Phenomena Identification and Ranking Tables for Accident Tolerant Fuel

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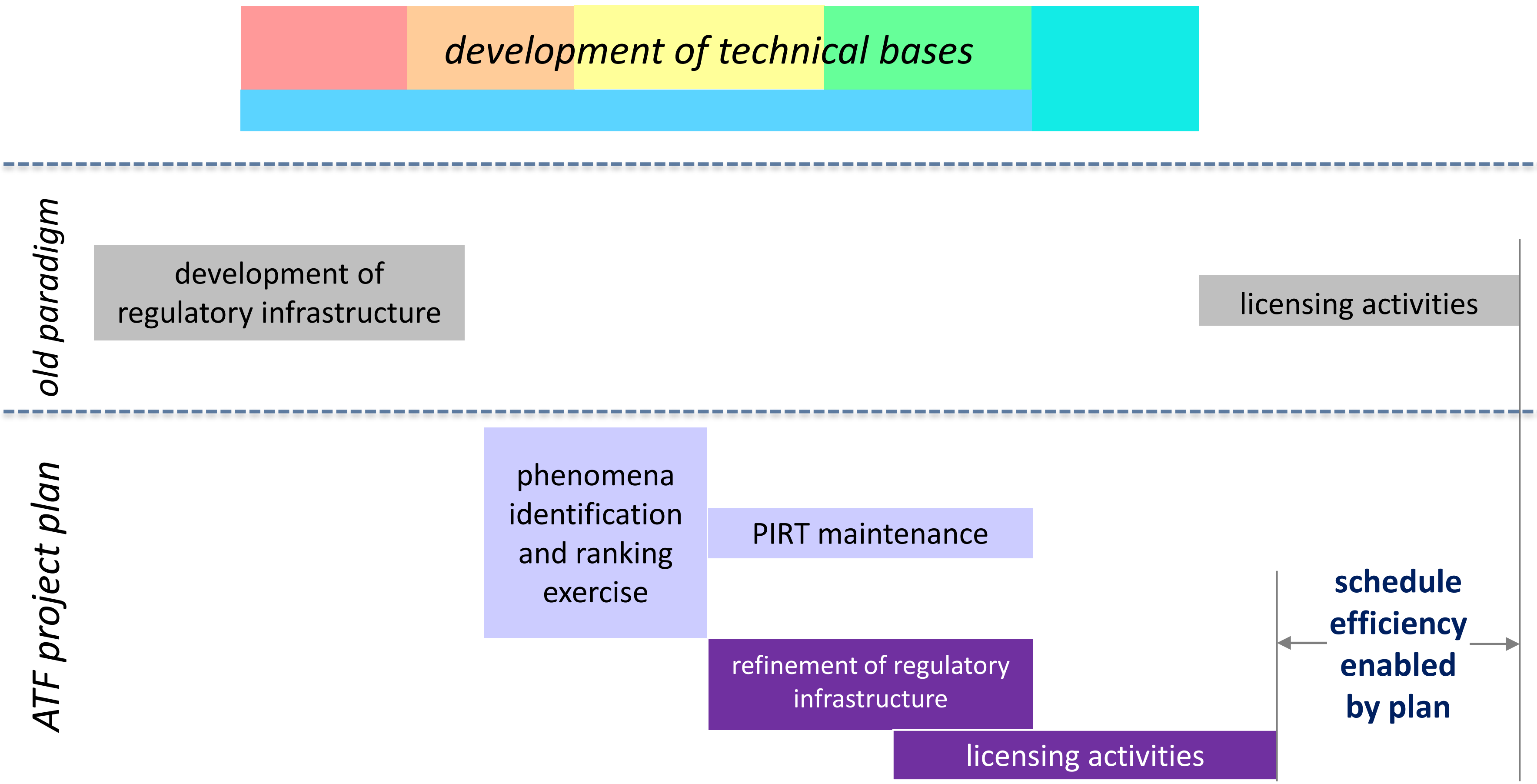
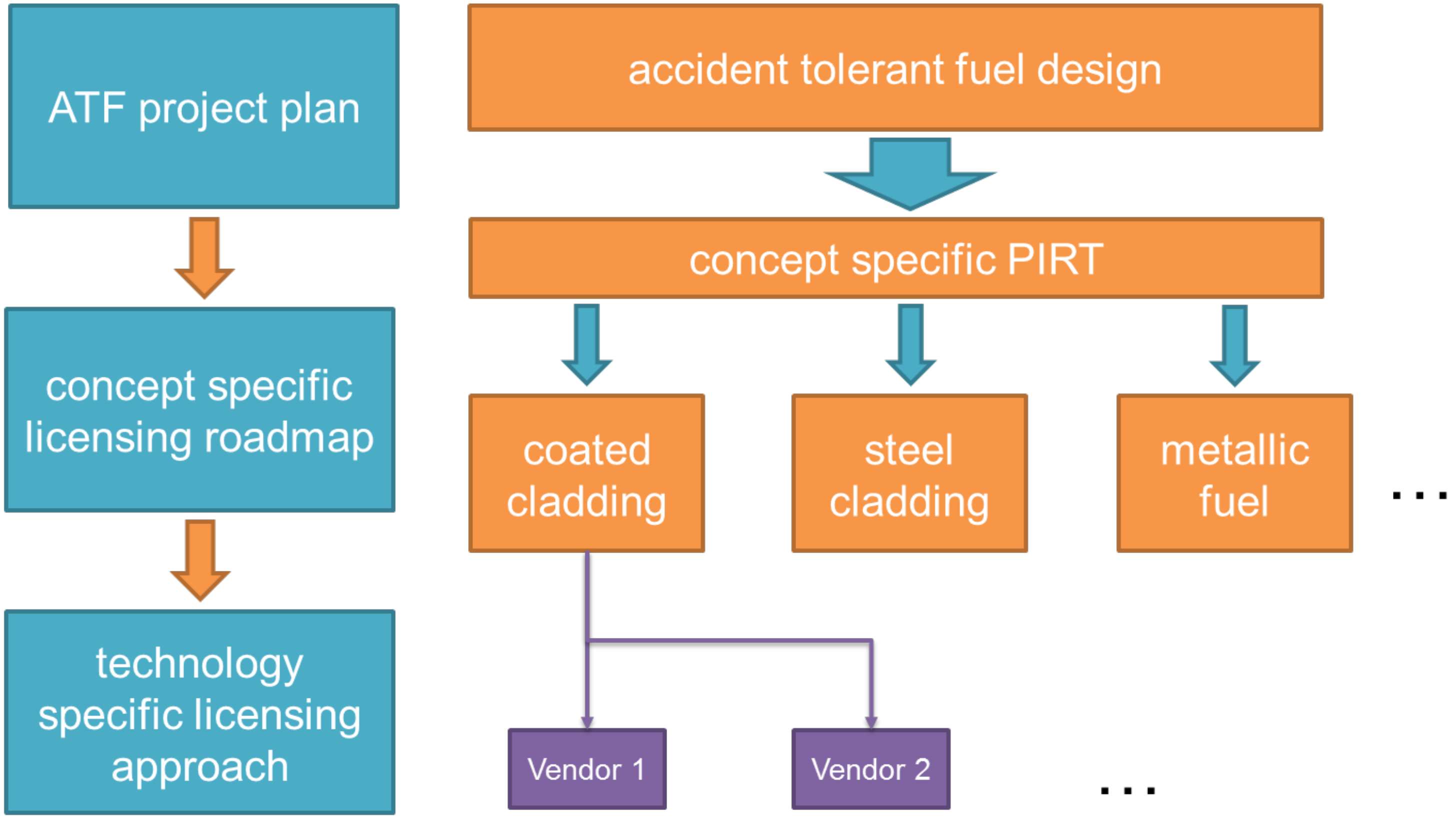
Graphic from ATF Commission Meeting April 12, 2018



