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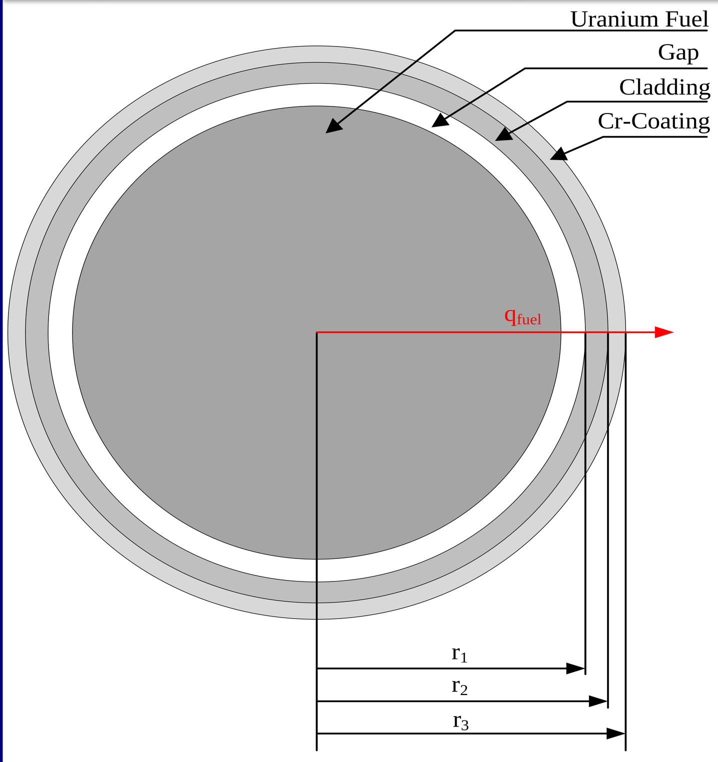
Analysis of Effect of Accident Tolerant Fuel with Cr-coated Zircaloy Cladding for Large Break-Loss of Coolant Accident

Jae-Ho Bae[a*], Soon-Joon Hong[a], Tae-Sun Ro[a], Beop-Dong Jeong[a], Tongkyu Park[a], Sungkyun Zee[a],
[a]FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea
*Corresponding author: jhbae0822@fnctech.com

Introduction

- Accident Tolerant Fuel (ATF) is being widely developed for improved fuel performance in normal operation, AOO and accident condition.
- Korea will soon apply for a license for loading of ATF fuel rod and assembly.
- It is necessary to identify changes in the expected thermal-hydraulics phenomena according to ATF loading.
- This study considered and analyzed Cr (Chromium)-coated ATF using MARS-KS code.
- The equivalent properties of Cr-coated cladding were applied to Zion plant to analyze the PCT according to the changes in properties through LBLOCA analysis.

Equivalent Properties



- Composition of Cr-coated ATF

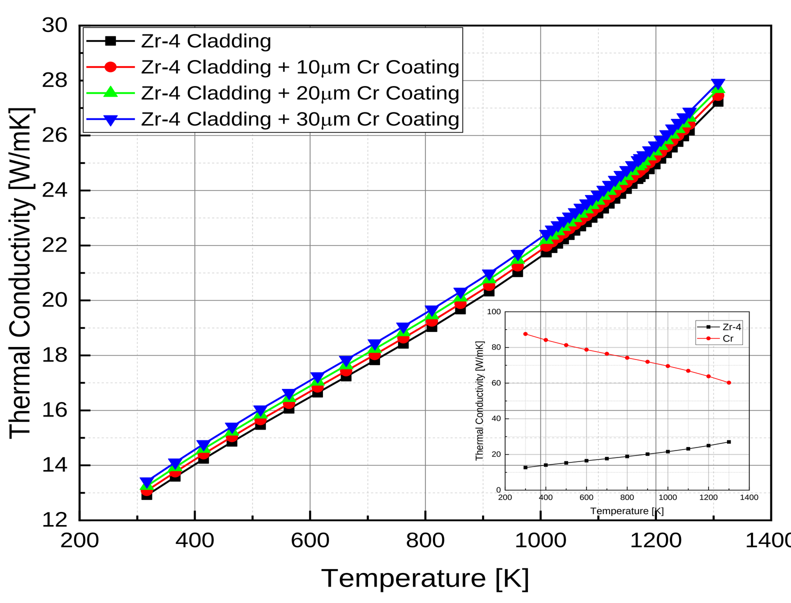
- MARS-KS code is limited in the modeling of heat structure of fuel rod, where mesh and property cannot be added outside the Zr cladding when using the gap conductance model.
- Therefore, equivalent property of Zr cladding and Cr coating is used for modeling the ATF.
- The Cr-coated cladding consists of UO2 pellet, gap, Zr cladding, and Cr coating.
- Thermal Conductivity
  - ✓ Equivalent thermal conductivity is obtained by preserving the temperature of both side of the Cr-coated cladding using heat diffusion equation.

