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Integrating Fuel Design with the Front and Back-End of the Fuel Cycle:

A Utility-Informed Perspective

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Back-End Fuel Performance Concerns

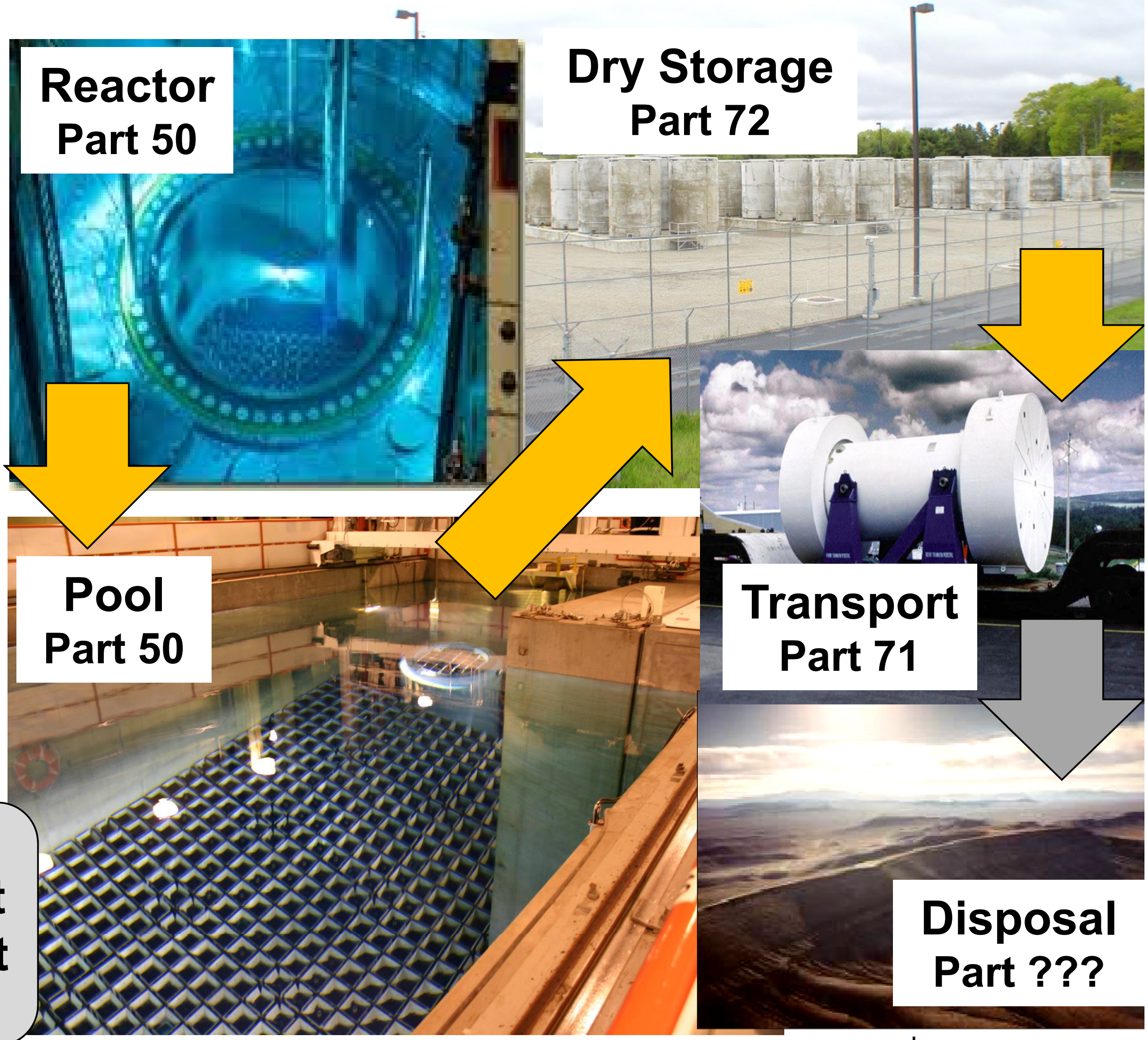
- Creep and creep rupture
- Hydride reorientation
- Delayed hydride cracking
- Severe accident performance
- Mitigating factors
  - internal rod pressurization
  - fuel-cladding interactions
- **Evaluation of issues is ongoing**

Question at hand: Can/should <u>confirmed</u> back-end issues be addressed with fuel design?

