Study for models simulating the oxides of the cladding when analyzing CEA Ejection

Chang-yeon Yoo[a*], Sung-ju Cho [a], Jae-il Lee [a]

[a]*New Plant Transient Analysis Team, KEPCO NF, 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 305-353, Korea*

[*]*Corresponding author: cyyoo@knfc.co.kr*

ABSTRACT*:* The fact that the oxides of the cladding is formed at high temperature and high burn up is generally known. The cladding oxide performs as additional thermal resistance, which has an adverse influence on the integrity of elements of fuel rods, such fuel pellet and cladding. Therefore it is needed to evaluate the effect of the cladding oxides on fuel rods when analyzing CEA (Control Element Assembly) Ejection. Two simulation models for the cladding oxides using RETRAN code are established to evaluate the effect of the cladding oxide when CEA Ejection occurs in the condition of HZP (Hot Zero Power) at the burn-ups of 30000 and 60000 MWD/MTU. According to the evaluation results, heat flux to the cladding becomes lower and more energy is stored in fuels due to the effect of cladding oxides. Also two simulation models show almost the same effect on fuel rods as thermal resistance.

KEYWORDS*: Oxide. RETRAN. CEA Ejection. Cladding. High Burn-up*

I. Introduction

The fact that the oxides of the cladding is formed at high temperature and high burn up is generally known. The cladding oxide is performed as thermal resistance and the integrity of elements of fuel rods, such as fuel pellet and cladding, becomes worse. Therefore it is needed to evaluate the effect of the cladding oxides on fuel rods when analyzing CEA Ejection. To evaluate the effect of the oxides of the cladding, two models for simulating the cladding oxides are suggested and both no-oxide case and oxide case are evaluated using two simulation models and comparison of calculation results are presented.

II. Methods and Results

In this section, an outline of CEA Ejection, two simulation models and evaluation results of CEA ejection with and without the cladding oxides are described. The first simulation model is the detailed model where the cladding oxide layer is added additionally outside the cladding and the second model is the simplified model to revise the cladding thermal conductivity considering the cladding oxides.

II.A CEA Ejection

CEA Ejection results from a circumferential rupture of the control element drive mechanism (CEDM) housing or of the CEDM nozzle. This accident causes the core power to increase rapidly due to the almost instantaneous addition of positive reactivity. However, the rapid increase in core power is terminated by a combination of Doppler reactivity feedback and delayed neutron effects. This increase in power results in a generation of high power trip and the reactor power begins to decrease as CEAs drop into the core. To evaluate the effect of the cladding oxides during this event, CEA ejection, two simulation models, the detailed model and the simplified model, are established.

II.B Model 1: Detailed Model

To analyze the CEA Ejection by RETRAN code, a fuel rod consists of 20 axial nodes with the same height and 9 radial regions cylindrically. 7 regions from the center of fuel rod are for the fuel pellet and the eighth region is for the gap and the last one is for the cladding. To simulate the cladding oxides in detail, another region for oxide layer is added as shown in Fig. 1. The cladding oxide layers with the same thickness at every axial node in axial axis are assumed. The thickness of oxide layer is increasing over fuel burn-up from the experimental data and the thickness of 9th region is decreasing due to the oxidation erosion of the cladding. These values are applied in RETRAN code geometric input. And the thermal conductivity of the cladding oxides is calculated based on the black oxide data of Gilchrist in MATPRO [1], which describes the material properties correlations used by SCDAP/RELAP5. This material property is applied to RETRAN code property input.

