Update on the Effort to Develop and Qualify New Low Enrichment Fuels

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RERTR Program Objective

The RERTR program mission is to minimize and, to the extent possible, eliminate the use of HEU in civil nuclear applications by working to develop necessary technology and to convert research reactors and radioisotope production to the use of LEU fuel and targets throughout the world.

RERTR Implementation

- Ensure that an LEU fuel alternative is provided that maintains an equivalent service lifetime of the fuel assembly.
- Ensure that the ability of the reactor to perform its scientific mission is not adversely affected.
- Ensure that conversion to a suitable fuel can be achieved without requiring major changes in reactor structures or equipment.
- Demonstrate that the conversion and subsequent operation can be accomplished safely.
- Determine, as possible, that the overall costs associated for conversion to LEU fuel does not increase the annual operating expenditure for the owner/operator.

Drivers for RERTR Fuel Development

Western Supplied Reactors				
	Reactor	Country	Power (MW)	HEU (Kg/yr)
1	BR-2	Belgium	80	29.0
2	RHF	France	57	54.8
3	ORPHEE	France	14	15.8
	JHR (planned)	France	100	-
4	FRM-II	Germany	20	37.5
5	MITR	USA	5	1.6
6	MURR	USA	10	23.5
7	NBSR	USA	20	13.0
8	HIFR	USA	100	91.0
9	ATR	USA	250	120.0
10	ATRC	USA	0.005	0.0
Approximate total HEU consumption (Kg/yr)				>350

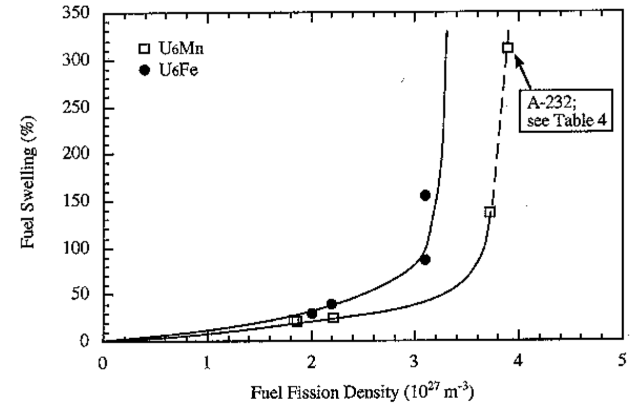
- **Ten western designed reactors cannot convert to LEU with currently available fuels (11 with JHR)**
  - **These reactors use >350 kg HEU per year**
- **20 Russian designed reactors require new fuels to convert to LEU**
  - **These reactors use ~340 kg HEU per year**
- **There are thus 31 total reactors (with JHR) in the world with total HEU usage of ~700 Kg per year that require the development of new LEU fuels**

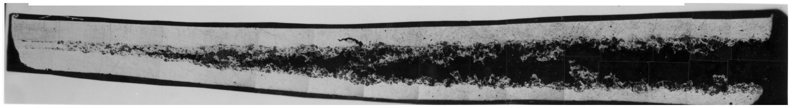
GTRI/RERTR Fuel Development Milestones

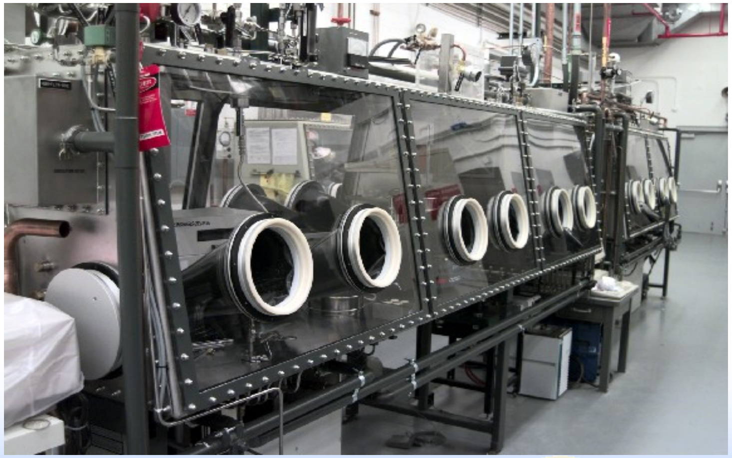
- Qualify fuels suitable for conversion of all targeted research reactors to LEU by FY10
  - Very-high-density fuels (U density > 8 g/cm^3) for conversion of high power research reactors
- Support conversions of western and Russian designed research reactors by 2014

