JENSEN HUGHES

Advancing the Science of Safety

ASSESSING THE BENEFITS OF ACCIDENT TOLERANT FUEL FOR NUCLEAR POWER PLANT RISK AND SAFETY

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DESIRED ATF CHARACTERISTICS – THE BIG PICTURE

- Physical properties of fuel / cladding
  - High melting temperatures
  - High fuel heat capacity (density x specific heat)
  - Resistance to steam & hydrogen corrosion
  - Adequate cladding tensile and creep strength
- Economic viability
  - Acceptable neutron absorption cross sections
  - Availability and costs of materials
- Capability to fabricate into full length cladding tubes and capability to achieve hermetic seal
  - Compatible with current generation LWR designs and coolants
  - Good fuel reliability under normal operating conditions
- No fuel storage or disposal issues

KEY FACTORS FOR ATF BUSINESS CASE

- To achieve significant safety enhancements ATF will need to provide improvements in:
  - Fission Product Retention (Including Fuel Melting Phase) (reduce releases during severe accidents)
  - Thermal Conductivity (Clad and Fuel Kernel) (enhance margin for LB-LOCA / AOOs)
  - Heat Capacity (Fuel Kernel) (increase margin in extended loss of cooling events including ELAP)
  - Melt Temperature (Clad and Fuel Kernel) (enhance ability to withstand loss of cooling events and extend time to maintain coolable geometry)
- To provide benefits for normal operations ATF will need to provide:
  - Manageable fuel enrichment (> 5% would require policy change and result in increased fuel cost)
  - Adequate fuel cycle length (Economic impacts if reduction in cycle length needed)
  - Adequate fuel burnup (Economic impact if reductions in burnup needed)
  - Adequate operating margins (Requires assessment of all Chapter 15 AOOs and DBAs / economic impact if new fuel designs lead to reductions in margin)

KEY ACCIDENT SEQUENCES BEING ASSESSED

- Beyond Design Basis Accidents (BDBAs)
  - Short-Term and Long-Term Station Blackout (ST-SBO / LT-SBO) Generally dominant and most challenging sequence for onset of core damage in NPP PRAs
  - Three Mile Island accident (PWR)
  - Fukushima accident (BWR)
- Design Basis Accidents (DBAs)
  - Large Break Loss of Coolant accident (LB-LOCA): Limiting core design event for many PWRs / core design limitation for core cooling
- Anticipated Operational Occurrences (AOOs) / Other Significant Events
  - Small Break Loss of Coolant Accident (SB-LOCA): Dominant LOCA sequence for NPP PRAs
  - Turbine trip with failure of bypass valves: Typical BWR limiting event for core design
  - Loss of Feedwater transient that results in entering Feed and Bleed cooling mode: Significant contributor to PWR core damage risk

KEY SAFETY EVALUATION METRICS

- Severe Accident Metrics:
  - Time to generation of 10 kg of H_2 (or other combustible gas)
  - Time to initial gap release (ATF fuels with gas gap)
  - Time to first melt (fuel or cladding)
  - Time to failure of other RCS component (e.g., hot leg creep rupture)
- Design Basis Accident / Anticipated Transient Metrics (Margin Improvement)
  - Margin to PCT / PFT during LB-LOCA
  - Clad oxidation during LB-LOCA
  - Margin to DNB (PWR) / MCPR (BWR) for normal operation and limiting AOOs
  - Margin to RCS pressure limit for limiting AOOs

ATF CONCEPTS UNDER EVALUATION

- Cr-coated Zr clad / UO_2 fuel matrix
- Cr-coated Zr clad / Cr-doped UO_2 fuel matrix
- Zr clad / U_3Si_2 fuel matrix
- Cr-coated Zr clad / U_3Si_2 fuel matrix
- SiC clad / UO_2 fuel matrix
- SiC clad / U_3Si_2 fuel matrix
- Zr metallic clad / U-Zr (50/50 wt %) metallic fuel (no clad to fuel gap)

