Preliminary Fuel Development and Reactor Design Milestones for LEU Conversion of U.S. High Performance Research Reactors

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1. Goal of the present work

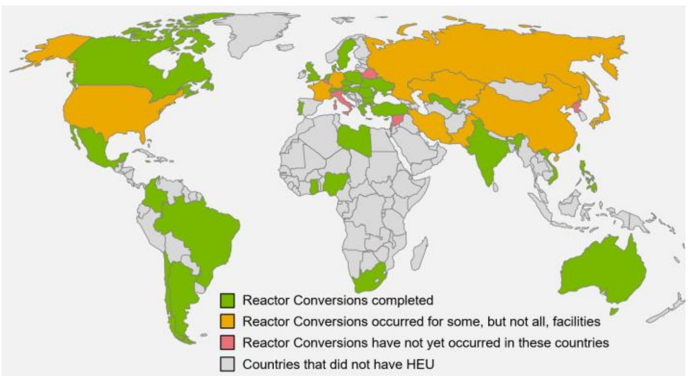
Currently, a new type of low-enriched uranium (LEU) fuel based on a very high-density alloy of uranium and 10 weight% molybdenum (U-10Mo) is expected to allow the conversion from highly enriched uranium (HEU) to LEU fuel for the six U.S. high performance research reactor (USHPRR) facilities:

- MITR (6 MWt) at the Massachusetts Institute of Technology
- MURR (10 MWt) at the University of Missouri-Columbia
- NBSR (20 MWt) at the National Institute of Standards and Technology
- ATR/ATRC (250 MWt/critical facility) at the Idaho National Laboratory
- HFIR (85 MWt) at the Oak Ridge National Laboratory.

For the USHPRR Project, the U.S. Department of Energy/National Nuclear Security Administration Office of Material Management and Minimization (M3) has developed, and is now qualifying to high burnup, U-10Mo LEU fuel. For HFIR conversion, design is underway with a longer LEU fuel to allow use of existing uranium silicide-aluminum dispersion (silicide) fuel to meet the required higher power densities.

2. Worldwide Success of Reduced Enrichment for Research and Test Reactors

Building on the successes of the Reduced Enrichment for Research and Test Reactors (RERTR), the M3 Reactor Conversion Program works collaboratively with many countries worldwide to convert research and test reactors to the use of LEU fuel.



Conversion of civilian research reactors from HEU to LEU, and the return of the HEU to the country of origin, is a critical component of the U.S. non-proliferation program. Worldwide, countries have converted 71 reactors to the use of LEU fuel, and an additional 31 have been confirmed to be permanently shut down. These 102 reactor conversions and shutdowns have occurred in over 40 countries and 6 continents and include 20 in the United States. The two recent conversions in Africa (Ghana and Nigeria) demonstrates an important milestone. Africa is the third continent to have completed all HEU to LEU reactor conversions, following Australia and South America. For the remaining conversions in Europe, the United States and elsewhere, reactor conversions currently underway now commonly require higher density fuel and qualification under more extreme conditions.

3. U.S. High Performance Research Reactor Project

Within the U.S. fleet of research and test reactors, each of these reactors serves different and unique missions in areas of key importance to medicine, science and engineering, principally:

- Research and development on new nuclear materials including new fuels and cladding; testing new applications for existing materials
- Neutron scattering is specially able to image materials, molecules and biological cells for the development of pharmaceuticals
- Crucial source of many radioisotopes used for nuclear medicine and industry

Isotope	Critical Uses	Isotope	Critical Uses
NTD Si P-31	High power electronics (e.g. hybrid-electric vehicles)	Lu-177	Treats stomach cancer
Ni-63	Explosives detection	W-188	Diagnose and treat cancers
Y-90	Treats liver cancer	Pu-238	Powers space exploration
Mo-99	> 40 M medical diagnostic scans per year worldwide	Ir-192	Treats prostate & breast cancers; industrial gauges
I-131	Treats thyroid cancer	Bk-249	Heavy isotope discovery
Sm-153	Treats bone cancer pain	Cf-252	Reactor start-up sources

- These and many other radioisotopes are produced mainly from a dozen high-performance research and test reactors, including USHPRRs, that provide many life-saving procedures and serve other critical needs for society.

