EVALUATION OF SAMG EFFECTIVENESS IN VIEW OF GROUP DECISION

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We evaluate the technical and organizational aspects of the severe accident management guideline (SAMG), focusing on the decision-making process in the technical support center (TSC). From the technical aspects, we conclude that the present SAMG is a good tool that can assist the TSC in efficiently managing probable severe accidents. However, we suggest that the clear separation of the emergency operating procedure (EOP) and SAMG, which shifts plant control from the main control room (MCR) to the TSC, might not be an effective framework from an organizational perspective. Studies on organizational behavior demonstrate that a group decision made under a risky situation might be polarized in either a risky or cautious way. We recognize that we cannot be free from the polarization effect since the current SAMG recommends that the TSC evaluate the advantages and disadvantages of strategies to be implemented and choose the best one based on a group decision process. Illustrative examples of accident management under risky conditions are recapitulated from previous studies of the authors and we propose that the SAMG should be more proceduralized to remove this polarization from the decision-making process.

KEYWORDS : Severe Accident, SAMG, Technical Support Center, Group Polarization

1. INTRODUCTION

Multiple mechanical failures combined with human errors could lead to a complete failure of safety-related systems during a postulated initiating event. That is, it can lead to the loss of cooling capability for decay heat and end with the melting of the reactor core and internal materials. During this severe accident, the core damage and subsequent release of radioactive materials into the eco-system would threaten public safety and jeopardize environmental stability. Even though the probability of a severe accident is very low, if it occurs, the risk to public health and safety would be enormous; therefore, the severe accident management guideline (SAMG) must be complete to enhance the defence-in-depth concept of the fourth level.

Over the past decades, severe accident research has been the main focus in the area of reactor safety. Numerous research programs have been performed to better understand the various phenomena, to develop better management strategies, and to develop new safety features such as the concept of passive safety against a severe accident. However, it should be recognized that there are difficulties in implementing these new strategies and adopting the new safety features into existing operating nuclear power

plants (NPPs). The SAMG was developed for the many operating plants designed without any consideration against severe accidents, referencing the guidance set up initially by the U.S. Owners Group. The development of a plant-specific SAMG is required and should reflect the results of recent studies, and therefore should be an on-going process.

In Korea, the SAMG for pressurized water reactor (PWR) plants was developed and implemented as per the “policy statement on severe accidents of nuclear power plants” issued in August 2001 by the Korean government. The plant specific SAMG for Korean PWR plants was developed referencing the Westinghouse Owners Group (WOG) SAMG [1]. It is notable that the SAMG is intended to cover severe accidents for which the emergency operating procedure (EOP) may not be applicable. Thus, both the EOP and SAMG have to be developed to constitute the overall procedure against an accident. When an accident occurs in a nuclear power plant and becomes a severe accident condition, the plant operators in the main control room (MCR) abandon the usage of the EOP and the newly established technical support center (TSC) uses the SAMG to deal with the plant’s severe accident condition. During the transition from the EOP domain to the SAMG domain, the plant control authority shifts from the MCR to the

Fig. 1. Accident Management Framework

TSC, where several expert members at a higher level of plant organization make the decisions to respond to the severe accident plant condition. This shift is recommended because a group is regarded as better able to effectively make decisions than an individual in the highly uncertain conditions of a severe accident.

However, studies on organizational behavior show—as explained in detail in section 4—that a group decision under risky conditions with high uncertainty has a tendency to be polarized either into a cautious direction or a risky one. This implies that the group is unlikely to make the best decisions. This tendency generally comes from the interactions between group members under pressure and might seem to contradict the general belief that a group decision made by sharing the knowledge of group members (one of the advantages of a group decision process) will be better at overcoming the high uncertainties of severe accidents than a decision made by an individual. Decision-making is one of the most significant processes for accident management because human errors from choosing an inappropriate strategy can badly affect accident management. However, the effectiveness of a group decision-making process under risky conditions was not fully considered in the development of the present SAMG. Of course, IAEA NS-G2.15 “Severe Accident Management Programmes for Nuclear Power Plants” §2.31-2.38 mentions that accident management should be an integral part of the overall emergency arrangements and that roles and responsibilities for the different members of the emergency response organization involved be clearly defined. The most important thing in accident management is to cope properly with the accident within the correct time frame. Therefore, early and correct decision-making by the TSC is crucial in accident management, and this paper evaluates this decision-making process as implemented by the current SAMG. We conclude by suggesting a direction for future development of an effective SAMG.

