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Development of Extended Station Blackout Recovery Guideline for OPR1000 and APR1400

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1. Introduction

Many regulatory requirements and recommendations following the Fukushima accident have been issued to cope with the extended station blackout (SBO) by the NRC, INPO, IAEA, ENSREG, WENRA, etc., and the nuclear safety improvement design features of each country have been enhanced to incorporate the lessons learned from the Fukushima accident. In particular, the Nuclear Energy Institute (NEI) of U.S. has presented the diverse and flexible coping strategy (FLEX) through NEI 12-06, "Diverse and Flexible Coping Strategies Implementation Guide"[1] to comply with the NRC Order 12-049, "Order to Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" [2]. The FLEX involving a three-phase approach is intended to mitigate the consequences of beyond-design-basis external events (BDBEE) by using installed equipment, on-site portable equipment, and pre-staged off-site resources.

There have been many evaluations to cope with the extended loss of alternating current (AC) power (ELAP) event after the Fukushima accident. PWROG has developed the FLEX support guideline (FSG) that provides the guidance to mitigate the consequences of ELAP event based on the FLEX [3]. The FSG is interfaced with emergency operating guidelines (EOGs) and severe accident management guidelines (SAMGs). However, the FSG developed by PWROG is not compatible with EOGs for both OPR1000 and APR1400 NPPs [4, 5].

Therefore, it is necessary to develop an extended station blackout recovery guideline (ESRG) to cope with an extended SBO event utilizing the newly adopted safety improvement design features against Fukushima accident for OPR1000 and APR1400 NPPs.

2. Extended SBO Recovery Guideline (ESRG)

2.1 Objective of ESRG

The objective of ESRG is to establish an essentially indefinite coping capability by relying upon installed equipment, on-site portable equipment, and pre-staged off-site resources during an extended SBO event. The ESRG provides the operator actions with extended SBO recovery strategy to maintain core cooling, spent fuel cooling and containment integrity in the event of an extended SBO. And this guideline provides technical information and bases to be used in developing the plant specific extended SBO recovery procedure (ESRP) for OPR1000 and APR1400 NPPs.

2.2 Structure of ESRG

The ESRG is written as sequential instructions in a step-by-step manner for performing a function or addressing plant condition to cope with an extended SBO event. The ESRG is implemented if all AC power is not expected to be restored in SBO optimal recovery guideline (ORG) or functional recovery guideline (FRG) of EOGs because the existing EOGs do not cover the extended loss of all AC power. This ESRG is interfaced with EOGs and SAMGs. Figure 1 shows the schematic diagram to perform the ESRG. The structure of the ESRG is similar to that of the existing EOGs which have the two-column format and the following sections:

- Purpose
- Entry Conditions
- Exit Conditions
- Operator Action Steps
- Safety Function Status Check
- Supplementary Information
- Placekeeper
- Bases

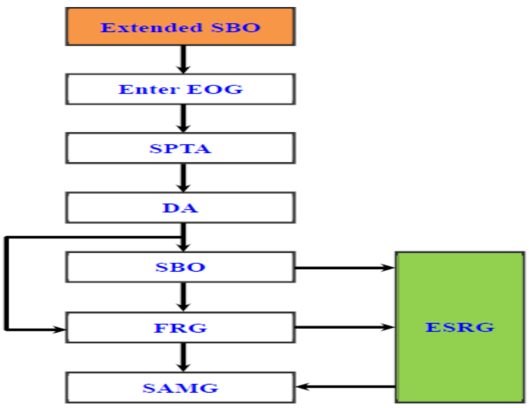

Fig. 1 Schematic diagram for ESRG

2.3 Evaluation on Operation Strategy of ESRG

The SBO operation strategy of the current EOGs for both OPR1000 and APR1400 NPPs is to maintain the

