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A Quantitative Feasibility Study on Potential Safety Improvement Effects of Advanced Safety Features in APR-1400 when Applied to OPR-1000

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1. Introduction

The Advanced Power Reactor 1400 (APR-1400) adopts several advanced safety features compared to its predecessor, the Optimized Power Reactor 1000 (OPR-1000), which includes an additional Emergency Diesel Generator, increase in battery capacity, in-containment refueling water storage tank (IRWST), and so on [1]. Considering the remarkable advantages of these safety features in safety improvement and the design similarities between APR-1400 and OPR-1000, it is feasible to apply key advanced safety features of APR-1400 to OPR-1000 to enhance the safety.

This study aims to test the feasibility of the applications using Probabilistic Safety Assessment (PSA). Particularly, three of those advanced safety features are selected as follows:

1. Providing an additional Emergency Diesel Generator (EDG);
2. Increasing the capacity of Class 1E batteries;
3. Placing a Refueling Water Storage Tank (RWST) inside containment, i.e., change from RWST to IRWST.

The selected safety features are incorporated into OPR-1000 PSA model using the Advanced Information Management System (AIMS) for PSA and CDFs are re-evaluated for each application and combination of three applications.

2. Methodology

2.1 Advanced Safety Features Applied to OPR-1000

The first advanced safety feature is an additional Emergency Diesel Generator. Nuclear power plants designated as OPR-1000 have electric power sources for safety-related systems that consist of an on-site stand-by power supply from one emergency diesel generator (EDG) and a backup alternative alternating current (AAC) diesel generator in emergency cases. APR-1400 reactors are provided with an additional independent EDG [1]. Such additional redundancy to the electric power sources guarantees satisfactory ability of the reactor to cope with Loss of Off-site Power and Station Blackout initiating events.

The second safety feature modification in OPR-1000 is an increase in the capacity of the batteries. Class 1E batteries, as a part of the onsite power system, are intended to provide direct current (DC) power for emergency operation of the Reactor Protection and Engineered Safety Feature systems when any source of the alternating current are not available [2]. Consequently, sufficient capacity and stable functioning of the batteries are vital for the safe operation of a nuclear power plant facing accident conditions. In order to enhance the safety margin of the plant, the capacity of the batteries were increased to 8 hours of operation time in the first constructed APR-1400 reactors, with battery capacity reaching 24 hours in later designs, which is 6 times more than the original OPR-1000 batteries capacity [2]. Such safety feature modifications could extend time for the recovery of AC power and cause the reduction of human error during operation. Only the capacity extension of the batteries for 8 hours is considered in this study.

The last chosen advanced safety feature is the In-containment Refueling Water Storage Tank (IRWST), which is in charge of the water supply for the Safety Injection System (SIS), the Shutdown Cooling System (SCS), and the Containment Spray System (CSS) [1]. The location of the RWST, as originally designed, was outside the containment building for the OPR-1000 design; nevertheless, the rearrangement of the storage tank into a containment gives advantages such as [1]:

- Injection and spray water in emergency cases supplied by IRWST return back to the tank through the IRWST spillways;
- Elimination of the isolation valves, which is used in OPR-1000 for the containment recirculation sump.

An impact of the applied safety features on the CDF of OPR-1000 is demonstrated by the CDF quantifications before and after applying three applications.

2.2 PSA Software

The core damage accident scenario analysis is considered in this study, which corresponds to PSA Level 1 combining the likelihood of initiating events and potential scenarios that could lead to core damage. The PSA Level 1 analysis is conducted by the Advanced Information Management System (AIMS), which easily performs PSA analyses, including PSA modeling, simulations for initiating events and CDF calculations within the three advanced design features introduced in the previous section.

The AIMS-PSA needs the PSA model to construct ET and/or FT models that represents safety system failures in the nuclear power plant and to generate minimal cut sets for CDF evaluation. As such, the PSA model developed by KAERI for Ulchin Nuclear Units 3 and 4, which are designated as OPR-1000 nuclear power plants, is used as an input for the software. Three advanced safety features are incorporated into the existing PSA model by applying some corresponding model changes. The CDF is reevaluated before and after the three selected safety features to display plant performance under different safety feature cases. Then, those results are compared to demonstrate an effectiveness of the applied safety features modifications.

3. Results

Six cases are selected for the feasibility study as shown in Table 1. For base case, the OPR-1000 PSA model is selected without any modifications, then three cases for each modification are tested one by one. In order to test the combined effect of modifications, two cases are selected. In case 5, all three modifications are tested altogether. And among them, two modifications which are practically applicable are tested in case 4.

Table 1: Six Cases for the Feasibility Study.

No.	Description
Base case	Base PSA model for OPR-1000
Case 1	The OPR-1000 PSA model with an additional EDG
Case 2	The OPR-1000 PSA model with increased battery capacity
Case 3	The OPR-1000 PSA model with the IRWST
Case 4	The OPR-1000 PSA model with an additional EDG and increased battery capacity
Case 5	The OPR-1000 PSA model with an additional EDG, increased battery capacity and IRWST

The quantitative evaluations of above cases have been done using AIMS PSA model by modifying the ET and/or FT corresponding to the nature of each case. In terms of CDF and CDF change, the results are shown in Table 2.

Table 2: Results of Evaluation for Each Case.

No.	CDF (/yr)	Change in CDF	%
Base case	7.0475E-06	-	-
Case 1	6.438E-06	6.10E-07	8.65%
Case 2	6.875E-06	1.73E-07	2.45%
Case 3	6.674E-06	3.74E-07	5.30%
Case 4	6.355E-06	6.925E-07	9.83%
Case 5	5.982E-06	1.07E-06	15.12%

The biggest change in CDF is obtained from case 1, in which an additional EDG is installed in Class 1E 4.16 kV switchgear (Train A). The case 3 which replaces the RWST inside containment also produces considerable CDF change since it can remove the significant post-accident operator error of switching the safety injection pump suction from IRWST to containment sump for long-term recirculation operation. The case 3 which extends the capacity of the Class 1E battery to 8 hours results in relatively small CDF change. Finally, the combination of all three cases leads to the change in CDF of more than 15%, while the combination of two practically applicable modifications produces the change in CDF around 10%.

4. Conclusion

Based on current results, it is concluded that three of key advanced safety features of APR-1400 can be effectively applied to OPR-1000, resulting in considerable safety improvement. In aggregate, three advanced safety features, which are an additional EDG, increased battery capacity and IRWST, can reduce the CDF of OPR-1000 by more than 15% when applied altogether. However, practically the application of IRWST to existing plant is unattainable. Therefore, it is reasonable to consider the application of first two candidates, which are an additional EDG and increased battery capacity. In this case, the combinations of two applications lead to reduction in CDF by 9.83%.

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