$$\frac{1}{k_{eq}} = \frac{1}{ln(r_3/r_1)}\left[\frac{ln(r_2/r_1)}{k_{12}} + \frac{ln(r_3/r_2)}{k_{23}}\right]$$

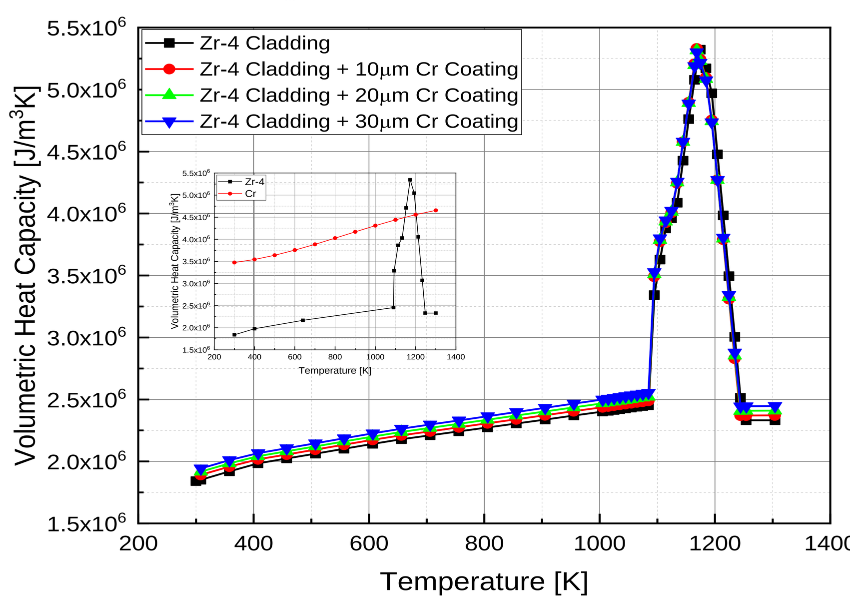
- Heat Capacity
  - ✓ The heat capacity is related to the temperature rise, so the equivalent heat capacity can be calculated according to the volume ratio.

$$(\rho C_p)_{eq} = \frac{V_{zr}(\rho C_p)_{zr} + V_{cr}(\rho C_p)_{cr}}{V_{zr}+V_{cr}}$$

✓ In this study, equivalent properties were calculated assuming 10, 20, 30 μm thickness of Cr coating on the surface of the Zr cladding.



