# A Study on the Possibility of End-Fitting and Outlet Feeder Oxidation during Large Break LOCA with ECCS Impairment

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## 1. Introduction

A new integrated severe accident code for PHWR called CAISER is being developed at KAERI. So far, the core degradation phenomena in a calandria tank including fuel melting, fuel rod slumping/melting and relocation of main components such as fuel channel have been modelled mechanistically and tested for preliminary validation. In this year the primary heat transport system behavior during severe accident will be developed based on RELAP5-CANDU model. As a preparatory step, the issue of the possibility of end-fitting and outlet feeder oxidation during the loss of coolant accident with a simultaneous failure of emergency core cooling system (LBLOCA + LOECC) needs to be investigated, and confirmed. This paper describes the result of the expected ranges of the temperatures of the end-fittings and outlet feeder during this accident based on the safety analyses results of Wolsong-1 Refurbishment Project, and the possibility of oxidation.

## 2. Methods and Results

According to the Wolsong-1 Refurbishment FSAR, a significant Zr-steam exothermic reaction on the fuel sheath as well as the inside surface of the pressure tube are known to occur for (LBLOCA + LOECC) accident. In the progress, the steam temperature at the fuel channel exit may reach near ~ 900˚C for RIH 35% break, and ~ 1000˚C for ROH 100% break even at ~ 2,500 sec into the accident, when steam is almost starved and significant hydrogen is produced. However in the DBA analysis using CATHENA, the metal-water reaction in neither the end-fittings nor the outlet feeder near the channel exit were considered, which may result in both non-negligible production of hydrogen and additional heat generation due to the oxidation in these components.

Figure 1 shows the growth rate of oxide layer in Zircaloy, carbon steel and stainless steel 304 as function of the temperature, where the carbon steel represents the feeder, stainless steel 304 represents the end-fitting, Zircaloy represents the fuel sheath and pressure tube. As can be seen in this Figure, the steel oxidation by steam starts at lower temperatures, and is faster than oxidation of Zircaloy at the same temperature, and is energetic with exothermic heat of reaction of ~ 272 kJ/mole[1].

Figure 2 shows the CATHENA modelling of the single channel analysis used for this study together with the name and location of the hydrodynamic volume used in the following Figures showing the safety analysis results.

### *2.1 Accident Scenario Studied*

RIH 35% Break LOCA with ECC Impaired was studied for the safety analysis as follows;

- Blowdown and Post-blowdown analyses results for the 6 representative single channel analysis results for the Critical Pass 3 and 4. O6-Mod, O6, S10, G5, B10 and W10.
- Major parameters investigated are;
  Header pressures, loop inventory, temperatures of the channel steam and $D_2$ Mixture, end-fitting and feeder at the channel outlet.

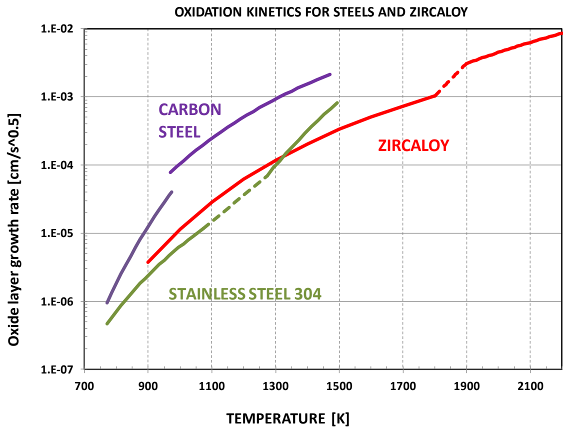


Fig.1 Oxidation Kinetics in Steam for Various Metals

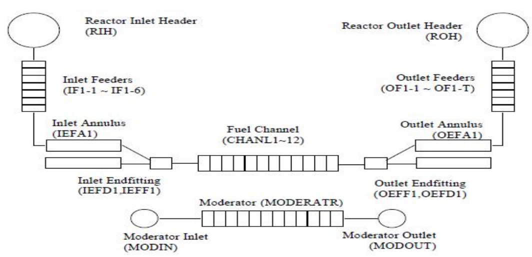


Fig.2 Single Channel Analysis Model for CATHENA Code

### *2.2 Major Parameters during Post-blowdown Phase*

Figures 3 to 7 show the results of the major related parameters of O6Mod, G5 and B10 channels such as the steam and $D_2$ Mixture temperatures at 12 axial bundle positions and the temperatures of outlet feeder and end-fittings at Pass 3 or 4 for 2500 seconds. Pass 3 and 4 represents the core pass composed of 95 fuel channels located respective upstream and downstream of the broken RIH. The predicted temperatures of the outlet feeder and end-fittings for Pass 4 are shown lower than those for Pass 3. This is because most of the pressure tube portions located at high power region of the channel center contact with the cold calandria tube due to PT ballooning early in the accident, say from 30 sec to 100 sec, and thus become cooldown. The outlet end-fitting temperature (node OEFF1) of O6Mod channel reveals that it reaches ~ 800˚C at 1000 sec, 900˚C at 1250 sec, which corresponds to a growth rate of stainless steel 304 oxide layer above 1.E-05cm/s$^{0.5}$ in Fig.1. Even in the lower power channel like G5 and B10, the temperatures of end-fittings are still quite high ~ 800ºC at 2500 sec. In addition, the temperatures of the other end-fittings such as node OEFA1 and OEFD1 are in the range of 400 ~ 500˚C in the channels surveyed. These results reveal that the metal-water oxidation model for the steel components needs to be included in the safety analysis codes for DBA and severe accident, especially because of its safety implication to the estimation of hydrogen source term for the later containment analysis as pointed out by Song and et al. [1].

