RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

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Question No. 04.03-2

TECHNICAL ISSUE --------------------------- LOSS OF CONTROL ROD WORTH DUE TO DEPLETION

REQUIREMENTS

10 CFR Part 50 Appendix A, General Design Criterion (GDC) 10 requires the reactor design to include appropriate margin to assure that specified acceptable fuel design limits (SAFDLs) are not exceeded during normal operation or anticipated operational occurrences (AOOs). GDC 20, “Protection System Functions,” requires automatic initiation of the reactivity control systems to assure that SAFDLs are not exceeded as a result of AOOs and that automatic operation of systems and components important to safety occurs under accident conditions. In addition, GDC 28, “Reactivity Limits,” requires that the effects of postulated reactivity accidents neither result in damage to the reactor coolant pressure boundary greater than limited local yielding nor cause sufficient damage to impair significantly the capability to cool the core. All of these requirements involve accurate knowledge of the total and differential worths of the control element assembly (CEA).

In accordance to the review guidance provided to the staff in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” a reactor must maintain adequate control and shutdown margin. Specifically, the SRP states: “The adequacy of the control systems to assure that the reactor can be returned to and maintained in the cold shutdown condition at any time during operation. The applicant shall discuss shutdown margins (SDM). Shutdown margins need to be demonstrated by the applicant throughout the fuel cycle.”

ISSUE

Based on the DCD, the APR1400 design includes two types of CEA, full strength and part strength CEAs. The full strength CEAs use B4C as neutron absorber. On page 4.3-7, the DCD states: “Methods of controlling the power distribution include the use of full- or part-strength

CEAs to alter the axial power distribution; decreasing CEA insertion by boration, thereby improving the radial power distribution; and correcting off-optimum conditions that cause margin degradations such as CEA misoperation." On page 4.3-17, the DCD also indicates: "The regulating CEA groups can be used to compensate for changes in reactivity associated with routine power level changes. In addition, they can be used to compensate for minor variations in moderator temperature and boron concentration during operation at power and to dampen axial xenon oscillations." On page 4.3-24, the DCD states: "Control action with part-strength rods or full-strength rods may be required to limit the magnitude of the oscillation." As such, some or all of the regulating rods may be inserted into the reactor in extended period of time and at various depths during power operations. Consequently, the full strength CEAs being used as regulating rods may lose their worth over time due to B-10 depletion. Consequently, the reactor may lose its ability to shutdown effectively and/or its safe shutdown margin.

In addition, the differential control rod worth curves may change over time for the CEAs that are used as regulating rods due to uneven axial depletion of B-10. Since regulating CEAs are inserted from the top of the core, they will gradually lose their worth from the bottom of the rods and the amount of loss varies depending on the location, depth, and duration of the insertion.

For the reasons discussed above, the staff is concerned with the potential loss of control rod worth of the CEAs that are used as regulating rods because the loss of control rod worth may hinder the system's ability to promptly and effectively shut down the reactor.

INFORMATION NEEDED

In its response to this RAI, the applicant is requested to provide an evaluation of:

1. the estimated CEA exposure as regulating rods and the bases for the estimate;

2. the corresponding loss of control rod worth because of B-10 depletion;

3. the changes in differential control rod worth, i.e., skewed control rod worth curve and revise Figures 4.2-14 and 4.3-6 to update the control rod differential curve and control rod worths if necessary;

4. the impact of loss of control rod worth on core shutdown time; and

5. the impact of change of control rod worth and differential control rod worth on the safety assessment of various relevant AOOs and accidents as specified in Chapter 15, "Transient Analyses" for the APR1400; and the need for updating the values of the setpoints in the core protection system, COLSS.

The applicant also needs to evaluate the impacts of loss of control rod worth and changes of differential control rod worth curve, if any, on all safety related analyses, including transient and accident analyses and revise the DCD and the associated technical reports as necessary. This information is needed for the staff to determine the APR1400 design meets the regulatory requirements of GDC 10, GDC 11, GDC 20, and GDC 28.

Response

Information request 1:

The estimated CEA exposure as regulating rods and the bases for the estimate;

Response to request 1:

The estimated CEA B-10 burnout, as a function of distance from the tip of the CEA is shown in Figure 1, "B-10 Burnout of Regulating Bank CEA of OPR1000* and APR1400 Cores". Table 1, "Comparison of the Bases for the Estimated CEA Exposure" presents the assumed conditions used to generate Figure 1. The total amount of B-10 burnout in APR1400 CEAs is greater than that of OPR1000 CEAs due to the APR1400's higher power density and higher capacity factor. It is estimated that the total amount of B-10 burnout in APR1400 CEAs is about [ ]TS higher than that of OPR1000 CEAs.

Note: The OPR1000 (12 Optimized Power Reactor type plants of 1000 MWe have been operating in South Korea since March, 1995 and each of them has 177 fuel assemblies and 73 control element assemblies) has been selected as the baseline for their similar designs(particularly very similar fuel assembly and CEA design when compared to APR1400) and operational history(having same PDIL with APR1400).

Information request 2:

The corresponding loss of control rod worth because of B-10 depletion;

Response to request 2:

It is predicted that the reduction percentage of CEA worth in APR1400 CEAs is about [ ]TS higher than that in OPR1000 CEAs, since CEA worth depends on B-10 number density. According to the OPR1000 evaluation report for B-10 depletion, it is shown that the maximum loss of CEA worth due to B-10 burnout is [ ]TS. In addition, the total rod worth of APR1400 CEAs, [ ]TS, is lower than that of OPR1000 CEAs, [ ]TS. Therefore, considering the total rod worth difference and the reduction percentage of CEA worth between APR1400 and OPR1000, it is estimated that the maximum loss of rod worth due to CEA depletion in APR1400 core is about [ ]TS, as calculated below;

[ ]TS

However, the estimated loss of CEA worth is based on a conservative regulating Bank CEA insertion history. The insertion history of the CEAs, as described in Table 1, is considered to be conservative since all regulating and shutdown banks, with the exception of the lead bank (bank 5), are not permitted for insertion in the core at HFP. Therefore, it is expected that the real total loss of rod worth due to B-10 depletion of CEAs in APR1400 cores would be much lower than [ ]TS. Figure 2 shows a CEA exposure comparison between regulating banks and shutdown banks in the APR1400 core.

