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Heavy ion irradiation of U–Mo/Al dispersion fuel

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Abstract

The usage of high-density U–Mo/Al dispersion fuel for high burn up in research and test reactors seems to be limited by the unfavourable interdiffusion layer between the fuel and the Al-matrix, which develops during irradiation. This interdiffusion layer was observed up to now only after costly and time consuming in-pile irradiation and could not be created in out-of-pile experiments. This paper presents a new approach of creating such an interdiffusion layer out-of-pile by irradiation with heavy ions. An appropriate choice of heavy-ion irradiation simulates irradiation damage and deposition of fission fragments as it happens during in-pile irradiation and induces a diffusion process between the fuel and the Al matrix. An irradiation experiment and post-irradiation examinations are presented.

1. Introduction

To minimize proliferation risks it is desirable to use – whenever possible – low enriched uranium (LEU) instead of highly enriched uranium (HEU) fuel for research and material test reactors. In order to achieve this goal high density fuels are required. For high performance reactors, U_3Si_2/Al dispersion fuel represents up to now the highest qualified uranium density of up to 4.8 gU/cm^3 [1]. But for high flux research reactors even a higher uranium density is required in order to convert the fuel from HEU to LEU. One of the most promising candidates is the metallic U–Mo/Al dispersion fuel. This fuel would allow a uranium density of around 8.5 gU/cm^3 and is currently under worldwide development [2].

However, since the year 2003 some concerns came up due to anomalous swelling of full size plates during irradiation at high neutron flux and

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heat load values. Post-irradiation examinations (PIE) of these plates revealed an Al-rich interdiffusion layer building up at the interface between U–Mo grains and the Al-matrix with a thickness of some 10 μm [3]. Cracks which are regarded as the reason of the breakaway swelling have been observed exactly between the interdiffusion layer and the matrix [4].

Therefore the build-up and the composition of the interdiffusion layer are of main interest. But because of the strong activation after the in-pile irradiation of the samples only a few types of examinations have been carried out like optical microscopy and scanning electron microscopy (SEM). Here we show an approach to generate an interdiffusion layer by out-of-pile irradiations with heavy ions thereby simulating the radiation damage created by fission fragments during reactor irradiation without the drawback of creating difficult to handle strong radioactive samples.

2. Sample preparation

Fuel plates containing atomized (spherical shape) U–6 wt%Mo and U–10 wt%Mo powder dispersed in aluminium were provided by the RERTR-team (reduced enrichment for research and test reactors) at ANL (Argonne National Laboratory) where they have been manufactured like miniplates for in-pile irradiation. The U-density in these specimens is about 8 gU/cm^3 and the maximum diameter of the spherical U–Mo grains was around 120 μm.

Initially specimens were cut into pieces of $5 \times 5\ mm^2$. Afterwards they were polished in order to get rid of the cladding and to make the meat layer accessible for irradiation with heavy ions. Since the penetration depth, and therefore the modification by irradiation with heavy ions, is in the order of some micrometers (see Fig. 1) a good polishing is of essential importance.

3. Irradiation condition

The irradiation experiment has been carried out at the Munich 14 MV tandem accelerator in Garching near Munich, Germany. All specimens were irradiated with I-127 at 120 MeV under high vacuum. Iodine was chosen because it allows on the one hand a high particle flux and on the other hand it represents a typical fission fragment. Since cooling of the specimen has to be achieved mainly by thermal conductivity, the specimens were screwed on an aluminum block. A maximum heavy ion flux as high as $4.4 \times 10^{11}\ s^{-1}$ (i.e., 10 W) was chosen in order to limit the specimen temperature to a maximum of 200 °C, which was measured *in situ* by a thermocouple on the rear side of the specimen. This temperature covers conservatively the temperature conditions in the meat of high flux reactors and is low enough to avoid a thermally activated diffusion or decomposition of the metastable γ-phase of the U–Mo fuel particles. After up to 13 h of irradiation a final fluence of 1×10^{17} $ions/cm^2$ on the surface of the specimen was achieved in an area of approximately $2 \times 2\ mm^2$. This ion (or fission fragment) density could be compared to a low or even medium burn-up. Fig. 2 shows the sample during irradiation under an angle of 30°. Since the energy of the iodine projectile is less than 1 MeV per nucleon, nuclear reactions (especially activation of the specimen) can be excluded.

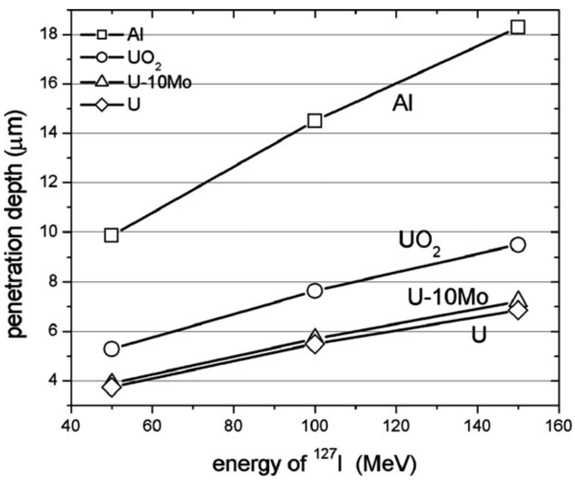

Fig. 1. Penetration depth of iodine into selected materials versus kinetic energy [5].

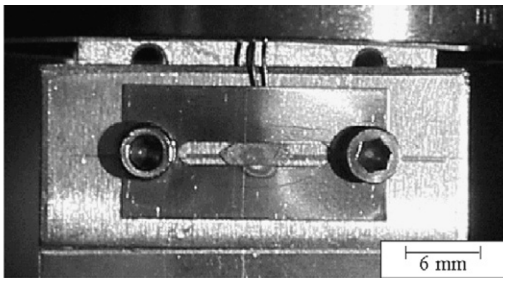

Fig. 2. Specimen – located in the slot between the two screws – during irradiation with heavy ions.