2nd Irradiation test and PIEs for developing neutron absorbing and burnable poison materials

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1. Introduction

$Dy_xTi_yO_z$ and $Gd_xTi_yO_z$ have been developed as neutron absorbing and burnable poison materials since these lanthanoid oxides have been considered as good irradiation resistant materials [1].

$Dy_xTi_yO_z$ has been used as a control rod material whereas $Gd_xTi_yO_z$ is considered as a burnable poison material.

The feasibility study of the 1st irradiation and PIE results was reported in [2]. The present paper describes the 2nd irradiation test results including a safety analysis and some preliminary PIE results.

2. Fabrication of the Pellets and an Irradiation Capsule

Dy_2O_3 and TiO_2 powders were mixed well in a tubular mixer and then milled in a zirconia crucible. The green pellets were made by hydraulically pressing the mixed powder. Based on the TMA sinterability scoping tests, the green pellets were sintered at high temperatures [3].

The $Gd_xTi_yO_z$ pellets were fabricated by similar procedures to that of the $Dy_xTi_yO_z$ with the exception of a somewhat higher sintering temperature.

The prepared pellets were loaded into two pellet capsules for the HANARO irradiation. The main characteristics of the pellets with a designation are listed below. The gap was charged with He gas of 1 bar at room temperature.

Pellet	Designation	Diameter (mm)	Height (mm)	Density (g/cc)
$Gd_xTi_yO_z$ (1450℃)	Gd20-3	3.503	3.048	5.29
	Gd20-4	3.503	3.052	5.34
	Gd20-5	3.508	3.045	5.32
	Gd20-6	3.492	3.032	5.32
$Gd_xTi_yO_z$ (1600℃)	Gd42-7	3.472	3.084	6.22
	Gd42-9	3.494	3.050	6.21
	Gd42-13	3.497	3.098	6.27
	Gd42-14	3.486	3.064	6.28
$Dy_xTi_yO_z$ (1600℃)	Dy40-5	8.503	5.866	6.70
	Dy40-6	8.503	5.931	6.68
$Dy_xTi_yO_z$ (1550℃)	Dy40-15	8.502	5.874	6.35
	Dy40-16	8.502	5.842	6.35

3. Irradiation Test and In-Pile Analysis

The $Dy_xTi_yO_z$ and $Gd_xTi_yO_z$ were second irradiated to test their applicability for neutron absorbing and burnable poison materials. The position of the capsule in the HANARO reactor was OR6 and the duration was 254 EFPD. This 2nd test was aimed at checking the in-pile performance of the developing candidate materials.

Integrity analyses were performed before loading them into the test reactor. In particular, thermal and stress as well as strain behaviors were estimated by the ABAQUS code with the following assumptions: (1) an axial symmetry, (2) negligible axial heat transfer, and (3) negligible radiation heat transfer through the gap.

For a simplicity of the calculation and conservatism, a thermal conductivity of 1.5 and 1.0 W/m-K was applied to $Dy_xTi_yO_z$ and $Gd_xTi_yO_z$, respectively.

The Ross and Stoute model [4] was used for the gap conductance between the pellet and the cladding. The Dittus-Boelter relationship was used for the heat transfer from the coolant to the cladding. The pellet centerline temperature was estimated with the assumption of no swelling for a conservatism. The peak linear heating rate was 108 W/cm for $Dy_xTi_yO_z$ and 172 W/cm for $Gd_xTi_yO_z$ under the HANARO irradiation conditions.

Taking into account the coolant conditions, gap properties, and the radial depression of the power density, the calculated centerline temperature in the $Dy_xTi_yO_z$ with a maximum power density was 467 °C. In the case of the $Gd_xTi_yO_z$, the thermal analysis result was as low as 130 °C. Generally, the power density is higher in $Gd_xTi_yO_z$ than in $Dy_xTi_yO_z$ so a higher temperature is expected in $Gd_xTi_yO_z$ than in $Dy_xTi_yO_z$. The lower centerline temperature is due to the small size of a $Gd_xTi_yO_z$ pellet and the majority power generation in the periphery.