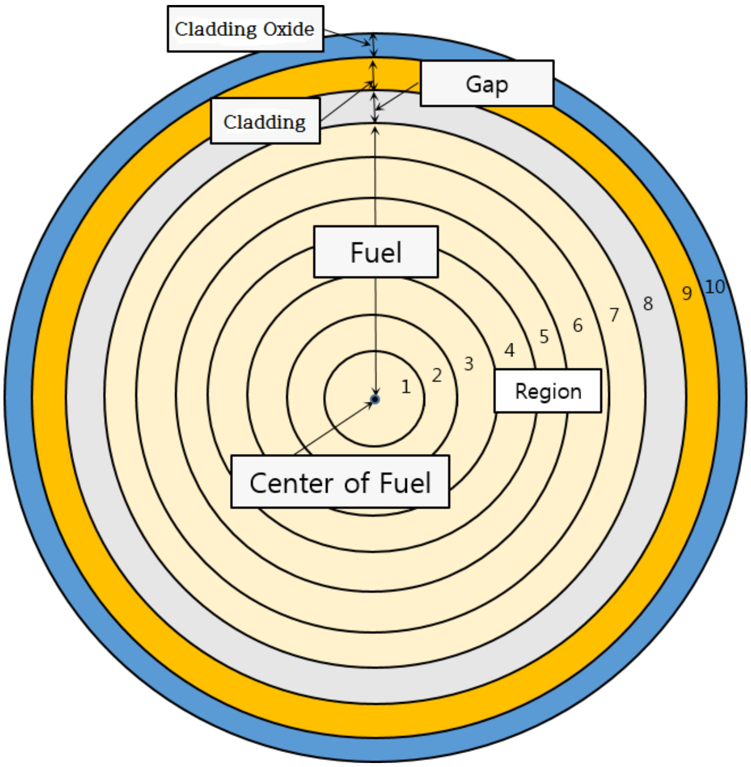

Fig. 1. Fuel rod regions simulated in RETRAN code with the cladding oxides.

II.C Model 2: Simplified Model

In respect of heat transfer from fuel center to coolant, the cladding oxides can be regarded as another thermal resistance. As an illustration of the thermal resistance in series, the cladding and the cladding oxides are shown in Fig.2. Therefore the effective thermal conductivity is calculated by equations (2-1) and (2-2) in the condition of the cladding oxides with the same thickness at every axial node [2]. The thermal conductivity of the cladding oxides is calculated from MATPRO data [1]. The cladding oxides are simply simulated just by replacing the thermal conductivity of the cladding with that of the cladding with changing the cladding thickness considering the cladding oxide thickness.

$$q = \frac{(T_1 - T_3)}{\frac{\ln(r_2/r_1)}{2\pi k_1 L} + \frac{\ln(r_3/r_2)}{2\pi k_2 L}} = \frac{(T_1 - T_3)}{\frac{\ln(r_3/r_1)}{2\pi k_f L}} \qquad (2\text{-}1)$$

$$\therefore K_f = \frac{\ln(r_3/r_1)}{\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2}} \quad (2\text{-}2)$$

Where,

q	= heat, Btu/hr
L	= height of one axial node of fuel, ft
r_1	= radius from fuel center to gap, ft
r_2	= radius from fuel center to clad, ft
r_3	= radius from fuel center to clad oxide, ft
T_1	= cladding inner surface temperature, ˚F
T_2	= cladding outer surface temperature, ˚F
T_3	= cladding oxide outer surface temperature
k_1	= thermal conductivity of cladding (ZIRLO), Btu/ft-hr-˚F
k_2	= thermal conductivity of cladding oxide (ZrO_2), Btu/ft-hr-˚F
k_f	= thermal conductivity of ZIRLO+ZrO2, Btu/ft-hr-˚F