RCS in hot standby condition without RCS cooldown as long as possible until Alternative AC (AAC) generator starts. Instead, RCS cooldown and depressurization strategy is adopted to prevent core uncovery when all AC power is not expected to be restored in the event of an extended SBO. The RCS cooldown and depressurization strategy has the following advantages:

- Decrease possibility of RCP seal degradation
- Minimize RCS leakage through any leak paths including the RCP seals
- Allow for injection from SITs; maintain RCS inventory, add boron to the RCS, and maintain shutdown margin
- Allow for lower head portable pump for both the RCS and the SG
- Minimize containment heat-up and resulting harsh environment

An operation strategy for external injection which is applicable to the phase 2 of FLEX is also considered depending on the recovery of AC power. More specific operator actions to cope with an extended SBO event are included in this ESRG based on the operation strategies. In addition, the operation strategies for spent fuel cooling and containment integrity will be also considered.

2.3.1 Supporting Analyses for Operation Strategy

The supporting analyses to evaluate the operation strategy applied to ESRG for core cooling have been performed using a best-estimate computer code of RELAP5/MOD3.3. The acceptance criteria applied to this analysis are the core cooling and the fuel integrity based on NEI 12-06. The major assumptions of this best estimate analysis are as follows:

- Full power operation
- Loss of all AC power at 0 sec
- Reactor trip due to loss of offsite power (LOOP)
- Decay heat of ANSI/ANS-5.1-1979 + 2 sigma
- RCP seal leakage with 25 gpm per RCP
- Auxiliary feedwater supply by turbine driven auxiliary feedwater pump for both SGs
- ELAP declaration within 2 hrs after event
- RCS cooldown at a rate of 50 ^{o}F/hr at 2 hrs after event until RCS hot leg temperature reaches 350 ^{o}F
- Four (4) SITs available

2.3.2 Results of Analysis

Figures 2 through 7 show the RCS response to RCS cooldown and depressurization strategy during an Extended SBO event for APR 1400. Figure 2 shows RCS temperature according to RCS cooldown. Figure 3 shows Pressurizer and SG pressure, and Figure 4 shows RCP seal leakage rate. While RCS pressure decreases by RCS cooldown, the SIT starts to inject borated water when the RCS pressure reaches to the SIT injection pressure as shown in Figure 5. The PZR level decreased and stayed at an empty state for a long time because the liquid volume of RCS decreased due to the RCP seal leakage and shrinkage of RCS inventory. However, as shown in Figure 6, the core level was recovered after SIT flow injection. Even though the core level reduces a little during cooldown period, it still covers the active core. This means that the fuel is not uncovered and fuel integrity is maintained during the event as shown in Figure 7.

It is concluded that RCS cooldown and depressurization strategy after ELAP declaration for APR1400 ensures the appropriate core cooling and fuel integrity during an extended SBO event. The necessity of further cooldown will be accomplished depending on the recovery of AC power including mobile generator and the plant conditions.