2. SEVERE ACCIDENT MANAGEMENT GUIDELINE FOR KOREAN PWR PLANTS

2.1 Overview of SAMG for an Operating NPP

The overall management of an accident in the nuclear power plant is performed following the abnormal operating procedures (AOP), EOP, and SAMG. When an incident occurs at a plant, the plant operators use the EOP and prioritize preventing core damage. If the EOP’s preventive actions are not successful and core damage occurs, then the operator should perform appropriate mitigative actions according to the SAMG. Fig. 1 shows the accident management framework following the accident progression.

For most PWR plants, the transition criterion from EOP to SAMG is defined by the onset of core damage, which is indicated by a core exit temperature (CET) about 700 degrees from the thermocouple. Once the transition occurs, the prompt establishment of the TSC is required, and then the responsibility of the plant control shifts from the MCR to the TSC according to the emergency operating plan. Once entering into the SAMG, key safety parameters should be monitored in a sequential manner following the diagnostic flow chart (DFC). Fig. 2 [2] shows the DFC, which the TSC staff uses to diagnose the plant status and choose an appropriate strategy.

The SAMG provides structured guidance to identify the actions needed to stabilize the plant and return it to a controlled stable condition against an accident involving significant core damage. When any safety parameter value exceeds its limit, the TSC staff refer to the corresponding severe accident guideline to mitigate the accident progression. Because of large uncertainties in the phenomena, the TSC is expected to choose appropriate strategies taking into account all consequences.

The basic philosophy of the SAMG is to do one’s best using the available equipment to minimize the impacts from severe accidents under the given circumstances.

Fig. 2. Diagnostic Flow Chart (DFC) in SAMG [Ref.2]

Therefore, implementation of the SAMG in the operating plants does not necessarily require a hardware change. Of course, this does not mean that installing additional new hardware is forbidden. In some countries or utilities, hardware to deal with hydrogen has been newly installed. As shown in Fig. 2, the key parameters monitored in the DFC include a steam generator water level, reactor coolant system (RCS) pressure, core temperature, containment water level, fission product releases at the site boundary, and containment pressure and hydrogen concentration in the containment vessel.

2.2 Recapitulation of SAMG Strategies

We evaluated the SAMG strategies for the Korean operating plant Kori unit 1. We analyzed the operator's actions to determine if they are realistic and effective, and if the guidelines really enhance the plant's capability to handle severe accidents in terms of mitigating the negative impacts of each action in the accident progression. In the following, we summarize the evaluation results of our previous studies [3-5], and we believe the conclusions are still valid for the SAMGs of many other operating plants.

The severe accident management strategies are contained in a set of 7 mitigative guidelines.

The guidelines specify a method for systematic,

logical evaluation of possible strategies for responding to various parameters. Table 1 summarizes the seven mitigative strategies with their objectives and the recommended actions for corresponding equipment, which have been adopted by operating plants in Korea. Among the seven mitigative strategies, Mitigation-01 (inject into SG) and Mitigation-03 (inject into RCS) are duplicated from the EOP strategies. The actions or measures for these two strategies are well confirmed by the design basis accident (DBA) analysis because the primary tool for managing accidents is the injection of water for core cooling, which was adopted in the EOP. However, the goals in the EOP and SAMG could be different. The goal of the strategies in the EOP is to prevent accident progression, and the goal in the SAMG is to mitigate the consequences as much as possible. Despite this, operator actions in these two strategies are the same.

