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Summary of the U.S. National Workshop Results for ATF Metrics Development

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Major attributes of accident tolerant fuels are associated with the behavior of fuel and cladding at high temperatures.

Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zircaloy system, can tolerate loss of active cooling in the core for a considerably longer time period (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance during normal operations.

To demonstrate the enhanced accident tolerance of candidate fuel designs, metrics must be developed and evaluated using a combination of design features for a given LWR design, potential improvements and the design of advanced fuel/cladding system.

Improved Reaction Kinetics with Steam
- Heat of oxidation
- Oxidation rate

Slower Hydrogen Generation Rate
- Hydrogen bubble
- Hydrogen explosion
- Hydrogen embrittlement of the clad

High temperature during loss of active cooling

Improved Fuel Properties
- Lower operating temperatures
- Clad internal oxidation
- Fuel relocation / dispersion
- Fuel melting

Improved Cladding Properties
- Clad fracture
- Geometric stability
- Thermal shock resistance
- Melting of the cladding

Enhanced Retention of Fission Products
-Gaseous fission products
-Solid/liquid fission products

Breakout Sessions –Outcomes

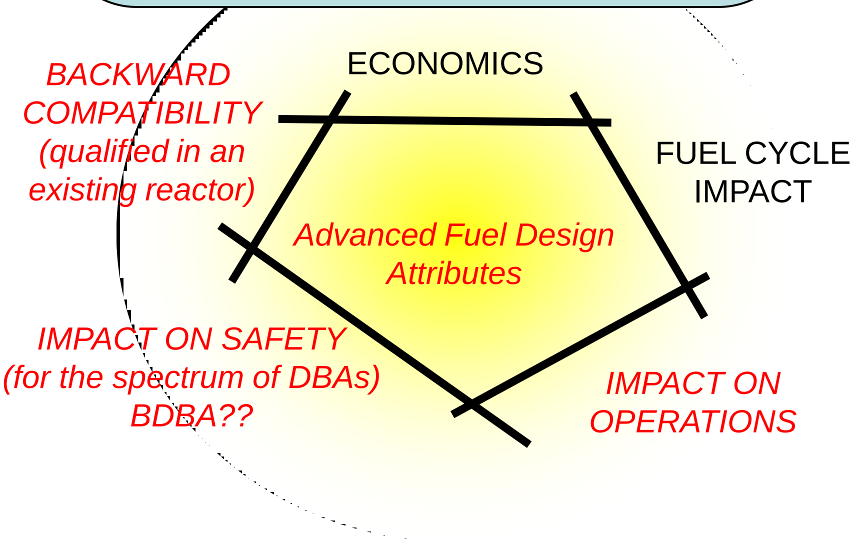
Cladding and Fuels Sessions

- Define critical attributes: properties, performance characteristics
- Map the merit of the attributes against potential operational or safety envelope benefits
- If possible, quantify the target value for the attribute/property
- Define required analyses (accident scenarios) to quantify the target value

Operations/Safety Constraints Session

- Potential assembly design changes within the design constraints
- Accident scenarios to be considered – safety envelope definition
  - Limiting components besides fuel assemblies
- Operations envelope based on margins required during transients
  - initial conditions for accident scenarios

Participants:
-DOE-NE
-NRC
-National Laboratories
-Universities
-Industry
- *Fuel and reactor vendors*
- *Utilities*



Cladding Breakout Section – summary of discussions

- Establish a common baseline.
  - Define key parameters for current Zr-based alloy cladding – normal operation.
  - Define key accident performance parameters for current Zr-based alloy cladding.
- Discuss attributes for advanced cladding options.
  - What parameters should be adjusted for enhanced accident tolerant cladding?
- Identify key measurements, parametric studies, and tests to measure key attributes.
  - Identify sensitivity analyses to be performed to highlight the most impactful properties/attributes.
  - Establish the testing envelope for each “class” of advanced cladding option (e.g. metallic, ceramic, hybrid).
- Develop a summary list of necessary test facilities; compare facility needs with current facility capabilities

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Fuel Breakout Section – summary of discussions

Enhanced Accident Tolerance

(Fission Product Retention

Cladding Compatibility)

Assessment of Advanced Fuel Design

Detailed System Analysis

(Fuel performance, accident progression)

Analysis will include Severe Accident, DBA (LOCA,RIA), AOO and Normal Operation

Assessment of Model Applicability

Similar treatment for cladding as for fuel

Behavioral models will be comprised of validated models, validated data and assumptions

Behavior/Phenomenological Response

- FPR (D(microstructure, composition))
- Thermal (T_m, k, C_p…)
- PCMI (CTE, σ_y, ε, E…)
- FCCI (chemical reactions)

Materials Properties and Characteristics

* Thermal – T_m, k ,C_p, CTE

* Mechanical – Yield Stress, Modulus, etc.

* Chemical –

Etc. (see Tables)

Reactors Breakout Section – summary of discussions

Considerations for potential ATF geometry deviations from traditional fuel geometries operated in existing LWRs and compatibility with co-resident fuel. These are captured within the parameter metrics.

Recommendations to ensure that ATF concepts are rigorously evaluated for parameters other than accident condition oxidation kinetics and fuel temperature effects prior to LTA operation, including:

A Failure Modes and Effects Analysis (FMEA) to be completed prior to ATF insertion to ensure that any potential ATF operating vulnerabilities are recognized and mitigated as possible;

Completion of a 50.59-like process to illuminate any necessary licensing or logistical preparations for operation of the ATF in a commercial LWR.

Reactors Breakout Section – summary of discussions (cont.)

The need to include a metric to address those concepts that require enrichments greater than 5 wt%.

there is an inherent limitation in the existing commercial industry infrastructure, and therefore concepts that do not rely on higher enrichment are preferred.

However, the recommended metric does not exclude concepts requiring higher enrichment. If the industry restrictions on higher enrichments are eliminated, this metric should be revisited.

Reactors Breakout Section – summary of discussions (cont.)

"It is important to recognize that the utility's requirements for reactor operation do not end with the licensing regulations. . . they begin there."

there is an inherent reluctance to introduce demonstration programs that bring risk to power production activities, require additional licensing activities, or impact refueling outage activities.

any ATF operation must necessarily address and minimize these impacts on the utility by ensuring (as possible) full compatibility with co-resident fuel and reactor components, and by limiting perturbations to the normal operation of the plant.

Thus, industry representatives DOE meetings have repeatedly suggested that there is a preference for implementing design changes in an evolutionary manner and a phased approach towards an ATF demonstration is preferred.

Discussions on the necessity to minimize the cost for ATF.

It is well known that the commercial nuclear industry has optimized the current zirconium alloy clad UO_2 fuel over several decades, that the current fuel design represents a large financial investment by fuel vendors and utilities, and that the current designs are considered very reliable and safe.

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High-Level Conclusions

- All thermal, mechanical and chemical properties of the fuels and cladding are relevant through a complex set of interactions in defining the metrics for accident tolerance depending upon the accident scenario and progression being considered.
- Considerable testing and analyses are needed to identify the dominant attributes and quantify the metrics
- Current analyses tools are not fully adequate to complete the task
- Fundamental data to assess new concepts do not exist
  - Experimental capabilities exist but the data needs are overwhelming
  - Requires strong collaborations and tight coupling with M&S
- Regulations and regulatory limits rely heavily on empirical knowledge on zircaloy-UO2 systems
  - Difficult to directly adopt to new systems/technologies