RERTR Fuel Development: 1996-2003

- U.S. RERTR fuel development effort restarted in 1996
  - Fuel density ≥ 8 g U/cm^3
  - Conventional fuel materials and conventional fabrication methods
- Dispersion fuel choices
  - U_6Me compounds
    - Intrinsic fuel performance problems
  - Focus on U alloys for fuel particles
    - U-Mo and U-Nb-Zr
- Five scoping irradiation tests completed in ATR including over 175 miniature fuel plates

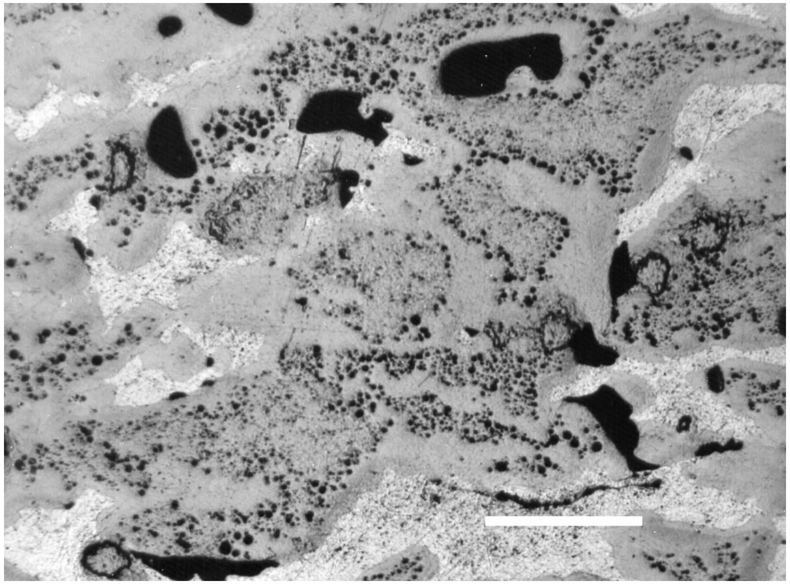




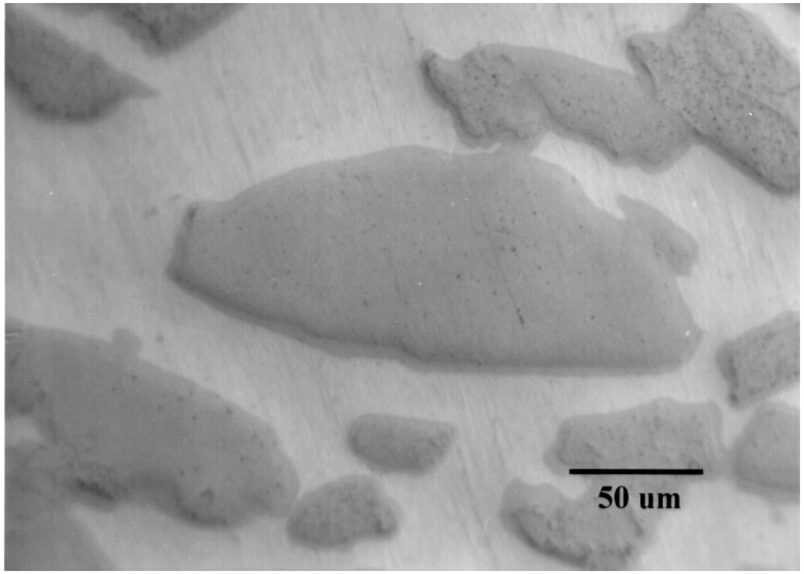


Alloy Down-selection

Irradiation test results from RERTR-1 & RERTR-2 indicated that U-Mo fuel exhibits much better fuel behavior than U-Nb-Zr



