Analysis about Effect of Power History on Fuel Performance under RIA condition

Jinho Jeong*, Yugwon Jo
Central Research Institute, Korea Hydro & Nuclear Power Co., Ltd
**Corresponding author: jinho.jeong@khnp.co.kr*

1. Introduction

Reactivity Insertion Accident (RIA) which include unintended control rod withdrawal, soluble burnable absorber dilution, control rod ejection is increase of reactor power due to unwanted insertion of reactivity. Most severe scenario in these case is rod ejection accident (REA) considered as design base accident of nuclear power plants [1]. REA is occurred due to mechanical failure of control element housing and control elements are ejected rapidly because of pressure difference between reactor coolant system and housing. Reactivity is inserted following control rod ejection and rod power near ejected control rod is excursed. The power excursion lead to increase of fuel temperature and fuel thermal expansion and these may cause pellet-cladding mechanical interaction (PCMI) failure.

PCMI failure criteria is determined by radial averaged enthalpy rise which means deposited energy to fuel and calculated by full half maximum width (FWHM) area of power pulse. The fixed PCMI criteria was used in the past, but U.S. NRC suggested revised criteria in recent [2]. Revised criteria is changed following excess hydrogen content of the cladding which had been accumulated during normal operation. Figure 1 shows PCMI criteria which is drawn by enthalpy rise versus hydrogen contents. Hydrogen is by-product of waterside corrosion, and certain ratio, called as hydrogen pick-up (HPU) ratio which depend on cladding materials, of generated hydrogen is absorbed to cladding [3]. Oxide thickness is increased as fuel burnup but it is not directly proportional to burnup. Some fuel performance indicator, oxide thickness, hydrogen contents, rod internal pressure (RIP), etc., are affected by both burnup and power history [4].

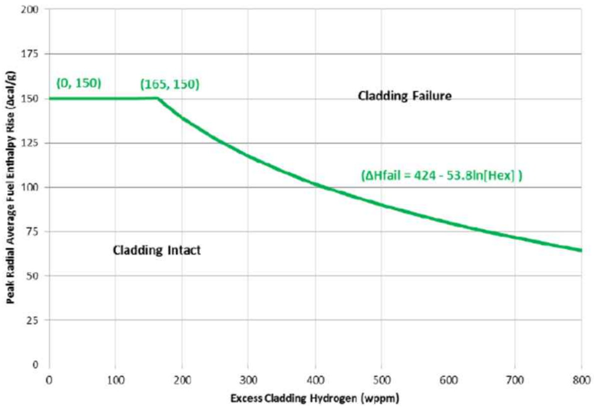

Fig. 1 PCMI Cladding Failure Threshold – SRA Cladding at High Temperature Reactor Coolant Conditions [2]

In this study, we analyzed the effect of the fuel power history on the fuel behavior under REA. It is assumed that fuel had different power history with same burnup. And we compared major indicator of REA.

2. Methods

In this study, 3-loop Westinghouse type plant and 17ACE7 fuel assembly was analyzed. To confirm power history effect, not REA margin, design parameters were used as nominal value. To make initial conditions of fuel, steady state fuel performance calculation was conducted. Steady state core power history were shown in Figure 2. Because fresh fuel is usually most limiting case, EFPD of steady state was considered for one cycle, 500days. Hypothetical pin power were used to meet the same burnup with different power history. This could remove the effect of burnup difference.

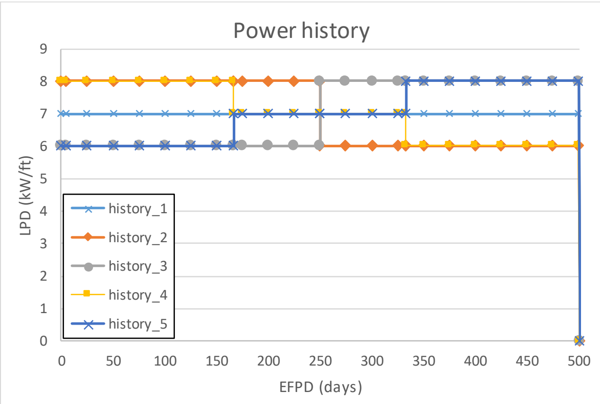

Fig. 2 Steady state power history

Next, transient core power pulse and cladding wall temperature were calculated by RAST-K / CTF coupling code. Before transient calculation, steady state RAST-K calculation was conducted to produce initial condition and restart file. It is assumed that control elements were ejected at HZP EOC conditions and ejection time was 0.1 second. Some factors, ejected rod worth, β_{eff}, FTC, MTC and axial offset, are adjusted to maximize the power pulse height and width. Figure 3 shows simulated transient power pulse.

