Evaluation of Fuel Rod Performance in the APR+ Design

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1. Introduction

A feasibility study for the APR+ development was carried out from August 2007 to July 2009. From the results of the feasibility study, a two-loop evolutionary pressurized water reactor (PWR) was selected for APR+, based on the APR1400 design along with a number of advanced design features which aim at enhancing safety and economics [1,2]. Major differences between APR+ and APR1400 are a thermal power increase and a changed core environment due to added fuel assemblies. The changed core environment affects the fuel rods in the APR+ core.

The purpose of this paper is to evaluate the performance of fuel rods in the APR+ design, considering the increased thermal power and changes of the APR+ core.

2. Evaluation of Fuel Rod Performance

Fuel assemblies loaded and burned up in the APR+ core must maintain their integrity up to the end of their life. The changes in burnup and the power history of the core affect various factors associated with the fuel integrity. These factors can be categorized into thermal performance integrity factors and mechanical performance integrity factors. The former includes a rod internal pressure and a fuel temperature. The latter includes a clad strain, a clad fatigue, a clad stress, etc [3]. The evaluation of fuel rod performance has been needed to assure that the fuel rods in the APR+ core keep their integrity in the changed core environment. Therefore the evaluation has been carried out in terms of both thermal performance and mechanical performance.

2.1 Thermal Performance

2.1.1 Scope

In order to evaluate the thermal performance of fuel rods within a burnup of 60,000 MWD/MTU in the APR+ core, the rod internal pressure and fuel melting temperature (or power-to-melt) have been evaluated. Input data for the evaluation were consulted with those of Shin-Kori Units 3&4 for the initial core design. In addition, the most conservative conditions were assumed physically and mechanically.

The internal pressure of the UO_2/Gd_2O_3 rod and the power-to-melt of the hot rod in the core are evaluated as a function of burnup.

2.1.2 Results

In order to maintain the integrity of the nuclear fuel burned up in the core, the rod internal pressure should be less than 2,250 psia (or meet non lift-off criteria) and the power-to-melt should be greater than 21 kW/ft. The rod internal pressure and the normalized power-to-melt for the APR+ core are shown in Fig. 1 and Fig. 2, respectively. Fig. 1 shows the rod internal pressure for UO_2 rod and Gd_2O_3-UO_2 rod as a function of rod average burnup. The rod internal pressure increases gradually but drops off at some burnups with the bounding radial fall-off factor given in Fig. 2. The maximum rod internal pressure is 2,144 psia at about 58 GWD/MTU. Fig. 2 shows the normalized power-to-melt with bounding radial fall-off. The minimum power-to-melt of 22.6 kW/ft occurs in the vicinity of 32 GWD/MTU.