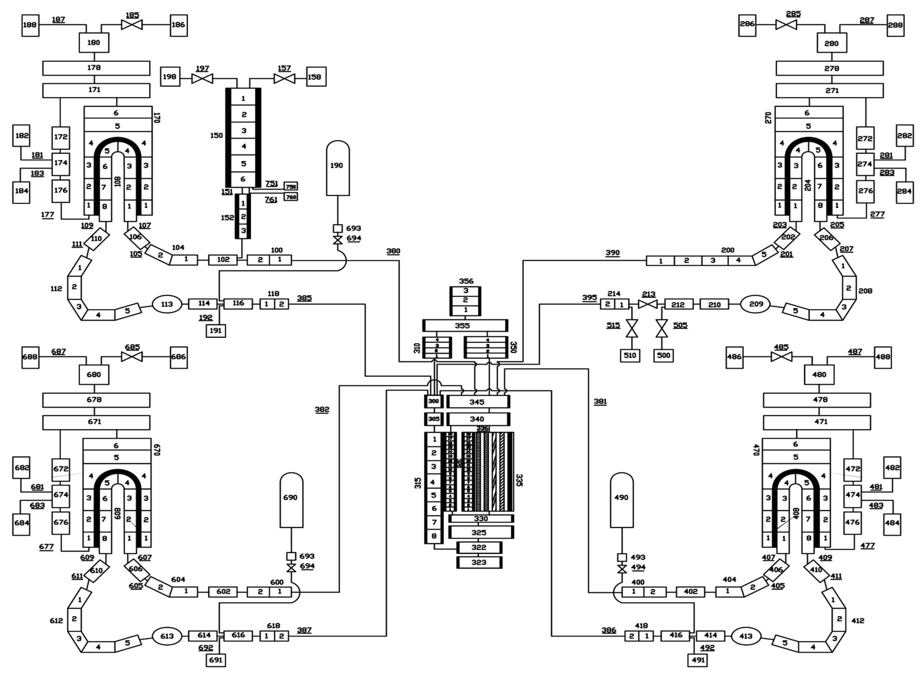
- Equivalent thermal conductivity



- Equivalent heat capacity

MARS-KS Modeling for Zion Plant

- ATF characteristics were applied for Zion plant that is pressurized water reactor of WH type operated in USA and is 3250 MWth of core power.
- The data of Zion plant was obtained from OECD-BEMUSE Phase IV, and modeling for MARS-KS code conducted.
- The steady-state results are similar to the reference presented by the OECD-BEMUSE Phase IV.



- Nodalization for Zion plant

Plant Parameter	Target	MARS-KS
Core power [MW]	3,250.0	3,250.0
Pressure in cold leg (MPa)	15.8	15.8
Pressure in hot leg (MPa)	15.5	15.5
Pressurizer level (m)	8.8	8.8
Core outlet temperature (K)	603.0	602.6
Primary coolant flow (kg/s)	17357.0	17428.8
Secondary pressure (MPa)	6.7	6.7
SG downcomer level (m)	12.2	12.0
Feed water flow per loop (kg/s)	439.0	439.2
Accumulator pressure (MPa)	4.14	4.14
Accumulator gas volume (m^3)	15.1	15.1
Accumulator liquid volume (m^3)	23.8	23.8
RCP velocity (rad/s)	120.06	120.06

