Evaluation of the CABRI Rep-Na8 RIA-Simulation Experiments with the FREY Fuel Performance Code

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1. Introduction

This paper provides an analytical assessment of RIA-simulation experiment, Rep-Na8, performed at CABRI(Rep-Na) test facilities in 1997. The test rod was refabricated from high burnup commercial UO2 fuel rods segments with 60 GWd/tU burnup.

The assessment consisted of two key tasks: 1) a review of the experiment data, which included available PIE reports, and 2) analysis of the experiments using the FREY fuel performance code to evaluate the thermal and mechanical behaviour of the test rod during and following the power pulse. The objective of this evaluation was to investigate the processes leading to cladding failure in high burnup fuel during RIA-simulation experiment.

2. Database Evaluation

2.1 The CABRI reactor facility

The CABRI experiment reactor[1] is located on the CEA site of Cadarache, in southern France. It was designed to generate fast power transients simulating RIAs. The transients were generated by depressurization of transient rods initially filled with He at 12 or 15 bars. Depending on the depressurization kinetics, the pulse width (measured at mid-height) ranged between 10 and 80 ms.

The tested rodlet was inserted in a test section located in a sodium loop, in the center of the CABRI driver core. The capsule was instrumented with two microphones, two flowmeters, several pressure transducers and thermocouples in the sodium channel. Delayed Neutron Detectors (DND) and a hodoscope detect possible movements of fuel material (e.g. in case of rod failure and fuel dispersal) and allow determining the axial power profile which remains constant during the pulse.

2.2 The Rep-Na experimental database

Since 1993, IPSN had conducted an important R&D program on the RIAs. The core of this program consisted of ten full-scale RIA tests conducted in the CABRI reactor. Seven tests were conducted using irradiated UO2 rods and three with MOX fuel rods. All the rodlets were cut from full-length commercial rods and refabricated by the FABRICE process

2.3 The Rep-Na8 experiment [2]

The REP-Na8 test was conducted using a highly irradiated rodlet (60 GWd/tM) with a standard Zircaloy-4 cladding (1.5wt% Sn) which was severely oxidized and hydrided, and locally spalled. The power pulse applied was wide (75 ms at mid-height) and an energy of 440 kJ/kg was injected, leading to a maximum estimated peak enthalpy of 456 kJ/kg. The power transient history during REP-Na8 test is shown in Figure 1 and 2.

After the test, the rod underwent detailed nondestructive and destructive examinations. The analysis of the acoustic signals, together with downstream temperature and mass-flow disturbances as well as significant Delayed Neutron Detector (DND) signal increase, allowed to conclude that the cladding lost its integrity at the 'D' acoustic event, which was axially localized at 42 cm from the bottom of fuel column. At that time and location, the injected energy reached 251 kJ/kg (280 kJ/kg at the Peak Power Node (PPN)) and the fuel enthalpy was estimated at 310 kJ/kg (» 343 kJ/kg at PPN).

The amount of gas detected in the coolant channel at the time of failure was 3 times lower than the total amount of gas available in the rodlet. That indicates (1) the crack at the time of failure was very narrow, supporting a PCMI[3] type loading, and (2) there was almost no axial gas transport within the rod during the pulse, thus impairing any potential local gas pressure loading. The post-test examinations showed wide and long cracks that could be explained as follows: First, at the time of failure, while the inner side of the cladding is hot, a small external crack initiated in a brittle blister, then propagated in a ductile way through the clad wall. Second, the crack propagated and opened during the cooling down phase of the test as suggested by the brittle axial propagation of the cracks. The residual thermal stresses in the cladding could explain this late axial propagation.

2.4 FREY Code Evaluation

The FREY [4] program is a Fuel Rod Evaluation System for the transient and steady state analysis of light water reactor fuel. This program was developed by

EPRI in 1994. Its capability of the thermomechanical analysis can be widely used for both licensing and best estimate analyses.

The data for the FREY code analysis are collected from CABRI database. The power transient history, core state at the test and rod geometry are take into considerated in this analysis.

