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# $UO_2$–Metal Composite Pellets for Accident Tolerant Fuels

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## 1. Introduction

Research groups in the nuclear fuel industry for LWRs are currently focused on the development of $UO_2$-refractory metal composites fuels, which have the potential to offer improved thermal conductivity.

Objective of this paper is to provide a comprehensive overview of the current state of $UO_2$-metal composite fuels, with a particular emphasis on their potential benefits for enhancing fuel performance and safety. The paper also examines the remaining challenges that need to be addressed to fully realize their potential.

## 2. Design and Fabrication

In order to meet the requirements of metallic components, it is imperative that they possess high thermal conductivity and melting temperatures. Moreover, during both the manufacturing process and in-reactor operation, the occurrence of chemical reactions with $UO_2$ must be minimized, and the level of neutron absorption must be kept to a minimum. Refractory metals such as W, Mo, and Cr have been identified as promising candidates, with Mo being widely studied as a leading candidate for the metal phase.

The significance of aligning the metal along the heat flow for enhancing the effective thermal conductivity of $UO_2$-metal composites has been emphasized by both measured and calculated data. To maximize the thermal conductivity while minimizing the amount of metal content, various design concepts are being explored, including the utilization of AI methodologies for composite design optimization.

In terms of manufacturing processes, conventional ceramic sintering methods are frequently employed. However, advanced techniques such as spark plasma sintering or wet-chemical processes are also being researched to achieve a high density and homogeneous microstructure.

## 3. Neutronics

One of the limitations of $UO_2$-metal composites is the reduction in fuel cycle length caused by the presence of metal with a high neutron absorption cross-section. However, this neutron penalty can be partially alleviated by restricting the addition of the metal phase to less than 5vol%. Additionally, the enhanced thermal conductivity of the composite leads to lower fuel operating temperatures, which facilitates neutron utilization through the MTC feedback effect.

Neutronic performance analysis has revealed that a $UO_2$–3vol% Mo microcell fuel with a U-235 enrichment of 4.95% can achieve the same fuel cycle length as a UO2 fuel with an enrichment of 4.65%.

## 4. Fuel Performance & Safety

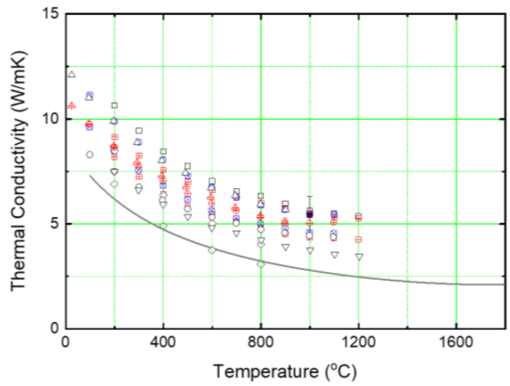


Fig. 1. Summary of experimental thermal conductivities of $UO_2$-5 vol% Mo, and $UO_2$-10 vol% Mo composite pellets compared to the thermal conductivity of $UO_2$.

Figure 1 presents the thermal conductivity data for $UO_2$-5vol% Mo and $UO_2$-10vol% Mo composite pellets retrieved from prior studies. The investigations have indicated that optimizing the arrangement of Mo within the $UO_2$ matrix with 3-5vol% of metal additives can increase the thermal conductivity by 70-150% compared to $UO_2$.

In the Halden irradiation test of 5vol% Cr microcell pellets, the results demonstrated that the centerline temperature of the microcell pellet was substantially lower than that of the $UO_2$ reference, which can be attributed to the increased thermal conductivity. The study also showed that the temperature change range during the irradiation was lower in the Cr microcell than in $UO_2$, which could provide an improved safety margin and enhanced temperature stability for high-power, fast- and high-duty-load follow operation.

A simplified approach to estimate fission gas release in metallic microcells suggested that fission gas release is clearly lower than in that the $UO_2$ pellet, due to its lower fuel temperature and the presence of walls. Due to both the reduced gaseous swelling and lower thermal expansion, gap closure in a fuel rod loaded with the metallic microcell pellets was expected to be delayed compared to a fuel rod loaded with the $UO_2$ pellets, implying that the occurrence of pellet-cladding mechanical interaction occurrence would also be postponed.

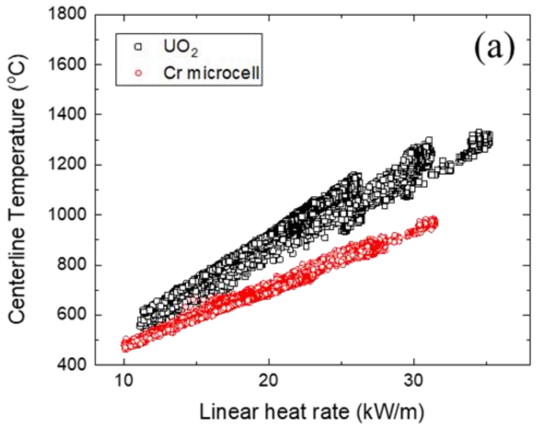


Fig. 2. Centerline temperature vs linear power in $UO_2$ and Cr microcell rods irradiated in Halden reactor.

A comprehensive analysis of large-break loss of coolant accidents in LWRs indicates that an increase in thermal conductivity of the fuel and the resulting decrease in stored energy at nominal power can have a modest effect on the peak fuel and cladding temperature during a transient event in a PWR. Reactivity initiated accident (RIA) analysis of the core using the Mo microcell fuel showed a significant reduction in the maximum fuel centerline temperature, which was approximately 200℃ lower than that observed in the reference $UO_2$ core.

One of the safety performance issues related to the use of $UO_2$-metal composite fuels is the potential impact of metal phase oxidation on fuel behavior in the event of steam ingress through cracks in the cladding. However, the expected impact of metal oxidation on pellet integrity in a cladding leakage scenario is believed to be insignificant, taking into account various factors such as the anticipated volume expansion after the termination of the reaction, as well as kinetic parameters such as steam flow, fuel temperature, and pellet microstructure.

## 5. Summary

Research on accident tolerant fuel of $UO_2$-metal composites is currently being conducted to improve fuel performance and nuclear reactor safety. Most fuel designs involve composites with a heterogeneous microstructure. Future work will focus on the fuel behavior under long-term irradiation and the material properties of irradiated fuel. Continuous research and development are needed to optimize the fuel design by maximizing the thermal conductivity improvement while minimizing the metal content, as well as developing engineering-scale manufacturing processes for implementation. Innovative approaches and advanced performance validation and licensing are also necessary.

## ACKNOWLEDGEMENT

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