Fuel Performance in Context

- In the reactor, LWR fuel operates under extreme conditions for years
  - high T
  - high P
  - high φ_n
- Conditions outside reactor are much more benign

Fuel performance requirements are best understood in context of entire lifecycle.



Reactor
Part 50

Pool
Part 50

Dry Storage
Part 72

Transport
Part 71

Disposal
Part ???

Fuel Performance in Context

Nuclear fuel in the reactor

Used nuclear fuel in storage

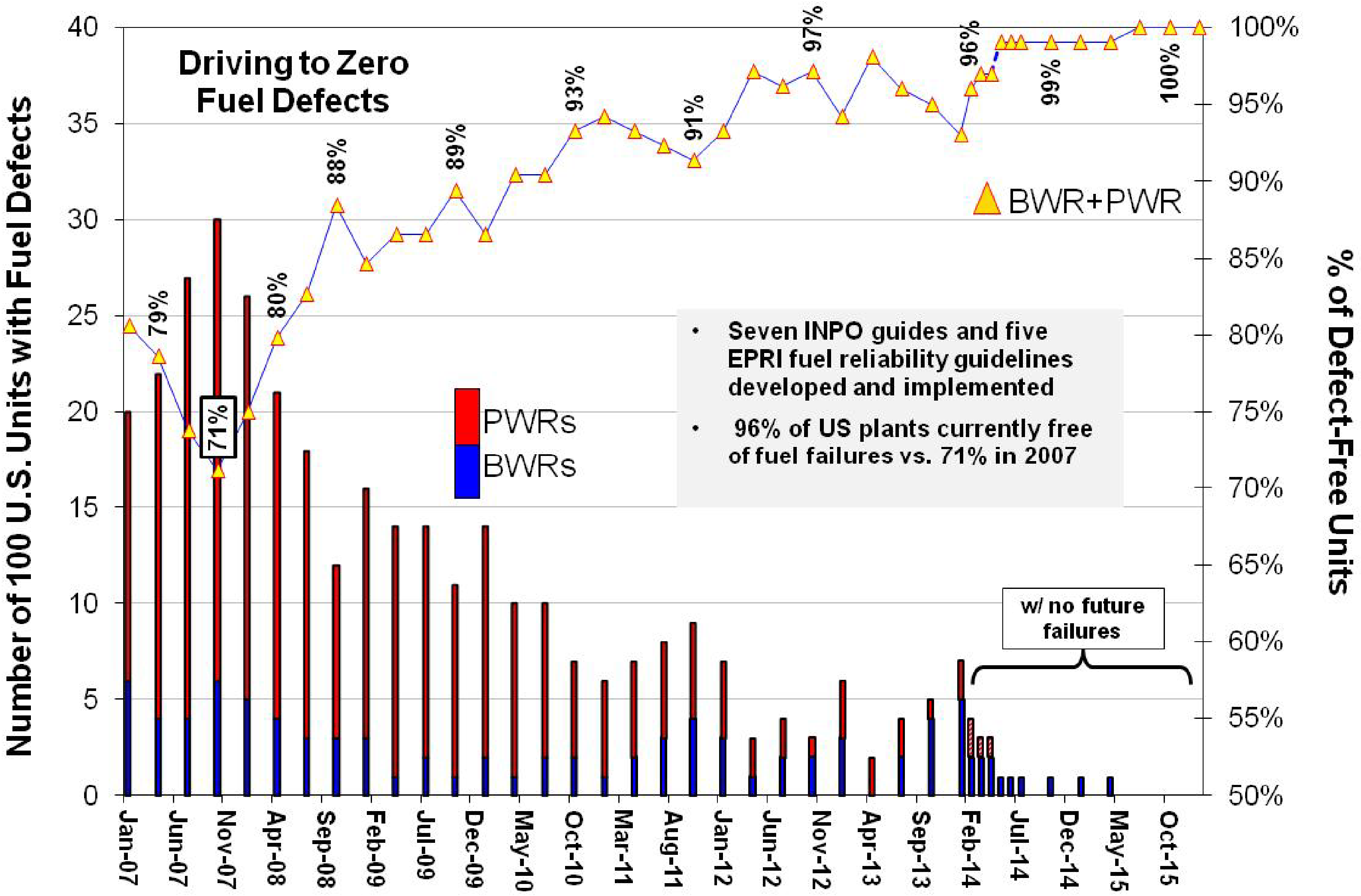
Nuclear fuel designed for robust in-reactor performance should tolerate more benign conditions experienced during storage *and subsequent transportation*.