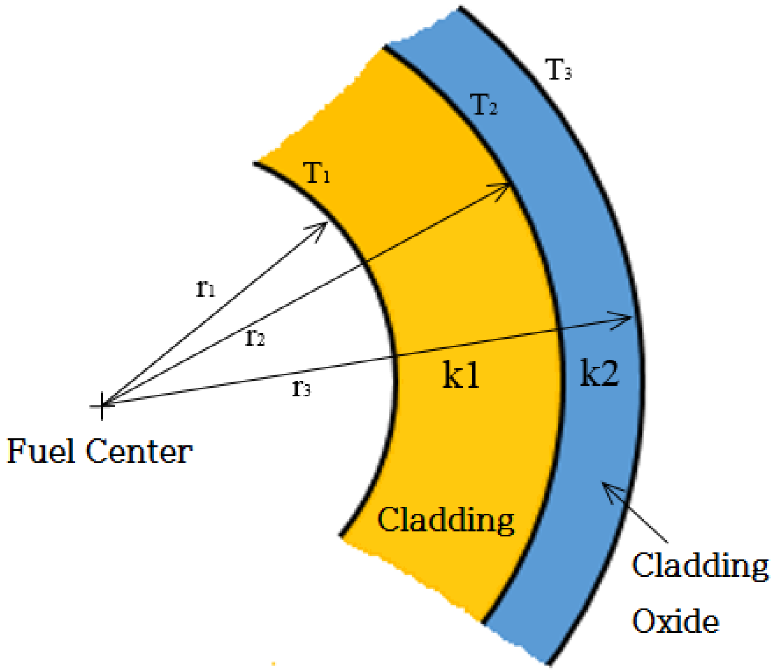

Fig. 2. Diagram of thermal resistance in series of the cladding and the cladding oxides.

II.D The effect of simulating the cladding oxides

To evaluate the effect of the cladding oxides, the calculations are performed in view of power, heat flux, enthalpy rise and fuel centerline temperature. As shown in Fig. 3 and 4, it is confirmed that nuclear power is not relevant to the cladding oxides. However, heat flux from pellet to cladding, which is calculated using the gap conductance and the temperature difference between pellet outer surface and cladding inner surface, is decreased and more energy is stored in the pellet as thermal resistance is increased because of the cladding oxides as depicted in Fig. 5 and 6. As shown in Table 1, Fig. 7 and 8, stored energy increase results in the increase of enthalpy rise. Compared with no-oxide case, 6.0 % for HZP 30000 MWD/MTU condition and 12.0 % for HZP 60000 MWD/MTU condition are increased. And 1.3 % for HZP 30000 MWD/MTU and 3.0 % for HZP 60000 MWD/MTU are increased in respect of the maximum fuel centerline temperature as shown in Table 1. Based on these results, the cladding oxides are considered as an additional thermal resistance and the important safety parameters such as the enthalpy rise and the maximum fuel centerline temperature during CEA Ejection may become worse. In addition, the thermal resistance is increased and the cladding oxide becomes thicker as fuel burn-up goes high. Regardless of the difference of cladding oxide simulation models, the difference of evaluation results between model 1 and model 2 in view of power, heat flux, enthalpy rise and the maximum fuel centerline temperatures is negligible.

Table 1. Effect of the cladding oxide compared with no-oxide case during CEA Ejection

Conditions	HZP 30000 MWD/MTU		HZP 60000 MWD/MTU	
Models	Model 1	Model 2	Model 1	Model 2
Increase of enthalpy rise, %	6.0	5.6	12.0	11.4
Rise of maximum fuel centerline temperature, %	1.3	1.3	3.0	3.1