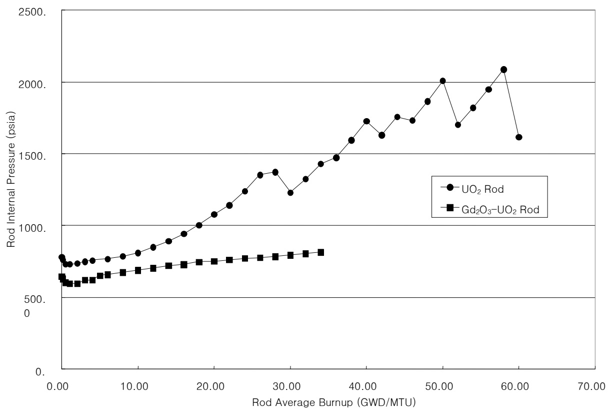

Fig. 1 Rod Internal Pressure

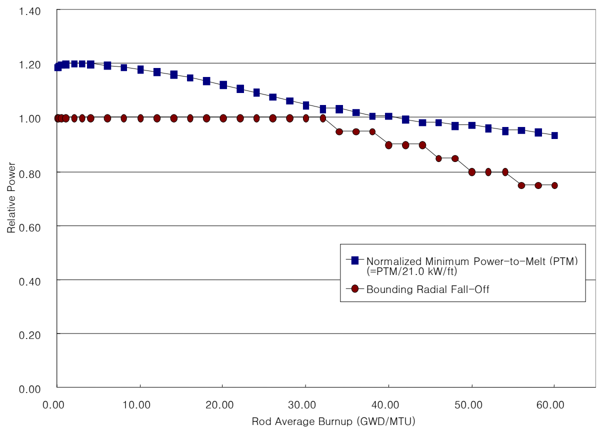

Fig. 2 Normalized Minimum Power-to-Melt

The evaluation results for the rod internal pressure and the minimum power-to-melt meet the design criteria and are summarized in Table 1.

Table 1. Evaluation Results for Thermal Performance

Design Factor	Result	Design Criteria
Rod Internal Pressure (psia)	2,144	< 2,250 or non lift-off
Power-to-Melt (kW/ft)	22.6	> 21

2.2 Mechanical Performance

2.1.1 Scope

The fuel rods should maintain their integrity for the fuel assemblies to burn up safely in the core. Major design factors for the mechanical integrity of the fuel rods are a clad collapse, a clad strain, a clad fatigue, and a clad stress. The mechanical integrity evaluation of the APR+ fuel rods has been conducted in the above aspects. For a conservative evaluation, the rod with the maximum burnup and power was used assumptively.

2.1.2 Results

A clad collapse is caused by a clad creep which results from a greater pressure of the coolant than a rod internal pressure. The clad collapse should not occur during the projected exposure. Therefore collapse time for the fuel clad should be longer than the burnup time of the fuel rod in the core. For the evaluation of the clad collapse, the minimum rod internal pressure and no gas release were assumed. The evaluation results show that there exists no clad collapse in the APR+ core within a fuel-loaded time of 45,000 hours.

A clad strain on the rod clad is caused by excessive strain of the clad when the rod internal pressure is greater than the coolant pressure or when the fuel pellet contacts the rod clad. The average radial plastic strain of the clad should not exceed 1.0% under Condition I and II events during all the life time of rod in the core. The evaluation result for the APR+ clad strain shows the total strain is 0.63% to the maximum under Condition I and II.

A clad fatigue results from loads repeated in operation. Thermal power and difference pressure between internal pressure and external pressure leads to the loads. The clad fatigue is evaluated by calculating the fatigue damage factor. For a conservative evaluation, the variation of the load was assumed to be from 10 % to 100 %. The result for the APR+ fatigue evaluation is 0.609 within a burnup of 60,000 MWD/MTU.

The stress on the rod results from the pressure difference between rod internal pressure and reactor coolant pressure. As the rod burns up in the core, the rod internal pressure can exceed the reactor coolant pressure due to causes including buildup of gas release from nuclear fission reactions and transient gas release. In such a case, tensile stress occurs on the rod clad. The maximum tensile stress for the APR+ fuel rod is 16,919 psi, which meets the design criteria.

The mechanical evaluation results for the collapse, the strain, the fatigue, and the stress meet the design criteria for the fuel rods and are summarized in Table 2.

Table 2. Evaluation Results for Mechanical Performance

Design Factor	Result	Design Criteria
Collapse	No Collapse	No Collapse
Clad Strain (%)	0.63	< 1.0
Clad Fatigue	0.609	< 0.8
Clad Stress (psi)	16,919	< 54,919

3. Conclusions

APR+ has been developed as a two-loop, 1,500 MWe class evolutionary PWR on the basis of the APR1400 design. To accommodate the increased power and major changes to the APR+ core, some of the RCS design parameters have been adjusted. Considering this, the evaluation for fuel rod performance factors has been carried out to confirm the fuel integrity in terms of thermal performance and mechanical performance.

The evaluation results of the thermal and mechanical performance factors meet the design criteria for fuel rods. The fuel integrity in the APR+ fuel rod design is assured in the aspect of both the thermal performance and the mechanical performance.

ACKNOWLEDGEMENTS

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