

Irradiation Test of Oxide-based Neutron Absorbers for Reactor Control Rods at HANARO

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1. Introduction

Control rods are key components in light water reactors, ensuring safe operation by regulating reactivity and enabling shutdown. Conventional absorbers such as B₄C and Ag-In-Cd (AIC) are widely used, but their performance is limited by irradiation-induced swelling, helium generation, eutectic interactions with cladding materials, and poor oxidation resistance. These issues not only shorten control rod lifetime but also pose safety concerns under accident conditions.

To overcome these limitations, oxide-based absorbers are being developed as advanced control rod materials. They offer advantages such as improved dimensional stability, reduced swelling, and enhanced resistance to oxidation and eutectic reactions. Our research has focused on designing oxide-based compositions, verifying manufacturability with conventional ceramic processes, and evaluating their neutronic and thermochemical behavior [1, 2]. This paper presents the status of in-reactor irradiation test performed at the HANARO research reactor (KAERI) and reports nondestructive examination results of irradiated control rod materials.

2. Design and Fabrication of Absorber Candidates

The essential requirements for neutron absorber used in control rods are adequate neutron worth, stability under irradiation (both structural and chemical), and easy of fabrication. To satisfy the requirement for neutron worth, lanthanide-based oxides were considered, while oxides of tetravalent transition metals (Ti, Zr, and Hf) were selected to ensure irradiation stability. By combining one lanthanide oxide with one tetravalent metal oxide, various compounds could be formed. Among these possible combination, 14 compounds were selected for irradiation testing. In addition, B₄C, the neutron absorber employed in commercial control rods, was included as a reference materials for comparison.

The pellets for irradiation test were manufactured using conventional ceramic sintering process. Depending on the composition, calcination and/or high-energy milling were applied to improve homogeneity in chemical mixing. The density of sintered pellets was

measured to be 95-97%TD. The density of the B₄C was 70%.

3. Irradiation at HANARO

A total of 16 test rods, including two B₄C reference rods, were fabricated and assembled into a test capsule. Fig.1 shows test rods, the irradiation capsule design and the assembled capsule.



Fig. 1. Test rods, capsule design and assembled test capsule.

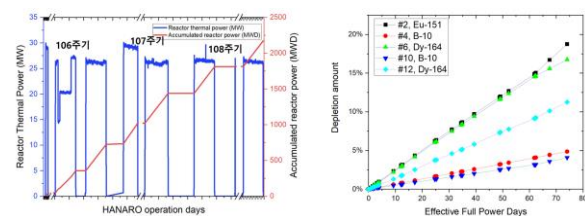


Fig. 2. Power history and depletion rate of isotopes .

The HANARO irradiation test began in May 2023 and was finished in early 2025, with a total irradiation exposure of about 240 EFPDs. Fig.2 presents the power

history at 74 EFPDs together with the corresponding calculated depletion of the isotopes. At the end of the test (240EFPDs), the depletion of the isotopes is expected to range from 16% to 48%. Detailed evaluations of the power and depletion histories are currently in progress.

4. Non-destructive PIE

The HANARO irradiation test capsule was transferred to the IMEF facility in July 2025 after a cooling period and was disassembled at the test rod level. Because the test rods containing europium require additional cooling, Non-destructive testing of X-ray scan was performed on the remaining 12 test rods. Fig. 3 presents the X-ray testing equipment and the measurement procedure. A two-dimensional digital radiography scan was conducted, with images acquired three times at 120° intervals.

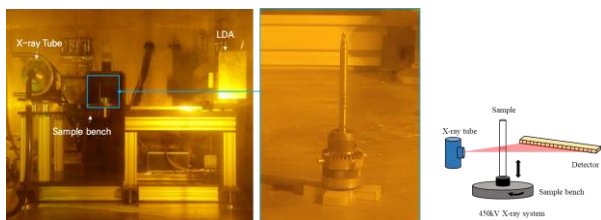


Fig. 3. 450kV X-ray scan system.

Fig. 4 shows the X-ray scan images of each test rod. For the rods containing oxide-based sintered pellets, the pellet geometry was clearly identifiable, and the cladding–pellet gap was distinguishable. Most pellets exhibited no notable features, although some specimens displayed indications such as chipped corners or possible cracks. In contrast, for the B₄C rods, the low material density made the pellet geometry less distinct, and the cladding–pellet gap could not be resolved. In these rods, a relatively larger number of features suggestive of cracking were observed.

5. Future Work

A destructive examination of the irradiated pellets is planned. The primary objective of this destructive PIE is to analyze irradiation swelling and degradation by observing changes in density, dimensions and microstructure.

REFERENCES

- [1] D.-J. Kim, J.H. Yang, D.S. Kim, J.-H. Yoon, H.S. Lee, K.-Y. Lim, J. Lee, J.-Y. Kim, Development of Technology of Control Rod Neutron Absorber Materials with Extended Control Rod Lifetime and Enhanced Safety for LWRs, Transactions of the Korean Nuclear Society Autumn Meeting Changwon, Korea, October 20-21, 2022
- [2] D.-J. Kim, J.H. Yang, D.S. Kim, J.-H. Yoon, H.S. Lee, K.-Y. Lim, J.-Y. Kim, Development Status of Control Rod Neutron Absorber Materials for Light Water Reactors with

Extended Control Rod Lifetime and Enhanced Safety, Ceramist Vol. 25, No. 4, pp. 475~486, 2022.

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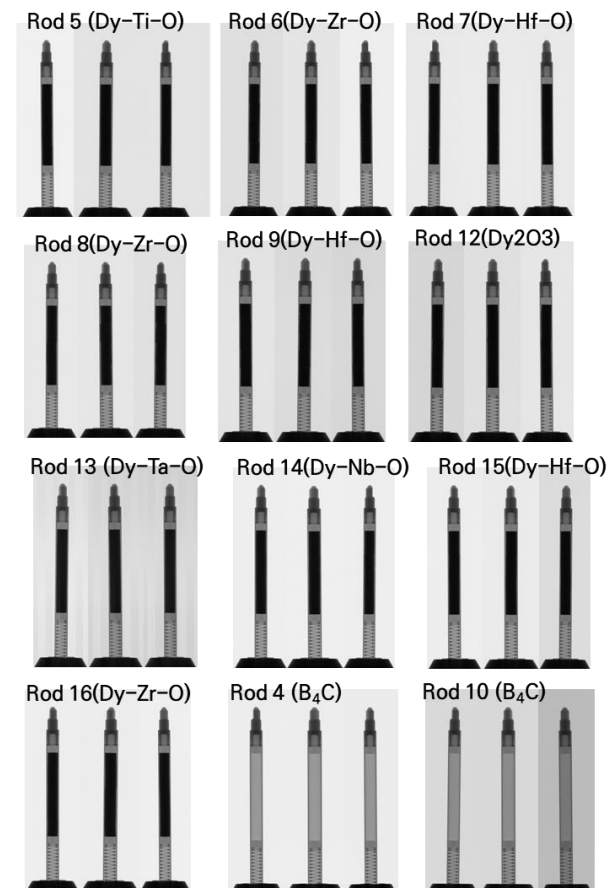


Fig.4. X-ray scan images of each test rod.