STATUS OF ATF EVALUATIONS

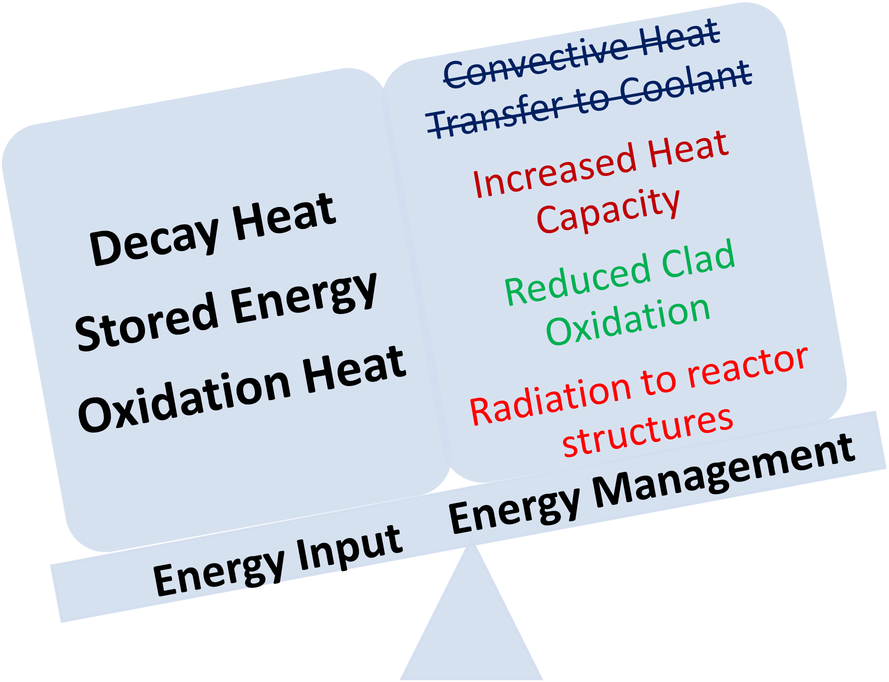
- Evaluations of ATF to date have focused on SBO Events
  - BDBA with largest potential benefit from ATF for many plants
  - Multiple studies conducted by different organizations
    - DoE-funded via National Labs (BNL / INL / ORNL)
    - Performed by fuel vendors
    - Industry-sponsored through EPRI
- Limited evaluations have assessed impact of ATF on TMI accident
  - Demonstrated that ATF may have been capable of averting core melt during this event
- Initial evaluations being performed to assess margins during limiting AOOs and DBAs
  - ATF concepts that replace the UO_2 fuel matrix can provide significant margin enhancements for some limiting licensing basis events (LB-LOCA)

EXAMPLE CATEGORIZATION OF CORE DAMAGE SEQUENCES

Sequence Where ATF Could Provide Significant Benefit	Sequences Where ATF Could Provide Benefit if FLEX Credited	Sequences With Early CD and ATF Needs to Provide Large Coping Time	Sequences Where ATF Provides Minimal Benefit
Transient with RPV depressurization and failure of LP injection	LT-SBO with delayed loss of cooling	LT-SBO with stuck open SRV and no LP injection	ATWS with inadvertent depressurization (failure to inhibit ADS)
Stuck open SRV with LP injection failure	SB/MB-LOCA with core damage due to failure of containment heat removal	ATWS with core damage due to containment failure	ATWS with inadvertent injection due to operator error
SB-LOCA with failure of HP injection	Transient with loss of main condenser and late core damage due to containment failure	LOOP with stuck open SRV and LP injection failure	LB-LOCA with no LP injection capability