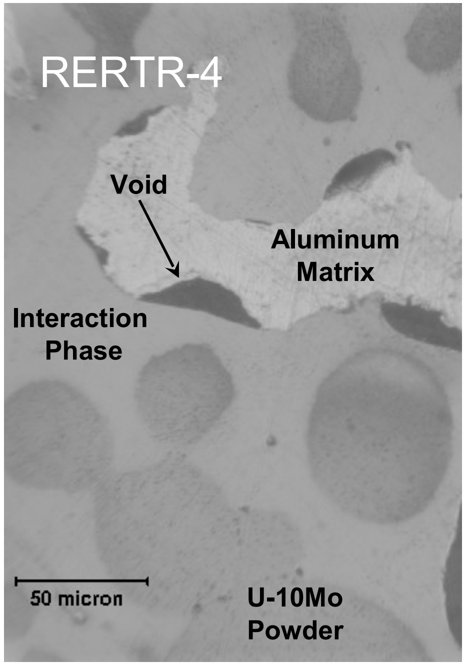
U-5Nb-3Zr at 41% ^{235}U burnup

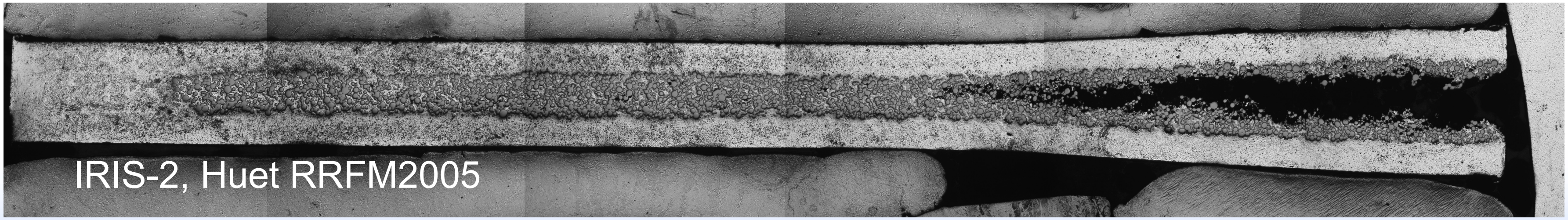


U-10Mo at 69% ^{235}U burnup

U-Mo Fuel Development – Recent History

- Several failures have recently occurred in U-Mo/Al dispersions
- These specimens were undergoing irradiation testing at the high power levels necessary for some targeted reactors
- There are no inherent problems with the irradiation behavior of the U-Mo itself – the failures are related to formation of a U-Mo/Al reaction product





LEU Fuel Technology

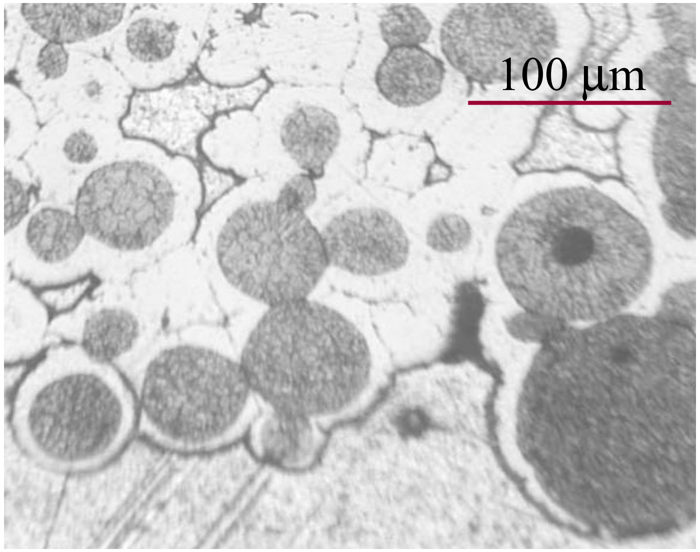
- **Potential fixes**
  - **Coat particles (low-density fuel only)**
  - **Modify the composition of matrix and U-Mo fuel**
  - **Change the matrix material**
  - **Remove the matrix (‘*monolithic’ fuel)***

