In-pile Behavior of MOX Fuel irradiated up to Eight Cycles in the Halden Reactor

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1. Introduction

Since the utilization of MOX fuel can lead to many benefits in the NPPs, the technology for MOX fuel have been developed.

As one of the technological developments, two MOX fuel rods have been tested in the Halden Reactor from the mid 2000. The in-pile experiment aims at proving fuel integrity up to a high burnup and post-irradiation examination would reveal the fuel performance.

The present paper describes the results obtained from the MOX fuel in-pile irradiation up to the eighth cycle. The measured data is also analyzed by a fuel performance code COSMOS.

2. The In-Pile Testing and its Behaviors

The test rig contains six rods in one cluster - three MOX and three inert matrix fuel rods. The two MOX rods contain fuel manufactured in the PSI using a dry milling process [1], whereas the other MOX fuel was provided by BNFL as a reference fuel. The fuel compositions were determined so that all the rods have comparable linear ratings and their dimensions are similar to those in the fuel rods used for commercial reactors.

A MOX rod is instrumented with a thermocouple (designated as MOX-TF) while another rod has an expansion thermometer (MOX-ET). Both rods have pressure transducers at the bottom end. An accurate axial and radial neutron flux distribution is determined by five self powered neutron detectors. Both MOX rods were initially filled with helium at 10 bar at room temperature.

The irradiation test commenced at the end of June 2000 and it has been going well with a good fuel integrity and without any faulty signals from instrumentations. The average burnup for the two MOX fuel rods reached over ~40 MWd/kgHM. The burnup accumulation is illustrated in Fig. 1.

The fuel maximum temperature was estimated to be ~1500°C at the mid-plane of the fuel stack in case of MOX-TF.

On the basis of the analysis of rod internal pressure, MOX-TF showed a ~2 v/o densification, whereas MOX-ET displayed a ~1 v/o densification. Since both MOX fuel rods were fabricated by the same manufacturing route and the same campaign, the differences are due to the lower linear heat rates in MOX-ET than in MOX-TF. The fuel swelling rate is estimated to be ~0.85%/10MWd/kgHM.

The significant fission release was estimated for both MOX rods, which can be made a conclusion on the basis that the increment of the rod internal pressure was larger than that expected from the fuel geometrical volume change. In addition, the peak fuel temperature was higher than the threshold temperature for the fission gas release.

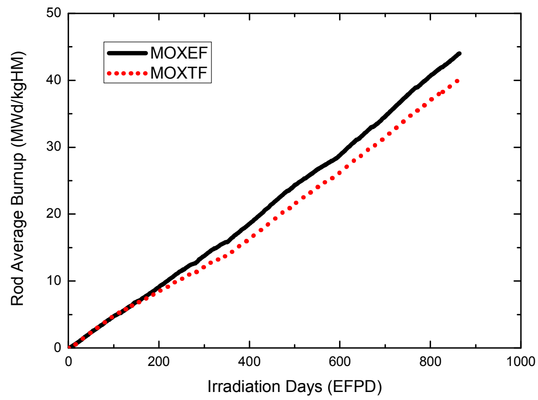

Fig. 1. Burnup accumulation during the eight cycle irradiation.

3. Analysis by the COSMOS

Considering the features of the MOX and UO_2 fuel with the high burnup characteristics, a computer code COSMOS has been developed for the analysis of both MOX and UO_2 fuel during steady-state and transient operating conditions [2]. The COSMOS code has already been verified with the MOX database as well as many other databases for the high burnup UO_2 fuels.

The in-pile testing results for the MOX fuel rods from June 2000 to the end of October 2005 were compared with the COSMOS code. Based on the extracted power history, the input for the COSMOS code was rigorously prepared.

The thermal conductivity was obtained from the model developed by KAERI [3]. The densification is given as an input parameter which is determined from the rod internal pressure measurement. The swelling of 0.85% per 10MWd/kgHM was given from the normalized rod internal pressure before the fission gas was not released significantly.

As for the MOX-TF, the measured and calculated fuel temperature at the thermocouple tip is compared as in Fig.

2. It can be seen that the estimated fuel centerline temperature at the tip of the thermocouple shows a very good agreement. As explained in details [4], the recovery effect of the thermal conductivity was included for the analysis due to the observed significant fission gas release. Otherwise, the COSMOS code over-predicted the fuel temperature by more than 200°C. The Vitanza threshold curve for the fission gas release is also shown in the figure. Since the maximum fuel temperature for the solid pellet at the peak linear heating rate (~mid plane of the fuel stack) is ~200°C higher than the threshold, substantial fission gas release is expected from the measurement of the fuel temperature. And this can be also confirmed by the rod internal pressure measurement. Therefore, the temperature comparison indicates that the thermal conductivity would be recovered with a significant fission gas release in a MOX fuel.

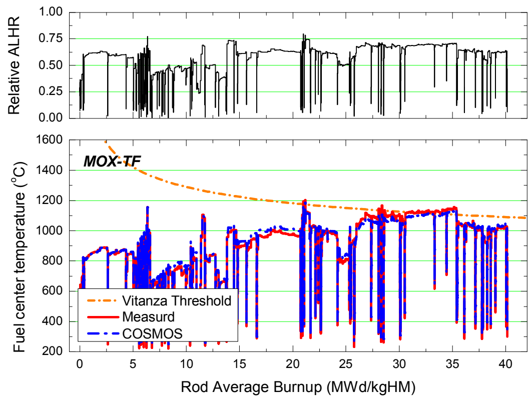

Fig.2. Comparison of the COSMOS calculated centerline temperature with the measured values for the MOX-TF

The rod internal pressure predicted by COSMOS is compared with the measured values. The substantial fission gas release was observed and this is simulated well by the COSMOS code as shown in Fig. 3.

In case of MOX-ET, the thermal behavior and rod internal pressure were also predicted well as in MOX-TF.

The precise prediction by the COSMOS code can be achieved by the integrated accurate fuel performance models such as the thermal conductivity, fission gas release, fuel geometrical changes and so on.

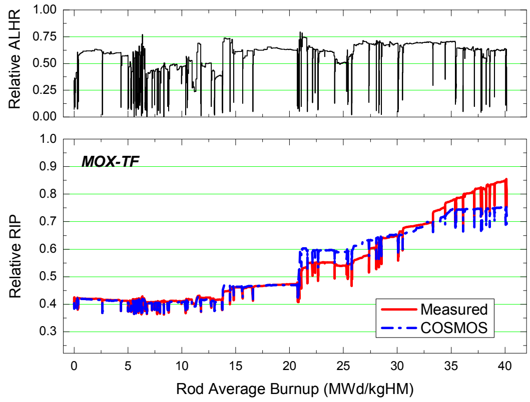

Fig. 3. Comparison of the COSMOS calculated RIP with the measured values for the MOX-TF

4. CONCLUSIONS

The eight cycle irradiation test of two MOX fuels has been going well in the Halden Reactor. MOX fuel rods have demonstrated a very comparable thermal and fission gas release behaviour with the commercial MOX fuel. The in-pile measured results were compared with the COSMOS code, which reveals the qualification of the thermal and fission gas release model implemented into the COSMOS code. The irradiation test would be completed at the end of 2006 and post-irradiation examination will be performed afterward.

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