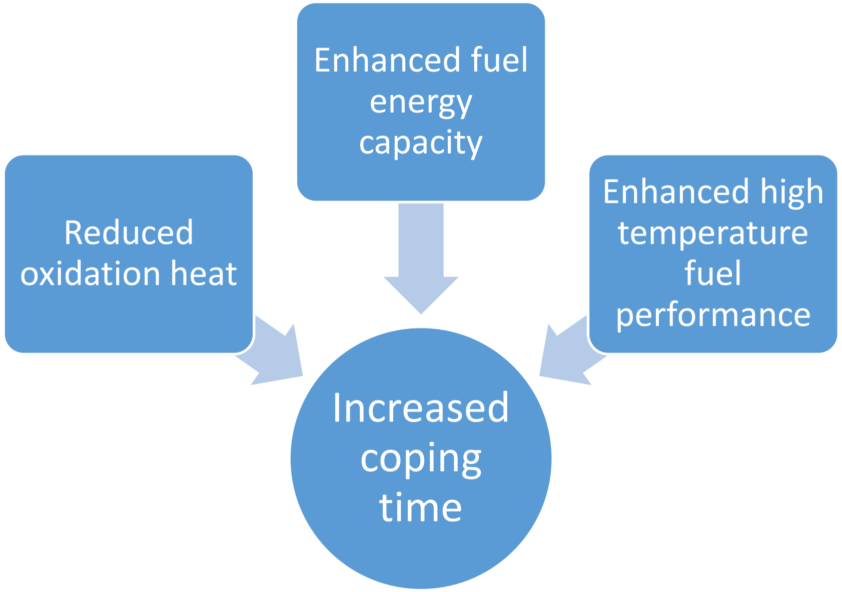
Examples provided are for BWR NPP

SBO ENERGY BALANCE / COPING TIME ENHANCEMENT



GOAL:

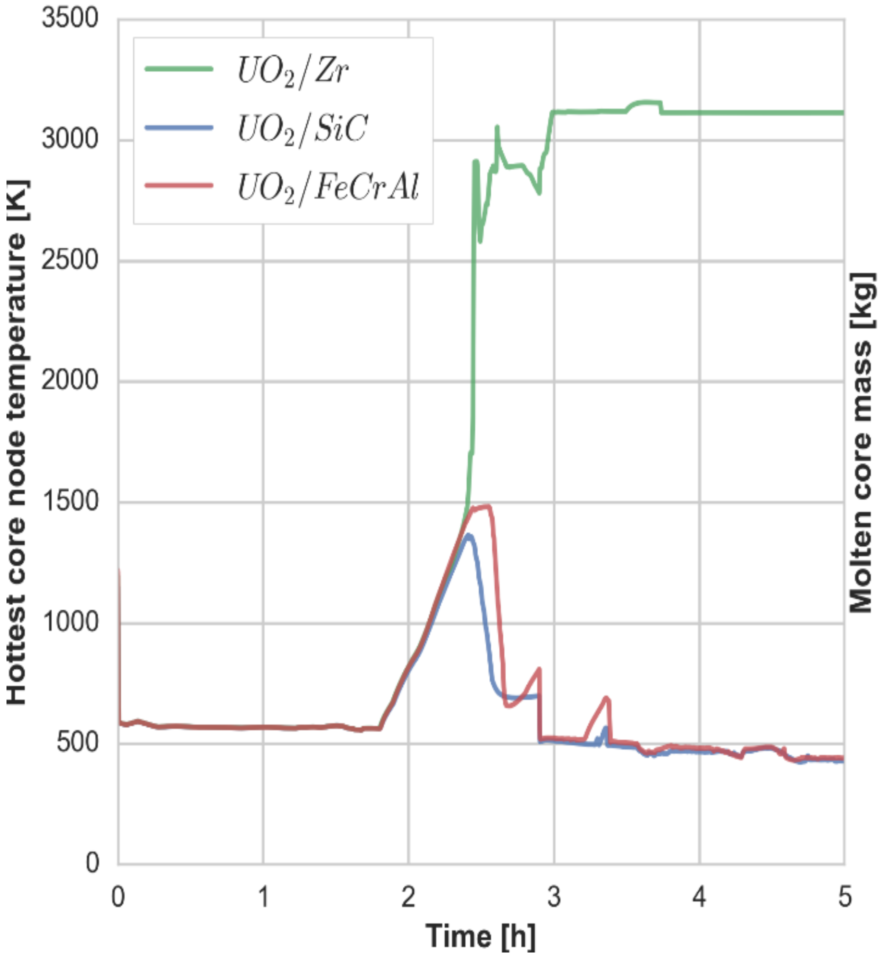
Extend time core remains in a coolable geometry