Historical Context: LWR Fuel Development

- Current LWR fuel system reflects over five decades of optimization for <u>in-reactor</u> performance for:
  - increased burnups
  - decreased fuel failures
  - substantial increases in nuclear plant availability
- Successful evolution of zirconium fuel system has balanced tangible benefits against costs
  - safety benefits accrue from widespread application
  - benefits in back-end cannot be decoupled from in-reactor performance
- **Minor changes to zirconium fuel designs often require substantial timeframes and resources for deployment**

Current Context: U.S LWR Fuel Performance

10^{-6} annual failure rate (~5 rods/yr out of 5 million in service)



Driving to Zero Fuel Defects

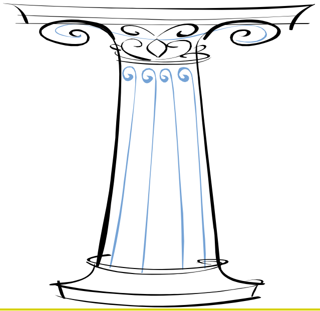
- Seven INPO guides and five EPRI fuel reliability guidelines developed and implemented
- 96% of US plants currently free of fuel failures vs. 71% in 2007

w/ no future failures

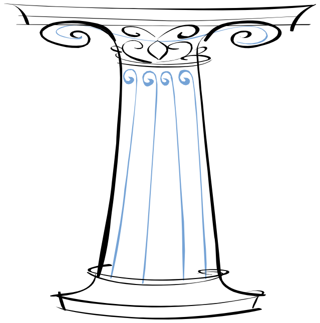
Drivers for New Fuel Development: Enhanced Accident Tolerant Fuel (ATF) Example

- Fukushima focused international attention on benefits of increased safety margins through improvement of fuel and core components

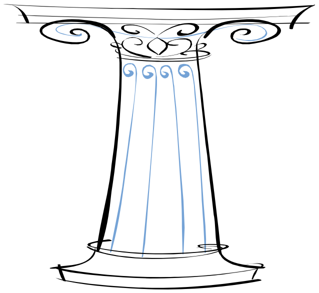
Maintain coolable core geometry following recovery



Eliminate or reduce hydrogen generation

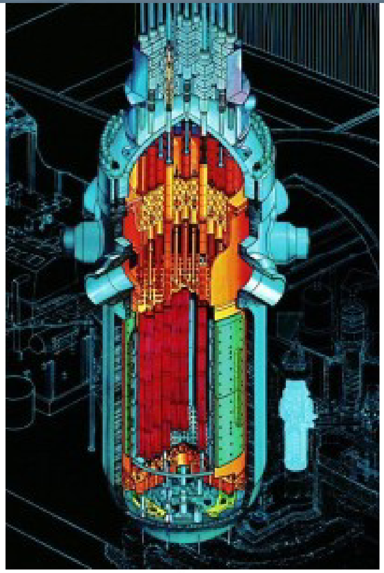


Maintain or improve performance



Reduction or elimination of exothermic zirconium oxidation reduces driving force for core and infrastructure damage AND provides commensurate back-end benefits.

Fukushima Confirmed Low Risks for Used Fuel Storage



- Negligible calculated risk for fuel in storage relative to operating reactors*
- Events at Fukushima support this paradigm**
  - drivers (energy and hydrogen) for onsite damage and offsite releases originated in reactor cores
  - neither used fuel nor pool performance issues contributed to infrastructure damage or offsite releases
  - pool structures survived seismic and tsunami events and reactor building explosions
  - used fuel integrity was maintained despite explosions, subsequent debris impacts, and extended periods without active cooling

*WASH-1400 (1975); EPRI NP-3365(1984); NUREG-1150 (1990)
** EPRI 1025058 (2012)

