The Study of the Effects of Rim Structure Formation on Fuel Performance in High Burnup LWR Fuels
– Results of International Project "HBRP-NT" –

Background

Burnup extension of light-water reactor (LWR) fuel is an option to reduce the total amount of spent fuel and eventually the fuel cycle cost. At the rim of high burnup fuel pellets, a crystallographic re-structuring is observed, commonly called the "rim structure", which is characterized by the existence of highly dense small sub-grains, whose size is approximately 100 nm, and the accumulation of small pores with average size around 1μm.

In order to develop new types of fuels for higher burnup utilization, it is necessary to clarify this phenomenon, the effect on fuel performances, and fuel safety. CRIEPI organized and managed the international project "High Burnup Rim Project" in 1992 - 2000, and clarified the threshold burnup and temperature of rim structure formation and fuel performances (e.g. the degradation of thermal diffusivity is not accelerated by rim structure formation) for UO_2 fuels. However, some important information such as the clarification of the differences in fuel performance between non-mechanical constraint HBRP disc fuels and LWR fuels, and the fuel properties of gadlinia-doped fuels, whose use is increasing for higher burnup in LWR, is not sufficient.

In order to study these items, CRIEPI organized and managed the international project "High Burnup Rim Project - New Technology (HBRP-NT)" in 2002 - 2005.

Objectives

(1) Clarification of fission gas release behaviour of high burnup fuels by means of the developed rig for accelerated irradiation that is to simulate LWR irradiation conditions including mechanical constraint.

(2) Clarification of the effects of rim structure on the fuel properties and behaviour of gadolinia-doped fuels by several post irradiation examinations (PIEs).

Principal Results

1. Figure 1 indicates the accelerated irradiation rig that is to simulate LWR irradiation conditions whose samples are disc shape (thickness: 1mm) and sliced from spent LWR fuel rods. The sliced sample whose burnup is around 61 MWd/kgU was irradiated in R2 reactor (Studsvik AB), and reached around 81 MWd/kgU by only 105 days (Table 1). These results indicate that the development of irradiation rig has been succeeded. The result of puncture test of this rig after irradiation suggests that the FP gas release ratio tends to be suppressed under the condition with mechanical constraint loaded.

2. Several PIEs in Institute for Transuranium elements (ITU) have been done by use of 5 wt. % gadolinia-doped fuels, which were irradiated in HBWR (Institutt for Energiteknikk) by HBRP. Scanning electron microscope (SEM) and transmission electron microscope (TEM) observation clarify that the microstructure evolution and the burnup and temperature threshold of rim structure formation is not different between UO_2 fuels and gadolinia-doped fuels. Figure 2 indicates the existence of grains partially sub-divided, that is the initiation of rim structure formation, in a gadolinia-doped fuel of around 55 MWd/kgU. Figure 3 and 4 show the results of thermal diffusivities by laser flash method and densities by Archimedes method as function of burnup, respectively. These results do not indicate that 5 wt.% gadolinia doped in fuels influences the threshold burnup and temperature of rim structure formation.

This research was a collaborative study of Mitsubishi Heavy Industries, Ltd., Nuclear Fuel Industries, Ltd., Global Nuclear Fuel - Japan Co., Ltd., Electricite de France, and CRIEPI. The Federation of Electric Power Companies of Japan requested the implementation of this study.

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Reference

T. Kameyama, T. Sonoda, S. Kitajima, A. Sasahara, Y. Nauchi, M. Kinoshita and et al., "Clarification of rim structure effects on properties and behaviour of gadolinia doped fuels 1-3", Fall meeting of Atomic Energy Society of Japan, Sapporo-Hokkaido (Sept. 27, 2006) (in Japanese)

Table 1 Results of accelerated irradiation examination by use of spent LWR fuel rod

Irradiation temperature (calc.) [°C]	500-950
Mechanical constraint	Pellet-clad contact (radial direction), Pressed by spring (axial direction)
Irradiation period [days]	105
Burnup [MWd/kgU]	~ 61(before irradiation) / ~ 81 (after irradiation)
Microstructure change	Increment of number density and size of FP gas pores Sub-division of grains, Extension of rim structure area

