

Preparation of LEU+ UO₂ and ATF Fuel pellets for Irradiation Tests

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1. Introduction

The development of advanced nuclear fuel systems has become increasingly important as light water reactors and emerging reactor concepts pursue improved fuel utilization, extended operating cycles, and enhanced safety margins. Conventional commercial UO₂ fuels are generally limited to enrichments below 5 wt% ²³⁵U, whereas higher enrichment levels provide an increased reactivity inventory and enable higher discharge burnup. Low-enriched uranium plus (LEU+) fuels, enriched above 5 wt% and below 10 wt% ²³⁵U, have therefore attracted attention as a near-term option for improving fuel cycle economics while maintaining compatibility with the existing light water reactor fuel infrastructure [1,2].

In parallel, accident-tolerant fuel (ATF) technologies have been developed to enhance fuel performance under normal operation, anticipated operational occurrences, and accident conditions [3,4]. Among them, thermally enhanced UO₂-based concepts aim to reduce the fuel centerline temperature without departing from the oxide fuel platform, and are particularly relevant for fuel systems in which additives or absorber phases degrade the intrinsic thermal conductivity of the UO₂ matrix.

Burnable absorbers are essential for controlling excess reactivity in long-cycle and high-burnup cores, and this requirement becomes more demanding for LEU+ core applications. Gadolinium oxide (Gd₂O₃) is widely used as an integral burnable absorber, but increasing its content in UO₂-Gd₂O₃ fuel degrades the thermophysical properties, particularly the thermal conductivity, and may also affect sintering behavior and phase homogeneity [5].

To address the thermal conductivity penalty of high-Gd₂O₃ fuel, a microcell-structured integrated burnable absorber (MIBA) concept has been developed by extending the ATF Mo-microcell fuel concept [6] to gadolinia-bearing UO₂ fuel. Here the ATF-derived feature is not the LEU+ fuel itself but the metallic microcell architecture applied to the absorber fuel, which provides additional heat conduction paths while preserving the reactivity control function of the oxide absorber phase.

In this study, LEU+ UO₂ and ATF-derived MIBA fuel pellets were fabricated as irradiation test specimens for the HANARO research reactor, and pre-irradiation characterization was carried out to establish baseline data for subsequent post-irradiation examination (PIE).

2. Fabrication and Characterization

LEU+ UO₂ fuel pellets with target enrichments of 6, 7, and 9 wt% ²³⁵U were fabricated from standard UO₂ powder and enriched U₃O₈ powder. The enriched U₃O₈ feedstock was obtained by oxidizing uranium metal with an enrichment below 20 wt% ²³⁵U and was used as the enrichment-adjusting component of the powder blend. The mixing ratio of the two powders was calculated for each target enrichment from the uranium isotopic composition of the starting materials. Because the target enrichment was achieved by introducing a minor enriched U₃O₈ fraction into the UO₂ matrix, the mixtures were homogenized by planetary milling, applied primarily to enhance the dispersion of the enriched U₃O₈ rather than to modify the powder morphology. The mixed powders were compacted into cylindrical green pellets by uniaxial pressing and sintered under the reducing conditions used for conventional UO₂ fuel fabrication.

MIBA fuel pellets were fabricated as an ATF-derived burnable absorber concept using UO₂-Gd₂O₃ granules and Mo powder. Prior to granulation, UO₂-20 wt% Gd₂O₃ mixed powder was prepared by planetary milling of UO₂ and Gd₂O₃ powders. The granulated oxide powder acts as the absorber-bearing fuel phase, while the Mo powder forms the intergranular metallic microcell structure. The granules and Mo powder were mixed under controlled conditions so that the Mo phase was distributed around the oxide granules while the granulated structure required for microcell formation was preserved. The mixed powder was then compacted by uniaxial pressing and sintered under conditions suitable for UO₂-based fuel while retaining the metallic Mo network.

For both pellet types, dimensions and mass were measured after sintering and the sintered density was calculated. Uranium isotopic compositions of the LEU+ pellets were measured by thermal ionization mass spectrometry (TIMS) using representative samples and compared with the nominal values calculated from the starting powder compositions. Phase constitution was examined by XRD, and microstructures were observed by optical microscopy and scanning electron microscopy.