• Test (10.07.1997)

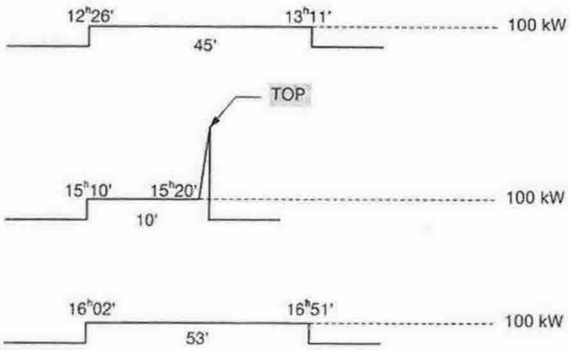

Figure 1. The power transient history during REP-Na8 test.

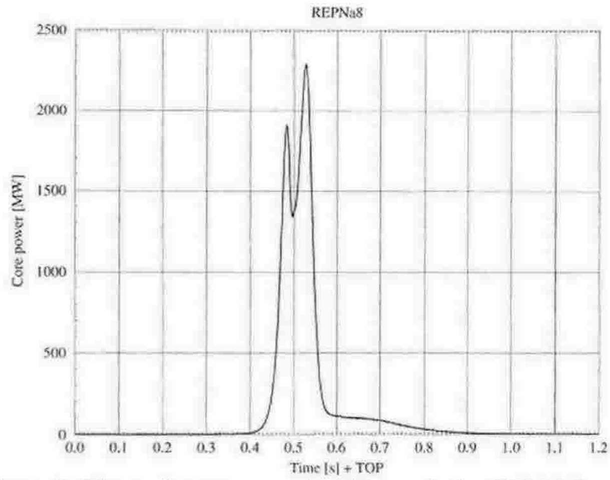

Figure 2. The peak power transient history during REP-Na8 test.

3. Conclusion

In REP-Na8, it was widely agreed that the loss of cladding integrity, evidenced by the ejection of a certain quantity of internal gas, was spatially and temporally correlated with the "D" acoustic event. REP-Na8 which was conducted on rodlets with severely embrittled cladding, led to loss of integrity. There was also no fuel dispersal observed in this case. So we could draw the following conclusions:

(a) The main mechanism leading to clad failure is pure PCMI resulting from fuel thermal expansion and fission gas swelling.

(b) Rod failed at H = 314 – 335 kJ/kg, with no fuel dispersal even though additional enthalpy of 126 kJ/kg were injected after the rod failed. This means there is a significant margin of at least 125 kJ/kg between clad failure and fuel dispersal thresholds; any safety criterion based on no clad failure to prevent coolability concerns would be extremely conservative.

(d) The FREY calculations slightly underestimated maximum fuel enthalpy levels with measured data for the CABRI Rep-Na 10 test with maximum fuel enthalpy levels up to 440 kJ/kg. The key conclusions from this evaluation is that the PCMI is the primary mechanism leading to cladding deformations with cladding temperatures below 600 °C.

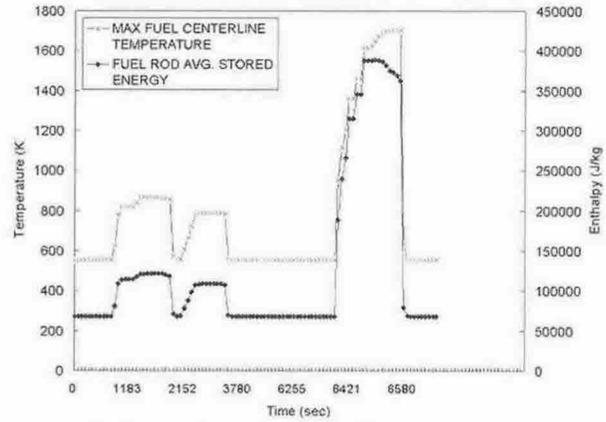

Figure 3. The maximum fuel centerline temperature and fuel rod average stored energy during the REP-Na8 test.

REFERENCES

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