Current Status of CABRI RIA-Simulating Test Program

Je-Geon Bang, Dae-Ho Kim, Ik-Sung Lim, Sun-Ki Kim, Yong-Sik Yang, Kun-Woo Song

Korea Atomic Energy Research Institute, 150 Deokjin-dong Yuseong-gu, Daejeon 305-353, Korea
jgbang@kaeri.re.kr

1. Introduction

In a pressurized water reactor, the reactivity initiated accident (RIA) scenario of primary concern is the control rod ejection accident (REA) [1]. At this early heat-up stage of the RIA, the clad tube material is still at a fairly low temperature (<650 K), and the fast straining imposed by the expanding fuel pellets may therefore cause a rapid and partially brittle mode of clad failure [2]. To investigate fuel behaviors during these RIA condition, CABRI REP-Na test program was initiated in early 1990s. The main purpose of the CABRI REP-Na test program was to study the validity of the RIA acceptance criteria on high-burnup 17×17 PWR fuel, with emphasis on the behavior of fuel during the early stage of the transient up to fuel failure [3]. Recently, international test program in CABRI has being prepared in order to simulate the fuel behaviors in water loop at reactor pressure level by replacing the existing Na loop with water loop. Through a total of 15 technical advisory group meetings, the test matrix in the CABRI water loop program has being established.

In this paper, main test results in CABRI REP-Na program are presented, and also the current status on the CABRI water loop program is briefly introduced.

2. CABRI REP Na loop test program

2.1 Overview of CABRI REP Na loop test

First of all, a total of twelve tests have been carried out in the program. Eight of the tests were performed on UO_2 fuel and four tests on MOX fuel, pre-irradiated to burnups ranging from 28 to 65 MWd/kgU. In addition to the CABRI REP-Na program, two tests were performed in November 2002 on PWR fuel rods with burnups around 75 MWd//kgU. These test rods, denoted CIPO-1 and CIPO-2, had advanced claddings such as ZIRLO and M5 cladding, respectively. The CABRI test reactor is a pool-type light water reactor, designed with a central flux area that can accommodate the insertion of a test device.

2.2 Main outcomes of CABRI REP Na loop test

Fuel cladding failure occurred in four tests, whereas no failure occurred in the remaining 8 tests. Among the four tests with fuel failure, there had UO_2 fuel and one MOX fuel. All failures were with Zircaloy-4 cladding, whereas no failure occurred in the three tests with M5 or ZIRLO cladding. The three UO_2 failures occurred at enthalpy below 80 cal/g and on fuel that had a burnup of about 60 MWd/kgU and significant oxide thickness from 80 to 130 μm. However, several other CABRI tests were run at comparable burnup and oxide thickness range, without resulting in fuel failure. Oxide spalling appears to be distinctive element that separates the failed and non-failed fuel in CABRI UO_2 tests, in that all three fuel rods that failed had spalling, while the rods that did not fail had uniform non-spalled oxide. Only one test for MOX fuel among four tests resulted in fuel failure. The failure occurred on a fuel rod that had a burnup of 55 MWd/kgU and moderate corrosion level of 50 μm oxide thickness. This is the only CABRI failure occurring on a non-spalled cladding. However, this failure occurred at 113cal/g, which is a rather high enthalpy level, where a failure may not be surprising, considering that this level in near the upper envelope of all CABRI data. Failures were not associated to a particular pulse width. The three UO_2 fuel rod failures occurred at all three pulse widths that have been used in CABRI test program, i.e. 9, 30, and 75 ms. The main outcomes from CABRI Na loop test program are listed in Table 1.

3. Current status of CABRI water loop test program

CABRI international program (CIP) in water loop test has been managed by IRSN in France with collaboration of EDF, CEA and the participating countries with support by OECD/NEA. This program focuses on the high burnup fuel and cladding behaviors in PWR condition during RIA. The test conditions are 155 bar and 280°C. Five test series were established including qualification test, CIP Q for various fuel pellet, cladding, corrosion level and burnup. The test matrix CABRI international program (CIP) in water loop are listed in Table 2. The test sequence is not fixed, therefore it may be changed.

4. Summary

Main outcomes from CABRI REP-Na program and the current status of CABRI international program (CIP) in water loop test program for investigating fuel and cladding behavior during RIA were presented.

