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Improvement of Diagnostic Flow Chart in Severe Accident Management Guidance of OPR1000 Reflecting Fukushima Accident Experience

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1. Introduction

While a possibility of severe nuclear accidents is very low, its consequence may be serious as seen in the Fukushima accident which occurred in Japan in 2011. By the reason it is very important to be prepared a complete procedure or a systematic guidance which helps plant staffs to control the severe accident in the nuclear power plant effectively and efficiently to minimize the consequences. EPRI suggested candidate for high-level actions to cope with such a severe accident and discussed their effects in the Reference [1]. Westinghouse owners group (WOG) developed generic severe accident management guidance (SAMG) for Westinghouse type power plants [2]. A diagnostic flow chart (DFC) is used in the technical support center (TSC) to help the TSC staffs who select appropriate severe accident mitigation guidance according to the plant states. In Korea, a SAMG for OPR1000 reactor was developed based on the foregoing WOG SAMG [3]. At that time, a station blackout rule did not consider a prolonged station blackout which took placed in the Fukushima accident. While a prolonged station blackout may result in the reactor vessel failure, the current DFC is focused on cooling the reactor core and thus it may not be effective in managing the plant resources when the reactor vessel ruptured. Thus, an improvement of the current DFC is required to overcome the aforementioned shortcoming.

2. Current DFC for OPR1000 Reactor

During TMI-2 accident, plant power was available during whole period of accident progression. The operator could restart an emergency core cooling system and injected emergency cooling water into the reactor vessel. The accident progression was terminated after emergency water injected into the reactor. Even though large amount of melted core materials were relocated to the reactor lower vessel, the reactor vessel was intact and held all core materials within the vessel. The DFC for the OPR1000 reactor was developed based on WOG DFC. Seven severe accident guidances (SAGs) are developed considering OPR1000 design characteristics: SAG-1 (Inject into Steam Generators), SAG-2 (Depressurize RCS), SAG-3 (Inject into RCS), SAG-4 (Inject into Containment), SAG-5 (Reduce Fission Product Releases), SAG-6 (Control Containment Conditions), and SAG-7 (Reduce Containment Hydrogen). The implementation order of these SAGs is shown in Figure 1. Most operator actions are focused on cooling the corium within the reactor vessel. For a certain plant, SAG-4 is effective to cool the corium by external vessel cooling. But external vessel cooling is not a viable means in the OPR1000 reactor, thanks to the reasons described in the next section.

3. Reflection of the Fukushima Lessons in Improvement of the Current DFC

The Fukushima accident is fundamentally different from TMI-2 accident in 1979. In the Fukushima accident the plant power was lost very long time, so operator could not inject water into RCS. As a result, the rupture of reactor vessel was inevitable. After the reactor vessel, the most molten corium drops to the reactor cavity and resides in the reactor cavity, not in the reactor vessel. The operator actions to inject into SGs, to depressurize RCS, and to inject into RCS, are useless after the reactor vessel rupture. Instead, injection into the reactor cavity is important to cool the corium in the reactor cavity. So we divided the plant status and operator actions based on the reactor vessel integrity.

When the reactor vessel is intact, current DFC is effective and efficient. But SAG-4 Inject into the containment is not needed for the OPR1000 reactor because the external vessel cooling is not possible in the OPR1000 reactor. To succeed cooling of the corium within the reactor vessel by the external cooling, sufficient water should be supplied to the outer surface of the reactor vessel and the critical heat flux should be higher than the thermal load to the reactor vessel surface. For the OPR1000 reactor, the critical heat flux is sufficiently higher than the thermal load if sufficient water is supplied to the reactor vessel outer surface and steam exit path exists. The OPR 1000 reactor is surrounded by the thermal shield. The structure of the thermal shield does not allow sufficient water supply to the outer surface of the reactor vessel. So external vessel cooling may not be possible in the OPR1000 reactor. Wet cavity may cause steam explosion at the time of the reactor vessel rupture and may results in the containment integrity challenge. Maintaining dry cavity eliminates the possibility of steam explosion in the reactor cavity at the reactor vessel rupture. So the step which determines the necessity of SAG-4 is omitted when the reactor vessel is intact.