The Mitigation-02 (depressurize the RCS) strategy has been adopted by both the EOP and SAMG. In the EOP domain, secondary depressurization via steam generators is used to minimize RCS inventory loss. On the other hand, the SAMG recommends depressurizing the RCS directly via all possible relief pathways including the pressurizer relief valves in spite of excessive losses of RCS inventory and the release of radioactive materials. This rapid depressurization was added to the strategy to alleviate the so-called high pressure melt ejection/direct

Table 1. Severe Accident Management Strategy

SAG	Objectives	Mitigation Actions & Equipments
Mitigation-01 Inject into SG	to provide heat removal on the secondary side to protect the integrity of steam generator tubes to scrub fission products leaked from the primary side	<ul style="list-style-type: none"> • Inject into SG : SG Feed System • Depressurize SG : SG PORV or steam dump
Mitigation-02 Depressurize RCS	to establish safety injection for core cooling to prevent high pressure melt ejection (HPME)	<ul style="list-style-type: none"> • Depressurize RCS : PZR PORV • Depressurize SG : SG PORV or steam dump
Mitigation-03 Inject into RCS	to provide water to remove heat away from the core to prevent or delay RPV failure to scrub fission product of corium	<ul style="list-style-type: none"> • Inject into RCS : HPSI, LPSI
Mitigation-04 Inject into CV	to establish core cooling and maintain RPV integrity to minimize the amount of corium concrete interaction to reduce fission product release	<ul style="list-style-type: none"> • Inject into CV : Spray, RWST
Mitigation-05 Control FP releases	to reduce the fission products going out of the containment to reduce the risk of public exposure	<ul style="list-style-type: none"> • Depressurize CV : Spray & FCL • Dump steam to condenser • Vent Aux. building
Mitigation-06 Control CV conditions	to maintain containment integrity to reduce fission product release to maintain equipment and instrumentation operability	<ul style="list-style-type: none"> • Remove heat form CV • Depressurize or vent CV
Mitigation-07 Control CV hydrogen	to prevent hydrogen explosion	<ul style="list-style-type: none"> • Recombine H₂ : Recombiner • Burn H₂ intentionally, igniter • Inerting : Spray & FCL

containment heating (HPME/DCH) risk. Even though maximum discharge of the RCS inventory is efficient in reducing pressure rapidly, it could accelerate severe core degradation and cause reactor pressure vessel (RPV) failure earlier because of early depletion of the cooling water. It was shown that once we could depressurize the RCS, the HPME/DCH is not an issue because the system pressure at the time of vessel failure becomes lower than the pressure limit to prevent the phenomena. [5] In paper [5], it was also shown that the RCS inventory needs to be used more economically for an improved RCS depressurization strategy. The rapid depressurization could delay the onset of core degradation for one hour while the water inventory available depletes rapidly. The depletion of water makes further core cooling impossible and thus accelerates the reactor vessel failure. On the other hand, the slow depressurization uses water economically and water for core cooling becomes available much longer. Therefore, core degradation is not delayed by much, but the reactor vessel fails much later. Consequently, the TSC might need to decide at the beginning whether to rapidly depressurize the RCS expecting the power to recover soon, or depressurize slowly focusing on delaying vessel failure when early recovery of power is not guaranteed. The TSC should take the risk, and this issue is discussed in detail in section 4.2.

One objective of Mitigation-04 (inject into containment)

is to establish core cooling and maintain RPV integrity. The so-called in-vessel retention (IVR) strategy and the feasibility of the strategy for an operating plant is evaluated in the author's paper. [3] The other objective is to mitigate the molten corium concrete interaction (MCCI), which is based on the idea that water in the cavity might be better at cooling the corium than no water at all. This does not guarantee sufficient cooling of the corium or mitigation of the MCCI because the capability of the ex-vessel to cool the corium is still an unresolved international issue. The current SAMG requires the TSC to decide whether or not to implement the strategy in Mitigation-04 after evaluating both the negative and positive impacts. However, it is quite doubtful whether the TSC could really inject water into the cavity, and the objective of the action is unlikely to succeed because of the uncertainties in the strategy. In conclusion, the current SAMG is very weak in handling the debris coolability issue. [4]

In Mitigation-05 (control fission product release), the major action is to find the leak path and to isolate it, which is a rather mechanical guideline without deep physics. The other actions recommended are 1) to lower containment pressure using spray or fan coolers in order to reduce the driving force of fission product release, 2) to dump the steam generator into the condenser, and 3) to dump the fission product to aux-building. If spray or fan coolers

