Feasibility Study of Advanced U-Mo-X Metallic Fuel System for SFR

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1. Introduction

U-Zr-Pu alloy fuels have been used for sodium-cooled fast reactor (SFR) related to the closed fuel cycle for managing minor actinides and reducing a high radioactivity levels since the 1980s. U-Zr-Pu alloy fuels form several radial zones with a Zr-depleted zone, caused by the redistribution of U and Zr elements in a fuel pin due to the difference of the chemical potentials during irradiation. Minor actinides (MA) and rare earth (RE) elements migrate toward cladding and also promote the formation of the radial zones during irradiation. The migration of minor actinides (MA) and rare earth (RE) elements, accumulating as fission products in the fuel, are also a concern because they are more reactive to cladding materials than fuel. Their reaction products with cladding materials have lower melting points than cladding. MA and RE show higher reactivity with cladding materials than U and Zr element during irradiation, results to deteriorate the soundness of the cladding materials and require the reprocessing treatment of the reacted cladding with MA and RE. The objective of this paper is to review the feasibility of the U-Mo-X metallic fuels having only one phase in the operation temperature [1-2], where X is a combination of Pu, Am, Np and Cm, in order to reduce the migration of MA and RE, and increase compatibility with cladding materials in SFR fuel.

2. Stable Irradiation Behavior of U-Mo-X Metallic Fuel Having Single Phase

U-Mo alloys in particular are known to stabilize the cubic γ-U phase at modest alloy content [2]. U-7wt.%Mo alloy has only single isotropic γ-U phase in the range of 550 - 1000 °C. U-19wt.%Pu-10wt.%Mo is U-16Pu-20Mo in at%, where the U/Pu ratio is 4. An isopleth of U/Pu ratio of 3 is available and shown in Fig. 1. The U-19wt.%Pu-10wt.%Mo alloy in the temperature range of 550 - 950°C has only single γ-U phase. A thermodynamic study shows that the U-Mo-X metallic fuels for SFR (ABR) had better performance characteristics than U-Zr-X in constituent redistribution. It is expected that U-Mo-X will have less migration of fuel constituents and zone formation than U-Zr-X that has three phases in the temperature range, since there is no large difference of the chemical potentials in single phase during irradiation. It leads to radial zones without the redistribution of U and Zr elements in a fuel pin. Minor actinides (MA) and rare earth (RE) elements in U-Mo-X alloy fuels would not migrate toward cladding and also not cause severe reactions with cladding materials during irradiation.

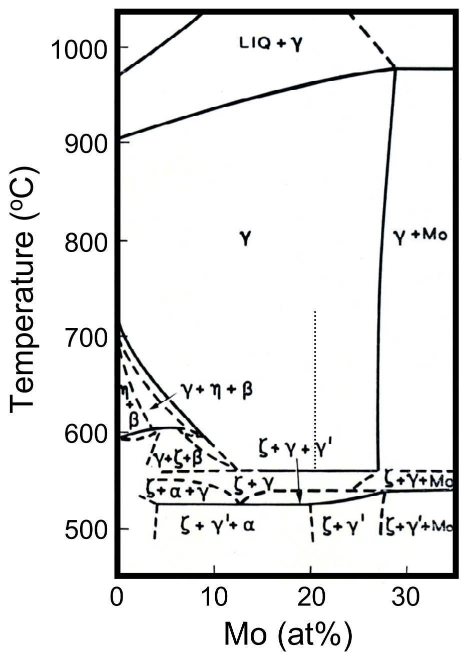

Fig. 1. Isopleth of U/Pu ratio 3 [3]. The dotted line indicates the phase field the U-19Pu-10Mo faces at typical fuel operation temperatures.

Early irradiation experiments with U-Mo metallic fuels for SFR showed the promise of acceptable irradiation behavior, if these alloys could be maintained in their cubic γ-U crystal structure [2]. Recently, U-Mo metallic fuel for research reactors has shown a stable in-reactor performance with fine fission bubble during irradiation, as shown in Fig. 2 [1]. U-Mo-X alloy fuels will show stable in-reactor performance, if the swelling of U-Mo-X alloy fuel can be constrained by strong cladding and fast fission gas release.

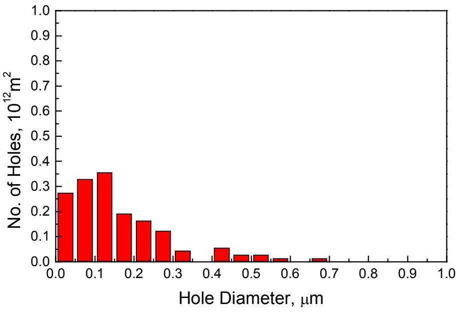

Fig. 2. Bubble distributions of U-10wt.%Mo alloy fuel, irradiated in high burnup (~70at.%U-235).

3. Fabrication of U-Mo Fuel Pin by Injection Casting Method

A proportioned charge of depleted uranium lumps with a purity of 99.9% and molybdenum pellets with a purity of 99.7% were induction-melted in a high-temperature-resistant crucible. As soon as the quartz tubes are lowered and dipped into the melt, Ar gas was fed into the melting chamber until an atmospheric pressure was achieved. Then, the melt was filled and freezed in the quartz tube. The alloy phase and the microstructure of the ingot were characterized with a X-ray diffractor and a scanning electron microscope (SEM). The U-7wt.%Mo alloy pin, fabricated by an injection casting, has a fine γ-U grain structure in as-cast state, shown in Fig. 4. Grain size of U-7wt.%Mo alloy pin is different according to the location of the ingot, due to a cooling rate difference by a thermal gradient along the quartz's longitudinal direction. The grain size of the lower part is more than 10 times that of the upper part.

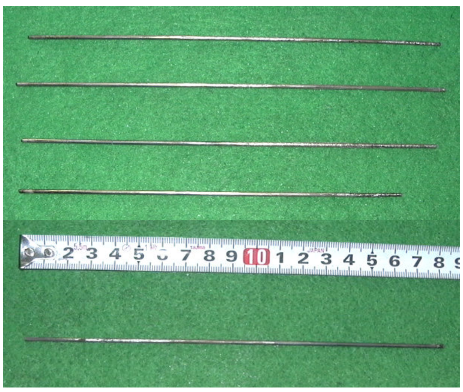

Fig. 3. U-7wt.%Mo fuel pins produced by the injection casting method.

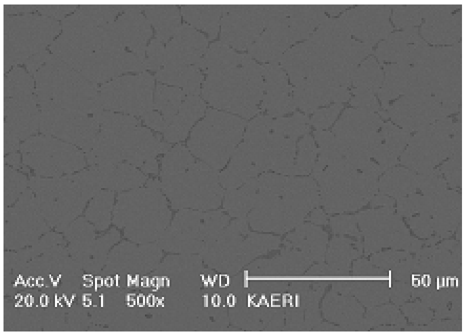

Fig. 4. Typical micrograph of U-7wt.%Mo alloy ingot, fabricated by injection casting method.

4. Conclusions

U-Mo-X alloys, having single cubic γ-U phase in operation temperature during irradiation, was studied for metallic fuel for SFR. It is expected that the U-Mo-X metallic fuels inhibit the migration of the fuel constituent toward cladding and the formation of the radial zones due to single phase of U-Mo-X alloy. It will prevent that minor actinides (MA) and rare earth (RE) elements in U-Mo-X alloy fuels migrate toward cladding and also cause severe reactions with cladding during irradiation.

Knowledgements

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