The Improvement of OPR1000 and APR1400 Emergency Operating Guidelines to Cope with the Multiple Failure Accidents and Beyond Design Basis External Event

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1. Introduction

Since the Fukushima Dai-ichi Nuclear Power Plants (NPPs) accident due to the Great East Japan Earthquake, nuclear industries worldwide have made a tremendous effort to enhance the NPPs to cope with the beyond design basis external events. In this context, the Korean regulatory agency recommended the licensees to establish coping strategies for Beyond Design Basis External Events (BDBEEs) and Multiple Failure Accidents on 2016. [1]

This paper briefly introduces the improvement characteristics of the Emergency Operating Guidelines (EOGs) to restore OPR1000 and APR1400 NPPs from BDBEEs such as Extended Loss of All AC Power (ELAP) and Multiple Failure Accidents such as Loss of Ultimate Heat Sink (LUHS), Anticipated Transient Without Scram(ATWS), Station Blackout(SBO), Multiple Steam Generator Tube Rupture(MSGTR), Total Loss of Feedwater (TLOFW), Interfacing System Loss of Coolant Accident (ISLOCA), Loss of Shutdown Cooling (LOSC), Small Break Loss of Coolant Accident (SBLOCA) with Safety Injection (SI) Fail, and Loss of Spent Fuel Pool Cooling (LOSFPC). These EOGs consist of a total of 10 guidelines, some of them would be utilized in conjunction with the Multi-Barrier Accident Coping Strategy (MACST) Operating Guidelines (MOGs).

2. EOGs Improvement for Multiple Failure Accident

The EOGs have been improved for reflecting the 9 Multiple Failure Accidents described in Notice No. 2017-34 of the Nuclear Safety and Security Commission as shown in Figure 1. [2][3]

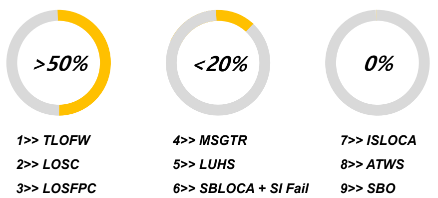

Fig 1. The degree of quantitative change of EOG

The Figure 1 shows that the three Multiple Failure Accidents (TLOFW, LOSC, LOSFPC) cause a lot of changes in the EOGs or development of new guidelines and the other three Multiple Failure Accidents (MSGTR, LUHS, SBLOCA+(HP)SI fail) cause a slight change in the EOGs. The remaining three Multiple Failure Accidents (ISLOCA, ATWS, SBO) does not affect the EOGs because they are already considered in the EOGs.

The left side of Figure 2 explains that if a TLOFW occurred, operator actions should be directed towards conserving the available SG water inventory and re-establishing feedwater flow to the Steam Generators (SGs) so that RCS heat removal capability is maintained or restored in EOG-07. Finally, the operator is given explicit instructions to go to the Functional Recovery Guideline (FRG) to initiate once-through-cooling (OTC) when the complete loss of the SGs as a heat sink is confirmed. However, to add a Multiple Failure Accidents recovery strategy in Optimal Recovery Guideline (ORG), initiating OTC strategy was added EOG-07 as shown in the right side of Figure 2. Therefore, the operator actions can be fulfilled quickly by adding a OTC strategy in EOG-07.

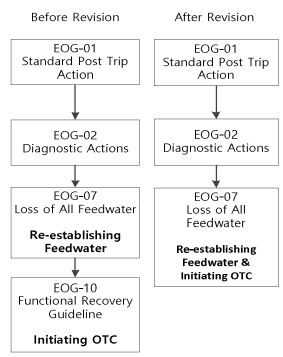

Fig 2. TLOFW recovery strategy

The SEOG-4(Shutdown EOG-4) has been developed using the strategy shown in Figure 3 to recover the LOSC.

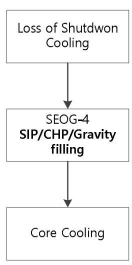

Fig 3. LOSC recovery strategy

The MOG-11 was developed to restore the level of the Spent Fuel Pool (SFP) after loss of SFP cooling function. After accident occurs, operator should continuously supply water to the SFP when the SFP level is decreased using the MACST equipment (Low Pressure Mobile Pumps, etc.) as shown in Figure 4. [3][4].

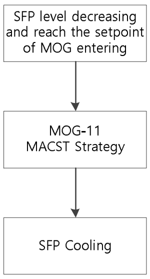

Fig 4. LOSFPC recovery strategy

The MSGTR is assumed that multiple SG U-tubes were ruptured at the same time. The potential exists for flow of reactor coolant via the tube rupture into the damaged SG and filling the SG steam space and the main steam line to the Main Steam Isolate Valve (MSIV). This could result in the inadvertent opening of the Main Steam Safety Valves (MSSV) and presents an undesirable spread of contamination. If the damaged SG level is rising due to RCS in-leakage, the operator actions should be directed to maintain the damaged SG level promptly to prevent over filling. Thus operator actions were changed in the EOG-5 as shown Figure 5. [2][3]

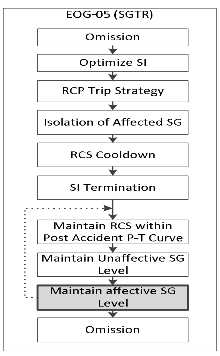

Fig 5. MSGTR recovery strategy

The LUHS is assumed that Loss of Essential Service Water System (ESWS) is failed. If a LUHS occurs, all components affected by ESWS cannot be used. Moreover, if ESWS is not recovered, the plant cannot fulfill the shutdown cooling.