Table 2. Summary of Positive and Negative Impacts of Current SAMG Strategies

Positive Impact	Strategy	Negative Impacts
Prevention of High Pressure Melt Ejection Prevention of Creep Rupture of RCS Piping Initiation of Low Pressure Injection	Depressurize the RCS	Steam Explosions in RPV Loss of RCS inventory due to PZR POSRV Use Containment Overpressure
External Cooling of RPV Lower Head Adequate Containment Water level to allow recirculation Cooling of Ex-Vessel Core Debris Scrubbing of FP Release from Ex-Vessel Core Debris	Inject into Containment	Containment Challenge from a Hydrogen Burn Insufficient Spray Source Fission Product Release during RWST Gravity Drain
Reduction in Off-Site Release	Control FP Release	Containment Challenge from a Hydrogen Burn Insufficient Spray Source Containment Flooding Isolating ECCS/Spray Recirculation
Provide a Containment Heat Sink Equipment Survivability Reduction of FP Leakage from Containment	Control CV Condition	Containment Challenge from a Hydrogen Burn Insufficient spray source Containment Flooding
Reducing Containment Hydrogen Preventing a Hydrogen Burn	Control CV Hydrogen	Containment Pressurization due to Steam Inerting Long-term Recombiner Operation

are actuated, the behavior of the containment pressure should be analyzed in connection with Mitigation-06 (control containment condition). Actions 2) and 3) are intended to switch the release path to the condenser and aux-building using valves and dump system before the fission product goes to the environment directly. Therefore, it is expected that the release will be reduced by gravity settling of fission products. These effects are quite evident.

In Mitigation-06, the objective is to control the containment temperature and pressure. The main measures for these strategies are containment spray and fan cooler systems, which were originally designed to work under the DBA condition. However, availability of fan coolers in aerosol rich conditions in a severe accident is very unlikely. In addition, spraying the containment makes steam condense and thus could result in an increase of hydrogen concentration, and possibly cause a local hydrogen deflagration. Thus, the use of spray and fan coolers, designed under DBA conditions, in severe accident conditions can even aggravate accident management.

The objective of Mitigation-07 strategy is to prevent hydrogen risk. The equipment available for this strategy includes a hydrogen thermal recombiner, hydrogen igniter, and containment heat removal system, i. e., spray and fan coolers. However, the hydrogen thermal recombiner should not be used under severe accident conditions with elevated hydrogen concentration: deliberate ignition of hydrogen caused by sparks from motors is not a credited model in a real situation, especially in an SBO scenario. The other actions remaining are using spray and fan coolers to make

the containment atmosphere inerted or a de-inerted condition. These actions can aggravate the hydrogen control as described in the evaluation of Mitigation-06. Thus, to be confident that we could really manage the hydrogen in containment, the use of engineered safety features like passive autocatalytic recombiners (PARs) are needed. [3] Korean utility has already started to install PARs in old operating plants.

In summary, we conclude that the SAMG is a good tool that might help the TSC handle an accident in a confusing and harsh environment. However, the current SAMG requires the TSC to evaluate the negative and positive impacts of strategies and make a decision based on insufficient information. The summary of impacts is described in Table 2, section 4.

3. ORGANIZATIONAL ASPECT OF ACCIDENT MANAGEMENT

With regard to an organizational aspect of the SAMG, the current process of abandoning the EOP and focusing on the SAMG comes from the fact that actions in the EOP region and those in the SAMG should be mutually exclusive. One example is spraying the containment to control the containment pressure. This is a recommended action in the EOP to control the containment pressure, but in a severe accident, spraying the containment can increase the hydrogen concentration and this might lead to a local hydrogen deflagration. Nevertheless, our evaluation

results in the previous section clearly shows that we cannot credit the current strategies of controlling hydrogen in the current SAMG, and it is contended that the hydrogen control should be performed through an engineered safety feature (ESF) like PAR. Hence, by removing the hydrogen control from the current SAMG, the conflict between the EOP action and SAMG action also reduces. The conflict should not be a major factor in designing organizational aspects for accident management.

