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PERFORMANCE OF METALLIC FUELS IN LIQUID-METAL FAST REACTORS*

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Performance of Metallic Fuels in Liquid-Metal Fast Reactors

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Interest in metallic fuels for liquid-metal fast reactors has come full circle. Metallic fuels are once again a viable alternative for fast reactors because reactor outlet temperatures of interest to industry are well within the range where metallic fuels have demonstrated high burnup and reliable performance. In addition, metallic fuel is very tolerant of off-normal events because of its high thermal conductivity and fuel behavior. Furthermore, metallic fuels lend themselves to compact and simplified reprocessing and refabrication technologies, a key feature in a new concept for deployment of fast reactors called the Integral Fast Reactor (IFR).

The IFR concept is a metallic-fueled pool reactor(s) coupled to an integral-remote reprocessing and fabrication facility. This concept capitalizes on the following attractive attributes of metallic fuels: high burnup performance, simple remote reprocessing and fabrication, capability to withstand loss-of-flow events with minimal temperature increase, and the potential to reverse a transient overpower event by axial extrusion of fuel without cladding breach. The IFR concept also appears to successfully address the major institutional issues that plague the nuclear industry today, which are: cost, inherent safety, transportation, proliferation, and diversion. Much of the technology that supports the concept was proven in the mid 1960s when 35,000 metallic-alloy fuel elements were remotely reprocessed and fabricated at EBR-II. Since then, performance to high burnup under both normal and transient operation and sustained operation above fuel-cladding eutectic temperatures has been demonstrated.

The purpose of this paper is to review recent metallic fuel performance, much of which was tested and proven during the twenty years of EBR-II operation. Early metallic fuel elements were designed with high-smear density with the intent that the control of fuel swelling through alloy addition and heat treatment would yield adequate burnup performance. However, the burnup capability of the early designs was limited and this was one of the primary reasons that metallic fuels were eliminated from contention in the late 1960s in preference to ceramic fuels. This problem has long since been solved with the early discovery that at smear densities of 75% or less, the fission gas bubbles will interconnect prior to the fuel contacting the cladding and the gas is released to the plenum. When this happens not only is the primary driving force for fuel swelling removed, but also the open porosity allows space to accommodate the solid fission products, which further reduces the stress on the cladding. This phenomenon of interconnected porosity and gas release is common to all metallic fuel alloys studied (Fig. 1) and is the key to achieving high-burnup performance.[1]

Of all the metallic-fuel alloys studied, U-Pu-Zr is the best choice because the alloy has not only demonstrated the essential gas release phenomenon through irradiation tests, but in addition the zirconium in this uranium base alloy leads to enhanced thermal performance. Compatibility of U-Pu-Zr fuel with austenitic stainless steel alloys is excellent, and the eutectic temperature and solidus temperature are more than adequate to meet reactor design objectives.

In recent years attention has focused on the off-normal performance of metallic fuels. To qualify EBR-II for transient operation, the entire core of EBR-II was subjected to repeated, multiple power transients at reactivity insertion rates of up to 10¢/s. Included in the core were metallic-fueled experiments with peak cladding temperatures up to 660°C and burnups to 8 at.%. No cladding breaches were observed and furthermore postirradiation examination of the fuel elements revealed no cladding diameter change as a result of transient operation. These results provided verification of the ability of the fuel to flow rather than create high stresses on the cladding under transient conditions as well as during steady-state operating conditions.

The most recent tests conducted on metallic fuel in EBR-II consisted of subjecting two successive experiments to reactor power ansients. Each fuel assembly was driven and sustained above the eutectic temperature of the fuel with the cladding. The assemblies contained identical complements of fuel elements ranging from 0 to 8 at.% burnup. The first test subjected the fuel elements to goal-peak cladding temperatures of 40°C above the eutectic temperature, while the second assembly experienced temperatures of 90°C above the eutectic temperature. Out-of-pile test results indicated that eutectic penetration and cladding breach should have occurred much before the end of the tests that lasted for 12 h at the peak temperatures. However, no cladding breaches occurred. These results demonstrated the reliability of metallic fuel at high temperatures in actual reactor conditions.

