Current Status of the Irradiation Test of MOX at the Halden Reactor and its Verification by COSMOS

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1. Introduction

Stockpiles of plutonium have been accumulating worldwide by the reprocessing of spent fuel and weapons disarmament. Excess plutonium can be adequately treated by an irradiation in the form of MOX or Inert Matrix fuel.

In this regard, two MOX fuel rods have been tested in the Halden Reactor from the middle of 2000. The primary aim of the in-pile experiment is to prove its fuel performance up to a high burnup.

The present paper describes the results obtained from the MOX fuel in-pile irradiation. Analysis of the measured data is also presented with 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.

The MOX-TF rod is instrumented with a thermocouple while the other MOX-ET has an expansion thermometer. Both rods have pressure transducers at the bottom end. MOX-TF is also instrumented with a stack elongation detector at the top of the fuel stack. An accurate axial and radial neutron flux distribution is determined by five SPNDs.

The irradiation test commenced at the end of June 2000 and it has been going well with a good fuel integrity and successful instrumentations. The average burnup for the two MOX fuel rods was ~30 MWd/kgHM. The burnup accumulation is illustrated in Fig. 1. The peak linear heating rate reached ~350 W/cm.

The measured fuel temperatures reached ~1300°C which indicates a fuel maximum temperature of ~1500°C at the mid-plane of the fuel stack in case of MOX-TF.

Both MOX rods were initially filled with helium at 10 bar at room temperature.

Concerning the fuel geometrical change, 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 observed for both rods since the increment of the rod internal pressure was larger than that expected due to the fuel geometrical volume change and the peak fuel temperature was higher than the threshold temperature for the fission gas release.

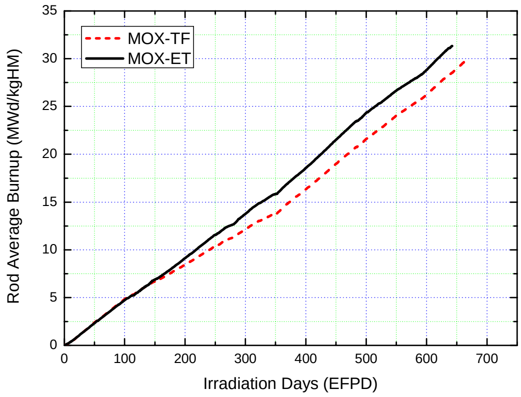

Fig. 1. Burnup accumulation during the six cycle irradiation.

3. Verification of 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 2004 were used for the COSMOS code verification. Based on the extracted power history, the input for the COSMOS code was rigorously prepared.

The thermal conductivity was calculated from the model developed by KAERI [3]. The relocation has been determined from the MOX test series which include a comparable MOX fuels. 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 release was not considerable.

As for the MOX-TF, the measured and calculated fuel temperature at the thermocouple of the MOX-TF 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 with considering the recovery effect of the thermal conductivity. 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. The fuel temperature measured at the TF is below that of the threshold curve but the maximum fuel temperature for the solid pellet at the peak linear heating rate was higher than the threshold with an increasing burnup since the temperature is generally lower (~200°C or more) at the TF's tip than at the solid pellet. So, substantial fission gas release is expected from the measurement of the fuel temperature and this is 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.

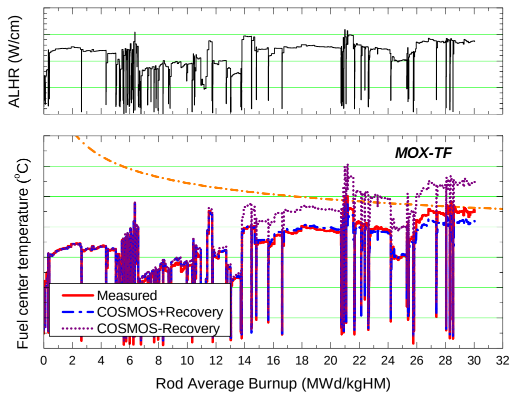

Fig.2. Comparison of the COSMOS calculated centerline temperature with the measured values for the MOX-TF

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 the 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.

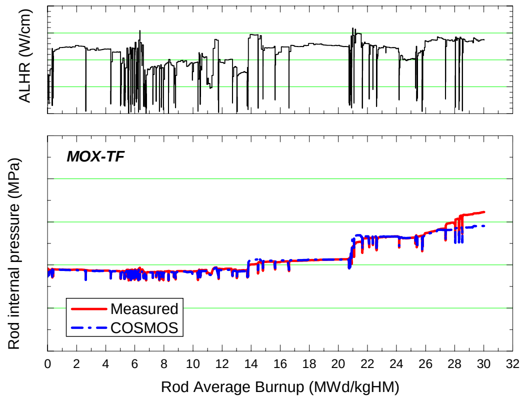

Fig. 3. Comparison of the COSMOS calculated RIP with the measured values for the MOX-TF

4. CONCLUSIONS

The six 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 used for the verification of the COSMOS code. The comparisons show the qualification of the thermal and fission gas release model implemented into the COSMOS code.

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