

Fabrication of LEU+ UO₂ and MIBA Fuel pellets for Irradiation Tests

Dong Seok Kim^{a*}, Yeon-Song Jung^a, Dong-Joo Kim^a, Jae Ho Yang^a, Ji-Hae Yoon^a, Ji-Hwan Lee^a
and Hyung-Jin Kim^{a,b}

^a*LWR Fuel Technology Research Division, Korea Atomic Energy Research Institute*

^b*Department of nuclear & Quantum Engineering, Korea Advanced Institute of Science and Technology*

*Corresponding author: dskim86@kaeri.re.kr

1. Introduction

The growing demand for safe, efficient, and economically viable nuclear power has led to the development of advanced nuclear fuel technologies. Low-Enriched Uranium Plus (LEU+) fuels, with uranium enrichment levels between 5% and 10% ²³⁵U, have gained attention as a promising alternative to conventional LEU fuels. The motivation for adopting LEU+ fuels lies in their potential to enhance fuel cycle efficiency, reduce operational costs, and align with evolving regulatory frameworks [1].

A key advantage of LEU+ fuels is their ability to extend fuel cycle lengths while maintaining a higher burnup limit. By increasing uranium-235 content, reactors can operate for longer periods without refueling, thereby improving economic efficiency and reactor availability. Westinghouse's LEU+ ADOPT™ fuel, for example, has been developed to optimize fuel utilization and extend operational cycles, contributing to cost reduction in nuclear power generation while maintaining safety standards [2].

Regulatory frameworks surrounding nuclear fuel enrichment are evolving to accommodate higher enrichment limits. The Nuclear Energy Institute (NEI) has assessed the technical and regulatory challenges associated with increasing enrichment and burnup levels, emphasizing their economic and operational benefits [3]. Additionally, many next-generation reactor designs, including Small Modular Reactors (SMRs), require fuels with higher enrichment levels. In this context, LEU+ fuel serves as an intermediate solution between conventional LEU fuels and High-Assay Low-Enriched Uranium (HALEU) fuels, which have enrichments up to 20% ²³⁵U.

Alongside LEU+ fuel, the concept of Microcell-structured Integrated Burnable Absorber (MIBA) has been introduced as a derivative of the Mo-Microcell technology in the Accident-Tolerant Fuel (ATF) family. MIBA incorporates a metallic microcell framework into UO₂-Gd₂O₃ fuel, designed to compensate for the degradation of thermal conductivity caused by high gadolinia content. This approach maintains the reactivity control function of burnable absorbers while enhancing the thermal performance of the fuel, thereby expanding the feasibility of high-content Gd₂O₃ fuels for advanced reactor applications.

This study aims to conduct experimental fabrication and evaluation of both LEU+ nuclear fuel pellets and MIBA pellets as preparatory steps for their adoption. The primary objective is to produce sintered fuel pellets,

acquire burnup and irradiation test data, and assess their performance under reactor conditions. Through this process, key insights into fabrication methods, thermophysical behavior, and in-reactor performance will be obtained, contributing to the broader effort of implementing next-generation nuclear fuels.

2. LEU+ UO₂ and MIBA Fuel Pellet Fabrication

The fabrication of nuclear fuel pellets is a crucial step in the development and evaluation of LEU+ fuels. Achieving precise control over enrichment composition and microstructure is essential for ensuring stable performance in a reactor environment. In particular, the fabrication of LEU+ fuel requires blending uranium sources with different levels of LEU to achieve the target enrichment level. In this study, a blending process was conducted.

The fuel fabrication process began with the precise measurement and mixing of LEU powders with different enrichment levels. To ensure uniformity, mechanical milling of powder was applied while also controlling the particle size distribution of the raw materials. A planetary mixing method was utilized for a designated period to minimize any local concentration variations. Following the blending process, the homogenized uranium powder was compacted into cylindrical pellets using uniaxial pressing, ensuring consistent density throughout the pellets. The pressed green pellets were then sintered under conventional conditions used in fuel pellet fabrication.

To verify the homogeneity of the enrichment of the uranium mixture, thermal ionization mass spectrometry (TIMS) analysis was performed. This method allows for the precise measurement of uranium isotope ratios, making it an effective tool for assessing the uniformity of the blended fuel powder and the sintered pellets. The analysis confirmed that the final blended powder met the target enrichment level without significant deviations, confirming that the mixture achieved a homogeneous and consistent enrichment distribution.

