Irradiation Integrity of Minor Actinide-Containing Metal Fuel – Low-burnup Irradiation Behaviour –

Background

In recent years, much attention is paid to the technologies for recovering minor actinides (MA), such as neptunium, americium and curium from spent nuclear fuel and burning them in fast reactors for the purpose of reducing the radioactive toxicity and heat generation of high-level wastes. The Central Research Institute of Electric Power Industry (CRIEPI) has been developing uranium-plutonium-zirconium (U-Pu-Zr) alloy fuel containing MA in cooperation with the Institute for Transuranium Elements (ITU) of the European Commission, considering this type of fuel has some advantages to transmute MA efficiently in fast reactors. The development of fast reactor metal fuel was commenced at Argonne National Laboratory in the U.S. and the irradiation behavior of U-Zr or U-Pu-Zr alloy fuel has been understood. However, there are only a few experimental data for MA-containing metal fuels. In this study, three types of metal fuel pins, which include the U-Pu-Zr fuel segments containing 5wt% or less MA and rare-earth elements (RE) as illustrated in Fig .1, were fabricated and irradiated in the fast reactor Phénix in France. In this experiment, three irradiation capsules, each of which contained three types of fuel pin, were prepared. The irradiation capsules were subsequently discharged from the reactor at low (~2.5 at.%), medium (~7 at.%) and high (~10 at.%) peak burnups. The post-irradiation examinations are now in progress at ITU.

Objectives

In order to demonstrate the integrity of MA-containing metal fuel during irradiation, the purpose of this study is to investigate the irradiation behavior of MA-containing U-Pu-Zr alloys at a low-burnup of ~2.5at.% through the destructive PIEs, such as plenum gas analysis and optical metallography.

Principal Results

1. Plenum gas analysis

Since a part of gaseous fission products (= FP gas) is released to upper plenum (Fig. 1) and increases inner pressure of the fuel pin, the FP gas release (= the ratio of FP gas release to total generation) is important for evaluation of the fuel integrity. The amount of FP gas released to the plenum was measured and FP gas release was estimated based on the calculated total amount of FP gas generated. The obtained FP gas release 46-51% is consistent with previously reported data of U-Pu-Zr fuel pins, and no significant difference due to MA addition was detected among three types of irradiated fuel pins. The result suggests that the FP gas release behavior from the metal fuel is not influenced by MA addition in the low burnup stage.

2. Metallography

Cross-sectional samples were taken from the MA-containing metal fuel segments of the respective fuel pins, then the irradiated fuel structure was observed by an optical microscope. The metallography results of U-Pu-Zr-5MA-5RE (wt%) irradiated up to ~2.5at.% burnup are shown in Fig. 2. In cross-sectional overview (Fig. 2-(a)), three distinct concentric zones are visible corresponding to the radial temperature distribution. The characteristics of fuel matrix morphology in each region (Fig. 2-(b) and Fig. 2-(c)) were similar to those of MA-free U-Pu-Zr fuels. These observation results suggest that MA addition does not vary the structure and morphology of matrix phases. On the other hand, some large precipitates appeared in the high-temperature central region (Fig. 2-(b)), and dark narrow layered precipitates spread along grain boundaries in the intermediate region (Fig. 2-(c)). These precipitates are expected to be rich in RE and americium, which were homogeneously dispersed throughout the whole fuel alloy before irradiation. Further observations and analyses of the MA-containing fuels irradiated up to medium and high burnups are necessary to examine influence of these precipitates on the fuel integrity.