REFERENCES

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Table 2. Test matrix CABRI international program

Test Series	Test	Test Rod	Objectives
CIPQ		REP Na6 rod, span 3, 3cycles MOX, Zr4	CWL qualification + phenomenology
CIP1	*CIP1-2 (option)*	CIP0-2 sister rod, UO2 77GWd/t, M5	Phenomenology, Code validation
CIP2	CIP2-1	UO2 85 GWd/t, M5 = reference or ENUSA rod , 80GWd/t, Zr-Nb	Product qualification, code validation
CIP4	CIP4-1 CIP4-2	MOX-E M5 EDF rod (55GWd/t) MOX-SBR-Beznau rod (54Gwd/t, Zr4)	Product qualification Product qualification, physical understanding
CIP5	CIP5-1	VVER Lovisa, 50GWd/t, Zr-1%Nb	Product qualification
CIP3	CIP3-1	CIP0-1 sister rod, span 5	Code validation,safety criteria, post-failure events
	CIP3-2	REP Na 7 sister rod	Code validation,safety criteria, post-failure events
	CIP3-3	Vandellos CIP0-1 sister rod, span3, UO2, 75 GWd/t	Code validation,safety criteria, phenomenology
	CIP3-4	EDF rod, M5 63-68 GWd/t	Product qualification
	CIP3-5	ENUSA rod, 67 GWd/t Zr-Nb	Product qualification, physical understanding

Table 1. Main outcomes from CABRI REP Na test program

Test and date	Rod and Burn-up	Pulse width (ms)	Energy Deposition cal/g	Corrosion µm	Results and observations
Na-1 (11/93)	GRA 5 64 MWd/kg	9.5	110 (at 0.4s)	80 spalling	Brittle failure at H_F = 30 cal/g Fuel dispersal (6g)
Na-2 (6/94)	BR3 33 MWd/kg	9.1	211 (at 0.4s)	4	No failure, H_{MAX} = 199 cal/g Max. strain : 3.5%, FGR : 5.5%
Na-3 (10/94)	GRA 5 53 MWd/kg	9.5	120 (at 0.4s)	40	No failure, H_{MAX} = 124 cal/g Max. strain : 2%, FGR : 13.7%
Na-4 (7/95)	GRA 5 62 MWd/kg	75	95 (at 1.2s)	80 no spalling	No failure, H_{MAX} = 85 cal/g Max. strain : 0.4%, FGR : 8.3%
Na-5 (5/95)	GRA 5 64 MWd/kg	9.5	105 (at 0.4s)	20	No failure, H_{MAX} = 108 cal/g Max. strain : 1%, FGR : 15.1%
Na-6 (03/96)	MOX 47 MWd/kg	35	125 (at 0.66s)	35	No failure, H_{MAX} = 133 cal/g Max. strain : 3.2%, FGR : 21.6%
Na-7 (1/97)	MOX 55 MWd/kg	40	165 (at 1.2s)	50	Failure at H_F = 113 cal/g Strong flow ejection
Na-8 (07/97)	GRA 5 60 MWd/kg	75	106 (at 0.4s)	130 lim. spalling	Failure at $H_F \leq$ 82 cal/g H_{MAX} = 98 cal/g, No fuel dispersal
Na-9 (04/97)	MOX 28 MWd/kg	34	197 at 0.5s 241 at 1.2s	〈20	No failure, H_{MAX} = 197 cal/g Max. strain : 7.4%, FGR : ~34%
Na-10 (07/98)	GRA 5 62 MWd/kg	31	107 at 1.2s	80 no spalling	Failure at H_F = 81 cal/g H_{MAX} = 98 cal/g, No fuel dispersal
Na-11	M5 63 MWd/kg	31	104	15	No failure, H_{MAX} = 93 cal/g Max. strain : ~0.5%
Na-12	MOX 65 MWd/kg	62	106	80 no spalling	No failure, H_{MAX} = 103 cal/g
CIP0-1 (11/02)	ZIRLO 75 MWd/kg	32	98	80 no spalling	No failure, H_{MAX} = 90 cal/g
CIP0-2 (11/02)	M5 77 MWd/kg	28	89	20	No failure, H_{MAX} = 81 cal/g