To manage the accident successfully, robust engineered safety features need to be installed, and correct and timely decision-making is essential. In the current SAMG, decisions to diagnose plant conditions and select the appropriate response strategies are made at higher levels, such as the technical support center, of the organizational hierarchical structure in emergency operations, unlike the MCR.

In this section, we will focus on the decision-making process in the plant operational organization, which should be reviewed in evaluating the effectiveness of the SAMG.

3.1 Operational Organization in Accident Management

During the transition from emergency operations to severe accident management, there is an important change in the plant operational organization according to the emergency plan. The EOP should not be used in most cases and the responsibility of plant control be transferred from the MCR to the TSC in the emergency response organization. Organizational aspects of EOP implementation are quite limited since they primarily involve the operations staff, with support from other staff as needed. However, SAMG implementation has more organizational implications including the delineation of the lines of responsibility for the actions, especially with regard to who is responsible for the evaluation, decision-making, and implementation of guidelines. In order to evaluate the effectiveness of accident management, it is essential to review the functions of the operational organization

including their authorities, responsibilities, and interactions. The operational organization in the TSC is shown in Fig. 3.

The decision-making processes in implementing the EOP and SAMG are based on the organizational responsibilities of the MCR and TSC, respectively. The MCR supervisor is responsible for all actions taken during normal and emergency operations. Once entering into the severe accident management domain, the TSC takes over the responsibility of the MCR to ensure a high level of performance in accident management. A typical on-site TSC staff includes a TSC director, TSC technical adviser, procedures expert, radiological expert, engineering advisors, and usually two accident management advisors to use the SAMG. The TSC director, as a decision authority, facilitates the decision-making process by describing the decision situation and asking for input from the team leaders, who are allowed to openly discuss, argue about, or agree on the best alternatives.

3.2 Decision-Making Process in SAMG

While the shift supervisor in the MCR is in charge of implementing the EOP, accident management is performed by TSC team leaders that evaluate the plant status and use the SAMG to determine the best recovery/mitigation strategies.

Each guideline of the SAMG contains one or more strategies and actions which might be used to respond to a plant safety parameter in the diagnostic flow chart, including a process for prioritizing challenges when more than one challenge exists. The guidelines present a method for a systematic, logical evaluation of the possible strategies that might be used in the given challenge. In addition, most SAMG strategies have both positive and negative impacts on either the progression or consequences of the accident; these impacts depend on the plant conditions at the time the strategy is implemented, and their magnitudes change as the accident progresses. Thus, a process for choosing the optimal strategy is required by weighing the

Fig. 3. Technical Support Center Organization

pros and cons of implementing each usable strategy. The decision-making process associated with the usage of the SAMG includes a number of discrete evaluations from the beginning of the SAMG usage, identifying SAMG challenges, selecting an optimal strategy, implementing the selected strategy, and finally evaluating the success or failure of the implemented strategy. Based on the TSC responsibilities in emergency organizations, decision-making during severe accident management is performed by a group of several expert team leaders, which is considered to be more effective than individuals.

The group is regarded to have some advantages in making a decision: 1) the amount of information and experience available can be increased by involving more individuals, 2) the group tends to generate more alternatives, possibly allowing a greater selection of satisfactory decisions, 3) communication and understanding are also increased when group decision-making is used. This, in turn, increases the likelihood of the decisions being accepted and supported. This is the reason why the group decision-making process is adopted when the TSC implements the SAMG.

In spite of these advantages, group decision-making has several drawbacks, such as in the amount of time needed to reach a consensus. Furthermore, the group tends to shift toward risky or cautious decisions as the uncertainty and risk rapidly increases, like under severe accident conditions. These inherent characteristics of the group decision have not been considered sufficiently in developing the current SAMG. Thus we need to consider and evaluate the effectiveness of the current SAMG organization reflecting this group behavior in risky dimensions because decisions in severe accident regimes inherently implies the utmost risks by nature.