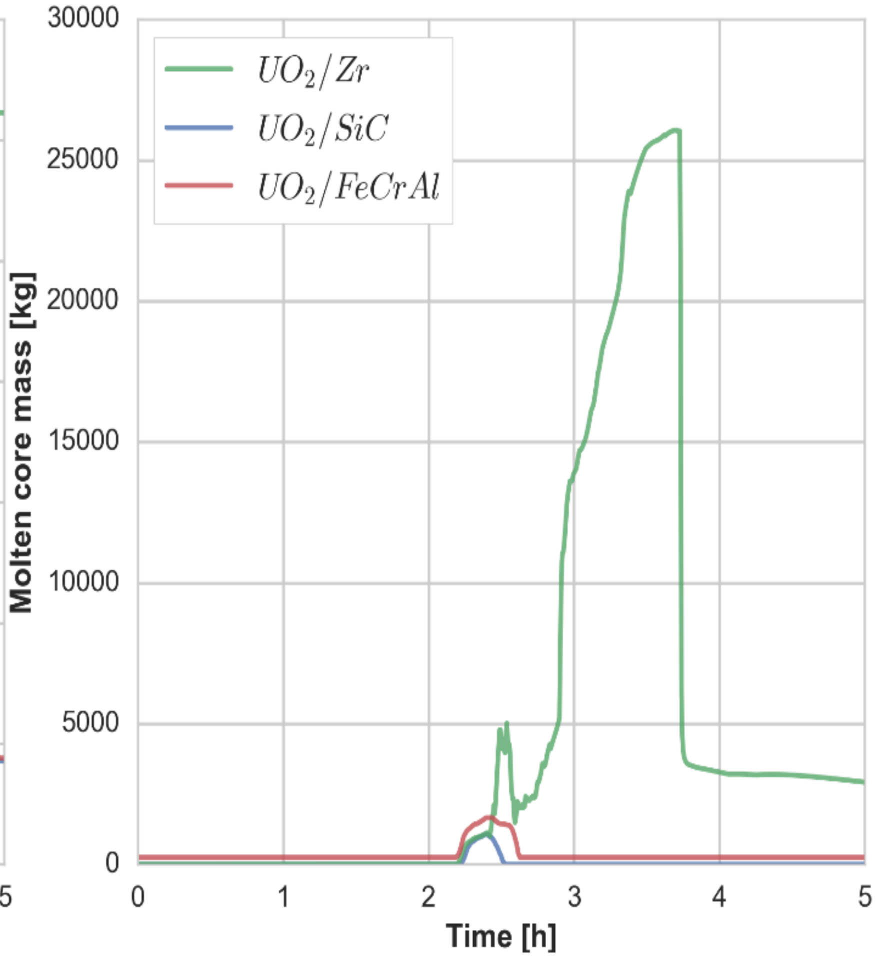


RESULTS FROM ASSESSMENTS OF SBO EVENTS

- Water injection required for adequate core cooling regardless of whether oxidation of fuel cladding occurs
  - Longer coping times from ATF can make FLEX more effective for some scenarios
- Thermal material properties control the duration of core heatup for short-term and long-term SBO
  - To achieve large extensions in mitigation times (> 8 hrs) need an order of magnitude increase in fuel heat capacity (specific heat x density)
  - Heat capacities of proposed ATF materials are not significantly different from the current Zr-UO_2 based fuel
- Extension of fuel failure times will result in other core / vessel components becoming limiting (threatening coolable core geometry)
- PWR SBO studies indicate hot-let creep rupture, which allows for core quenching by accumulator dump, can delay fuel damage 1 – 2 hours

ATF IMPACT FOR TMI UNIT 2 ACCIDENT





Conclusion: ATF may have permitted avoidance of core damage at TMI.

RESULTS FROM ASSESSMENT OF AOO / DBA EVENTS

- Preliminary assessments of limited set of AOOs and DBAs (focusing initially on LB-LOCA)
- Initial conclusions
  - ATF concepts that only replace cladding provide small benefits
  - Potentially significant margin improvements obtained for ATF concepts that replace UO_2 fuel matrix (e.g. Cr-doped UO_2, U_3Si_2 and metallic fuels)

Materials: Fuel/Clad	UO_2/Zr	UO_2/Zr	UO_2/ FeCrAl	UO_2 / FeCrAl	Cr-Doped UO_2 / FeCrAl	Cr-Doped UO_2 / FeCrAl	U_3Si_2/SiC	U – Zr / Zr (Metallic – No Gap)
Oxidation	None	CP	None	C-P	None	C-P	None	C-P
PCT (°F)	2096	2116	1992	2032	1709	1717	1499	1411
Margin +	----	**-20**	**104**	**64**	**387**	**379**	**597**	**685**