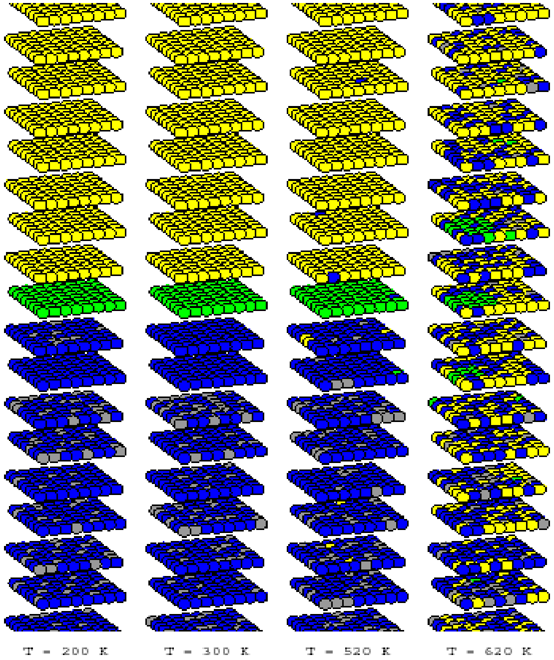
- **Strategy**
  - **Pursue multiple technology paths until data permits down-selection**

Fuel Development Path Forward

- **Modeling and analysis of failures**
  - Analysis of U-Mo/Al failures (neutron diffraction, microprobe)
- **Irradiation testing**
  - Aggressive program for testing U-Mo-X/Al-Y and alternative fuels
  - Use of multiple reactors for testing
  - Miniplates -> full-size plates -> elements
  - Fast process feedback (in-canal examination)
- **Fabrication development**
  - New processes for new fuels
  - Commercial fabricator involvement early in process
- **Extensive international collaboration**
  - **International RERTR Fuel Working Group**
  - **Argentina, Canada, France, Korea, Russia, United States**

Fuel/Matrix Chemistry

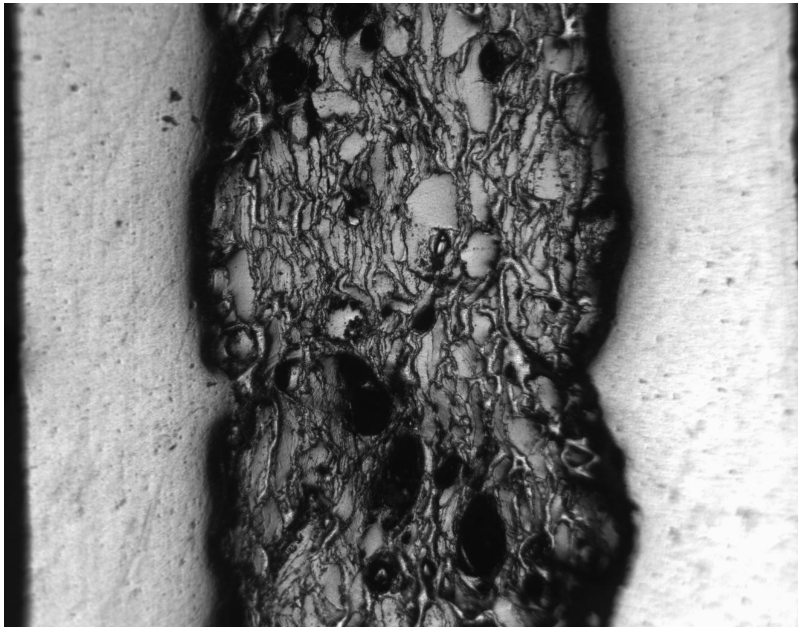




- Fuel remains, more or less, conventional
- Observation, alloy theory, and simulation indicate that silicon additions to the matrix may be beneficial in slowing fuel matrix reaction
- Ternary element additions to U-Mo fuel particles may promote formation of UAl_3 over higher aluminides
- Zr-based and coated particle fuels under investigation in cooperation with CNEA (Argentina)

