*Transactions of the Korean Nuclear Society Spring Meeting*
*Taebaek, Korea, May 26-27, 2011*

# Feasibility Study to Advanced Design Features of the APR1000 through CEA Ejection Accident Analysis

Yo-Han Kim, Chang Keun Yang, Hwan Soo Lee, Sang Jun Ha
*KEPCO Research Institute, 65 Munji-ro Yuseong-gu, Daejeon, 305-760, Korea*
*johnkim@kepri.re.kr*

## 1. Introduction

To supply various power level options to customers abroad, Korea Electric Power Corp. (KEPCO) has preliminarily designed the Advanced Power Reactor 1000 (APR1000) plants [1] since the end of 2009. The APR1000 has been designed to consider the operational experience of Optimized Power Reactor 1000 (OPR1000) plants and some Advanced Design Features (ADFs) to meet the requirements of Generation III+ nuclear power plants.

In this study, the Control Element Assembly (CEA) ejection accident was analyzed to confirm the feasibility of the ADFs. On the viewpoint of CEA ejection, the 24-month fuel cycle, 30% mixed oxide (MOX) fuel loading, or cold head design was reviewed among the ADFs. The results were compared each others.

## 2. Advanced Design Features

### *2.1 Cold Head Design*

The cold head design [2] of the APR1000 has been considered to mitigate the thermal stresses of the reactor vessel head and extend its lifetime. The APR1000 has been designed to operate for 60 years at least, so the design concept has been chosen as one of the ADFs. To achieve the design goal, the flow paths to bypass more coolant to the head has been developed, and the flow distribution in the core or corresponding bypass paths has been adjusted. Through the design, the mean bulk fluid temperature in the upper head region is decreased as cold as that in the cold leg. The RETRAN base model [3, 4] composed of 123 volumes and 173 junctions has been modified to reflect the design.

### *2.2 24-Month Cycle & MOX Fuel*

The APR1000 has been designed and optimized to utilize all $UO_2$ 18-month fuel cycles. Provisions, however, have been prepared to allow the use of up to 24-month fuel cycle or 30% MOX fuel assemblies in the core. The initial core of the APR1000 has been designed to provide 18 months of operation at an average plant capacity factor of 90%, in the length of periods the equilibrium fuel cycles could be extended to 24 months. 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, and a reduced shutdown margin, *etc.* Despite these unfavorable effects, the APR1000 has been designed to accommodate up to 30% MOX fuel while ensuring sufficient safety margins. To reflect these features, the point kinetics core model has been developed for average and hot channels of the APR1000 according to the KNAP [4] methodology. 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 the 30% MOX fuel loading, it was assumed that the hottest channel was occurred in MOX fuel assemblies [5].

## 3. CEA Ejection Accident Analysis

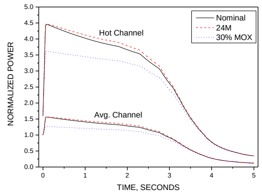
The conditions led to CEA ejection is classified into 4 cases, such as hot zero power (HZP) at the beginning of cycle (BOC), hot full power (HFP) at BOC, HZP at the end of cycle (EOC), and HFP at EOC. In this study, the HFP and HZP at BOC cases, which were commonly treated as the most severe cases in this accident, were selected to examine the feasibility of the features. The initial conditions and assumptions used in this analysis are as listed in Table 1.

Table 1. Initial Conditions and Assumptions

| Parameter | Value |
|---|---|
| Fuel | $UO_2$ or MOX |
| Fuel Cycle, months | 18 or 24 |
| Core power Level, % to Rated Power | 102 or 0 |
| Core Inlet Temp. $^oF$ | 558~572 |
| Core Mass Flow, % to Rated Flow | 95 |
| Pressurizer Pressure (Pressure Case), psia | 2,130~2,350 |
| Pressurizer Level, % | 52.6~60.0 |
| Moderator Temperature Coefficient, $\Delta\rho/^oF$ | 0.0 |
| Total SCRAM Worth, $10^{-2}\ \Delta\rho$ | -6.0 |
| Postulated CEA Ejection Time, sec | 0.05 |
| Maximum Radial Peaking factor | 2.855 |

For the three core models, *i.e.*, $UO_2$ fuel 18-month cycle, $UO_2$ fuel 24-month cycle, and 30% MOX fuel 18-month cycle, the system responses were analyzed through two cases, *i.e*., the pressure case to confirm the maximum pressure and the enthalpy case to confirm the maximum fuel temperature or radial averaged enthalpy.