4. Preliminary Fuel Development Milestones

Within the USHPRR Project the fuel qualification (FQ) pillar provides the key steps of fuel testing and qualification for the U-10Mo 'monolithic' alloy fuel, as well as for the silicide fuel being pursued for conversion of HFIR. Since the U-10Mo fuel has not been previously tested for these types of reactors, or qualified for any reactor which experienced appreciable burnup, it is necessary to characterize and document the fuel performance and properties for both fresh and irradiated fuel. As such, the USHPRR Project designed and executed test and qualification irradiation campaigns to demonstrate the U-10Mo fuel suitability.

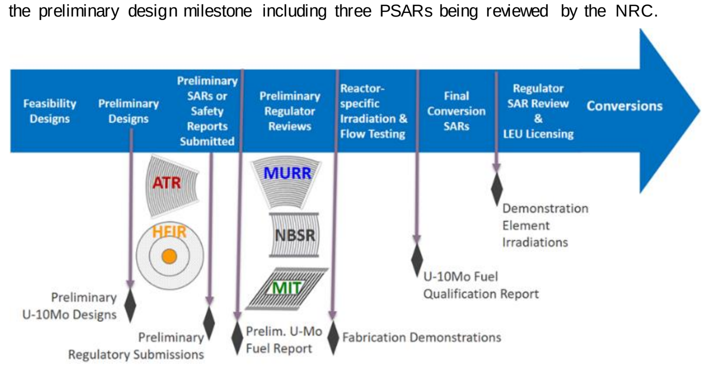
This extensive set of U-10Mo data is now available in a report for preliminary regulatory review as the Preliminary Report on U-Mo Monolithic Fuel for Research Reactors [1]. In this compendium that was submitted for U.S. Nuclear Regulatory Commission (NRC) review, the U-10Mo monolithic material properties and fuel performance data are compiled from 13 irradiation campaigns comprised of 154 large-size

Date	Plates	U-10Mo Irradiation Test Accomplishments
Scoping Phase – 79 plates tested		
2001	2	First proof-of-principle test of U-Mo monolithic fuel (small discs/roll bonding fabrication process).
2004	10	Evaluate friction bonding cladding bonding technique, various U-Mo compositions and foil thickness. First test of mini-plate geometry.
2005	13	Evaluate friction bonding and transient liquid phase bonding cladding bonding techniques.
2006	6	First test of hot isostatic pressing (HIP) cladding bonding method.
2007	20	Use friction bonding and hot isostatic pressing cladding bonding techniques. Investigate different diffusion barriers interlayers to reduce U-Mo/Al interaction.
2008	28	Evaluate HIP and other cladding bonding techniques. Evaluate interlayer alternatives. Two large-size fuel plates.
Development Phase – 75 plates tested		
2009	12	Large-size (medium length, full width) fuel plates. Evaluate selected fuel design using HIP and alternative cladding bonding techniques.
2010	59	Mini-plate test to evaluate selected fuel design over a wide range of operating conditions. Three large-size fuel plates. Evaluate selected fuel design at high volumetric power (2011-12).
2011	4	First test of selected fuel design in large-sized, curved fuel plates in constrained fuel element geometry under moderate irradiation conditions.

plates and mini-plates, over half of which were the selected U-10Mo fuel design with a thin zirconium interlayer bonded to an aluminum alloy cladding as described in the table. The results of these irradiation tests demonstrated that the fuel is suitable across a wide range of burnup to over 100% of the fission density LEU fuel can achieve.

5. Preliminary Reactor Design Milestones

Development and qualification of high-density fuels in tandem with advancements in reactor design have successfully enabled many RERTR conversions. For the USHPRRs, each reactor is both unique and optimized for high performance. These reactors are among the most compact in the world, and optimized so that LEU design is a very challenging design effort. Following feasibility studies, work conducted from 2010 to 2019, completed re-designs of each reactor's unique fuel element for U-10Mo, thus achieving the preliminary design milestone including three PSARs being reviewed by the NRC.



For HFIR conversion, design work that precedes fabrication demonstration is now underway with a longer silicide fuel. This work precedes qualifying existing silicide fuel with test articles specific to the boron-containing LEU HFIR fuel element design, and for the new application requiring higher power densities than previously irradiation tested.

These preliminary design milestones are very important, as the preliminary designs of the USHPPRs are required to mature design and engineering specifications that are developed to allow fabrication demonstration to finalize specifications and to produce test articles for final design irradiation testing. All these activities will support the final U-10Mo Fuel Qualification Report and the production of LEU core fuel loads that will be used after regulatory review of the conversion SARs.

6. Acknowledgements and References

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- Sponsored by the U.S. Department of Energy/National Nuclear Security M3 Office.

7. References

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