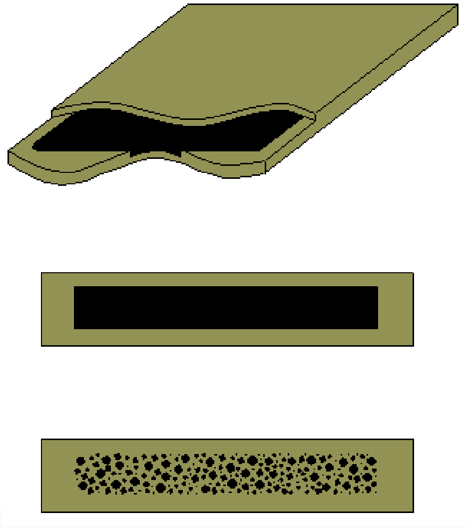
Magnesium Matrix Fuel

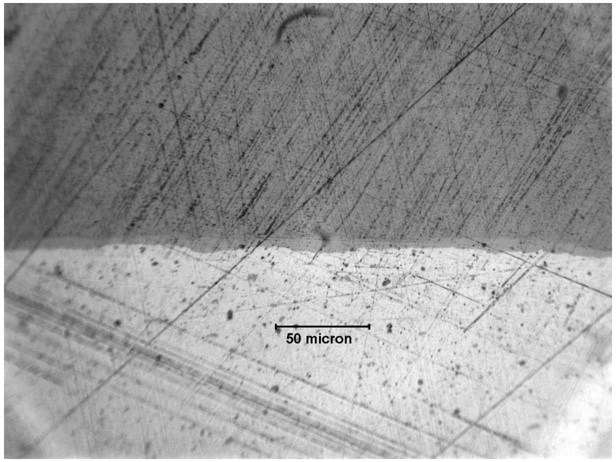
- **Irradiation testing results from RERTR-3 positive at ~ 40% ^{235}U burnup**
  - No fuel-matrix interaction
- **Principle issues**
  - Difficult to fabricate using conventional roll-bonding methods
  - Compatibility with recycle and corrosion behavior must be verified
  - Verification of behavior at high burnup/high temperature
- **Additional Mg-matrix test plates will be included in RERTR-7 irradiation experiment**



Monolithic Fuel

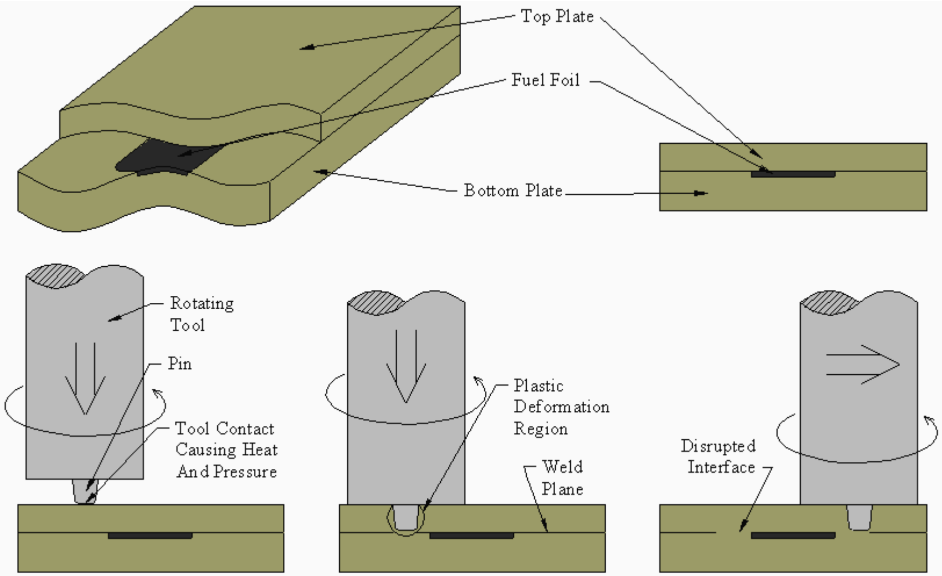
- Monolithic fuel contains a single fuel foil in place of the fuel powder-aluminum matrix
- Highest possible uranium loading
- Lower relative surface area gives less reaction with aluminum
- Positive irradiation test results to 80% ^{235}U burnup in RERTR-4 experiment
- Requires development of new fabrication methods



