated period for performing WOG SAG-1 ~ 3, and PWROG SAG-3 ~ 5. To provide a clear understanding on assumptions in the time ranges for each case, the timeline was visualized in Fig. 4. For a more realistic assessment, it is essential to reflect sufficient realistic factors such as the practical time elapses for proceeding SAMG operations and other realistic conditions which had been observed during SAMG training experiences.

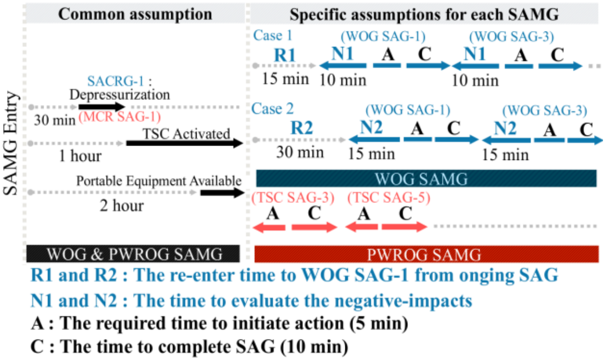

Fig. 4. Timeline for Assumptions of each SAMG

2.2 Preparation of MAAP5 inputs

In WOG SAMG, entering certain SAG is determined one directionally from top to bottom by DFC and SCST. For simulating this DFC and SCST in MAAP code, inputs were modeled in a logical sequence according to Fig. 1. The assumptions for the time spent of each case were reflected in this input systematically as shown in Fig. 4. In PWROG SAMG, the DPG worksheet provides optimal mitigation strategies to TSC by evaluating the plant conditions of the parameter-based. The DPG worksheet as shown in Fig. 2 is color-coded to assign a severity level to the parameters. Each parameter is assigned a setpoint range for those colors in order to select a priority SAG. For this preliminary evaluation, the setpoints required for the DPG worksheet were set temporarily referring to the set point values implemented in existing domestic WOG-based SAMG for Westinghouse 3-loop plant.

2.3 Comparison of major system behavior

Main parameters with which the mitigative effectiveness would be assessed comparatively were selected as the maximum core temperature and the mass of water in the core. Comparison of these parameters can provide intuitive recognition on the differences in the effectiveness of mitigation supported by two different SAMG frameworks.

3 Analysis Results

3.1 Accident Progression in each case

According to the common assumptions, the time sequences before getting the availability of portable equipment after a severe accident are the same in both SAMG framework cases. However, differences arise in the entry timing of a SAG due to the difference where WOG SAMG is proceeded along the sequential flowchart of DFC and SCST but PWROG SAMG is governed by priorities determined by DPG Worksheet. The overall differences in time sequences are shown in Table I. The PWROG framework by its scheme doesn't lead to the simple sequential execution of SAG-3, 4, and 5. Instead, certain SAG entry is determined by priorities of parameters of DPG Worksheet indicated by colors at every Worksheet update time. Moreover, because that PWROG SAMG doesn't require time spent on negative impact assessment, its SAGs can be executed in more timely and effective ways.

Table I: TLOFW Accident Sequence

Event	WOG-based (sec)		PWROG SAMG (sec)
	Case 1	Case 2	
TLOFW	0.0	0.0	0.0
Reactor Scram	30.9	30.9	30.9
SAMG Entry	4315.5	4315.5	4315.5
WOG SACRG-1 Entry PWROG SAG-1 Entry	6115.5	6115.5	6115.5
TSC Activated (No method)	7915.5	7915.5	7915.5
Portable equipment Available	11515.5	11515.5	11515.5
WOG SAG-1 Entry PWROG SAG-3 Entry	13315.5	14515.5	11815.5
WOG SAG-3 Entry PWROG SAG-5 Entry	14815.5	16315.5	12715.5

3.2 Comparison of effectiveness in mitigation

Fig 5. presents the water mass of the core. It can be observed that the core water level recovery in the PWROG SAMG case is the fastest, while in WOG-based Case 2, the water level recovery is the slowest. Consistently, Fig. 6. presents that the maximum core temperature of the PWROG SAMG case is mitigated in the earliest time. This enhancement of mitigative effectiveness would be what can be expected when PWROG SAMG would be implemented. Because, even a SAG itself can be executed in a shorter time spent by not requiring TSC to assess and review the negative impacts which might be induced by actions taken in each SAG.

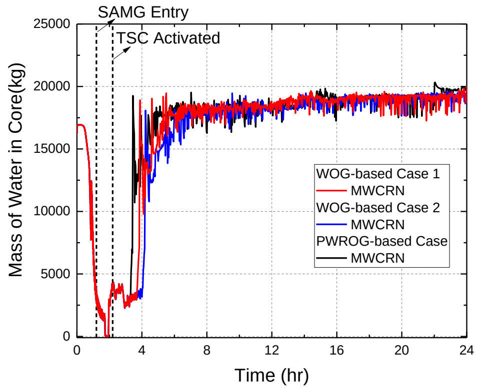

Fig. 5. Mass of water in the core

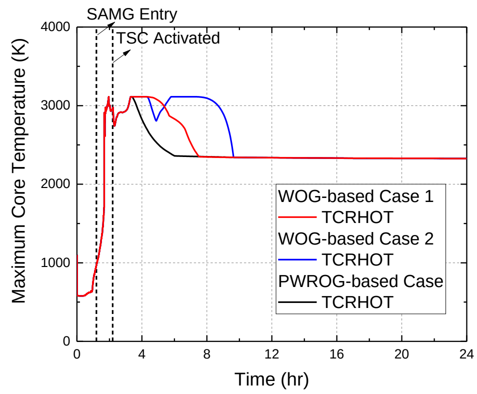

Fig. 6. Maximum core temperature

4. Conclusions

Through a preliminary comparative study, even though a number of tentative assumptions were used, it was shown that the mitigative effectiveness of PWROG SAMG might be better than that of WOG SAMG. It can be interpreted as that the philosophy and the fundamental scheme of PWROG SAMG might be established along the pursuit of the achievement of the enhanced safety so the enhanced expertise, the advanced knowledge, and insights from integrated experiences might be reflected in PWROG SAMG. The main crucial factor of this enhancement can be considered as timely updated SAG prioritization and removal of the process where TSC should use their time and effort for evaluating the negative impacts of certain mitigative actions to make their decisions during accident progression.

Further analysis of scenarios with various initial events and mitigation strategies is required to more practically represent the validity of the PWROG SAMG. In addition, analysis of more complex scenarios in which the several means to implement mitigation strategies are restored would be effective in indicating differences from the WOG SAMG. Moreover, it is also significantly important to identify a realistic time range for enabling more realistic evaluations and obtaining more practical findings.

Acknowledgement

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