PIRTs provide basis for concept-specific licensing roadmaps



Assessment of ATF degradation and failure phenomenon is needed

Assessment must be:

- Comprehensive
- Timely
- Independent
- Designed to support regulatory stability and predictability
- Designed to support regulatory efficiency

Calibrating PIRT Efforts

- PIRTS are one method to develop greater understanding
- **Scope consistent with degree of departure from current state-of-practice**
- Consider concept maturity and licensing schedule

Example: Fuel System Review

- Fuel system safety review provides assurance that:
  - the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs)
  - fuel system damage is never so severe as to prevent control rod insertion when it is required
  - the number of fuel rod failures is not underestimated for postulated accidents
  - coolability is maintained during design-basis accidents
- To satisfy these objectives, acceptance criteria are needed for fuel system damage, fuel rod failure, and fuel coolability.

Example: Fuel System Review Continued

Standard Review Plan (SRP) Section 4.2 identifies the known mechanisms for fuel system damage, fuel rod failure, and fuel coolability loss for zirconium clad uranium dioxide fuel.

Fuel System Damage

- Stress, strain, or loading limits for spacer grids, guide tubes, thimbles, fuel rods, control rods, channel boxes, and other fuel system structural members
- Fatigue of structural members mentioned above
- Fretting wear at contact points
- Oxidation, hydriding and CRUD buildup
- Dimensional changes and mechanical compatibility
- Rod internal gas pressure
- Worst case hydraulic loads
- Control rod reactivity and insertability

Fuel Rod Failure

- Hydriding
- Cladding collapse
- Overheating of the cladding
- Overheating of the fuel pellets
- Excessive fuel enthalpy
- Pellet/cladding interaction
- Bursting
- Mechanical fracturing

Fuel Coolability

- Cladding embrittlement
- Violent expulsion of fuel
- Generalized cladding melting
- Fuel rod ballooning
- Structural deformation

Example: Fuel System Review Continued

