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Completion of a MOX Fuel Irradiation Test in the Halden Reactor up to 50MWd/kgHM

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1. Introduction

Since the MOX fuel can be utilized in LWRs with many advantages, the relevant MOX fuel technologies have been developed.

As one of the technological developments, two MOX test fuel rods have been irradiated in the Halden Reactor. The in-pile experiment aimed at proving the MOX fuel's integrity up to a high burnup and post-irradiation examination would reveal the fuel performance. The irradiation commenced from June 2000 and it was completed in October 2006.

The present paper summarizes the MOX fuel in-pile irradiation test. 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 dry milling process was developed by KAERI and it was a technology for manufacturing a homogeneous MOX 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 PWRs.

To measure the fuel temperature, 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 SPNDs. Both MOX rods were initially filled with helium at 10 bar at the room temperature.

The irradiation test commenced at the end of June 2000 and when it was completed it revealed good fuel integrity without any faulty signals from the instrumentations. The average burnup for the two MOX fuel rods reached ~50 MWd/kgHM. The burnup accumulation is illustrated in Fig. 1.

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

On the basis of the analysis of the measured rod internal pressures, 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 same maximum densification of 2.0% was applied for the analysis by COSMOS. The fuel swelling rate was estimated to be ~0.85%/10MWd/kgHM. The swelling rate was obtained by analyzing the measured rod internal pressure.

Since two MOX rods have been irradiated under the high linear heating rate level, a significant fission release was estimated for both MOX rods. This can be also deduced from the increment of the rod internal pressure which was larger than that expected from the fuel geometrical volume change.

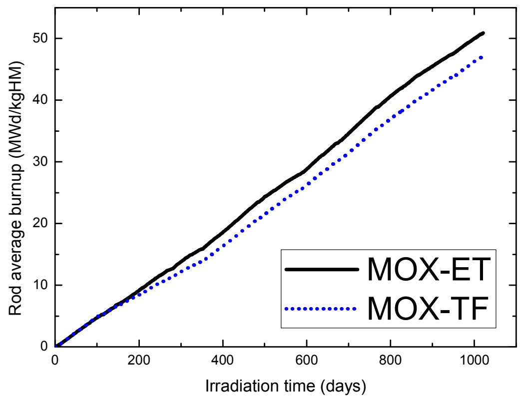

Fig. 1. Burnup accumulation in the Halden reactor.

3. Analysis by the COSMOS

Considering the features of the MOX 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.

All the in-pile testing results for the MOX fuel test rods from June 2000 to October 2006 (> 1,000 irradiation days) were compared with the COSMOS code. Based on the power history extracted from the on-line measured linear heating rates, the input for the COSMOS code was rigorously prepared.

The thermal conductivity was obtained from the model developed by KAERI [3]. The densification is attained as an input parameter which is determined from the rod internal pressure measurement. A swelling rate of 0.85% per 10MWd/kgHM was given from the normalized rod internal pressure before the fission gas release significantly.

As for the MOX-TF, the measured and calculated fuel temperature at the thermocouple tip was compared as shown 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 detail [4], the recovery effect of the thermal conductivity was considered 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.

Wide discrepancies around 200°C were caused by the faulty measured fuel temperatures by the thermocouple's signal spikes.

Since the maximum fuel temperature for the MOX-TF was higher than the threshold temperature for the fission gas release, a 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 from a MOX fuel.

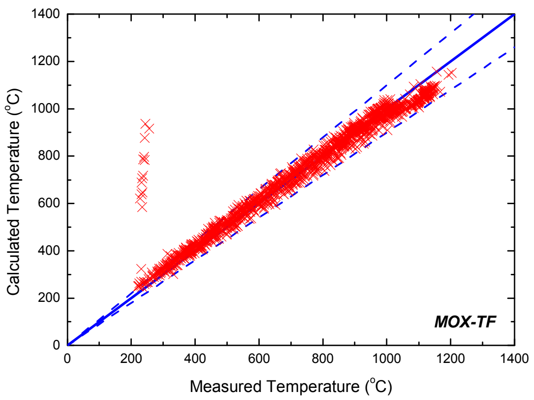

Fig.2. Comparison of the COSMOS calculated centerline temperature with the measured values for the MOX-TF

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

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

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

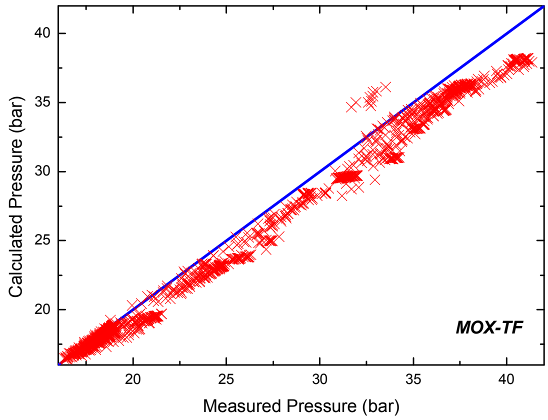

Fig. 3. Comparison of the COSMOS calculated RIP with the measured values for the MOX-TF

4. CONCLUSIONS

A successful irradiation test of two MOX fuels has been achieved in the Halden Reactor. The burnup of the MOX fuels reached ~50MWd/kgHM and all the instrumentations produced reliable in-pile and on-line data. MOX fuel rods demonstrated a very comparable thermal and fission gas release behaviour with the commercial MOX fuel. The measured in-pile results were compared with the COSMOS code results, which revealed a qualification of the thermal and fission gas release models implemented in the COSMOS code. The post-irradiation examinations will be performed in the near future.

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