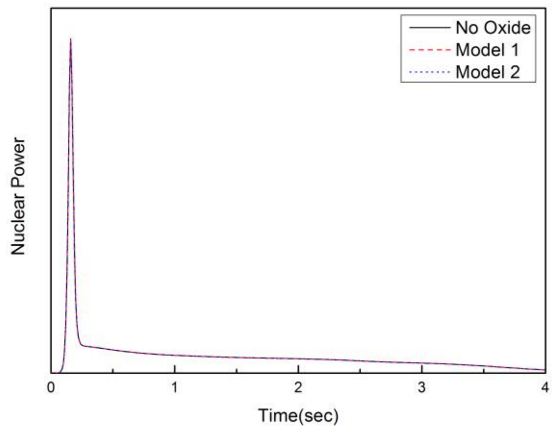

Fig. 3. Power over time in the condition of HZP at 30000 MWD/MTU

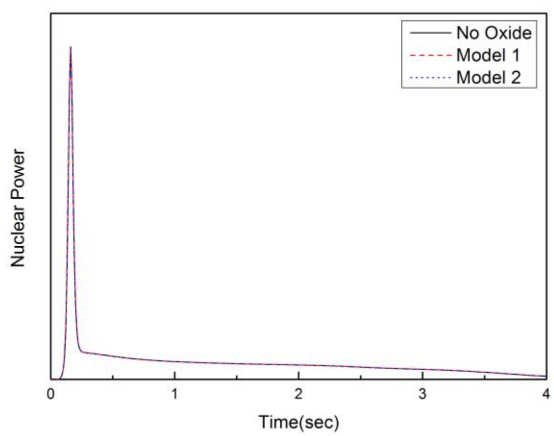

Fig. 4. Power over time in the condition of HZP at 60000 MWD/MTU

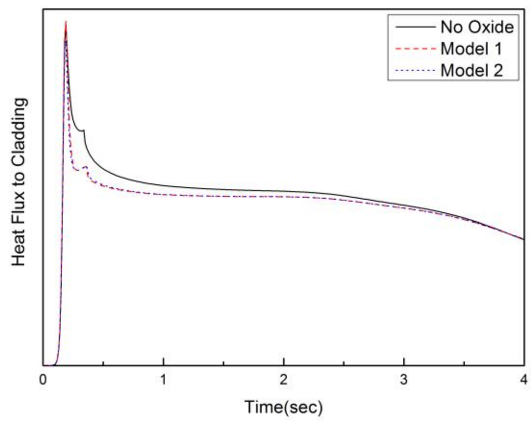

Fig. 5. Heat Flux to the cladding over time in the condition of HZP at 30000 MWD/MTU

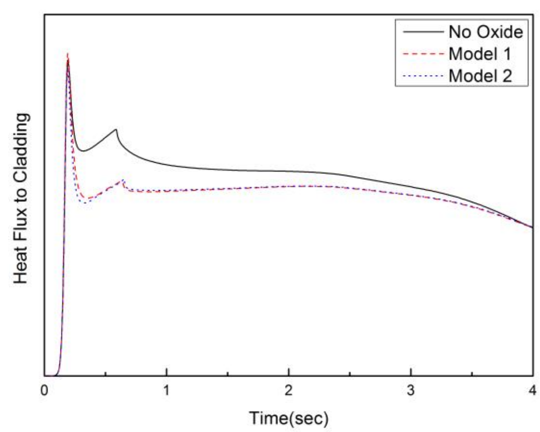

Fig. 6. Heat Flux to the cladding over time in the condition of HZP at 60000 MWD/MTU

