Coping Strategies for Beyond-Design-Basis External Events: Insights from the U.S. EDMG and FLEX Approaches

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1. Introduction

An extended loss of all AC power occurred at the Fukushima Daiichi nuclear power plant, on March 11, 2011, by a large earthquake and subsequent tsunamis. This event led to loss of reactor core cooling and containment integrity functions at several units of the site, ultimately resulting in large release of radioactive materials into the environment. Extreme events, or beyond-design-basis external events (BDBEEs), as occurred in the Fukushima Daiichi plant, may threaten plant safety by disabling critical safety functions of nuclear power plants for an extended period. Therefore, coping strategies need to be developed to further enhance nuclear safety by maintaining or restoring core cooling and containment integrity for BDBEEs.

This paper reviews the U.S. EDMG and FLEX approaches from the perspective of coping strategies, and proposes an integrated strategic approach to cope with BDBEEs by extending the concepts of EDMG and FLEX. The proposed integrated coping strategies include operation strategies for specific accident conditions, extension or revision of emergency operating procedures (EOPs), integration between EOPs and severe accident mitigation guidelines (SAMG), and so on.

2. Review of the U.S. EDMG & FLEX

The main purpose of the U.S. EDMG (Extensive Damage Mitigation Guideline) is to provide mitigation strategies to maintain and restore core cooling, containment, and spent fuel pool (SFP) cooling capabilities to cope with the loss of large areas of the nuclear facility due to large fires or explosions. EDMG includes establishment of the initial command and control, and mitigation strategies for maintaining and restoring safety functions. This paper reviews the EDMG approach by focusing on plant operation strategies.

Fig. 1 shows typical mitigating strategies suggested in an EDMG for PWRs. As shown in Fig. 1, the main strategy for core cooling is to use the turbine (or diesel)-driven AFW pump. The basis for establishing these mitigating strategies is the assumption that RCS is intact.

- Makeup to RWST
- **Manually Depressurize SGs to Reduce Inventory Loss**
- **Manual Operation of Turbine (or Diesel)-Driven AFW Pump**
- **Manually Depressurize SGs and Use Portable Pump**
- **Makeup to CST**
- Containment Flooding with Portable Pump
- Portable Sprays

Fig. 1. Mitigating strategies of EDMG for PWRs

The objective of the diverse and flexible coping strategy (so called FLEX) is to establish an indefinite coping capability to prevent damage to the fuel in the reactor and spent fuel pools and to maintain the containment function by utilizing installed equipment, on-site portable equipment, and off-site resources. This capability will address both an extended loss of alternating current (AC) power (ELAP) and a loss of the ultimate heat sink (LUHS), which could arise from a BDBEE.

Fig. 2 shows the level of defense-in-depth that will be increased when FLEX is implemented at a site. The current FLEX approach focuses on enhancing the station blackout (SBO) coping capability by adopting diverse and flexible coping strategies.

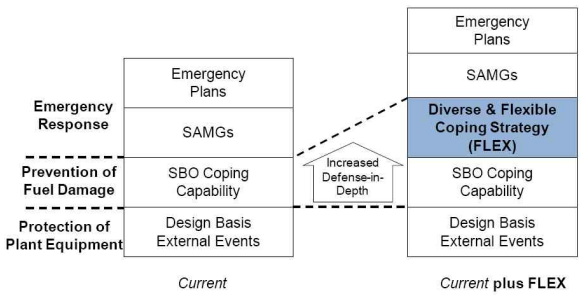

Fig. 2. Enhanced defense-in-depth by FLEX

Fig. 3 shows the overall process for site-specific FLEX implementation. The first step of FLEX capability development is the establishment of the baseline coping capability to address a simultaneous ELAP and LUHS event. The second step involves the evaluation of the external hazards that are considered credible to a particular site. External hazards have been grouped into five classes: (1) seismic events; (2) external flooding; (3) storms such as hurricanes, high winds, and tornadoes; (4) extreme snow, ice, and cold;

and (5) extreme heat. The third step involves definition of site-specific capabilities with consideration of the aggregate set of on-site and off-site resources for the hazards that are applicable to the site. The site should aggregate all of the considerations such as protection of FLEX equipment, deployment of FLEX equipment, procedural interfaces, and utilization of off-site resources. In addition, considerations also have to be given to programmatic controls including quality attributes, equipment design, equipment storage, procedure guidance, maintenance and testing, training, staffing, and configuration control.