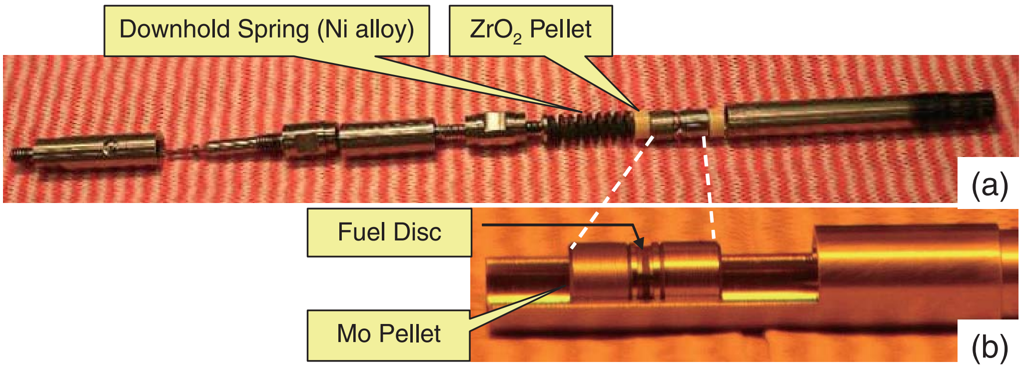

Fig. 1 Mounting of irradiation rig.(a) Single parts, (b) fuel disc in centering ring between Mo pellets

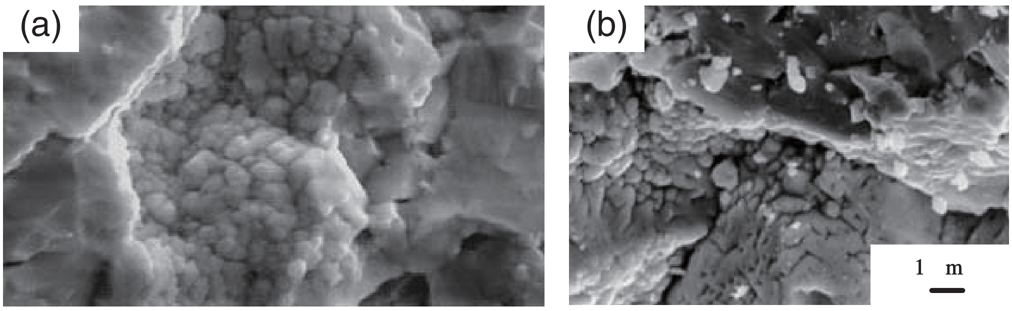

Fig.2 SEM images of (a)(U,Gd)O_2 fuel of 53 MWd/kgU, 880°C, and (b) UO_2 fuel of 51 MWd/kgU, 880°C

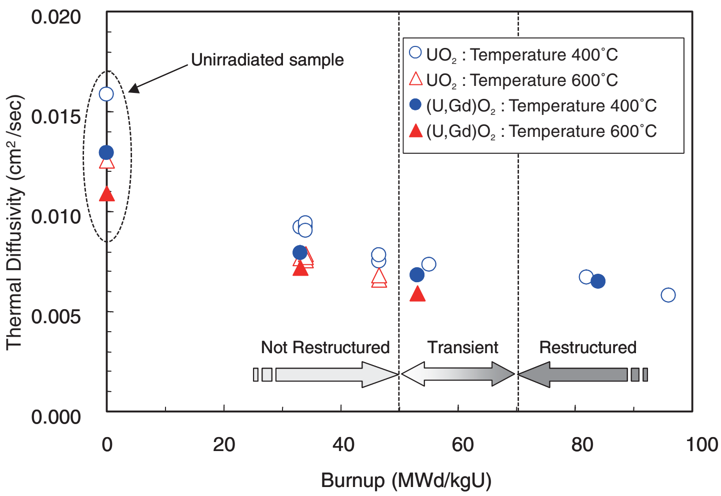

Fig.3 Thermal diffusivities of UO_2 and (U, Gd)O_2 fuels as a function of burnup (No-adjustment of porosity)

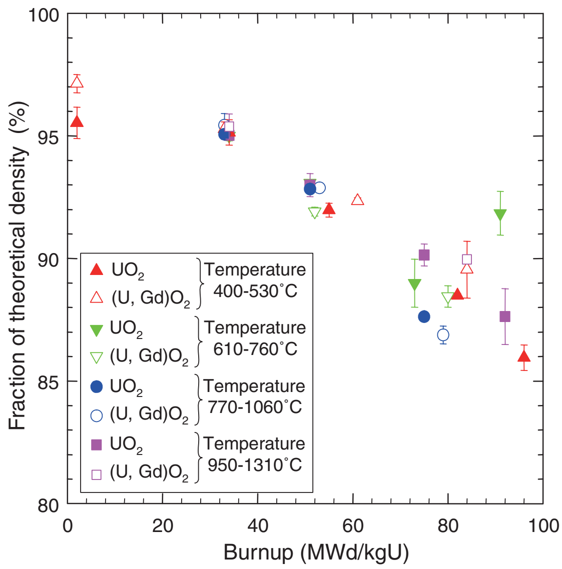

Fig.4 Densities of UO_2 and (U, Gd)O_2 fuels as a function of burnup