3. Results and Discussion

3.1 LEU+ UO₂ Fuel Pellets

TIMS analysis confirmed that the measured enrichments of the fabricated pellets were consistent with the nominal target values of 6, 7, and 9 wt% ^{235}U , indicating that the enriched U_3O_8 component was sufficiently homogenized within the UO_2 matrix during powder processing and sintering. No significant enrichment deviation was observed among the fabricated pellets, supporting the applicability of the present blending route.

The sintered pellets maintained their cylindrical geometry and showed adequate densification under conventional UO_2 sintering conditions. As shown in Fig. 1, optical micrographs revealed a typical UO_2 grain structure with mean grain sizes of approximately 9.8, 7.4, and 12.6 μm for the 6, 7, and 9 wt% ^{235}U pellets, respectively, without distinct heterogeneous regions attributable to the enriched U_3O_8 addition. The XRD patterns were indexed to the fluorite UO_2 structure, and no secondary phase originating from U_3O_8 was detected.

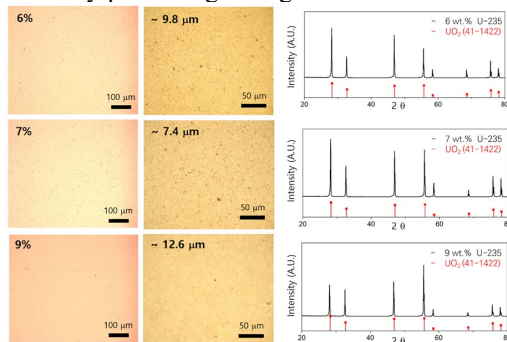


Fig. 1. Microstructures and XRD patterns of LEU+ UO_2 fuel pellets with target enrichments of 6, 7, and 9 wt% ^{235}U .

3.2 MIBA Fuel Pellets

The sintered MIBA pellets maintained their cylindrical geometry without macroscopic cracking or severe distortion, indicating that the applied fabrication route is suitable for irradiation test preparation.

Microstructural observations showed that the Mo phase formed a continuous metallic microcell structure surrounding the $\text{UO}_2\text{-Gd}_2\text{O}_3$ granules. This structure is expected to provide heat transfer pathways that compensate for the thermal conductivity degradation associated with the high Gd_2O_3 content, while preserving the burnable absorber function. Thermal property measurements are planned to quantify the heat transfer effect of the Mo Microcell structure.

4. HANARO Irradiation Test Plan

Irradiation testing of the fabricated pellets is planned in the HANARO research reactor to evaluate their in-pile performance. The test cluster is designed to include LEU+ fuel rods with different enrichments together with high- Gd_2O_3 burnable absorber pellets having the microcell structure.

For the LEU+ fuel test, an accelerated irradiation approach based on pellet diameter reduction was considered. Reducing the pellet diameter decreases the

fuel volume and the uranium mass in each test rod, thereby increasing the burnup accumulation rate and enabling high-burnup performance data to be obtained within a relatively short irradiation period in HANARO.

After irradiation, PIE will be performed by comparing the irradiated fuel characteristics with the pre-irradiation baseline data obtained in this study. The examination will focus on dimensional stability, microstructural evolution, and burnup behavior of the LEU+ pellets, and on the stability of the absorber-bearing oxide phase and the Mo microcell structure in the MIBA pellets.

5. Conclusions

LEU+ UO_2 and MIBA fuel pellets were fabricated and characterized as part of a pre-irradiation study for HANARO irradiation testing. LEU+ pellets with target enrichments of 6, 7, and 9 wt% ^{235}U were prepared by blending standard low-enriched UO_2 powder with enriched U_3O_8 powder derived from oxidized uranium metal, and TIMS confirmed that the intended enrichment levels were achieved without significant deviation.

MIBA pellets were fabricated using $\text{UO}_2\text{-20 wt% Gd}_2\text{O}_3$ granules and Mo powder, and microstructural observations confirmed that the absorber-bearing oxide regions and the Mo microcell structure were retained after sintering.

The pre-irradiation data obtained in this study will serve as baseline information for PIE and support the feasibility of the present fabrication routes for advanced fuel development.

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