Pre-Calculation of CABRI Water Loop test CIP3-1 with FRAPTRAN code

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1. Introduction

OECD/NEA WGFS(Work Group on Fuel Safety) has being researching RIA(Reactivity Insertion Accident) using CABRI and NSRR tests. In 2010, WGFS set and distributed benchmark problems for CABRI CIP3-1 test, being tested in newly planned water loop facility [1]. Main goal of the problem is to identify predictability of transient nuclear fuel codes and make a consensus on the test conditions and pre-calculation result. KINS participating in the WGFS code benchmark project, implemented pre-calculation of CABRI CIP3-1 water loop test with FRAPTRAN 1.4 code. Pre-irradiated in reactor rod condition is prepared with FRAPCON and RIA test coolant conditions are calculated with TRACE thermo-hydraulic Code. This process is validated with CIP0-1 sodium loop test. Pre-test calculation results of CIP3-1 are presented such as clad hoop strain, burst time, elongation.

2. Methods and Results

In this section rodlet initial conditions and CABRI test conditions are described. Initial conditions including rodlet burnup, radius and oxide thickness are prepared with FRAPCON code [2]. And coolant conditions are pre-calculated with TRACE code [4] for more precise result such as coolant temperature, pressure and heat transfer coefficient.

2.1 Benchmark problem for CIP3-1

Rodlet for CIP3-1 test was re-fabricated with the father rod, irradiated in common Westinghouse type PWR Vandellos-2 reactor during 1994 and 1999. Father rod was irradiated during 5 cycles, 2078 day. Core average power is about 17.88kW/m and father rod's relative power is given at each cycle. Core inlet and outlet temperature, pressure and coolant flow rate is given also. A Father rod characteristic is as below.

Table I: Father rod description

Fuel fissile height	3657.6 mm
Cold plenum volume	9.16 cm^3
Cold free volume	19.83 cm^3
Filling gas pressure	23.5 b
Filling gas temperature	21°C
Filling gas composition	He

Rodlet was cut from the father rod at upper region. Rodlet burnup is about 73GWd/t at middle. Diameter of rodlet is ranged from 9.53mm to 9.58mm and Oxide thickness from 50μm to 115μm. Specified rodlet characteristics is as below

Table II: CIP3-1 test rodlet description

Rodlet fuel stack length	538 mm
Rodlet free volume	2.78 cm^3
Rodlet plenum volume	2 cm^3
Rodlet He filling P. at 20°C	50.5 bar

CABRI water loop is designed to test in 155 bars and 280°C water is injected from bottom with 4m/s. Test channel has a diameter of 15mm.

During CIP3-1 RIA test, CABRI power profile is given. Power pulse is characterized with 9.5ms FWHM and energy deposited at peak node is 115cal/g.

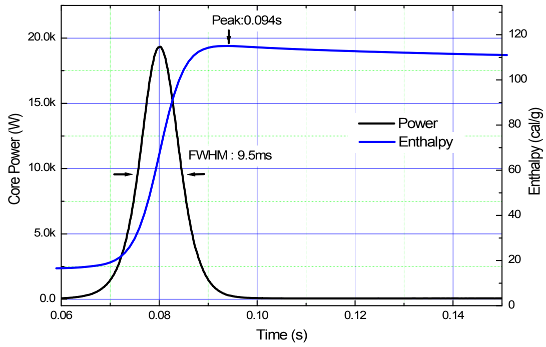

Fig. 1. Core power and rodlet energy deposited for CIP3-1.

CABRI CIP0-1's father rod has similar irradiation history with CIP3-1's in Vandellos-2 reactor. But its rodlet has 74GWd/t average burnup and oxide thickness is ranged from 60μm to 90μm. For the case of CIP0-1, rodlet fuel stack length is 541mm, Helium filling pressure at 20°C is 3.04bar. CIP0-1 test was done in the sodium loop, at 3bar, with 280°C, 1257 l/m sodium into 14.2mm diameter test channel.[5]

2.2 Calculation process

FRAPTRAN code [3] was developed specially for nuclear fuel and cladding responses during transient. In general, pre-irradiated test rodlet conditions are calculated by FRAPCON include clad oxide thickness, hydrogen content and permanent strain by thermal and irradiation creep, and fuel burnup, density, relocation and fission gas release etc.

At first, father rod steady state is calculated for checking and estimating rod pre-irradiation conditions like rod internal pressure, rodlet power fraction against to father rod and inlet temperature decision for proper rodlet oxide thickness.