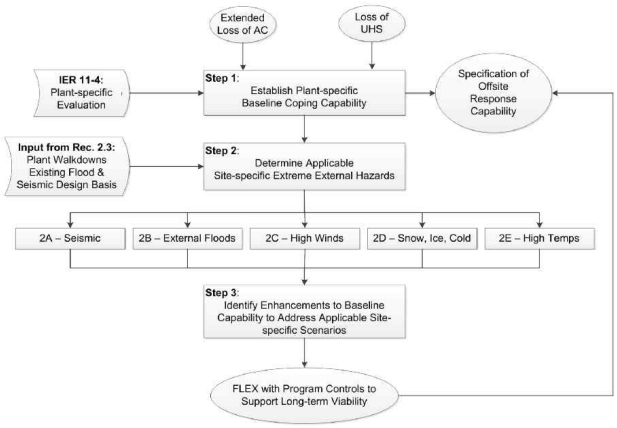

Fig. 3. Site Assessment Process of FLEX

3. Coping Strategies for BDBEEs

This study proposes integrated coping strategies for BDBEEs, which represents an extension from the strategies of EDMG and FLEX, as shown in Fig. 4. FLEX provides baseline coping capabilities for the ELAP and LUHS conditions. EDMG provides mitigation strategies for a total loss of control, or total loss of AC and DC power. The integrated coping strategies proposed in this study provide comprehensive strategies by extending the accident conditions of EDMG and FLEX to include a loss of RCS inventory and pressure control. The study also specifies necessary mitigation strategies depending on the accident conditions, integration between EOPs and SAMGs, and extension or revision of EOPs.

The key elements of the integrated coping strategies can be summarized as follows.

- If the RCS inventory and pressure control is intact, core cooling and RCS heat removal using the turbine-driven (TD) AFW system at the main control room (MCR) or at a local place is required. In the case where the TD-AFW system is unavailable, RCS heat removal using portable equipment should be initiated.
  If the RCS inventory and pressure control is lost, the RCS inventory should be first restored. In particular, to prevent core damage, new systems such as diesel-driven safety injection pumps need to be installed. Provided that the safety function cannot be maintained using all available means of installed equipment, mitigation strategy should be initiated using portable equipment until the offsite resources are brought into the site for long-term RCS makeup and residual heat removal.
- In the case of loss of control at the MCR and a remote control panel, simplified guidelines tailored to this specific condition (e.g., U.S. EDMG) should be provided along with alternate instrumentations.

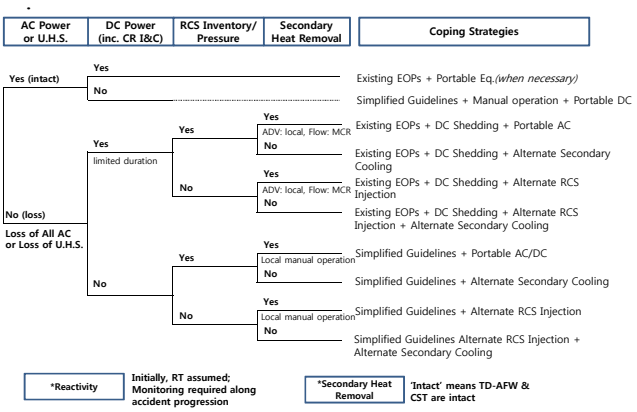

Fig. 4. Integrated Coping Strategies for BDBEEs

4. Conclusion

This paper reviewed mitigation strategies adopted in the U.S. EDMG and FLEX approaches, and then proposed extended coping strategies for BDBEEs. The extended coping strategies provide comprehensive mitigation approach including restoration of the RCS inventory and pressure control as well as mitigation strategies of the U.S. EDMG and FLEX. More detailed strategies will be developed in the near future following an evaluation of the various accident mitigation strategies being implemented worldwide in the aftermath of the Fukushima accident.

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