4. GROUP DECISION-MAKING PROCESS IN TSC

4.1 Group Polarization under Highly Uncertain and Risky Condition

The performance of group decision-making has long been of interest to social psychologists. The prevailing views are either that group decisions will be more conservative than individual decisions, or that group decisions will represent an averaging (or simple convergence) of individual decisions.

An experiment [6] found that groups tend to exert the most influence toward those group members who deviate at the extremes: as the opinion of a deviant member is perceived to move toward the group's central tendency, the amount of communication directed toward him decreases. In support of the view that groups exert conservative influences on the individual, Barnlund [7] found that group members were more cautious and deliberate. He concluded that "the necessity of explaining a conclusion forced group members to be more self-

critical" and "group discussion was found to stimulate more careful thinking, to lead to a consideration of a wider range of ideas, and to provoke more objective and critical testing of conclusions." Thus, in general, group discussion was regarded to moderate extreme viewpoints, and opinions or courses of action would be compromised among members. It is often assumed that a group is more effective in solving problems and making decisions than individuals.

This expectation that a group conclusion is more conservative and objective is reflected in designing the current SAMG organizational structure. Because there are large uncertainties in the phenomena of severe accident progression, it was thought necessary to identify the current status of accident progression and handle the accident through a group decision. However, one set of circumstances for which this assumption no longer holds true is in decisions or choices that embody a clear dimension of risk.

In the 1960s, researchers studying group decision-making discovered that groups tended to produce riskier decisions than individuals, which they termed risky-shift phenomenon. [8, 9] The typical findings of organization behavior research is that on the average, subjects shift toward greater risk: that is, group discussion influences the group to accept alternatives with lower odds of success. This group-induced shift toward risk has been obtained with a wide range of decision content, including hypothetical decisions and situations where positive and negative consequences to subjects may actually result from their decisions. However, several other studies at that time found also just the opposite, i.e., a cautious shift, with group behavior erring on the side of undue conservatism. After several years, social psychologists realized that the risky shift was part of a more general process. That is, groups tended to make more extreme decisions than individuals, and the directions of this shift did not depend on the initial views of the group members. The entire phenomenon was then termed "group polarization." [10]

Several ideas [11,12] have been proposed to explain why group polarization occurs. One explanation is the social comparison approach. Prior to group discussion, individuals believe they hold better views than other members. During group discussion, they see that their views are not so far from the average, so they shift to more extreme positions. A second explanation is the persuasive arguments view. It contends that group discussion reinforces the initial views of the members, so they take a more extreme position. Both explanations are supported by research. It may be that both processes, along with others, cause the group to develop more polarized attitudes. Group polarization leads groups to adopt extreme attitudes. This concept of polarization in group decisions, irrespective of each individual's initial tendency, is conceptually shown in Fig. 4.

In the current SAMG, the TSC will implement a strategy evaluating the positive and negative impacts as summarized in Table 2. However, the TSC decision is

Fig. 4. Decision Shift by Group Polarization

Table 3. Top Events of SBO Accident

Case	No Depressurization	Depressurization by opening PZR POSRV	
		3 POSRVs	1 POSRV
Key Events	Time	Time	Time
Depressurization Initiation (when CET becomes larger than 650°C)	-	8.643 sec	8.643 sec
SIT Injection	-	9,063 sec	10,038 sec
SIT Empty	-	9,817 sec	33,606 sec
Clad Melt	13,472 sec	14,448 sec	10,639 sec
UO2 Relocation into Lower Plenum	16,800 sec	14,735 sec	37,679 sec
Vessel Breach	17,469 sec	22,980 sec	37,861 sec
Pressure at RPV Failure	16.7 MPa	0.39 MPa	0.78 MPa

not free from the group polarization described above, and the choice of strategy by polarization can have disastrous results in accident management if the chosen strategy is not optimal for the situation.

The impacts of strategy are not easy to evaluate because the magnitude of these impacts changes as an accident progresses and thus depend on the plant conditions at the time the strategy is implemented. The current SAMG is not prescriptive enough to choose the appropriate strategy and the final decision is left to the TSC group. These problems have not been considered sufficiently in developing the current SAMG, and an illustrative simulation can be effective to understand this group polarization effect on real decision-making situations.