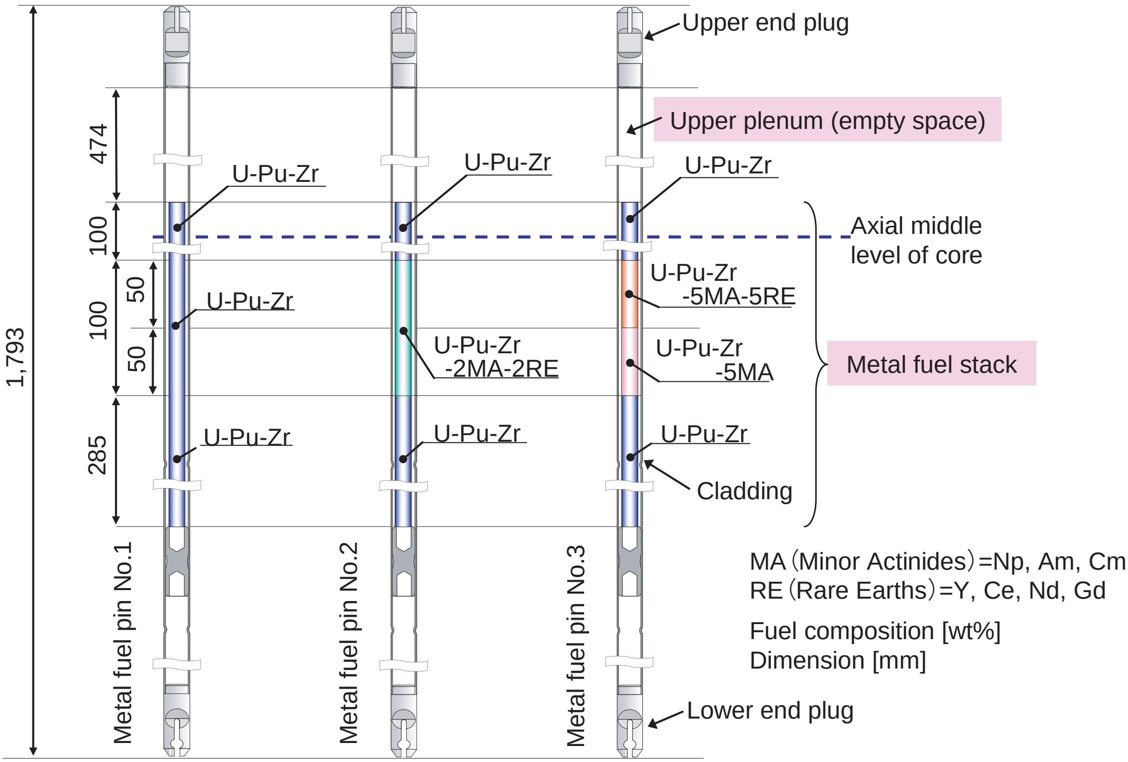
Future Developments

Post-irradiation examination of MA-containing metal fuels irradiated up to low (~2.5at.%), medium (~7at.%) and high (~10at.%) burnups will be continued to clarify the change in the fuel behavior due to the progress of irradiation and to demonstrate MA transmutation performance of the metal fuel.

Main Researcher: Hirokazu Ohta,
Research Scientist, Advanced Nuclear Fuel Cycle Sector, Nuclear Technology Research Laboratory.

Reference

H. Ohta, et al., 2009, "Post-irradiation Examinations of Fast Reactor Metal Fuels Containing Minor Actinides – Fission Gas Release and Metallography of ~2.5at.% Burnup Fuels –", Proceedings of Global 2009, Paris, France.



- Several metal fuel rods of ϕ=4.9mm are inserted in a stainless steel cladding tube of ϕ=6.55mm including thickness=0.45mm.
- In metal fuel pin #2 and #3, MA-containing alloys indicated in green, orange or red colors are sandwiched by usual U-Pu-Zr alloy stacks indicated in blue one.
- RE-containing alloys, which simulate contamination of MA recycled, are also prepared.

Fig.1 Structure of three types of metal fuel pin irradiated in Phénix reactor.

5

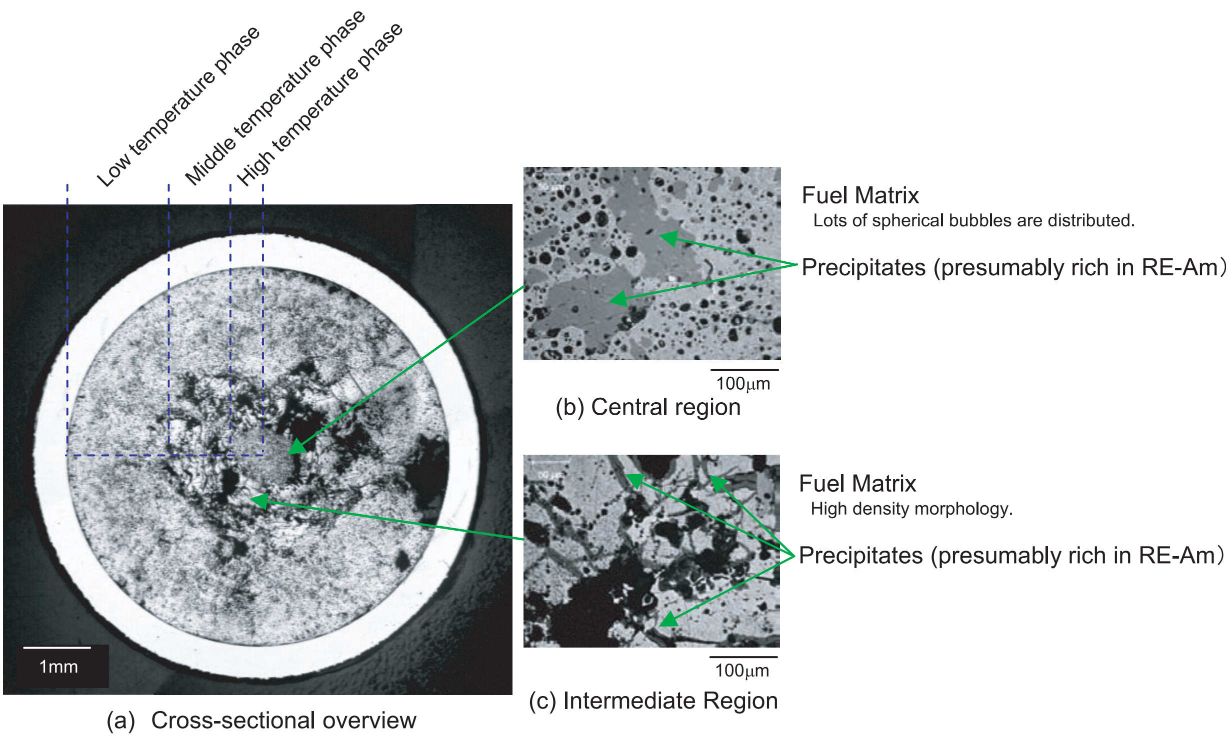


Fig.2 Optical metallography of irradiated U-Pu-Zr alloy containing 5%MA and 5%RE.