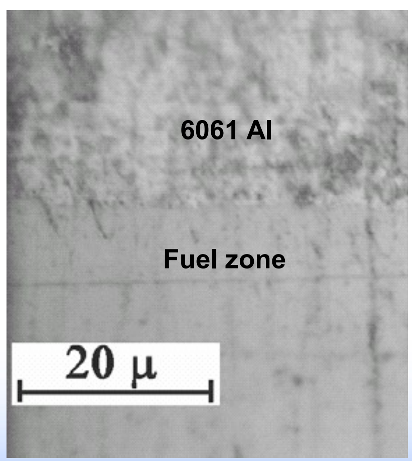


- U-10 Mo foil
- ^{235}U burnup ~ 80% in RERTR-4 test

Friction Stir Welding

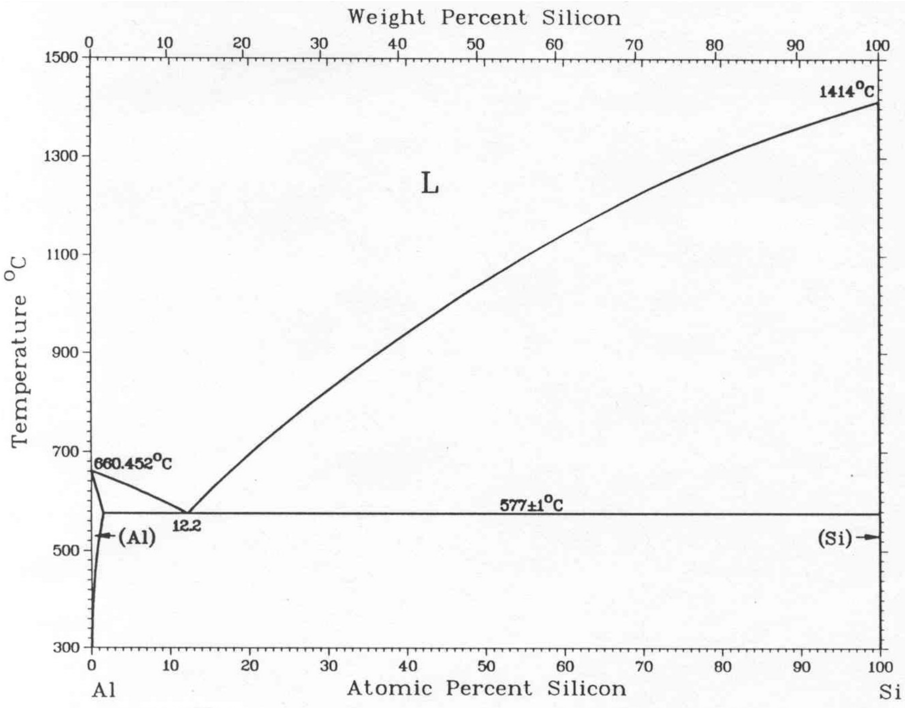


Friction stir welding uses mechanical disruption of the fuel/clad and clad/clad interface to ensure a metallurgical bond