4.2 Illustrative Example of TSC Decision- Making for Accident Management

Many studies on SAMG strategies have been performed to develop more effective severe accident management strategies [5,13,14], but no research result that takes into account this group polarization on an organizational

framework is available. In order to highlight the TSC group decision-making process under a risky condition and thus propose the direction for the development of a severe accident management guideline, we would like to recapitulate previous studies by the authors.

Evaluation on the effects of PZR POSRV numbers for depressurization was performed for an operating plant Ulchin 1&2 in Korea using the MELCOR 1.8.6 code. The Ulchin 1&2 are 3-loop Framatome PWRs with three reactor coolant pumps and three steam generators at 2,775 MWt of power. The details of the simulation can be found in the authors' paper. [5] Rapid depressurization is required in Mitigation-02 as shown in Table 1. Looking at Table 2 of the present SAMG, the TSC needs to decide a strategy to implement evaluating the negative and positive impacts. Experiments opening one valve and three valves were simulated and the results are summarized in Table 3. The RCS pressure at the time of RPV failure is much lower than the pressure set point of 2.75 MPa, which was introduced to the SAMG to alleviate the negative impacts of HPME/DCH. The simulation shows that we can satisfy this set

point in case we could open any POSRVs regardless of their number. However, the vessel failure is greatly delayed if we depressurize by opening one POSRV only. As is also described in section 2.2, the present SAMG does not mention this effect and recommends opening three POSRVs to rapidly depressurize the system. Given that the HPME/DCH can be alleviated by RCS depressurization with opening any number of POSRVs, the focus or purpose of Mitigation-02 strategy needs to be different from the present one and this necessitates a decision in choosing a strategy as follows.

With regard to efficient accident management, it is important to provide plant staff more time to recover failed safety systems until the RPV fails. In addition, RPV integrity should be maintained as long as possible in order to mitigate the phenomena challenging containment integrity. For the case of opening three POSRVs, the vessel fails at 6.38 hours after an SBO begins. On the other hand, by opening one POSRV, the vessel breach time is delayed to 10.5 hours and the probability of recovering power at 10.5 hours increases to about 96%, referring the PSA result. [15] Thus the grace time to recover the failed safety systems might be increased and the termination of accident progression could be ensured with greater confidence. In case water can be top-flooded at this time, it was also shown that ex-vessel corium coolability could be ensured according to a rough estimation using the recent OECD/MCCI experimental data. [16]

This simulation clearly shows that the consequences of accident management could be very different depending on which strategy is chosen. If the TSC ascertains that power will recover within 6 hours, operators should open three POSRVs for accident management keeping the vessel integrity. If the power is estimated to recover later than this, the TSC should choose to open one POSRV waiting for the power to recover. Choosing the latter strategy means that TSC should be ready to accept a highly risky condition because the focus of accident management shifts to preserving containment integrity not vessel integrity. Hence, in a condition where there is insufficient information, the decision-making by TSC should get involved, and the consequence of a decision gives huge difference depending on whether it was right or not. Unfortunately, in this case the decision of the TSC is not free from the polarization described above.

The TSC could give a polarized decision not balancing the negative and positive impacts well. There is no evidence that we could overcome this deficiency by controlling the group members' tendency or other communication skills. The only way, so far, seems to remove the group decision-making process itself as much as possible. This means that the SAMG should be proceduralized as much as possible taking into account recent research results.

Another example for the needs of proceduralization of the SAMG comes from the evaluation of Mitigation-4 strategies. [4] Mitigation-4 is a strategy to inject water

into the reactor cavity and the current SAMG mentions only implementing the strategy with the evaluation of the negative and positive impacts of the strategy as in Table 2. However, the simulation by the authors for an operating plant shows that the operator should flood the cavity within 10 hours after the SBO accident initiates. To make Mitigation-4 strategy more effective, it should describe how to detect either the breach of the reactor vessel or discharge of corium into the reactor cavity, when to flood the cavity, and so on. We like to clarify that all the values used in this argument comes from the MELCOR code simulation and it is quite possible that in a real situation the values might be different from the calculation. However, severe accident management should be based on the knowledge we have at this time. Even though there are uncertainties in simulating a severe accident, this kind of information is not provided in the present SAMG and thus it may be hard to rely on the decision of the TSC for effective accident management.