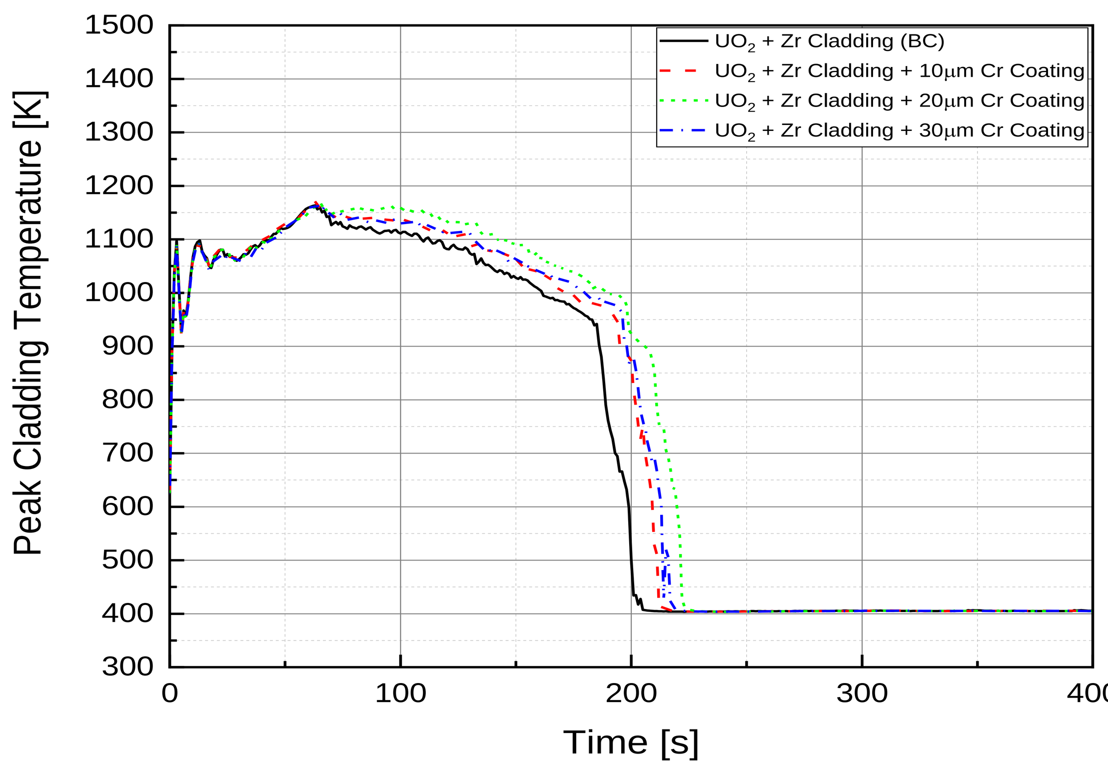
- Steady-state results

Modeling for Cr-coated cladding

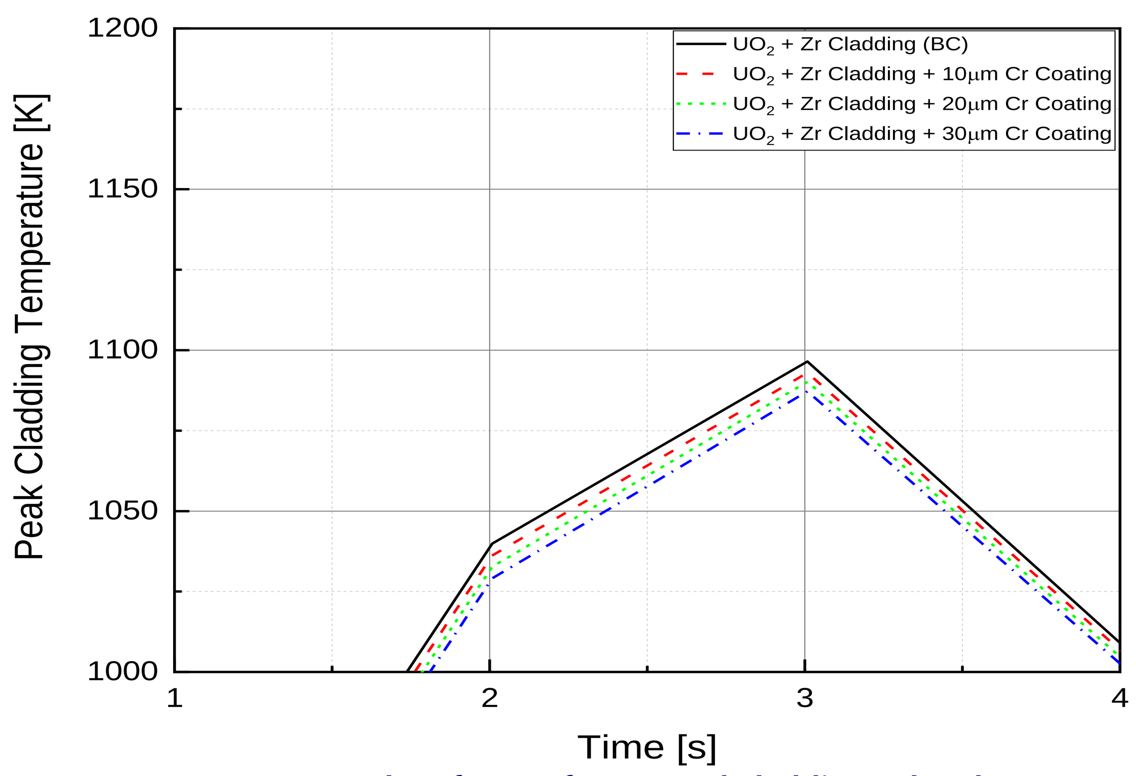
- The coated cladding has different diameter of the fuel rod compared to Zr cladding.
- Therefore, changes in variables other than equivalent properties should also be considered in MARS-KS modeling.
- The Cr-coated cladding is modeled in consideration of the following:
  - ✓ Heat Structure
    - Properties of cladding (thermal conductivity/heat capacity): Zr properties are replaced by the equivalent properties of Zr and Cr.
    - Radius of cladding: The radius of the cladding is increased by thickness of Cr coating.
  - ✓ Hydraulic Component
    - Hydraulic volume of core: Volume is decreased by increasing the diameter of fuel rod due to Cr coating.
    - Flow area of core: Flow area is decreased by increasing the total diameter of fuel rod due to Cr coating.
    - Hydraulic diameter of core: Hydraulic diameter is decreased increasing the total diameter of fuel rod due to Cr coating.