Comprehensive evaluations were conducted to assess the quality of the fuel pellets. Density measurements were performed to confirm that the required specifications were met, while scanning electron microscopy (SEM) and optical microscopy were used to examine grain size, phase homogeneity, and porosity. In parallel, the fabrication of MIBA fuel pellets was carried out using the conventional microcell fuel pellet fabrication process. MIBA pellets were produced by mixing UO₂-Gd₂O₃ granules with Mo powder to form

the metallic microcell structure, which enhances thermal conductivity and compensates for the degradation typically caused by high gadolinia content. The sintered MIBA pellets were evaluated for density and microstructure, with a focus on phase distribution of Gd_2O_3 and the integrity of the metallic microcell network.

The results of this study confirm that LEU+ fuel pellet fabrication can achieve a homogeneous enrichment distribution while maintaining the desired fuel properties, and that MIBA fabrication is feasible with stable microstructural integrity. The fabricated pellets of both fuel types will undergo irradiation testing at the HANARO research reactor, where their in-reactor performance will be further evaluated.

3. HANARO Irradiation Test

The HANARO research reactor serves as a key facility for nuclear fuel research, supporting irradiation tests that assess the performance of newly developed fuels. These tests are crucial for evaluating dimensional stability, fission product release, and microstructural evolution of the fuel under reactor conditions. Given the complexity of irradiation experiments, extensive preparatory work, safety evaluations, and experimental planning are required to ensure reliable results [4,5].

In this study, an irradiation test plan was established to evaluate the performance of the fabricated LEU+ fuel pellets as well as the MIBA pellets. Prior to irradiation, the fuel pellets were characterized to establish baseline physical and microstructural properties, including enrichment homogeneity, density, grain size, and phase distribution. The prepared fuel samples will be loaded into specialized test capsules and positioned within the HANARO reactor, with neutron flux, temperature, and irradiation duration carefully considered as key experimental parameters.

Following irradiation, post-irradiation examination (PIE) will be conducted as planned. For LEU+ fuel, the examination will focus on enrichment stability, burnup behavior, and microstructural changes. For MIBA, particular attention will be given to the stability of the metallic microcell framework, the thermal performance under high gadolinia content, and the distribution of fission products relative to the absorber regions.

This irradiation test aims to evaluate whether both LEU+ and MIBA fuels maintain stable performance under high-temperature and neutron-flux conditions. The results will serve as fundamental data for improving reactor safety and efficiency, supporting the broader adoption of LEU+ fuel and validating the feasibility of high-content burnable absorber fuels in advanced reactor systems.

4. Summary

This study focused on the fabrication and irradiation testing of advanced nuclear fuels, specifically LEU+ fuel and the MIBA fuel. For LEU+, uranium sources

with different enrichment levels were blended to achieve the target enrichment, then compacted into pellets and sintered under controlled conditions. Evaluations of density, microstructure, and TIMS confirmed that the pellets met the required specifications.

In parallel, MIBA pellets were fabricated by incorporating a metallic microcell framework into UO_2 - Gd_2O_3 fuel, aiming to compensate for the degradation of thermal conductivity associated with high gadolinia content. Preliminary evaluations demonstrated stable pellet integrity and microstructural uniformity suitable for irradiation testing.

An irradiation test at HANARO is planned under controlled neutron flux, temperature, and duration conditions. PIE will assess dimensional stability, microstructural evolution, and fission product behavior for both fuel types. In particular, PIE will verify enrichment stability and burnup performance in LEU+, while evaluating the thermal performance and absorber effectiveness of MIBA.

The results of this study will contribute to validating the performance of LEU+ fuel and establishing the feasibility of MIBA as a high-content burnable absorber fuel. Together, these efforts will support the advancement of ATFs and their future application in commercial reactors and next-generation systems such as SMRs.

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REFERENCES

- [1] NEI White Paper, Feb (2019)
- [2] Westinghouse Electric Co., Press, (2024)
- [3] OECD-NEA, Nuclear Technology Development and Economics, (2024)
- [4] S. Yang et al., Transactions of the Korean Nuclear Society Spring Meeting Jeju, Korea, May 18-19, 2023
- [5] S. Yang et al., Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 26-27, 2023