Fabrication of LEU+ UO_2 Fuel pellets for Irradiation Tests at KAERI

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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% 235 U, have gained attention as a promising alternative to conventional Low-Enriched Uranium (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% 235 U.

This study aims to conduct experimental fabrication and evaluation of LEU+ nuclear fuel pellets as a preparatory step for its adoption. The primary objective is to produce sintered fuel pellets and acquire burnup test data to assess their performance under reactor conditions. Through this process, key insights into fuel fabrication and irradiation behavior will be obtained, contributing to the broader effort of LEU+ fuel implementation.

2. LEU+ Fuel Pellet Fabrication

The fabrication of nuclear fuel pellets is a crucial step in the development and evaluation of Low-Enriched Uranium Plus (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 low-enriched uranium (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 at the conventional condition of fuel pellet fabrication method.

To verify the homogeneity of the enrichment of 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 also the sintered pellet. The analysis confirmed that the final blended powder met the target enrichment level without significant deviations, to confirm 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.

The results of this study confirm that LEU+ fuel pellet fabrication can achieve a homogeneous enrichment distribution while maintaining the desired fuel properties. The fuel pellets produced through this process 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. Prior to irradiation, the fuel pellets were characterized to establish baseline physical and microstructural properties. 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. The examination will focus on analyzing changes in the fuel's physical properties and microstructure. The collected data will be essential for verifying the safety and performance of LEU+ fuel in a reactor environment.

This irradiation test aims to evaluate whether LEU+ fuel maintains stable performance under high-temperature and neutron-flux conditions. The results will serve as fundamental data for improving reactor safety and efficiency, contributing to future advancements in nuclear fuel technology.

4. Summary

This study focused on the fabrication and irradiation testing of Low-Enriched Uranium Plus (LEU+) fuel. To achieve the target enrichment, uranium sources with different LEU levels were blended, and compacted into pellets and sintered under controlled conditions. Evaluations of density, microstructure, and thermal ionization mass spectrometry (TIMS) confirmed that the pellets met the required specifications.

An irradiation test at HANARO is planned under controlled neutron flux, temperature, and duration conditions. Post-irradiation examination (PIE) will assess dimensional stability, microstructural evolution, and fission product behavior. The results will contribute to validating LEU+ fuel performance and supporting its future application in nuclear reactors.

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