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Study on the Thermal-Hydraulic Stability of High Burn up STEPⅢ Fuel in Japan

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ABSTRACT

Japanese BWR Utilities have performed a joint study of the Thermal Hydraulic Stability of High Burn up STEPⅢ Fuel. In this study, the parametric dependency of thermal hydraulic stability threshould was obtained. It was confirmed through experiments that the STEPⅢ Fuel has sufficient stability characteristics.

1. INTRODUCTION

In Japan, burn up extension of BWR fuel has been pursed for the reduction of fuel cycle cost as well as the amount of spent fuel. High burn up fuels have been developed and commercialized in a stepwise manner so that new design may not lead to fuel failures, this is the incremental progress in three steps.

Since the La Salle-2 instability incident of 1988, concerns about the stability issues grew worldwide. Even before this, Japanese BWR utilities and vendors jointly ran a series of programs of experiments and analysis on this matter. Among them are 3-D code development and a series of out-pile-tests.

Thermal hydraulic stability experiment was one of those study programs. Experiments of 2x2 test bundle which simulated 8x8 arrayed fuel conditions using out-pile test loop were performed to survey the channel stability threshold, boiling transition (BT) threshold during oscillations, and post-BT peak cladding temperature. These results have been used for licensing and verification of analytical code.

Smaller rod diameter and increase in the number of rods in the fuel assembly tend to make higher burnup fuel more prone to instability. We thought it is important to confirm the thermal-hydraulic performance of STEPⅢ Fuel in terms of instability using both experimental measurement and analysis.

This paper describes the outline of experimental and analytical works relevant to instability done specifically for STEP Ⅲ Fuel.

2. HIGH BURNUP STEP Ⅲ FUEL

High burnup fuels have been developed and commercialized in a stepwise manner, as shown in Fig.1 and described below;

(1) STEP Ⅰ Fuel (8x8 Array, 62 fuel rods)
Average discharge exposure 33 GWd/t
Maximum assembly exposure 40 GWd/t
Commercialized from 1987

(2) STEP Ⅱ Fuel (8x8 Array, 60 fuel rods)
Average discharge exposure 39.5 GWd/t
Maximum assembly exposure 50 GWd/t
Commercialized from 1991

(3) STEP Ⅲ Fuel
(9x9 Array, 74(Type A) or 72(Type B) fuel rods)
Average discharge exposure 45 GWd/t
Maximum assembly exposure 55 GWd/t

High burnup STEP Ⅲ Fuel is aimed at increasing burn up to about 45 GWd/t (average discharge exposure). Japanese BWR Utilities selected two types of fuels designs for STEP Ⅲ fuel (type A and type B). [1] [2] Fig.2 shows the structure of STEP Ⅲ fuel.

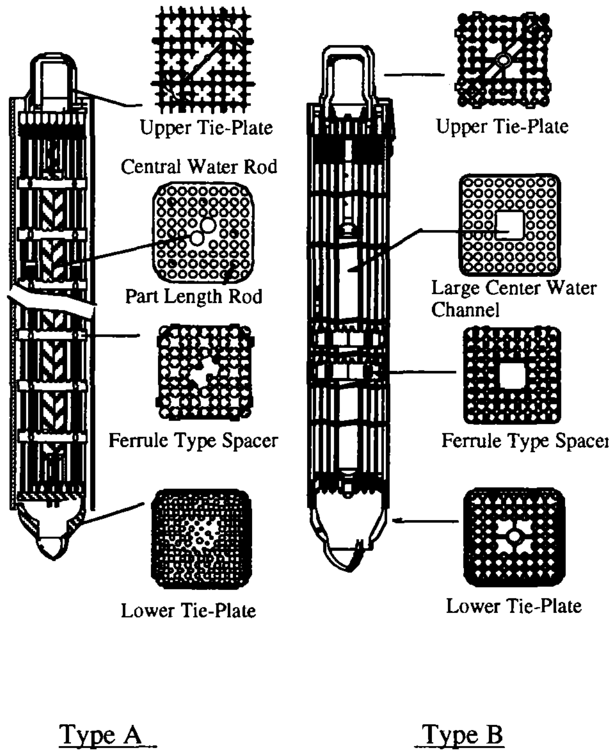

Fig.2 Structure of STEP Ⅲ Fuel

Generally higher increase of enrichment is necessary to extend burnup increases, but this causes harder neutron spectrum which in turn increases void coefficient and reduces shut down margin. A necessary countermeasure for this is to increase H/U ratio.

