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Non-LOCA Safety Analysis for the APR1000 Preliminary Design

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1. Introduction

The preliminary design project of the Advanced Power Reactor 1000 (APR1000) has been performed by Korea Electric Power Corp. (KEPCO) and Korea Hydraulic & Nuclear Power Co. (KHNP) since the end of 2009. The APR1000 has been developed to implement accumulated operational experience and advanced safety features (ADFs) in the Optimized Power Reactor 1000 (OPR1000) plant to meet the requirements of Generation III+ nuclear power plants. As a design basis accident (DBA) analysis, a Non-Loss of Coolant Accident (Non-LOCA) analysis has been performed to confirm the performance of the structures, systems, and components (SSCs) under a wide spectrum of anticipated initial conditions and assumptions.

2. Advanced Design Features

2.1 Operator Action Time & Turbine Trip Delay

The operator actions are considered to be revealed in sufficient time according to adequate procedures to ensure the reliability of such actions. Even though the appropriate operator action time can be evaluated and used according to ANSI/ANS-58.8 'Time Response Design Criteria or Safety-related Operator Actions', the safety analysis for the APR1000 conservatively does not credit the operator actions up to 30 minutes, which is extended from 15 minutes of OPR1000, in any DBAs.

In the OPR1000 plant, a loss of offsite power is considered as a basic assumption for Non-LOCA analyses, and a 3-second delay for turbine trip following reactor trip is credited based on the feasibility study on grid stability. In the cases of the conditions of foreign conditions, however, the grid stability could not be guaranteed. Therefore, in these cases, the 3-second delay could not be considered, and the safety margins could be reduced. To compensate for adverse conditions, provisions to assure the 3-second delay of turbine trip upon reactor trip have been developed for the APR1000.

2.2 24-Month Cycle & MOX Fuel

The APR1000 has been designed and optimized to utilize all UO_2 18-month fuel cycles to attain an average plant capacity factor exceeding 92%. As options, however, the designs of UO_2 24-month fuel cycle or 30% MOX fuel assemblies in the core have been considered in order to meet possible customer requirements.

The MOX fuel loading could be characterized by its relatively large thermal absorption cross section, which leads to higher critical boron concentrations, smaller control rod worth, reduced shutdown margins, *etc.* From the viewpoint of thermal hydraulic behaviors, the MOX fuel reveals poor heat transfer characteristics, and raises the peak fuel temperatures in DBA conditions. Despite these unfavorable effects, the APR1000 has been designed to accommodate up to 30% MOX fuel while ensuring sufficient safety margins.

2.3 50Hz Reactor Coolant Pump

In Korea, the reactor coolant pumps (RCPs) used for nuclear power plants are designed to be appropriate to 60 Hz grid conditions. About 80% of nations, however, are applying electric power frequency of 50Hz. Accordingly, the requirement of 50Hz RCPs has been raised to meet the foreign grid conditions for APR1000 development.

3. Modeling

3.1 Basedeck Development

To simulate the plant phenomena, such as normal operation, anticipated operational occurrences (AOOs), accidents, *etc*., the major SSCs of APR1000 have been modeled to consider the models and correlations of RETRAN. Most of the models have been interpreted from the Korea Non-LOCA Analysis Package (KNAP) Topical Report with proper investigations into the differences between APR1000 and OPR1000. To model the plants, the APR1000 design data were used, and some OPR1000 data were selected to compensate for lacking reference data. The base model consists of 123 volumes and 173 junctions to simulate DBAs.

3.2 ADFs Modeling

The extended operator action time and the modified turbine trip delay were considered in the base model of the Non-LOCA safety analysis. The UO_2 24-month cycle or 30% MOX fuel were modeled in the neutron kinetics model, hot spot model, thermo-physical properties, *etc*., in the case of reactivity induced accidents (RIAs). The 50Hz RCP was modeled in pump description data according to the manufacture design data and used for loss of reactor coolant flow accident analyses.

4. Non-LOCA Safety Analysis

4.1 Operator Action Time

The feasibility of extended operator action time could be confirmed by the single dropped rod digital transient analysis (DTA) and the boron dilution analysis (BDA).

Through the DTA, the key parameters of Core Operating Limit Supervisory System (COLSS) / Core Protection Calculator (CPC) to ensure operator actions were generated to meet the 30 minute requirement. The PFDTME (Penalty Factor Delay Time Margin Evaluation), as a parameter of COLSS/CPC, was calculated as about 10 seconds. Since the total CPC delay time was 3 seconds, an additional margin of roughly seconds was confirmed. The calculated fuel failure for this event was about 7.3%, and thus the dose rate was bounded by the CEA ejection accident of about 10%.

The BDA was performed to determine the minimum time required to dilute to criticality in any plant operation modes under the extended operator action time. The purpose of this analysis is to assure that sufficient time exists in the event of boron dilution for its detection and termination by an operator before the shutdown margin (SDM) is lost. The time to complete loss of SDM for each operational mode was calculated. The results showed that the start-up range monitoring ratio of Mode 4 (Shutdown Cooling System case only) and Mode 5 could not meet the minimum requirement. Therefore, in order to compensate the adverse results, two items to be changed in Tech. Spec. have been suggested.

4.2 24-Month Cycle & MOX Fuel

The accident most strongly influenced by these ADFs is the CEA ejection accident. No other RIAs mentioned in Safety Analysis Report (SAR) Chap.15.4 are affected by the ADFs.

To reflect ADFs, a point kinetics core model has been developed for average and hot channels of the APR1000 according to the KNAP. The average and hot channels were modeled to represent the whole core and the hottest channel caused by the accident, respectively. In the case of 30% MOX fuel loading, it was assumed that the hottest channel occurred in the MOX fuel assemblies. Through the analysis, it was found that the 24-month UO_2 cycle showed similar results to the nominal design, an 18-month UO_2 cycle. The 30% MOX fuel core, however, showed more severe trends in terms of the maximum fuel temperatures due to the poor heat transfer characteristics of MOX fuel. To mitigate the adverse effects caused by MOX fuel loading, some changes to the core design are recommended.

4.3 50Hz Reactor Coolant Pump

To confirm the ADF, complete loss of reactor coolant flows and a single RCP rotor seizure were analyzed. Under the same initial conditions and assumptions, the 50Hz model showed similar trends to the 60Hz model except for the DNBR trends. It was also found that the most severe cases, from the viewpoint of departure from nucleate boiling ratio or reactor coolant system pressures, respectively, were changed through a sensitivity analysis. As a result, a one-dimensional neutron kinetics model was suggested in order to compensate the lower DNBR trends. Note that, for the OPR1000 plants, the one-dimensional model has been used for these accidents. In the preliminary design phase of APR1000, however, the point kinetics model has been used due to a lack of core design data.

5. Conclusion

A Non-LOCA safety analysis for the APR1000 was performed to confirm the feasibility of the ADFs of APR1000. Considering the effectiveness of the analyses and their results, among the Non-LOCAs noted in SAR Chap.15, representative events or accidents are selected and analyzed under a wide spectrum of anticipated initial conditions and assumptions. Through the analysis, it was confirmed that the APR1000 design concept is effective in terms of retaining the nuclear steam supply system integrity of public safety under the selected events and accident conditions. In addition to the aforementioned confirmation, some recommendations to improve the safety characteristics of the APR1000 are given.

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