In practice, the control rod worth is generated without assumed B-10 depletion. At the beginning of every cycle, the effectiveness and suitability of the predicted rod worth value is confirmed by comparing the acceptance criteria with the measured values of individual and total rod worth, which are obtained through reactor physics testing. Figure 3 shows the distribution of deviation as a difference unit of (M-P) between the measured and the predicted worths for bank 5 and the total rod worth for Cycles 1 through 16 of HANBIT unit 3, which is one of OPR1000 cores. Particularly, Figure 4 shows the distribution of deviation as an relative difference unit of (M-P)/P*100 for only total rod worth between the measured and the predicted worths for Cycles 1 through 16 of HANBIT unit 3. The maximum deviation between the measured and the predicted rod worth for bank 5 (lead bank) and total rod worth over 16 cycles was [ ]^{TS} and [ ]^{TS}, respectively. At HANBIT unit 3, all control rods were replaced after the 8th and 15th planned preventive maintenance period, respectively. The deviation between the measured and the predicted rod worths for bank 5 (lead bank) and the total rod worth at Cycle 8 were [ ]^{TS} and [ ]^{TS}, respectively. At Cycle 15, the deviation was [ ]^{TS} and [ ]^{TS}, respectively.

Despite not including the depletion effect on rod worths, the predicted values show good agreement with those measured, which do include the depletion effect. All observed results were within the uncertainty allowance, 6.52 %. In addition, it is judged that the B-10 depletion effect is not as significant as expected, based on the bank 5 rod worth measured over most cycles.

Information request 3:

The changes in differential control rod worth, i.e., skewed control rod worth curve and revise Figures 4.2-14 and 4.3-6 to update the control rod differential curve and control rod worths if necessary;

Response to request 3:

As shown in Figure 2, about 70% of the total B-10 depletion occurs in the first [ ]^{TS}. The remaining 30% is distributed over the rest of the CEA. Therefore, the change of differential control rod worth mainly occurs near the CEA tip, and the remaining change is distributed over [ ]^{TS}. Since the axial power distribution is skewed to the upper core when the reactor becomes tripped by inserting the control rods, the loss effect of rod worth near the CEA tip, which is located on the lower core once a trip has occurred and the rods have come to rest, is negligible.

Because the depletion of the tips of CEAs is negligible, no revision to DCD Figure 4.2-14, “CEA Position Requirements during Reactor Scram” and Figure 4.3-6 “Planar Average Power Distribution Unrodded Full Power, Equilibrium Xenon, 4,000 MWD/MTU of the First Cycle” is necessary.

Information request 4:

The impact of loss of control rod worth on core shutdown time; and

Response to request 4:

The shutdown reactivity curve being used to perform the safety analysis is determined by a conservative design process which considers various conditions including burnup during the cycle, power level, and control rod insertion with the presence or absence of Part Strength CEAs (PSCEAs). Various axial power distributions are generated; ASI values (-0.6, -0.3, 0.0, +0.3, +0.6) are selected and used as the initial power shapes to generate the shutdown reactivity curves. After the reactivity curves are generated at each ASI, the least inserted reactivity for each axial position is selected for constructing the composite curve. Additionally, the most limiting value for each axial position is selected by comparing this curve with the typical generic curve. Because sufficient conservatism is applied to the design process, the impact of CEA depletion on the shutdown reactivity curve is negligible.

Information request 5:

The impact of change of control rod worth and differential control rod worth on the safety assessment of various relevant AOOs and accidents as specified in Chapter 15, "Transient Analyses" for the APR1400;and the need for updating the values of the setpoints in the core protection system, COLSS.

Response to request 5:

Since the estimated total loss of rod worth due to CEA depletion [ ] TS is much smaller than the rod worth uncertainty [ ] TS, and considering that CEA depletion is implicitly included in the rod worth uncertainty based on the deviation between the measured and the predicted worth, there is no impact to safety assessments due to considering the CEA depletion negligible. In addition, current safety analyses which would be affected by accounting for the CEA depletion (single CEA withdrawal, bank withdrawal, CEA ejection and CEA drop accident) are more conservative for neglecting the depletion, since the differential rod worth is decreased due to CEA depletion.

The COLSS/CPCS parameters which would be affected by accounting for CEA depletion are rodded Fxy and rod shadowing factor due to changes in peaking factor and detector response due to rod insertion. The COLSS/CPCS setpoints do not need to be updated to account for CEA depletion due to the resulting decrease in peaking factor and detector response which would result.

Table 1. Comparison of the Bases for the Estimated CEA Exposure

TS

TS

Figure 1. B-10 Burnout of Regulating Bank CEA of OPR1000 and APR1400 Cores

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Figure 2. B-10 Burnout of Regulating and Shutdown Bank CEAs of APR1400 Core

TS

Figure 3. HANBIT Unit 3 Difference (M-P) for Bank 5 & Total Rod Worth

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Figure 4. HANBIT Unit 3 Difference ((M-P/P)*100) for Total Rod Worth

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

There is no impact on any Technical, Topical, or Environmental Report.