5. CONCLUSION

We have recapitulated the technical adequacy of the present SAMG. Even though it is a good tool against the hard conditions of a severe accident, the SAMG needs engineered safety features to reliably control the hydrogen. Clear-cut separation between the EOP and SAMG needs to be re-evaluated taking into account the research results of organizational behavior. From the organizational aspect of the present SAMG, an important change with regard to the plant operation organization is moving individual decision-making of a shift supervisor in the MCR to group decision-making in the TSC. It is often assumed that a group is more effective in solving problems than individuals. The prevailing views on decision-making are either that group decisions will be more conservative than individual decisions or that group decisions will represent an average (or simple convergence), of individual decisions. This expectation that a group's conclusion is more conservative and objective is reflected in designing the current SAMG organizational structure. Because there are large uncertainties in the phenomena of severe accident progression, it was thought necessary to identify the current status of accident progression and to handle the accident through a group decision. Thus, when entering into the SAMG regime, the control of managing the accident shifts from the MCR operators to the members of the TSC, which is constituted of a group of plant executives.

One set of circumstances for which this assumption on group decision no longer appears to hold is in decisions or choices that embody a clear dimension of risk. Organization behavior research finds that on average, subjects shift toward greater risk or a more cautious direction irrespective of the members' initial tendency. That is, a decision through group discussion is apt to be polarized.

The phenomenon of group polarization is complex and it is not clear what will happen when the TSC makes group decisions managing a severe accident.

According to the current SAMG, the TSC needs to evaluate the advantages and disadvantages of the strategy to be implemented and choose a specific strategy based on the group decision, which cannot escape this polarization effect. If the TSC comes up with a risky decision through this risky shift with group polarization, the result could be catastrophic.

Of course, we do not know whether a line organization, like the current MCR organization, could make a better decision or not. There is no research and evidence on this problem, but the polarization of group decisions was supported by many experiments in many different conditions. Therefore, we would like to say that the decision-making process in the EOP, which is more clear and proven than the SAMG, might be better for the severe accident management. Furthermore, a better way seems to proceduralize more of the SAMG to eliminate these group decision-making process as much as possible. In addition, this conclusion could depend on the design of the NPP and/or degree of understanding of the related strategies on accident management. It could be argued that the current design does not cover all severe accidents and therefore, the SAMG cannot be described in a procedural way. In other words, the SAMG inevitably includes some diverging points that need specialists' discussions depending on the severe accident progression. We must keep in mind that all the severe accidents occurred so far were not managed properly, including TMI and the recent Fukushima accident. We do not have much information on how the decisions were made in the initial period of the accident at Fukushima either, so we believe it is right to raise questions whether right decisions at the right time for accident management were made. Since there is sound evidence that group decisions are not the best strategy under risky conditions, the current SAMG needs to be more proceduralized to remove this group polarization. Recent research results show that it is possible to make the SAMG more proceduralized at least for some strategies.

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NOMENCLATURE

AOP	: Abnormal Operating Procedure
CET	: Core Exit Thermocouple
CV	: Containment Vessel
DBA	: Design Basis Accident
DCH	: Direct Containment Heating
DFC	: Diagnostic Flow Chart
EOP	: Emergency Operating Procedure
ESF	: Engineered Safety Feature

FCL	: Fan Cooler
HPME	: High Pressure Melt Ejection
MCCI	: Molten Core Concrete Interaction
MCR	: Main Control Room
PAR	: Passive Autocatalytic Recombiner
POSRV	: Pilot-operated Safety and Relief Valve
PZR	: Pressurizer
RCS	: Reactor Coolant System
RPV	: Reactor Pressure Vessel
RWST	: Reactor Water Storage Tank
SAMG	: Severe Accident Management Guideline
SBO	: Station Black Out
SIAS	: Safety Injection Actuation Signal
SIT	: Safety Injection Tank
TSC	: Technical Support Center

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