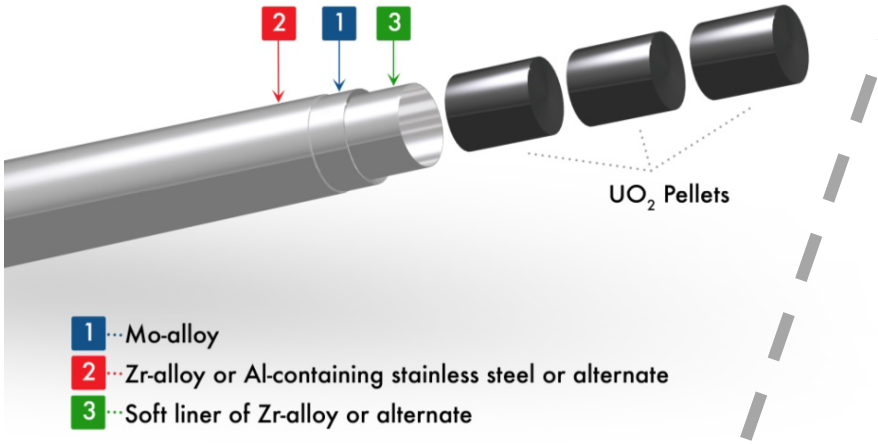
Opportunities and Challenges with New Fuel

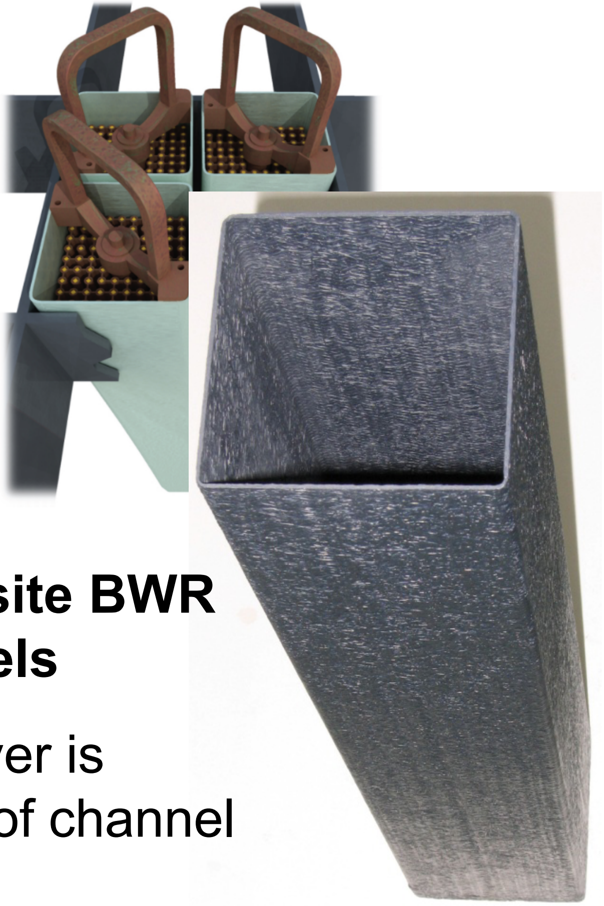
- New materials may eliminate key fuel failure modes (e.g., hydride formation) but could (re-)introduce others
- DOE-NE performance metrics for ATF explicitly capture performance for storage, transportation and disposal
- Emphasis on back-end vs. in-reactor performance mirrors tension in ATF R&D between accident tolerance and normal operational performance
  - performance for severe accident conditions cannot be at expense of performance for normal/off-normal operation and design-basis accidents and commercial viability
  - **performance for back-end cannot be at expense of in-reactor performance and commercial viability**

ATF Example: EPRI R&D for New Cladding and Channel Designs

Mo-Alloy Fuel Cladding

- Corrosion resistant under normal ops
- High strength to ~1500ºC
- Potential for steam oxidation resistance at > 1000ºC
- Compatible with current fuel/core designs & normal ops





SiC Composite BWR Fuel Channels

- Primary driver is elimination of channel distortion
- Eliminates >35% of Zr from BWR core

Closing

- Consideration of storage, transportation, and disposal issues is informing enhanced accident tolerant fuel design and assessment
- Opportunities may emerge for LWR fuel design enhancements that could result in benefits for the back-end
- **Back-end performance issues alone do not warrant or justify major changes to fuel or cladding design**
- **In-reactor performance continues to drive fuel design**

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