Evaluation of the CABRI Rep-Na10 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-Na10, performed at CABRI(Rep-Na) test facilities in 1998. The test rod was refabricated from high burnup commercial UO2 fuel rods segments with 64 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-Na10 experiment [2]

This test was conducted with a rod that was the sibling of the one tested in REP-Na1[1]. Both rods came from the same assembly and underwent the same irradiation history. They had identical characteristics at the end of commercial irradiation, in terms of burnup, waterside corrosion layer thickness and extensive oxide spallation. The REP-Na10 rodlet was tested with a 31 ms pulse width and an injected energy of 448 kJ/kg. The peak enthalpy has been estimated at 460 cal/g. The microphones detected a strong signal, axially located at 25.5 cm from BFC and just below PPN. Similarly, a strong acoustic signal correlated with a significant DND signal increase indicated a rod failure. The power transient history and injected energy during REP-Na 10 test is shown in Figure 1 and 2.

The injected energy at time of failure reached 314 kJ/kg at PPN and 309 kJ/kg at failure axial location. No evidence of fuel ejection was observed although an additional enthalpy of 125 kJ/kg was injected after the rod failure. The flow-meters and pressure transducers did not even detect any passage of gas bubble in the sodium channel. The fuel enthalpy at the time of failure was estimated at 330 kJ/kg. Post-test visual examinations showed only one small axial crack, approximately 7 cm long, located around PPN. Other NDE and DE are still underway.

2.4 FREY Code Evaluation

The FREY [3] 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.

3. Conclusion

In REP-Na10, 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. REPNa10 tests, conducted on rodlets with severely embrittled cladding, led to loss of integrity with enthalpy levels 330 kJ/kg in

REP-Na10. There was also no fuel dispersal observed in this test. 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.
(c) The result of REP-Na10, which had the same physical characteristics as REPNa-1, REP-Na1's early failure and related fuel dispersal were very likely related to the narrower pulse experienced by the rod (9.5 ms versus 31 ms for REP-Na10).
(d) The FREY calculations slightly underestimated maximum fuel enthalpy levels with measured data for the CABRI Rep-Na 10 test. The key conclusions from this evaluation is that the PCMI is the primary mechanism leading to cladding deformations with cladding temperatures below 600 °C.

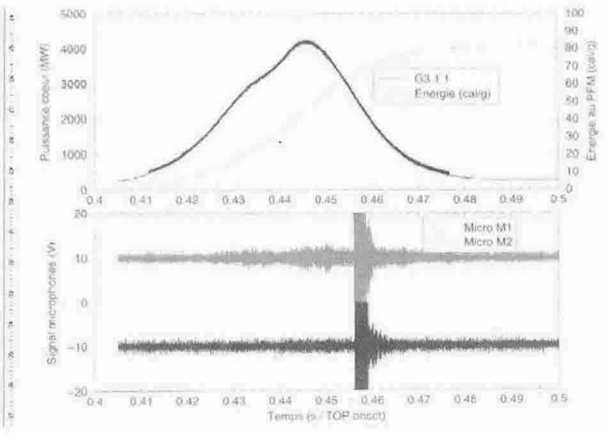

Figure 1. The power transient and injected energy history during REP-Na10 test.

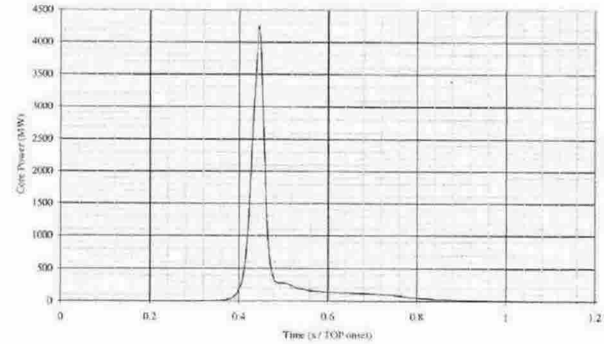

Figure 2. The peak power transient history during REP-Na10 test.

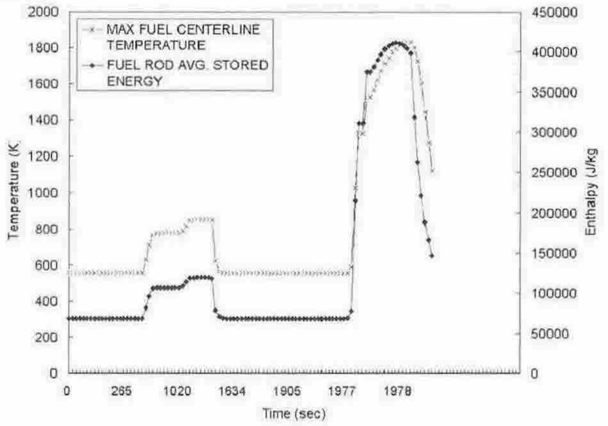

Figure 3. The maximum fuel centerline temperature and fuel rod average stored energy during the REP-Na10 test.

REFERENCES

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