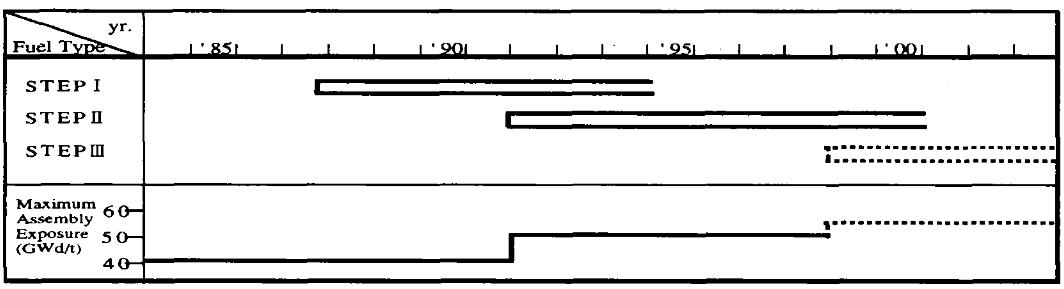

Fig. 1 Introduction schedule of high burnup fuels

Consequently STEP Ⅲ fuel design applies bigger water rods in fuel bundles. In type A fuel, two large water rods are positioned in the center replacing seven fuel rods. And In type B fuel, a rectangular water channel is positioned in the center to replace nine fuel rods.

STEP Ⅲ fuel also applies 9×9 array, which decreases average linear heat generation rate by 20 % and provides much greater flexibility in fuel bundle design.

3. STUDY OF THE THERMAL HYDRAULIC STABILITY OF STEP Ⅲ FUEL

Thermal hydraulic stability experiment for 8×8 fuel was carried out in the past and the following results have been obtained. [3]

(1) Flow instability characteristics in a complicated channel of BWR's.
(2) Stability data at typical BWR conditions.
(3) Verification of the Stability Analysis codes were done.

Typical resuls are shown in Fig.3 and fig.4.

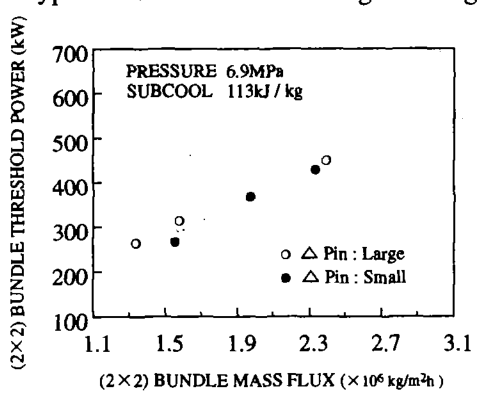

Fig. 3 Effect of mass flux and inlet pressure loss.

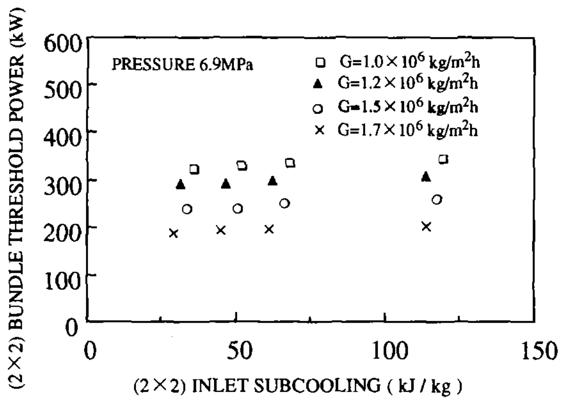

Fig.4 Effect of inlet subcooling.

The stability performance is considered as one element to be taken care of in the core and fuel design. Since STEP Ⅲ fuel is 9×9 fuel, it tends to have intrinstic disadvantage as far as this instability is concerned. This is because of smaller diameter, which tends to reduce time delay in heat conduction, and increase pressure drop. New design tries to offset this by use of the following;

- Improved low pressure drop spacer (Type B)
- Low ΔP upper tie-plate (Type A, Type B)
- Partial length rod to reduce pressure drop in two-phase flow portion of the bundle (Type A)

Then, we confirmed the stability performance of STEP Ⅲ Fuel both experimentally and analytically.

The tasks of this time study are shown below.

- Stability tests using high temperature thermal hydraulic test loop.

  The test bundle geometry used for the stability test is a 3×3 heater rod bundle which has about 1/8 of the cross section area of the STEP Ⅲ fuel.

  For parallel channel simulation, a bypass channel was connected with 3×3 test bundle.

  Stability tests were performed for multiple combinations of the test parameters. These conditions cover the natural circulation flow and minimun pump flow points in the BWR operational conditions.

- Verification of stability analysis code.

  The test results were used for verification of a stability analysis code.

Details of test results and analysis are reported in different papers presented at this Topical Meeting.

4.CONCLUSIONS

It is confirmed through experiments that the STEP Ⅲ fuel has sufficient stability characteristics. The predicted threshold powers were always below the measurement data, demonstrating the conservatism of the stability analysis codes.

ACKNOWLEDGEMENT

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