Development of U-Pu-Zr Metallic Fuel Fabrication Technology for Fast Reactor

Background

Uranium-plutonium-zirconium (U-Pu-Zr) alloy with high actinide density and high thermal conductivity is expected to improve fast reactor performance such as breeding ratio according to circumstances and favorable inherent safety, compared with the conventional oxide fuels. In view of these points, CRIEPI has developed the U-Pu-Zr metallic fuel for sodium-cooled fast reactor as one of the promising technologies for the practical use of future nuclear fuel cycles. The metallic fuel is fabricated in a rod shape called a "slug" instantly by casting process in which molten alloy is injected into evacuated cylindrical quartz molds. Engineering scale casting tests have already been conducted successfully to fabricate U-Zr alloy slugs that meet the requirements (dimension, composition, throughput etc.). As for the U-Pu-Zr alloy, a small scale casting process is developed at this stage. Commercial metallic fuel slugs are designed to contain Pu in the composition range of 5 to 25 wt%, which affects thermal property of the alloy depending greatly on the Pu content. Taking the Pu content into consideration, therefore, adequate casting conditions must be determined. In an introduction period of metallic fuel fast reactors, furthermore, oxide powder products of U and Pu in the conventional fuel cycle must be reduced to feed U-Pu alloys to the casting process. One of the most simple and promising ways is to apply the electrochemical reduction technique to the U-Pu mixed oxides.

Objectives

To develop fabrication technology of U-Pu-Zr metallic fuel that is required for introduction of the metallic fuel fast reactors; to determine the preparation procedure for high-purity U-Pu alloy ingots applying the electrochemical reduction technique, and the casting condition of U-Pu-Zr alloy that satisfies the requirements for the fuel slugs.

Principal Results

1. Development of preparation procedure for U-Pu alloy ingots

The electrochemical reduction of U-60wt%Pu mixed oxide pellets with low density was conducted in molten lithium chloride salt at 923 K as shown in Fig.1. As a result of the reduction, the U-Pu alloys were obtained with porous structure and re-oxidized easily even in high purity argon gas atmosphere. Therefore, they were melted immediately in the molten salt at 1073 K to consolidate in an ingot shape. Subsequently, the salt was removed from the ingots by distillation in a vacuum. Fig.2 shows the U-Pu alloy products, in which the oxygen contents were less than 1000 ppm. Almost all inputs of U and Pu were recovered as the ingots after the processes of reduction, consolidation and salt distillation. These results show that high-purity U-Pu alloy ingots are sufficiently fed to the casting process from the starting material of U-Pu mixed oxide powder by applying the developed preparation procedure .

2. Development of casting condition of U-Pu-Zr alloy slugs

The U-Pu-Zr alloy slugs (Pu =0, 8.5 and 20 wt%) were fabricated in the rod shape of 5 mm in diameter and 280 mm in length using the injection casting furnace shown in Fig.3. Casting conditions such as temperature of the alloy melt were adequately adjusted according to the composition of the alloys. The casting tests were conducted repeatedly reusing the slug and the remnants in the crucible as the subsequent feed materials. Fig.4 shows a typical fuel slug of U-20wt%Pu-10wt%Zr alloy. It showed a solid bar (slit at both ends to be 200 mm) and sufficiently smooth surface with metallic color in the whole region. The fuel inspection results of the alloy slug are indicated in Table 1, as a typical result. Excellent quality of every fuel slug was confirmed in view of length, diameter, density and straightness with reference to target specifications. Vertically homogenized composition was also confirmed by chemical analysis, including americium as a decay product of Pu-241. These results show that the U-Pu-Zr alloy slugs are fabricated by applying the casting conditions determined in the present studies according to the U-Pu-Zr alloy composition.

The present results of reduction of U-Pu mixed oxide and fabrication of U-Pu-Zr alloy slug reveal feasibility on metallic fuel fabrication technology required for an introduction period of metallic fuel fast reactors.

Future Developments

The developed techniques are soon applied to fabrication of U-Pu-Zr alloy fuel slugs, which will be irradiated in experimental fast reactor "JOYO". It is the first irradiation tests of the metallic fuel in Japan and valuable experimental data will be obtained by following post irradiation examinations.

Main Researcher: Kinya Nakamura and Tetsuya Kato,
Research Scientists, Advanced Nuclear Fuel Cycle Sector, Nuclear Technology Research Laboratory

References

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K. Nakamura et al., "Metallic Fuel Fabrication Study for Irradiation Tests in JOYO", Proceedings of International Conference on Nuclear Energy System for Future Generation and Global Sustainability (Global2005), Tsukuba, Japan, 9-13 Oct, 2005.

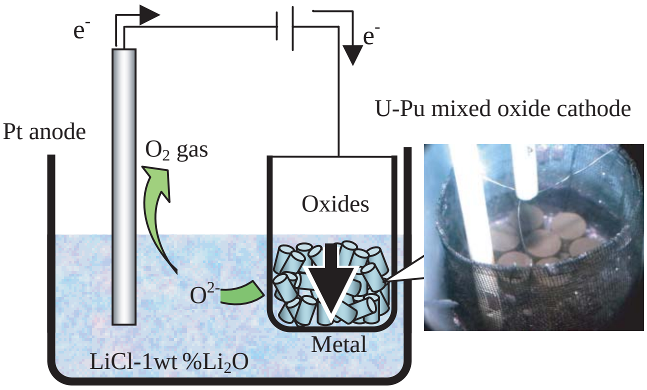

Fig.1 Electrochemical reduction process of U-Pu mixed oxides.

Fig.2 U-60wt%Pu alloy ingot (total 19g) prepared through the processes of electrochemical reduction, consolidation and salt distillation from the starting material of U-Pu mixed oxide.

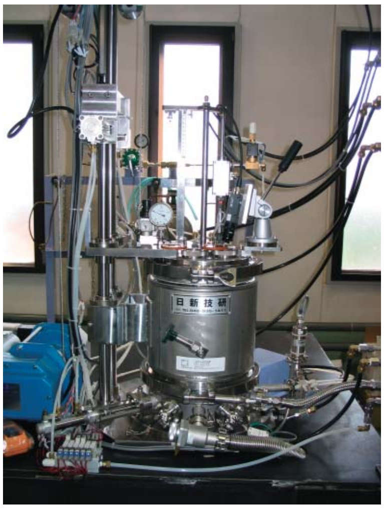

Fig.3 Injection casting furnace for U-Pu-Zr alloy.

Fig.4 Cast U-20wt%Pu-10wt%Zr alloy slug (200mm in length) fabricated by injection casting method. Smooth and metallic surface in the whole length can be seen.

Table 1 Typical results of quality conformance inspection for the U-20wt%Pu-10wt%Zr alloy slug fabricated by injection casting method

Characteristic		Inspection Results			Requirements
Length		200mm (before slit at both ends: 275mm)			200±1mm
Diameter		5.02mm			5.05±0.05mm
Density		15.6 g/cm^3			15.3～16.1 g/cm^3
Straightness		Go through a tube of ID 5.18mm and 200mmL			Go through a tube of ID 5.5mm and 200mmL
Composition (wt%)		Top	Middle	Bottom	
	U	69.0	69.2	68.2	Balance
	Pu	20.5	20.5	20.5	20.0±1.0 wt%
	Zr	10.2	10.0	11.0	10.0±1.0 wt%
	Am	0.3	0.3	0.3	