# Applicability evaluation on the conservative metal-water reaction(MWR) model implemented into the SPACE code

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## 1. Introduction

The SBLOCA (Small Break Loss-of-Coolant Accident) evaluation methodology for the APR1400 (Advanced Power Reactor 1400) is under development using the SPACE code. The goal of the development of this methodology is to set up a conservative evaluation methodology in accordance with Appendix K of 10CFR50 [1] by the end of 2012. In order to develop the Appendix K version of the SPACE code, the code modification is considered through implementation of the code on the required evaluation models. For the conservative models required in the SPACE code, the metal-water reaction (MWR) model, the critical flow model, the Critical Heat Flux (CHF) model and the post-CHF model must be implemented in the code.

At present, the integration of the model to generate the Appendix K version of SPACE is in its preliminary stage. Among them, the conservative MWR model and its code applicability are introduced in this paper.

## 2. Metal-water reaction models in the SPACE code

Appendix K requires that the MWR is conservatively calculated using the Baker-Just equation [2], while the model included in the existing SPACE code is based on the Cathcart model [3]. So, the Baker-Just equation is implemented into SPACE code to replace the built-in Cathcart model.

Cathcart model calculates the oxide thickness on the cladding surfaces using Eq.(1) for oxidation reaction between zirconium and water which happens in hot temperature condition. However, it does not alter the thermal-physical properties of the cladding as the oxide layers develop.

$$t_{ox}^{n-2} = (t_{ox}^{n-1})^2 + (K\Delta t)\exp(-\frac{A}{RT}) \qquad (1)$$

The MWR model is coupled with the fuel deformation model so that if a rod ruptures, the inside of the cladding can react. The MWR heat source term for the cladding surface mesh point is added into the total heat source term for the heat structure.

The amount of heat added to the cladding's outer surface between time-point n and n-1 is given by multiplying the volume of cladding undergoing reaction by the density of zirconium and the reaction heat release:

$$Q' = \delta_{Zr}\pi\left[(r_o - t_{ox}^{n-1})^2 - (r_o - t_{ox}^{n})^2\right]\frac{H}{w_{Zr}} \qquad (2)$$

Eq.(3) shows the Baker-just equation implemented into the SPACE code. This has similar formular with Cathcart model.

$$\frac{dx}{dt} = \left[\frac{B}{x_o - x}\exp\left(-\frac{G}{T_S}\right)\right] \qquad (3)$$

Where,

$$B = 10^{-6} A / (2\rho_m^2)$$

$$G = \Delta E / R$$

Similar equation is also used for the cladding's inner surface if cladding rupture occurs in case of two models.

## 3. Model description and evaluation results

The conservative aspects of the implemented model are assessed using SPACE nodding shown in figure 1. This nodding is designed to simulate a simple vertical pipe having heat structure. Water of 570 K flows to the inside of pipe as 90 kg/sec for 100 seconds. From 100 seconds to 300 seconds, water is injected as 2.0 kg/sec. Heat power of 5MW is sustainably released from heat structure.

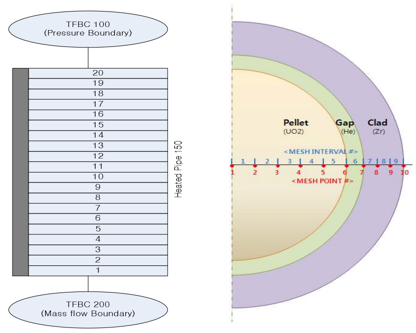


Figure 1. Noding diagram for SPACE model

Figure 2 compares axial temperature distribution by applying the two models. The result shows that all temperatures are similar. However, as shown in figure 3, temperature difference on the cladding surface of 17th node by Baker-just model is higher than Cathcart model. According to Eq.(2), heat source term by metal oxide reaction is added into the total heat source term for the heat structure. So, relatively high differential temperature appears by applying Baker-just equation rather than Cathcart model.

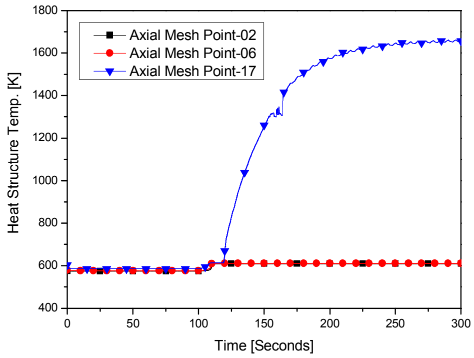


Figure 2. Axial temperatures for Component No.150

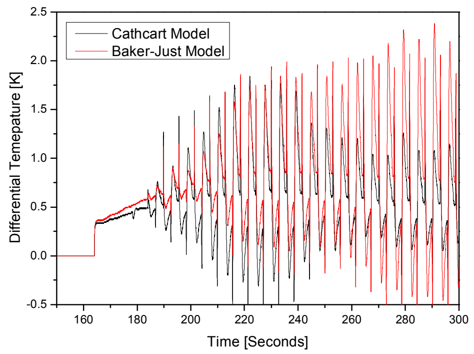


Figure 3. Differential temperature comparison between two models

Figure 4 compares the oxidation rate on the inner/outer surface between two models. Oxide reaction does not happen at low temperature of outer surface but is increased around the rupture time. As shown in figure 4, reaction on the outer surface happens firstly and reaction on the inner surface starts after rupture. Rupture of inner surface happens around 165 seconds for two cases. Major result shows that oxidation rate by Baker-just equation is bigger than Cathcart model.

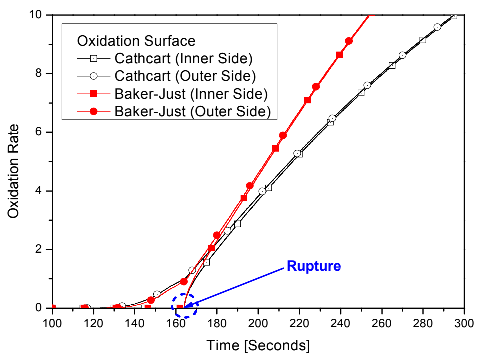


Figure 4. Oxidation rate comparison between two models

## 4. Conclusion

The Baker-just equation as the conservative model was implemented into the SPACE code. Also, This model was preliminarily assessed for a conservative prediction of the oxidation reaction under a hot temperature condition. The results show that the model required by Appendix K was successfully implemented into the best-estimate version of the SPACE code. Other required models and correlations are going to be implemented and evaluated by the end of 2012.

## Acknowledgements

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## Nomenclature

| | |
|---|---|
| $A$ | 35,889 $mole/cal$ |
| $\Delta E$ | Activation energy, $kcal/mole$ |
| $H$ | Reaction heat |
| $K$ | 2.252E-6 $m^2/\sec$ |
| $R$ | 1.987 $cal/(K-mole)$ |
| $T$ | Cladding Temperature, $K$ |
| $t_{ox}^{n-1}$ | Old time outer surface oxide thickness, m |
| $t_{ox}^{n-1}$ | New time outer surface oxide thickness, m |
| $r_o$ | Cladding outer radius, m |
| $w_{Zr}$ | Zirconium mole rate |
| $\rho_m$ | Metal density, $kg/m^3$ |
| $\delta_{Zr}$ | 6500 $kg/m^3$ (Zirconium density) |

## REFERENCES

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3. Cathcart, J.V et al., "Zirconium metal-water oxidation kinetics Ⅳ, Reaction rate studies. ORNL/NUREG-17, 1977.