Pilot Study of NUREG-0800, Chapter 4 (Reactor) for Two Non-LWR Technologies

Sodium-Cooled Fast Reactors and

Modular High-Temperature Gas-Cooled Reactors

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There is a need to provide appropriate non-LWR review guidance for applicants and regulators

Objective

- Provide an approach for the "next steps" beyond the recent DOE-NRC joint initiative activities to develop advanced reactor design criteria
  - Begin a regulatory gap analysis to identify LWR-specific review references
  - Pilot adaptation of an SRP Chapter for the sodium-cooled fast reactor (SFR) and modular high temperature gas-cooled reactor (mHTGR) technologies

The task is quite broad, so the pilot scope was limited to gauge the viability of the approach

- SRP Chapter 4, which addresses reactor components, was selected for adaptation
  - Exemplified by differences in advanced non-LWR technologies compared with the current LWR-based description in Chapter 4
  - SFR and mHTGR technologies were selected for adaptation because of their diverse designs and the availability of significant historical design detail
- Incorporated stakeholder feedback on initial adaptation draft
- Draft adaptations for other SRP component chapters are expected to be less challenging
  - Based on learning curve with Chapter 4 experience
  - Recognition that Chapter 4 contains the most difficult review material
  - Revised Chapter 4 information provides foundation for subsequent chapter adaptations

The basis for the SRP Chapter 4 adaptation was a previous gap analysis performed by the DOE laboratory team

- The SRP Chapter 4 gap analysis focused on:
  - the content of SRP Chapter 4 (body),
  - technical reports referenced in Chapter 4,
  - regulatory guides referenced in Chapter 4,
  - consensus standards referenced in Chapter 4, and
  - appendices of 10 CFR 50 referenced in Chapter 4
- Limited effort was made to review standards, ASME codes, or code cases to verify their applicability to the SFR or mHTGR designs
- Limited effort was made to recommend the correct references for review of the SFR and mHTGR designs

Standard LWR terminology can be confusing when applied to advanced non-LWRs

- General stakeholder concern was expressed over operational mode terminology relative to advanced non-LWRs
  - hot standby, hot shutdown, hot zero power
  - cold shutdown, cold condition
- Temperature aspect of these terms is obvious, but traditional use of the terminology also implies the reactivity condition of the reactor and the readiness to perform certain maintenance operations
- Distinction between hot and cold conditions can be further complicated by using a coolant that solidifies at room temperatures.
- Generally kept hot and cold terminology “as is”
  - In SFR-RP, cold conditions are defined as the state under which interventions such as fuel reloading, inspections, and repair functions can be performed (above sodium melting point)

SRP Chapter 4 sections were adapted for SFR and mHTGR to be more performance-based

- In general, the LWR SRP is very prescriptive, specifying detailed requirements based on over 40 years of experience with LWR fuels and other reactor components
- For example, alternatives for critical heat flux (CHF) and departure from nucleate boiling (DNB) are necessary for these technologies
  - Replaced with performance-based considerations
- mHTGR fuel system design is fundamentally different from current LWR fuel system design
  - Requires consideration of fuel manufacturing process and coated particle fuel performance during normal and off-normal operation
  - Extensive rewrite of mHTGR Section 4.2; Fuel System Design was required (NUREG 1537 used as guidance)

Some sample SFR adaptation challenges for Chapter 4 include:

- Clarification of terminology with respect to fuel pins in Section 4.2
  - Fuel rod and fuel pin are equivalent in SFR; proposed “fuel slug” for fuel pin in metallic fuel segments (similar to oxide fuel pellets)
- In Section 4.2, proposed that the applicant provide limits for cladding strain, fuel and cladding temperatures, and time-at-temperature as fuel acceptance criteria for both metallic or oxide fuel forms
- It is required that the "net reactivity feedback” (from all feedback mechanisms) be negative at temperatures elevated above the normal operating range
  - Some coefficients (such as sodium void worth) may be positive in some designs
- Eliminated LWR-based thermal-hydraulic limits in Section 4.4 (CHF, DNBR, etc.)
- Alternative requirements for ATWS (10 CFR 50.62) in Section 4.6
  - Regulation currently only addresses LWRs

Some sample mHTGR adaptation challenges for Chapter 4 include:

- Incorporated the unique fuel performance attributes and radionuclide retention capabilities of TRISO-coated particle fuel into a fuel design review (SRP Section 4.2)
  - Considered the importance of the particle fuel manufacturing process
  - Includes pebble bed and prismatic block fuel designs
- “Postulated accidents” was replaced with licensing basis events (LBEs) terminology
- Consideration of LWR-based density coefficients in SRP Section 4.3

Conclusions and Observations

- The pilot has identified the types of updates needed to speed the development and review of non-LWR licensing submittals:
  - Codes and Standards development
  - Regulatory Guidance Documents
  - Other technical references and documentation
- Adaptations for other SRP chapters merit consideration
  - Fuel form plays a major role in the ease with which SRP can be adapted for non-LWR technologies
- Risk-informed, performance-based requirements need to be confirmed
- Given the number of existing molten salt vendors and the prospect of a molten salt design certification application in 2019, consideration should be given to expanding current efforts (ARDCs and possibly SRP adaptation) to MSRs