HIP/TLPB

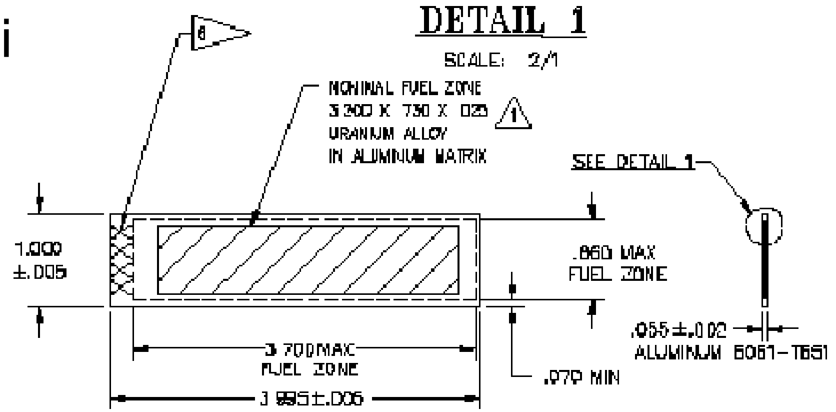
- Hot Isostatic Pressing (HIP) and Transient Phase Liquid Bonding (TLPB) under development
- HIP development in cooperation with BWXT
- TLPB utilizes Al-Si eutectic phase formation at interlayer
  - Developed in 1950's for RR fuel
  - Eutectic liquid acts as a flux
  - Silicon diffuses into aluminum



Miniplate Testing

Scoping tests cover a wide range of variables and compositions

- RERTR-6 (April 2005)
  - Baseline test for monolithic and Al-Si matrix fuel
  - Currently under irradiation in ATR
  - PIE begins January 2006
- RERTR-7 (November 2005)
  - Higher burnup, higher power (350 W/cm^2)
  - Addition of Mg-matrix fuel
  - Zr clad fuel, Si coated particles (CNEA)
- RERTR-8 (March 2006)
  - Early testing at high power (>500 W/cm^2) to uncover fuel performance issues



Full-size Plate Testing

AFIP test rig allows testing of MTR-scale plates at high surface heat flux (> 350 W/cm^2)

- IRIS-5 test in the French OSIRIS reactor (January 2006)
- AFIP-1/AFIP-2 test in ATR (October 2006)
  - Monolithic fuel, Al-Si, and Mg-matrix
  - Burnable poison concepts
  - In-canal thickness measurement and indication of debonding using ultrasonic transducers
- AFIP-3
  - Density-zoning and small radius of curvature (HFIR, BR2, JHR reactors)

Fuel Element Irradiation

Demonstration of robust fuel performance and manufacturability

- Phase I (2007-2008)
  - 'Normal' fuels
  - ATR testing of 4 elements
  - OSIRIS testing of 2 elements
- Phase II (2008-2009)
  - More complex fuels
  - ATR testing of 2 elements

