Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

The Current Status of CABRI International Program for RIA Analysis

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1. Introduction

The CABRI project starts in order to establish the database for high burnup fuel performance in Reactivity Initiated Accident (RIA) conditions. The project is investigating the ability of nuclear fuel to withstand the rapid power increases within a few milli-seconds due to rapid reactivity insertion such as the ejection of a control rod assembly. As Korea is one of CABRI members, we are involved in this RIA research project for the regulation purpose.

The tests in the CABRI facility including the REP-Na or S series was initially designed for safety studies for the fast breeder reactors cooled with sodium. In the early 2000s, The CABRI facility is adapted to meet the needs of the research programs for Pressurized Water Reactors (PWR), replacing the sodium loop by the pressurized water loop. Functional tests on the water loop have been engaged in 2010.

The CABRI International Program (CIP) included in the CABRI project involves twelve experiments in the CABRI reactor: two of them, CIP0-1 and 2, have been performed in the sodium loop in 2002, the remaining ten will be performed using the CABRI water loop. The water loop is designed to examine the ability of high burnup fuel up to 100 GWD/t for UO2 and up to 75 GWD/t for MOX under coolant conditions representative of PWR (15.5 MPa; 280 ℃ and a flow rate ~6 m^3/h) [1].

The goal of this study is to summarize the current status of these tests, find the meaning from the test results, and predict the future issues related to RIA.

2. Current Status of CIP

2.1 Schedule of CIP

As of 2010, the definition of the CIP test matrix can be gathered in the reference [2]. However, the objectives and definition of the tests can be varied and proposed after CIP Steering Committee meeting a year, based on the results of preliminary calculations about each test case. For example, CIP2 series did not exist because the both results of CIP2-1 and CIP1-2 seem similar.

2.2 Preliminary Calculation

Simulating RIA starts with the assumption of the rapid energy deposition. The calculations for CIP have been performed for the range of injected energy values of 90~170 cal/g, and the range of the pulse width of 10~30 ms. The results including predicted maximum fuel and clad temperatures are summarized in Table 1. The cases of CIP3-3, 3-4, 3-5, and 5-1 whose outlines were not clearly determined yet are omitted. For reference, two experimental results from CIP0-1 and CIP0-2 are added.

The real test shows that CIP0-1 and 0-2 did not fail because no hydrides blister was present close to PPN and the thickness of hydrides rim was relatively low [8]. The cladding strain, which directly causes failure, due to the inner gas pressure may be important, especially in MOX fuels. MOX fuels are known as they produce the more amount of fission gas. As seen in the differences between CIPQ and CIP3-2, the burnup level and the injected energy are also the main factor.

The meanings of every test are too massive to be treated in this study. It is recommended to follow the references of each test.

3. Extension of CIP

A proposal for the extension of the CIP is recently discussed and it needs to reflect what will be important after the end of CIP tests. The tentative 20 tests within 2012~2019 are additionally expected to understand the following aspects [8]:

a. Post dry-out phenomena

The two complementary tests related to CIPQ and CIP1-2 are suggested to check the transient behavior of the phenomena like heat exchange, ballooning and cladding rupture.

b. Fuel ejection and coolant interaction

The two complementary tests related to CIP3-1 and CIP4-2 are suggested to evaluate the propagating effect on the surrounding structures including intact rods due to the pressure pulse from a failed rod.

c. Influence of initial power

Two tests are suggested to understand how the initial power state of fuel rods at RIA has an impact on the power pulse characteristics and the transient behavior.

d. Influence of late energy deposition

Two tests are suggested to understand the effect of the late energy deposition on the time the rod remains at high temperature after boiling crisis.

e. Advanced fuel or MOX

f. Other 10 tests for additional topics

The above tests could be changed according to the CIP results, but the main stream of the future issues can be induced from them. As for us, the option (d), (e) are negligible, because the late energy deposition is perceived as the concern for boiling water reactors and no MOX is permitted.

4. Discussion

The current CIP tests basically lay on the investigation of the fuel behavior under higher burnup and of new cladding materials developed. The object of each case in CIP reflects the current interests at RIA. Under RIA, PCMI has been known as the main mechanism which causes the fuel failure. Much progression has been made in understanding and modeling the PCMI, and it provides the basis to establish the PCMI failure limit. The previous concerns about PCMI were mainly related to claddings. The next step can be to focus on the fuel pellet behavior which determines the load to a cladding. For example, the pellets whose grain size inclines to being lager for the better performance are being developed by additive doping, even though the safety issues still remain unsolved. The doped pellet may become one of the issues in future, because the pellet behavior with a large grain size has not been fully estimated yet in spite of its promising use value.

As understanding RIA since the start of CIP, the recognition on RIA has evolved, and the issues or the interest can be varied. The fuel with intermediate burnup becomes one of concerns as shown in CIP5-1. The extension of CIP has been suggested, and it emphasizes the consequence of a potential fuel failure and the phenomena themselves at RIA, compared with CIP.

Meanwhile, CIP is involved in regulation. The results of CIP are able to provide the base of the regulation criteria for fuel safety. The criteria directly linked to PCMI do not exist, but the design limits developed make it possible to avoid PCMI failure. At present, the three criteria related to RIA have been applied: the first criterion limits uniform strain of the cladding to no more than one percent, and the second states that fuel melting should be avoided, and the third states that peak radial average fuel enthalpy must remain below 230 cal/g. Because these regulation criteria are not sufficient to preclude the fuel failure, tests like CIP is required to update the criteria and make them more reflecting the real situation.

5. Summary

CIP aims at promoting understanding the phenomena occurred at high burnup UO2 and MOX fuels with advanced claddings when RIA, in the frame of the increase of discharge burnup beyond the current. The extension of CIP is being discussed to more focus on the consequence of a potential fuel failure or the fuel pellet as a complement to CIP. These tests address the future issues considering the fuel safety. At the same time, the results of the tests help provide the base of the regulation criteria for fuel safety. The tests could be varied according to the phase of the times.

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Table 1. Calculation results of available tests. It was assumed that spallation occurred at the beginning of the test and calculation was performed without oxide layer.

	CIP0-1	CIP0-2	CIPQ	CIP1-2	CIP3-1	CIP3-2	CIP4-1	CIP4-2
Clad, Fuel	Zirlo,UO2	M5, UO2	Zr-4,MOX	M5, UO2	Zirlo,UO2	Zr-4,MOX	M5, MOX	Zr-4,MOX
Burnup (GWD/t)	71	76	47	77	75	55	65	60
Zirconia (um)	77	20	25	11-17	60-100	~40	20	50-80
Pulse width at half-max. (ms)	32	28	30	30	9.5	9.5	30	30
Injected energy* at PPN** (cal/g)	99	90	150	110	115	170	150	150
Max. fuel T. (C)	1542	-	-	1520	-	2100	1996	1976
Max. clad T. (C)	535	-	1110	896	1000	1200	-	-
Dry out duration (s)	N/A	N/A	4.5	4	4	5	6	8.5
Fuel failure	**no**	**no**	**probable**	**probable**	**probable**	**probable**	**probable**	**probable**
Fuel enthalpy at boiling onset (cal/g)	N/A	N/A	118	87-102	110	110	115	120
Reference	[3]	[4]	[5]	[6]	[5]	[5]	[7]	[7]

* Total energy deposition from the base of the room temperature (fabricated)
** PPN : Peak Power Node