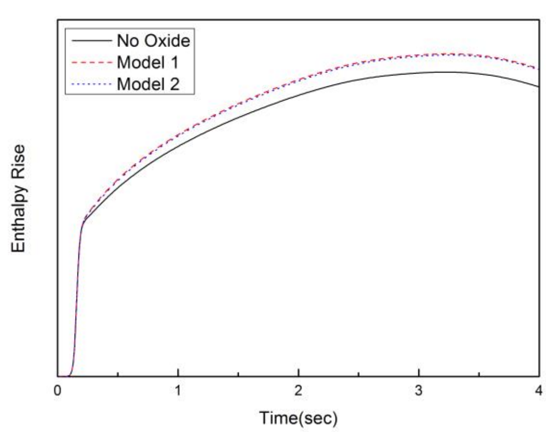

Fig. 7. Enthalpy Rise over time in the condition of HZP at 30000 MWD/MTU

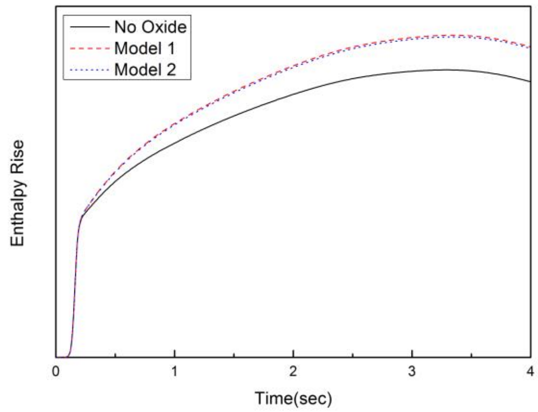

Fig. 8. Enthalpy Rise over time in the condition of HZP at 60000 MWD/MTU

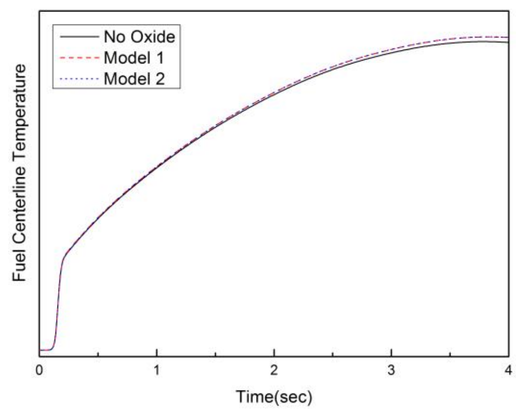

Fig. 9. Fuel Centerline Temperature over time in the condition of HZP at 30000 MWD/MTU

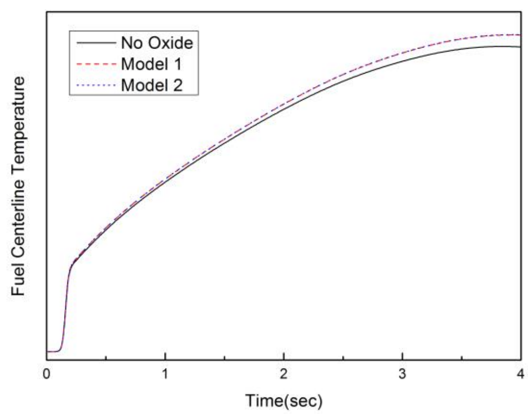

Fig. 10. Fuel Centerline Temperature over time in the condition of HZP at 60000 MWD/MTU

III. CONCLUSIONS

To evaluate the effect of the cladding oxide, two simulation models of the cladding oxides using RETRAN code are established. According to the results, heat flux to the cladding is reduced, the enthalpy rise and the maximum fuel centerline temperature are increased compared with no-oxide case. And when the cladding oxide becomes thicker, the increment of enthalpy rise and the maximum fuel centerline temperature becomes bigger compared with no-oxide case comparing the results between 30000 MWD/MTU case and 60000 MWD/MTU case. In addition, from the calculation results of model 1 and model 2, it is confirmed that two models simulate the effect of the cladding oxide very similarly. Based on all these results, it is confirmed that more heat is stored in the pellet due to the increase of thermal resistance by cladding oxides.

REFERENCES

1. SCDAP/RELAP5-3D Code Development Team, SCDAP/RELAP5-3D CODE MANUAL VOLUME 4: MATPRO – A LIBRARY OF MATERIALS PROPERTIES FOR LIGHT-WATER-REACTOR ACCIDENT ANALYSIS, BECHTEL BWXT IDAHO. LLC, p.5-13, 2003.
2. Frank P. Incropera, David P. Dewitt, Theodore L. Bergman, Adrienne S. Lavine, Introduction to Heat Transfer 5th Edition, JOHN WILEY & SONS, pp.116-118, 2005.
3. COMPUTER SIMULATION & ANALYSIS, INC., RETRAN-3D – A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems Volume 3 : User's Manual, Computer Code Manual, November 2004.