The stress and strain analysis with relavant in-pile information revealed that there was no contact between the pellet and the capsule cladding (Zircaloy-4).

4. Post Irradiation Examination

Post irradiation examinations were conducted on the two pellet capsules – four pellets for the $Dy_xTi_yO_z$ capsule and eight for $Gd_xTi_yO_z$ – after the successful irradiation test. Visual examination was performed by using the hot cell periscope and an in-cell video camera. The visual inspection showed that both pellet capsules remained intact during the irradiation test. From the cutting of the $Dy_xTi_yO_z$ capsule, it was confirmed that all the $Dy_xTi_yO_z$ pellets maintained their geometrical integrity during the irradiation as shown Fig. 1. In case of the $Gd_xTi_yO_z$ capsule, the Gd42 series pellets – Gd42-7 ~ Gd42-14 – were easily extracted whereas the Gd20 series pellets – Gd20-3 ~ Gd20-6 – were not pulled out since the pellets seemed to be stuck to the cladding. Consequently, the Gd20 series pellets crumbled during an extraction. The right four pellets are Gd42 series pellets and the left two pellets are some chips extracted by force from the capsule in Fig. 2. This proves that the Gd20 series pellets have experiecned a higher swelling rate than Gd40 pellets.

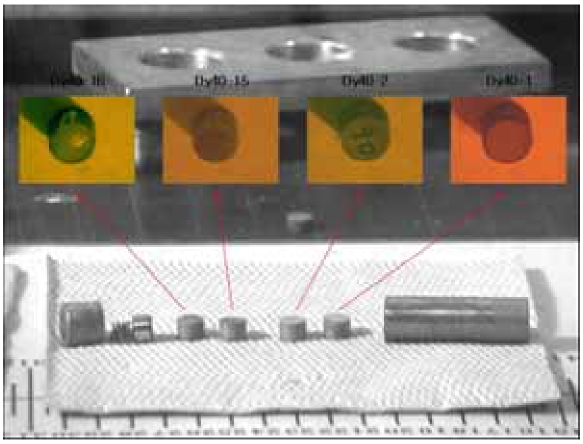

Fig. 1. Visual inspection after an irradiation of the $Dy_xTi_yO_z$ pellets.

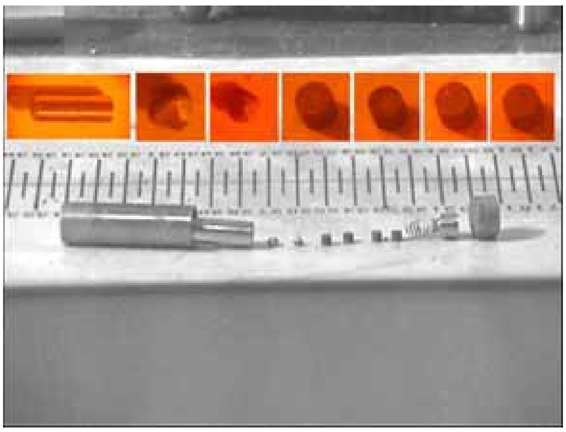

Fig. 2. Visual inspection after an irradiation of the $Gd_xTi_yO_z$ pellets.

The geometry and density measurements as well as the microstructural observation are under way. In addition, a chemical analysis will be carried out in the near future for measuring the physical efficiency of the neutron absorption.

5. Conclusions

$Dy_xTi_yO_z$ and $Gd_xTi_yO_z$ pellets were irradiated in the HANARO reactor to evaluate their in-pile performance for developing neutron absorbing and burnable poison materials. The irradiation for 254 EFPD was successful and the PIE is under way. Some preliminary PIE results showed the in-pile performances with a stable geometry except for the Gd20 series where the pellets were stuck to the pellet capsule so they were not pulled out. Further PIEs will be carried out for a geometrical and density measurement as well as the chemical analysis for measuring the physical efficiency of the neutron absorption.

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