On the basis of the father rod calculation, rodlet st-st. calculation results in restart file for FRAPTRAN transient calculation. Plenum volume is adjusted that rodlet internal pressure of st.-st. calculation to be similar to that of father rod calculated value. Rodlet inlet temp also adjusted for proper rodlet initial oxide thickness. Re-fabricated rodlet helium filling was modeled by correcting the restart file with relevant number of gas moles and helium fraction set to 1.

Coolant conditions during transient also needed for FRAPTRAN calculation. To prepare reasonable coolant conditions, rodlet and channel geometry and coolant conditions are modeled with TRACE code. Coolant temperature, pressure heat transfer coefficient history at the surface of rodlet by TRACE code is used for FRAPTRAN input deck. Coolant temperature responses for TRACE modeling is validated with CABRI CIP0-1 test. It was also used for CIP3-1 coolant condition generation.

2.3 Calculation results

Pre-calculation of TRACE showed that boiling is not occurred with 115 cal/g energy deposited equivalent power and 4m/s coolant condition. When more than 1.09 times of the transient power is applied coolant boiled. Coolant pressure maintained initial value during transient. Coolant temperature rise up to 587.8K and saturation temperature at peak is 618K.

FRAPCON father rod calculation shows node burnup is 73GWd/t, oxide thickness is 92.3 μm and hydrogen content is 644ppm at the rodlet location. Plenum pressure at the end of irradiation is 12.9Mpa (Massih model) and 20.3Mpa (FRAPFGR model).

FRAPCON calculation for rodlet initial condition produces rodlet initial conditions including 73GWd/t burnup, 58~103 μm oxide thickness and 404~722 ppm hydrogen content.

FRAPTRAN simulation of CIP3-1 test predicted rodlet is failed at 0.079s at 329mm from the bottom. Enthalpy at time of failure is 59.96cal/g. Fuel and clad elongation is predicted 8.06 and 3.56mm at peak each.

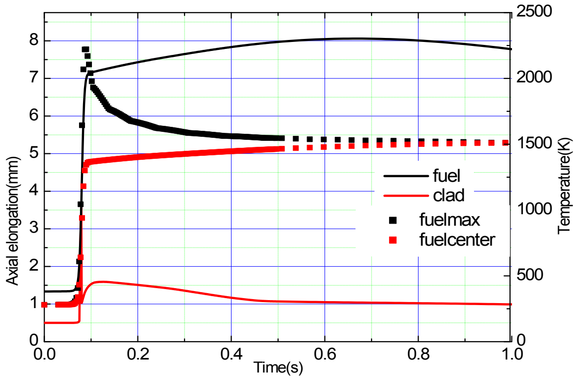

Fig. 2. Fuel and clad axial elongation and fuel centerline temperature and maximum temperature at failure node

Fuel centerline temperature rises up to 1300K at power peak and slightly increase. Maximum fuel temperature at peak node is increased to 2231K then decreased by heat transfer to clad and coolant. Radial location of maximum temperature is near pellet surface at power peak and migrates to the center of fuel since radial power distribution within pellet.

Clad hoop strain is predicted as 0.67% at peak and permanent hoop strain is 0.06% maximum and 0.05% at burst node.

Internal pressure is 15.77Mpa slightly higher than coolant pressure when the rodlet is failed. FRAPTRAN predicts gap size is drop to zero and fuel surface displacement exceeds cladding inside surface displacement. Therefore cladding is failed by pellet cladding interaction not by ballooning.

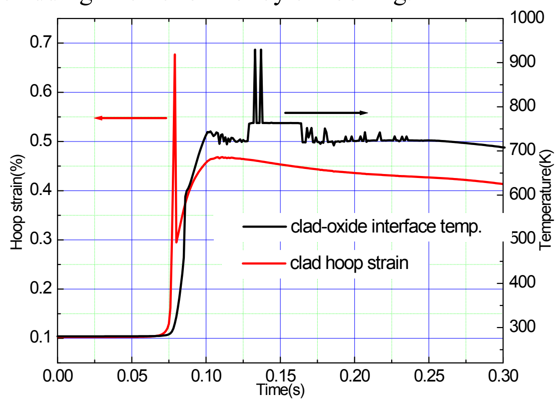

Fig. 3. Clad hoop strain and clad-oxide interface temperature

Fission gas release is calculated as 0.364 by 0.09s. About 40% of total FGR is released by the time of burst.

3. Conclusions

CABRI water loop test CIP3-1 is simulated with FRAPCON/FRAPTRAN codes. TRACE code shows no boiling is occurred with CIP3-1 test condition. FRAPTRAN predicted that rod burst at 0.79s and 239mm by pellet cladding mechanical interaction, enthalpy deposited at burst is 60cal/g.

REFERENCES

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