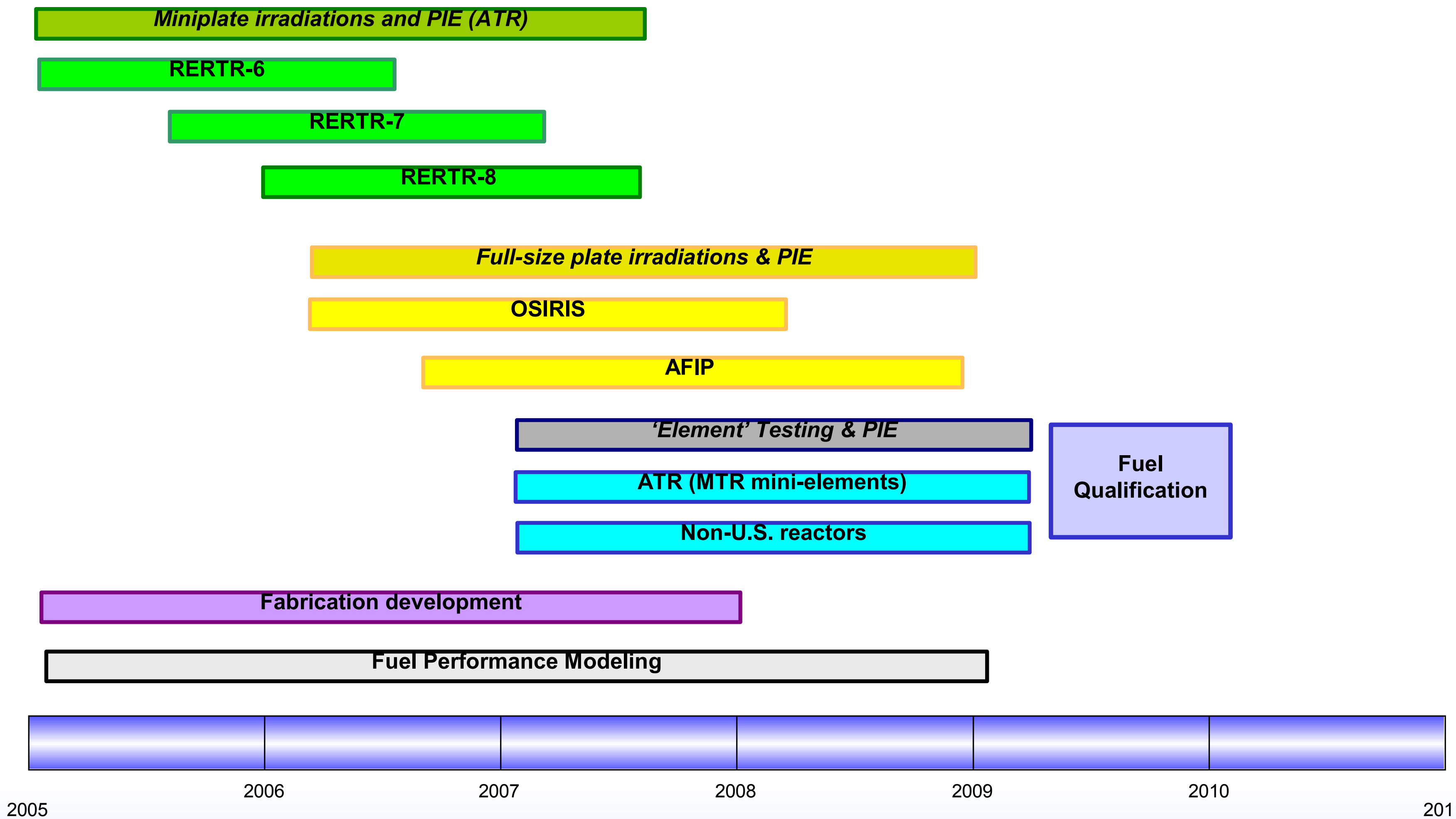
Reactors targeted by Phase I qualification

	Reactor	Country	Power (MW)	HEU (Kg/yr)
1	RHF	France	57	54.8
2	ORPHEE	France	14	15.8
3	MITR	USA	5	1.6
4	MURR	USA	10	23.5
5	NBSR	USA	20	13.0
6	ATR	USA	250	120.0
7	ATRC	USA	0.005	0.0
			Total HEU (kg/yr)	>220

Reactors targeted by Phase II qualification

	Reactor	Country	Power (MW)	HEU (Kg/yr)
1	BR-2	Belgium	80	29.0
2	FRM-II	Germany	20	37.5
3	HIFR	USA	100	91.0
4	JHR (to be built)	France	100	?
			Total HEU (kg/yr)	>150

RERTR U.S. Fuel Qualification Schedule



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Summary

- New emphasis on RERTR fuel development under GTRI
  - Very high density fuel qualification by 2010
  - Reactor conversions complete by end of 2014
- Fuel qualification based on utilization of both U.S. and non-U.S. fuel irradiations
  - Diversity in 'supply'
  - Diversity in testing conditions
  - Possibility for international fuel qualification package
- RERTR International Fuel Development Working Group has been formed to jointly address fuel performance issues