C-P = Cathcart – Pawel correlation

POTENTIAL RISK MANAGEMENT BENEFITS OF ATF

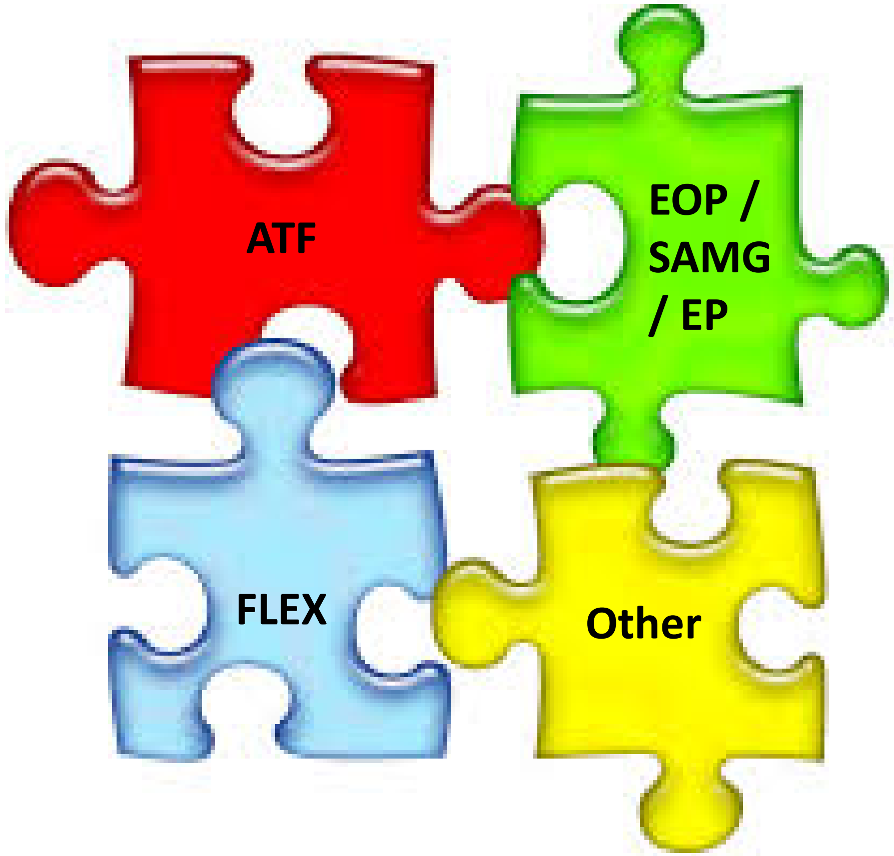
- Risk assessment outcomes considered critical for obtaining economic cost benefits from ATF
  - Derived benefits from risk-informed applications (4(b) / 5(b) / 50.69)
  - MSPI and SDP margin improvements
  - Fire PRA margin enhancements
  - Increased credit for / confidence in FLEX
  - Reduction in security and EP burdens?
- Subgroup of Safety Benefits Task Force developed prioritized grouping of benefits for input to business case development
  - Large benefits but large hurdles to achievement
  - Significant benefits but long term needed for development / licensing / deployment
  - Smaller benefits but near-term deployment possible

APPLICATIONS MODEL DEVELOPMENT AND USE

- Initial generic assessments evaluated ATF impacts for human actions to mitigate SBO sequences
  - Approximately 12% reduction in CDF for base PRA (no FLEX credit)
  - Approximately 17% reduction in CDF with credit for FLEX
- Current utility efforts aim to develop ATF-capable applications model to support business case development
  - Map key ATF characteristics to PRA sequences and prioritize
  - Modify identified PRA sequences to permit evaluation of ATF impacts
    - Modifications to human failure probabilities for longer available times
    - Expanded consideration of repair for long coping times
    - Modifications to system success criteria where appropriate
  - Evaluate risk reductions from ATF and perform sensitivity studies

CONCLUSIONS

- ATF is capable of providing enhanced NPP safety and risk reductions for accident scenarios
- ATF is only one element of a comprehensive approach to enhance NPP safety
- Overall objective is integrated approach to achieve an **Accident Tolerant Plant** that ensures safety



QUESTIONS?

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