Analysis Results

- The PCT (Peak Cladding Temperature) was compared when Cr coating is applied.
- In the blowdown phase, the blowdown peak is shown to be calculated lower than Zr cladding.
- This is judged to be due to the higher equivalent thermal conductivity of coated cladding than Zr cladding, which results in faster release of fuel energy in early phase of LOCA.
- Reflood peak is calculated higher compared to Zr cladding when applying Cr-coated cladding.
- In the reflood phase, the effects of other thermal-hydraulic variables are significant, and it is not possible to accurately determine whether the effects are due to coated cladding.



- Results of PCT of Cr-coated cladding



- Results of PCT of Cr-coated cladding (Blowdown)

	Zr-4	Zr-4+ 10μm Cr	Zr-4+ 20μm Cr	Zr-4+ 30μm Cr
Phase	PCT [K]			
Blowdown peak	1096.5	1093.0	1090.2	1087.2
Reflood peak	1163.4	1171.2	1169.6	1165.4

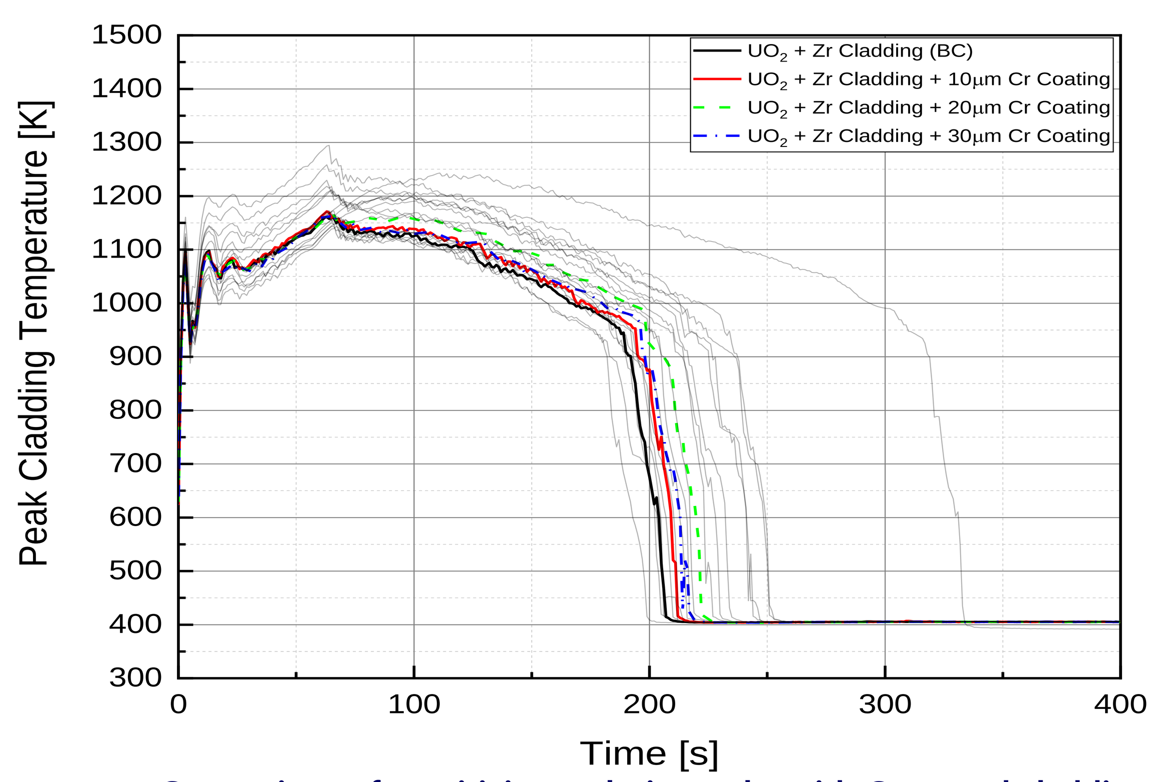
- Comparison of PCT

Relative Comparison of Cr-coated Cladding Effect

- It is necessary to conduct relative comparison of how much difference caused by change in properties affects PCR relative to other sensitivity parameters.
- The sensitivity parameters and ranges of Zion LBLOCA analysis is presented in OECD-BEMUSE Phase IV.
- In contrast to most sensitivity parameter effects, it is shown that effect of Cr-coated is less than the others.
- Although there are PCT results of the Cr-coated cladding within the range of sensitivity parameters, the results are comparable to the effects of the sensitivity parameters in some case.
- Thus, it is evaluated that the effect on PCT due to Cr-coated cladding is not negligible.

No.	Parameter	Range	
		Min	Max
1	Fuel conductivity	$value_{BC}$ – 0.4 W/mK	$value_{BC}$ + 0.4 W/mK
2	Gap conductivity	$value_{BC}$ × 0.8	$value_{BC}$ × 1.2
3	Power after scram	$value_{BC}$ – 8%	$value_{BC}$ + 8%
4	Power before scram	$value_{BC}$– 3.3%	$value_{BC}$+ 3.3%
5	Hot rod power	$value_{BC}$– 7.6%	$value_{BC}$+ 7.6%
6	LPIS delay (3/3)	-	$value_{BC}$+ 30 sec
7	Accumulator liquid volume (3/3)	$value_{BC}$– 33 ft^3	$value_{BC}$+ 33 ft^3
8	Accumulator pressure (3/3)	$value_{BC}$– 100 psig	$value_{BC}$+ 100 psig
9	Containment pressure	see BEMUSE report	
10	Hot/cold conditions for pellet radius	see BEMUSE report	

- Sensitivity parameter of Zion LBLOCA analysis



- Comparison of sensitivity analysis results with Cr-coated cladding

Conclusion

- A realistic Cr-coated cladding modeling method for MARS-KS code is currently unavailable, so the method for modeling using equivalent properties of Zr and Cr is used.
- The equivalent properties are applied to LBLOCA analysis of Zion plant, and the effect of the change in properties on PCT is analyzed.
- The PCT is calculated low when coated cladding is applied in blowdown phase, and, in reflood phase, the effect on PCT could not be accurately analyzed due to non-linear effects by complex phenomena.
- The results of sensitivity calculation show that effect of Cr coating is not negligible, and should be modeled in the safety analysis.