After the reactor vessel failure, the actions to inject into SGs, to depressurize RCS, and to inject into RCS, are not necessary. So the step which determines the necessity of SAG-1, SAF-2, and SAG-3 are deleted. Among the parameters which are used to determine the controlled end stable plant status, the core exit temperature is useless. Instead, the containment water level is useful. A modified DFC for the OPR1000 reactor is illustrated in Figure 2.

It is important to make a provision for instrumentations which can identify the presence of corium in the reactor cavity. The representative one is the cavity temperature indicator. The gas temperature of reactor cavity becomes very high for dry cavity condition if the corium resides in the reactor cavity. When the reactor cavity is wet, the gas temperature is at a saturated state or slightly higher than the saturation temperature, making the external vessel cooling difficult in the OPR1000 reactor. So it is recommended to maintain the cavity dry while the reactor maintains its integrity. After the reactor vessel fails, it is needed to inject water into the reactor cavity to cool the corium in the reactor cavity and prevent core concrete interaction as shown in Figure 2.

4. Conclusions

While the current DFC for the OPR1000 reactor was developed without considering a prolonged station blackout, the Fukushima accident proved a possibility of such type of events. If power is not available for a long period of time, it is expected that the reactor vessel failure is inevitable. In that case, the accident management strategies should be taken depending on where the corium is located. A newly proposed DFC can help TSC staffs in managing effectively severe accident at the OPR1000 reactor. To implement properly the new DFC, it is important to prepare relevant instrumentations, which can identify the presence of corium in the reactor cavity.

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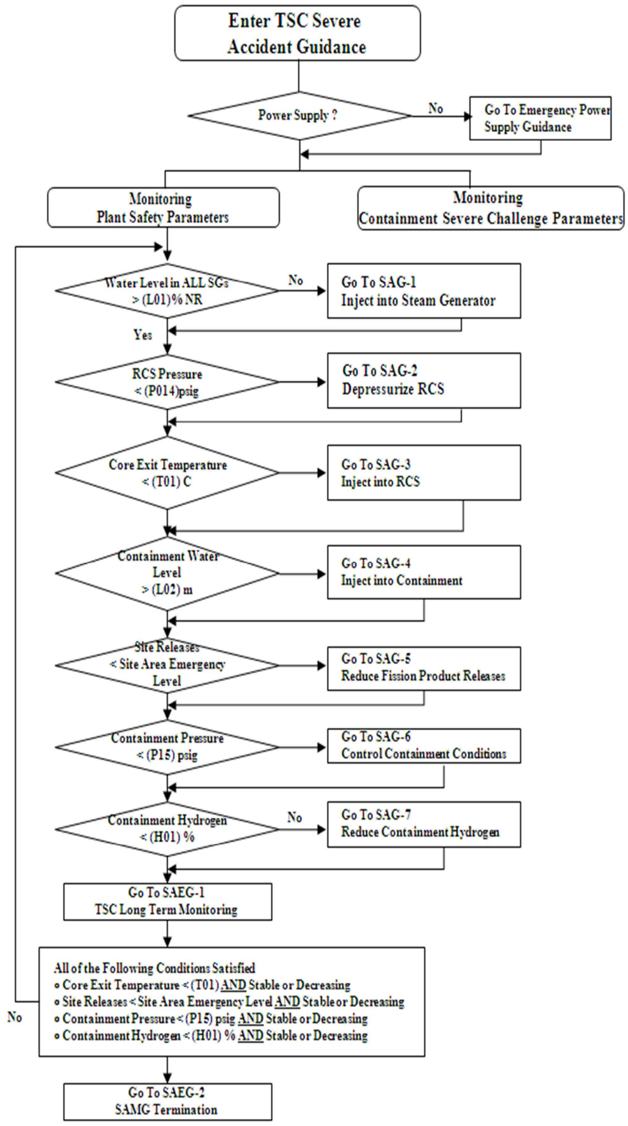