In summary, metallic fuels are capable of delivering excellent burnup performance along with being able to successfully accommodate off-normal events. These performance features along with the simple reprocessing technique available make metallic fuels an attractive option for future fast reactors.

REFERENCES

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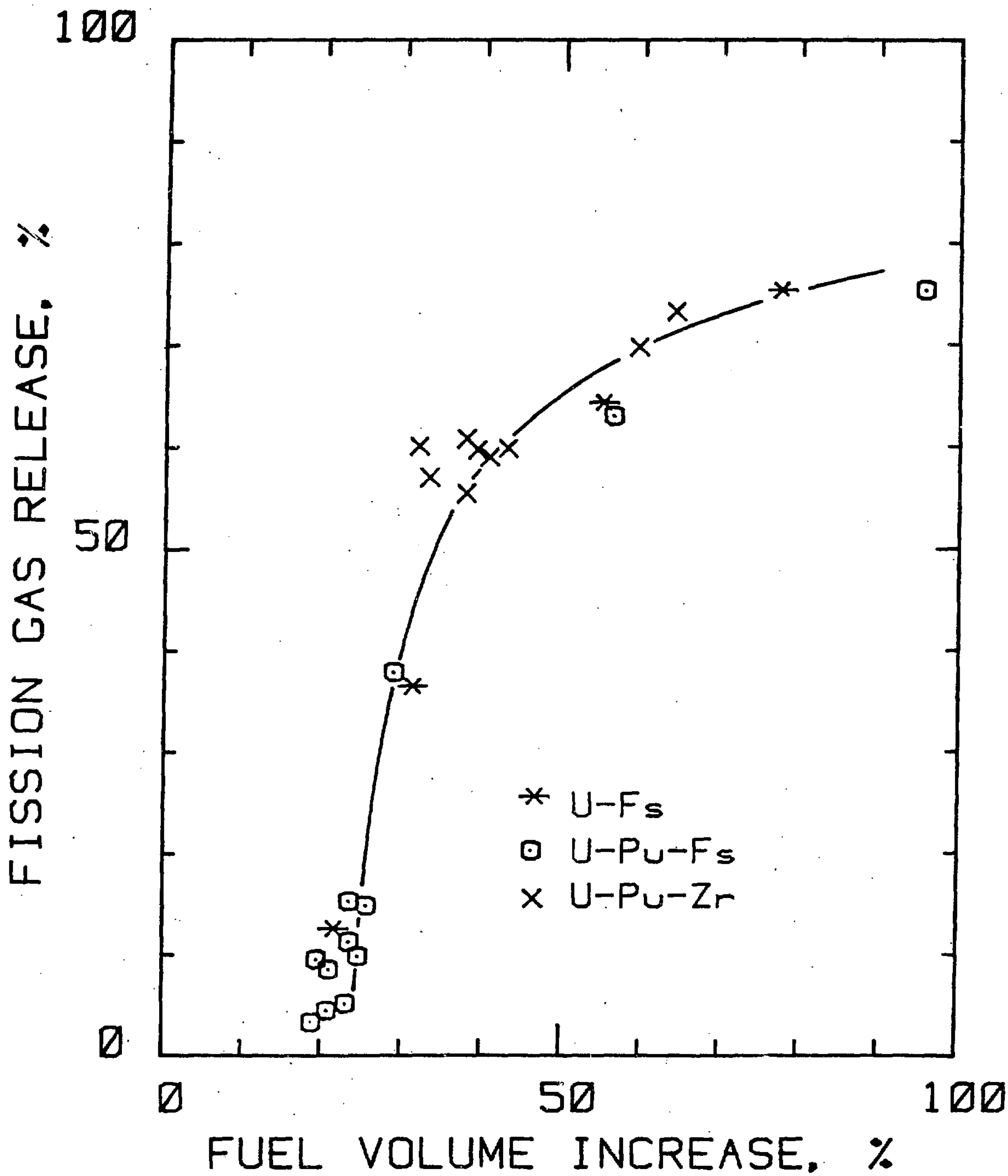

Figure 1. Effect of fuel swelling on fission-gas release in metal fuels.