The power trends of three models show the similar trends except the magnitudes (Fig. 1, 2). Due to the difference of ejected rod worths, the 30%MOX (30% MOX fuel 18-month cycle) shows less values than those of the Nominal ($UO_2$ 18-month cycle) and 24M ($UO_2$ 24-month cycle) models. In fact, as more $PuO_2$ fraction is considered, the boron concentration is increased, and the ejected rod worth is decreased.



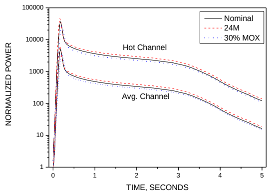
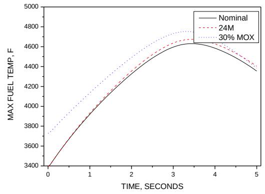


Figure 1. Power (HFP)  Figure 2. Power (HZP)

The maximum fuel temperature (Fig. 3) and radial averaged fuel enthalpy (Fig. 4) showed the similar trends each other. However, in spite of the lower rod worth or power levels, the 30%MOX fuel temperature shows higher values than those of Nominal and 24M models due to the unfavorable thermo-physical characteristics of the fuel. It could be confirmed also through the trends of maximum cladding temperatures (Fig. 5) and minimum DNBRs (Fig. 6) during the transients.



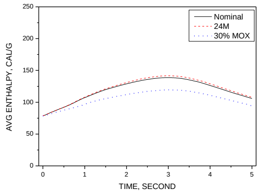
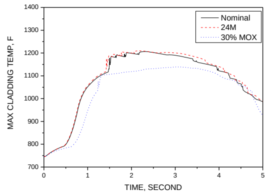


Figure 3. Max. Fuel Temp.  Figure 4. Fuel Enthalpy



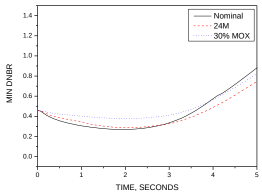
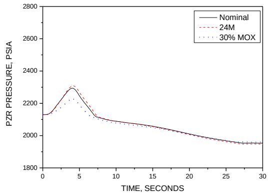


Figure 5. Max. Clad Temp.  Figure 6. Minimum DNBR

Despite the same characteristics of gap or cladding, the 30%MOX shows the lower cladding temperature and higher DNBRs due to the lower power levels than those of Nominal and 24M. To compensate the margin decrease in fuel performances, the core design procedure should be adjusted to moderate the adverse effects caused by MOX fuels through flatter axial power distributions, less radial peaking factors, less control element assembly worths, *etc*.

The pressurizer pressure (Fig. 7) and steam generator pressure (Fig. 8) show the similar trends to the power variation during the transient. The 24M shows little higher values and 30%MOX shows lower values than those of Nominal model.



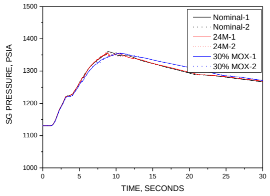


Figure 7. PZR Pressure  Figure 8. SG Pressure

## 4. Conclusion

The feasibility study to confirm the APR1000 ADFs was performed through the CEA ejection analyses. Despite the less rod worth or power trend, the 30%MOX shows the higher fuel temperature than those of Nominal or 24M models. To mitigate the adverse effects caused by MOX fuel loading, the change of core design procedure was recommended. However, despite some unfavorable results, it was concluded that the three core models could satisfy the design safety limits in the case of CEA ejection accident through the feasibility study.

## Acknowledgements

This study has been going on under the funding of Korea Electric Power Corporation.

## REFERENCES

[1] M. K. Kim, *et al.*, Design Requirements and Safety Design Features of APR1000, Nuclear Industry, **30**(3), pp.72-78, Korea Atomic Industrial Forum, 2010.

[2] K. B. Yoo, *et al*., Basic Design Development of APR1000 – Safety Analysis, TM.F02.M2010.1016, KEPCO Research Institute, 2010.

[3] Y. H. Kim, *et al*., System Response Analysis of CEA Ejection Accident with KNAP for APR1000, The Seventh Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety, Chuncheon, Korea, November 14- 17, 2010.

[4] C. K. Sung, *et al*., Topical Report on Non-LOCA Analysis Methodology, KNAP, TR-KHNP-0009, Korea Hydro and Nuclear Power Co., 2004.

[5] S. G. Popov, *et al*., Thermophysical Properties of MOX and UO2 Fuels Including the Effects of Irradiation, TM-2000-351, Oak Ridge National Laboratory, 2000.