Fig. 1. Current Diagnostic Flow Chart for OPR1000

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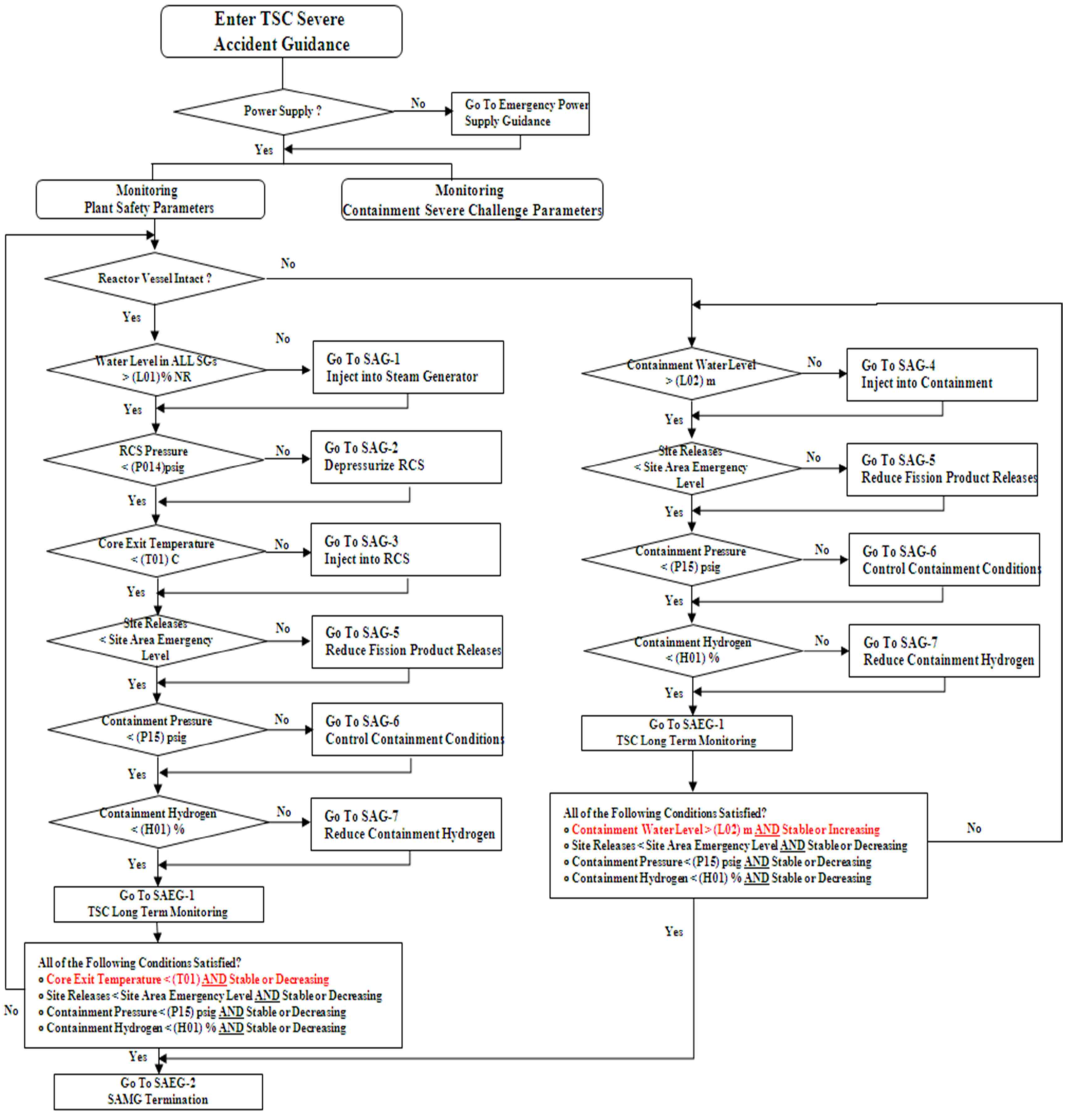

Fig. 1. New Diagnostic Flow Chart for OPR1000