If a LUHS occurred, operators should use the MACST equipment to maintain the safety functions. Thus, the LUHS mitigation strategy including MOG instruction was added in the EOG-08 as shown in Figure 6. The main LUHS recovery strategies are as below:

- Open the main equipment room
- Maintain SFP level
- MACST equipment staging
- RCS cooldown
- Maintain SG level
- Using the MACST equipment (high flow mobile pump, etc.)

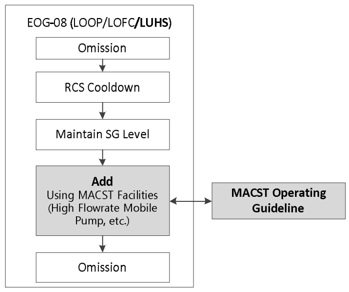

Fig 6. LUHS recovery strategy change

A LOCA is an accident which is caused by a break in the RCS pressure boundary. A LOCA is characterized by an initial decrease in RCS pressure. Thus, Safety Injection (SI) pumps are actuated automatically. But SBLOCA with SI fail accident is assumed that all SI pumps are not actuated. If SBLOCA with SI fail occurs, rapid RCS cooldown is to be performed for SIT injections, SCP (APR1400) or LPSI (OPR1000) injection as shown Figure 7. [2][3]

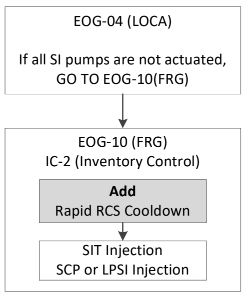

Fig 7. SBLOCA with SI fail recovery strategy

3. EOGs Improvement for BDBEEs

The Fukushima Dai-ichi accident was result of a tsunami that exceeded the plant's design basis earthquake and consequently flooded the site's emergency power supplies and electrical distributions system. The BDBEEs (e.g., seismic, flooding, tsunami, etc.) such as Fukushima Dai-ichi accident has characteristics that could challenge the design of Structures, Systems, and Components (SSC's) and lead to potential loss of critical safety functions.

The 3-phase MACST strategies have developed All nuclear power plants in Korea to cope with ELAP resulting from BDBEEs. [3][4]

Table I: 3-Phase MACST strategies

Phase 1	Accident mitigation using stationary equipment.
Phase 2	Accident mitigation using onsite mobile equipment.
Phase 3	Restoration of stationary equipment. accident mitigation using stationary and all mobile equipment including offsite resources.

If a ELAP occurred, operators should use the MACST equipment to maintain the safety functions. Thus, the ELAP mitigation strategy and MOG instruction was added in the EOG-09 as shown in Figure 8. [2][3]

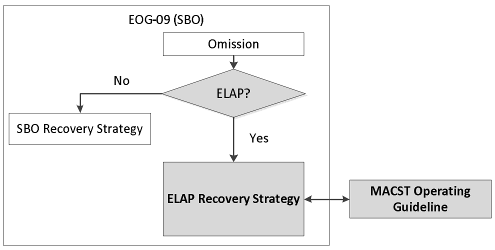

Fig 8. ELAP recovery strategy

The main recovery strategies for ELAP are as below:

First, an RCS cooldown is performed using natural circulation and stationary equipment in accordance with maximum cooldown rate. Second, the operators attempt to restore a source of electrical AC power, using the 1MW mobile D/G. To maintain the Safety Fuctions for core cooling, SFP cooling and containment integrity using the MACST equipment (low pressure mobile pump, high pressure mobile pump etc.) are used. Third, operator maintain the plant stable, using stationary and all mobile equipment.

4. Conclusions

The Fukushima Dai-ichi accident was a result of a tsunami that exceeded the plant's design basis earthquake and consequently flooded the site's emergency power supplies and electrical distributions system in 2011.

All of NPPs in Korea have developed MACST strategies to cope with BDBEEs.

Also, the EOGs have been improved and/or newly developed for reflecting Multiple Failure Accidents and BDBEEs.

REFERENCES

[1] Notice No. 2016-2, 2016-3 of the Nuclear Safety and Security Commission.
[2] Emergency Operating Guideline for OPR1000, KEPCO E&C, KHNP, 2019.
[3] Emergency Operating Guideline for APR1400, KEPCO E&C, KHNP,2019.
[4] MACST Operating Guideline for Hanul 3&4, KEPCO E&C, KHNP, 2019.
[5] MACST Operating Guideline for Shin-Hanul 1&2, KEPCO E&C, KHNP, 2019.