Fuel System Damage

- Stress, strain, or loading limits for spacer grids, guide tubes, thimbles, fuel rods, control rods, channel boxes, and other fuel system structural members
- Fatigue of structural members mentioned above
- Fretting wear at contact points *
- Oxidation *, hydriding * and CRUD buildup
- Coating spallation with resulting hydride blister?
- Nodular corrosion?
- Dimensional changes and mechanical compatibility *
- Dissimilar metal interaction?
- Rod internal gas pressure *
- Worst case hydraulic loads
- Control rod reactivity and insertability

Fuel Rod Failure

- Hydriding *
- Cladding collapse
- Overheating of the cladding *
- Overheating of the fuel pellets
- Excessive fuel enthalpy
- Pellet/cladding interaction *
- Bursting (timing impacted?)
- Mechanical fracturing *

Fuel Coolability

- Cladding embrittlement *
- Violent expulsion of fuel *
- Generalized cladding melting
- Fuel rod ballooning *
- Structural deformation
- Sump clogging source material?

ATF designs may introduce new mechanisms or result in significantly different limits for existing mechanisms

* - mechanism is expected to be different for some ATF designs

Example: Source Term / Severe Accident Analysis

- Severe accident codes are repository of phenomenological understanding gained through NRC and international research since the TMI-2 accident
- Integrated models required for self-consistent analysis
  - Accident initiation *
  - Reactor coolant thermal hydraulics *
  - Loss of core cooling *
  - Core melt progression *
  - Fission product release *
  - Reactor vessel failure *
  - Transport of fission products in RCS and Containment *
  - Fission product aerosol dynamics
  - Molten core/basement interactions
  - Containment thermal hydraulics
  - Fission product removal process
  - Release of fission products to the environment
  - Engineered safety systems – sprays, fan coolers, etc
  - Iodine chemistry

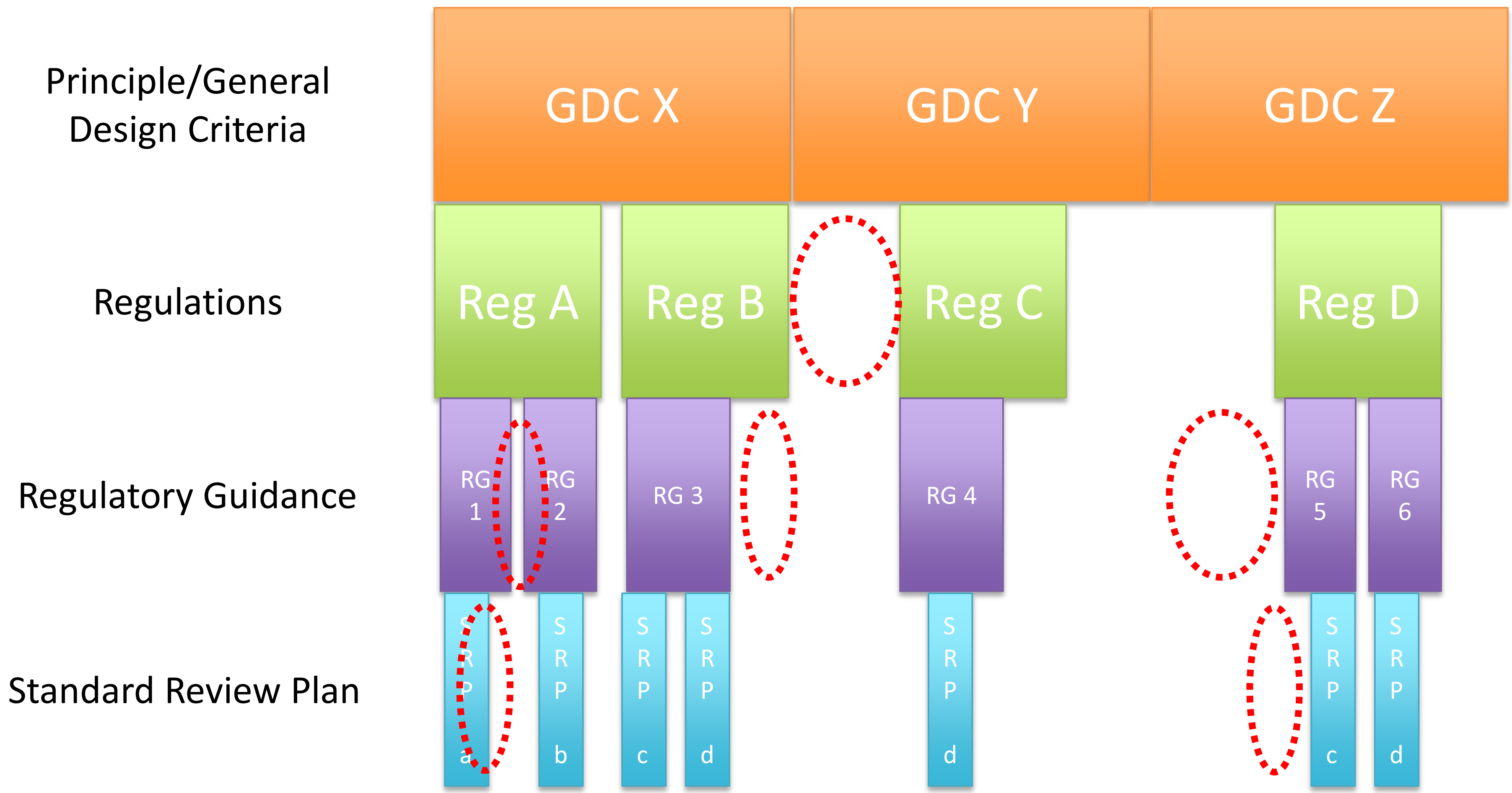
ATF designs may introduce new mechanisms or result in significantly different limits for existing mechanisms