To calculate steady state and transient conditions of fuel, FRAPCON/FRAPTRAN fuel performance code was used [5] [6]. FRAPCON calculate steady state fuel performance for making initial condition before transient. In addition, excess hydrogen contents was used for comparing the PCMI criteria with enthalpy rise of each fuel. Input data for FRAPCON is geometry of fuel rod, power history and coolant condition. After the calculation, maximum excess hydrogen content was extracted.

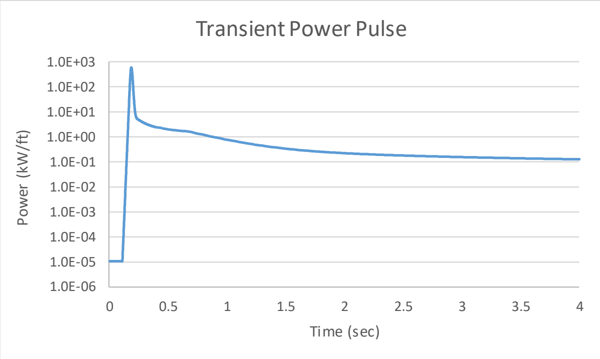

Fig. 3 Transient Power Pulse

FRAPTRAN calculate fuel performance under transient conditions. Input data for FRAPTRAN is geometry of fuel rod, rod during power, cladding wall temperature and restart file made by FRAPCON. Major indicator under RIA is RIP, fuel enthalpy and enthalpy rise, pellet and cladding temperature, and so on. These values were also extracted.

3. Results

Table 1 shows the enthalpy rise of each power history with PCMI failure threshold. Enthalpy rise of each cases is almost same because same power pulse shown in figure 3 was used. However, excess hydrogen content has difference for each cases because HPU is affected by power history. Nevertheless, excess hydrogen contents were too few to decrease the PCMI margin. Accumulated hydrogen and concentration difference was not enough to affect the PCMI criteria margin due to short irradiated time of fresh fuel.

Table 1 Enthalpy rise and hydrogen content of each resutls

	Enthalpy rise (cal/g)	Hydrogen content (wppm)
History_1	49.03	48.85
History_2	49.02	48.86
History_3	49.05	40.3
History_4	49.02	48.96
History_5	49.06	40.39

Figure 4 shows the pellet centerline temperature. Pellet centerline temperature also had no difference. Pellet centerline temperature is affected by fuel thermal conductivity if rod power is same. However, according to MATPRO model, fuel thermal conductivity is changed by not power history but fuel burnup [3]. In this study, fuel thermal conductivity was not difference for each cases because burnup of each cases is same.

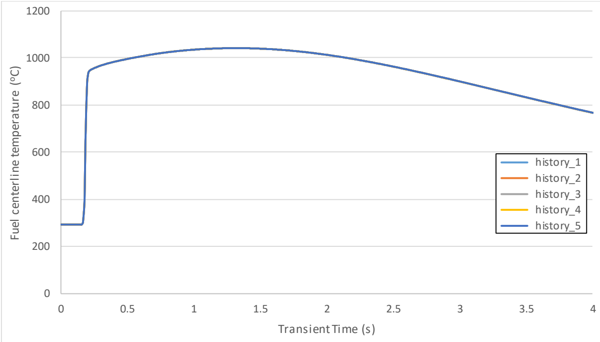

Fig. 4 Transient fuel centerline temperature

4. Conclusion

In this study, we investigated the effect of power history under RIA. Hypothetical rod which had different power history with same burnup was considered. There are no significant difference in major fuel performance. Some values, oxide thickness or hydrogen contents, were changed following power history but it is ignorable. The most limiting case is fresh or once burned fuel so that irradiation time is too short to affect the fuel performance. It seems that it is better to consider burnup or deposited energy than power history under RIA.

REFERENCES

[1] OECD/NEA, "Nuclear Fuel Behavior Under Reactivity-initiated Accident (RIA) Conditions," NEA No. 6847, 2010.

[2] U.S. NRC DG-1327, "Pressurized Water Reactor Control Rod Ejected and Boiling Water Reactor Control Rod Drop Accident," Washington, DC..

[3] W. G. Luscher, K. J. Geelhood and I. E. Porter, "Material Property Correlations," Pacific Northwest National Laboratory, 2015.

[4] J. Kim, D. Kook, J. Sim and Y. Kim, "Review on Spent Nuclear Fuel Performance and Degradation Mechanism under Long-term Dry Storage," *JNFCWT,* vol. 11, no. 4, pp. 333-349, 2013.

[5] K. J. Geelhood, W. G. Luscher, P. A. Raynaud and I. E. Porter, "FRAPCON-4.0," PNNL-19418, Vol.1 Rev.2, 2015.

[6] K. J. Geelhood, W. G. Luscher, J. M. Cuta and I. A. Porter, "FRAPTRAN-2.0," PNNL-19400, Vol.1 Rev.2, 2016.