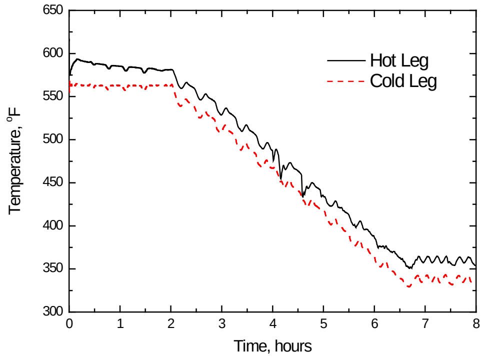

Fig. 2 RCS Temperature

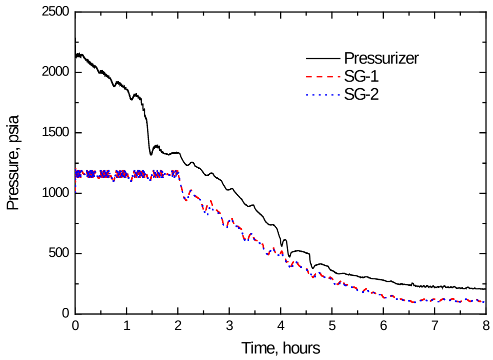

Fig. 3 PZR and SG Pressure

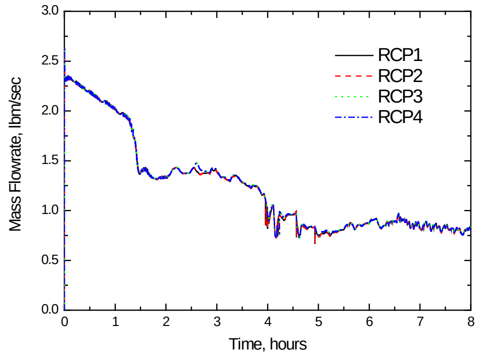

Fig. 4 RCP Seal Leakage

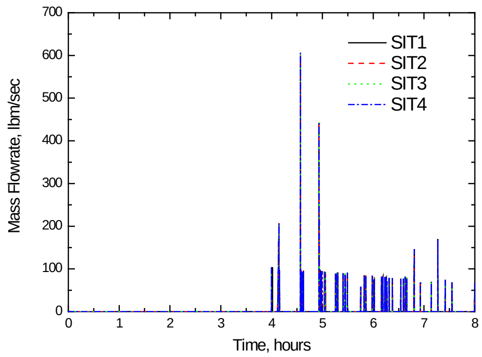

Fig. 5 SIT Flow

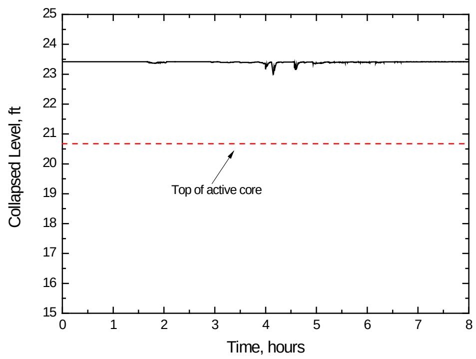

Fig. 6 Core Level

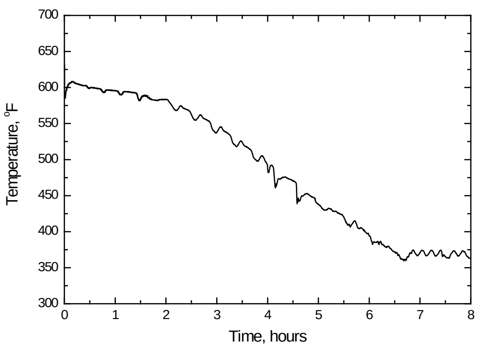

Fig. 7 Fuel Cladding Temperature

4. Conclusions

It is required to implement the mitigation measures against an extended SBO event following Fukushima accident for each plant. In accordance with the implementation of the Fukushima action items, the ESRG has been developed to mitigate the consequences of an extended SBO event as an operating guideline with recovery strategy. This guideline provides the operator actions to maintain core cooling, spent fuel cooling and containment integrity during the event. The ESRG is also performed to satisfy all safety functions and to prevent from entering SAMGs during an extended SBO event.

Therefore, this ESRG is entirely appropriate to cope with an extended SBO event by utilizing the newly adopted safety improvement design features following Fukushima accident for OPR1000 and APR1400 NPPs. This guideline will be considered in the establishment of accident management planning in near future.

REFERENCES

[1] NEI 12-06, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide, August 2012
[2] NRC Order 12-049, Order to Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events, March 2012
[3] WCAP-17601-P, Rev.0, Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcoak & Wilcox NSSS Designs, August 2012
[4] Emergency Operating Guidelines for OPR1000, 2012
[5] Emergency Operating Guidelines for APR1400, 2014
[6] Evaluation on the APR1400 NCC Operational Strategy in light of the Lessons Learned from the Fukushima Accident, 2014