* - mechanism is expected to be different for some ATF designs

Example: Source Term / Severe Accident Analysis

- New cladding and fuel materials may react differently with fission products
- Fission product release parameters may change
  - Non-UO_2 fuels may have different fission product release characteristics
- Core degradation may progress differently
  - Changes in the relative melt temperature of cladding/fuel systems mean cladding could melt before fuel sinters, invalidating key assumptions about core geometry in severe accidents (for example candling)
  - New cladding and fuel materials may have different eutectic interactions

What will NRC do with PIRT results?

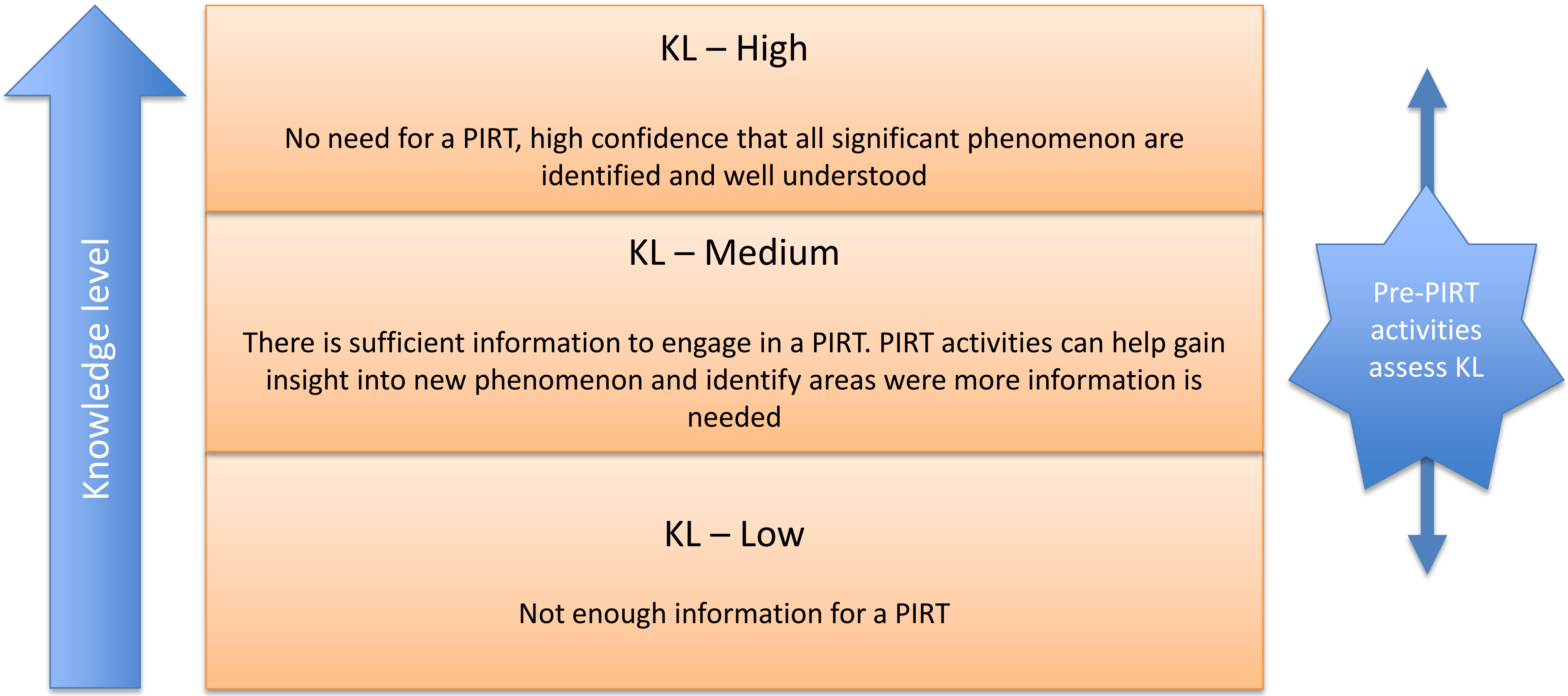


PIRTS will help identify if there are issues not contemplated or covered by the current regulatory infrastructure.

Pre-PIRT Activities

- NRC concept-lead would begin with "pre-PIRT investigation" to determine:
  - if a PIRT is needed
  - if there is sufficient information to start a PIRT
  - to inform the objectives and scope of the PIRT
- Envisioned to be a literature review and discussion with experts on nuclear and non-nuclear applications of ATF features

Relationship of concept maturity to PIRT activities



PIRT Proposal

- Three types of PIRTS
  1. Concept-specific PIRTS for normal operation, transients and design basis accidents *in reactor*
  2. Severe accident PIRT that covers a wide range of ATF concepts
  3. Storage and transportation PIRT that covers a wide range of ATF concepts

Generic ATF Severe Accident PIRT

- Obtain greater understandings of the design basis accident (DBA) source term and evaluation of whether the existing technical basis applies to ATF concepts
- Two key considerations, how concept changes:
  - fission product release quantities
  - melt progression and fuel/cladding interaction and thus release timing

Generic ATF Spent Fuel Storage and Transportation PIRT

- Key considerations, how ATF changes:
  - mechanical integrity of cladding and cladding failure modes
  - neutronics/criticality
  - Long term storage degradation and failure modes

Structured Discussion

When should potential operational flexibility for ATF be defined?

- Is it useful to do a PIRT without this information?
- What delays might arise if we conduct a PIRT or conduct testing without knowledge of the “use”?
- What delays might arise if the “use” requires rulemaking?

What is the best separation and categorization for PIRTs?

- By technical issue/panel expertise needs
- Work scope/schedule drivers
- Concept maturity
- Proposal:
  1. Normal and DBA performance
  2. Severe accident and source term
  3. Storage and transportation

What is the best timing and sequencing for PIRTs?

- Pre-PIRT activities
- Order of concepts
- Order of categories (i.e. DBA, SA, Storage, etc.)
- Lead time for resulting investigations

Who are the experts?

- What are the appropriate credentials for panel members?
  - Publication/citation index
  - Years of experience
- How are experts solicited?
  - Public notice
- How is alignment reached on panel membership?
  - Stakeholder feedback
  - Public comment

What is the product?

- Content
  - Documentation of the PIRT process
  - Discussion of expert selection
  - Training/orientation of experts, elicitation process, (2) scope of areas considered, (3) results of PIRT,
- Characteristics
  - Must be objective database
  - Significance level and knowledge level supported by references
  - May have provisions for both proprietary and public information

Who leads the PIRT?

- Transparency is key
- Lead may differ for each PIRT
- Considerations of NRC lead
  - NRC is experienced in conducting PIRTs
  - NRC's schedule requirements may drive PIRT schedule
  - NRC has the ability to handle proprietary information
- Considerations of non-NRC lead
  - Access to information
  - Potential streamlined contracting process for obtaining experts

Other Subjects?

Next Steps

- To be completed during the meeting…

Backup

The PIRT Process

1. Define the issue that is driving the need for a PIRT
2. Define the specific objectives for the PIRT
3. Define the hardware and the scenario for the PIRT
4. Define the evaluation criterion
5. Identify, compile, and review the current knowledge base
6. Identify plausible phenomena, that is, PIRT elements
7. Develop importance ranking for phenomena
8. Assess knowledge level for phenomena
9. Document PIRT results