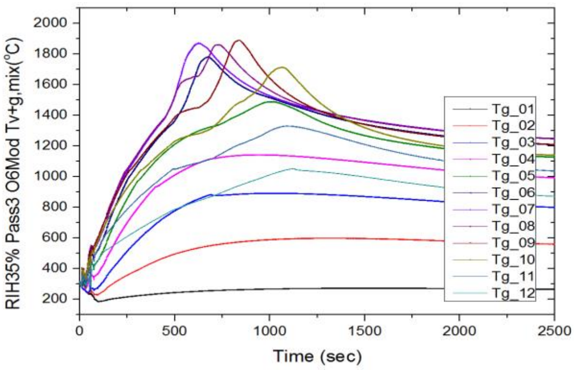


Fig.3. Channel Steam and $D_2$ Mixture Temperature of O6Mod Channel at Pass 3 for RIH 35% Break LOCA with ECCS Impaired

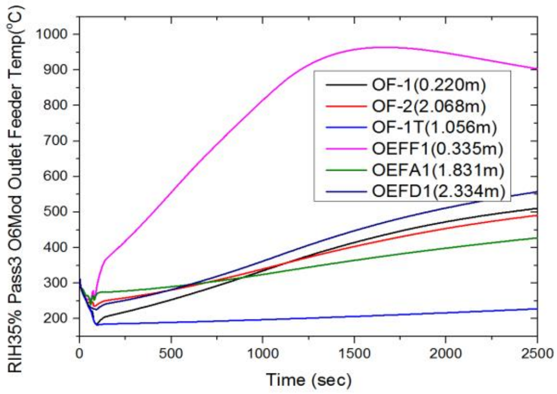


Fig.4. Outlet Feeder and End-Fitting Temperatures of O6Mod Channel at Pass 3 for RIH 35% Break LOCA with ECCS Impaired

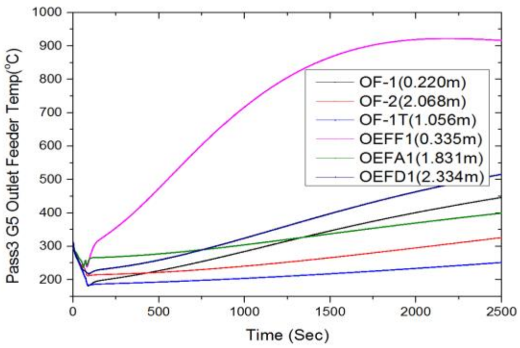


Fig.5. Outlet Feeder and End-Fitting Temperatures of G5 Channel at Pass 3 for RIH 35% Break LOCA with ECCS Impaired

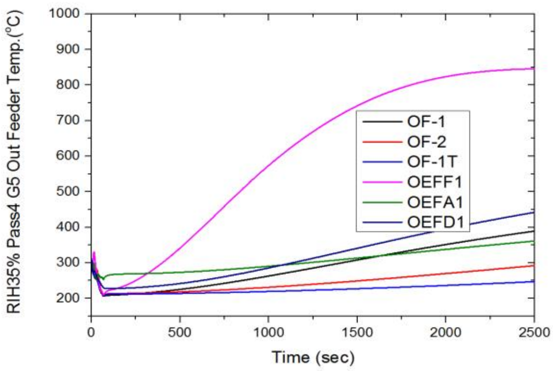


*Fig.6.* Outlet Feeder and End-Fitting Temperatures of G5 Channel at Pass 4 for RIH 35% Break LOCA with ECCS Impaired

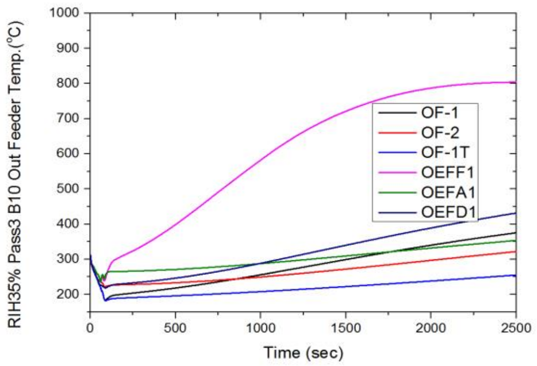


Fig.7. Outlet Feeder and End-Fitting Temperatures of B10 Channel at Pass 3 for RIH 35% Break LOCA with ECCS Impaired

## 3. Conclusions

In the current DBA analysis using CATHENA, the metal-water reactions are considered in neither the end-fittings nor the outlet feeder near the channel exit even for the large break LOCA with a simultaneous failure of emergency core cooling system. However the issue addressed by S. Nijhawan [2] at outlet feeder oxidation and consequent hydrogen production may not be negligible in the severe accident or even in the so called, "limited core damage accidents such as double failure accident scenarios" in CANDU-6 has not been taken seriously in the CANDU safety community. In this paper, a study on the possibility of steel oxidation in CANDU-6 during LBLOCA with ECCS impairment was carried out by investigating the safety analysis results of Wolsong-1 Refurbishment Project, and it was shown to be possible for the CANDU-6 components such as end-fittings and, maybe even the outlet feeders. This highlights that the current analysis tools need to include the appropriate models. This result is quite important because the current safety analysis would have resulted in underestimated production of hydrogen and additional heat due to the lack of implemented steel oxidation model. Should the underestimation of hydrogen be significant, its safety implication needs to be addressed by both the containment analysis and the severe accident mitigation strategy.

## ACKNOWLEDGMENTS

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[2]Sunil Nijhawan, Improved Regulatory Oversight and Immediate Retrofits for Operating Pressurized Heavy Water Reactors for Beyond Design Basis Accidents, Paper-54387, Proceedings of the 20th International Conference on Nuclear Engineering, July 30-August 3, 2012, Anaheim, California, USA.