U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

COMMISSION MEETING WITH THE ADVISORY COMMITTEE ON REACTOR SAFEGUARDS (ACRS)

June 9, 2023

Agenda

- Joy Rempe
  - Overview
- Ronald Ballinger
  - SHINE Operating License Application Review
- Walt Kirchner
  - Methodology for Establishing Plume Exposure EPZs at NuScale SMR Plant Sites
- David Petti
  - Draft 10 CFR Part 53 Rulemaking Language
  - Kairos Power, LLC, Construction Permit Application for Hermes

Seventeen Reports Issued since June 2022 Meeting

- New Reactor Rulemaking and Guidance
  - 10 CFR Part 53 – Final Letter on Rulemaking Language and Associated Guidance
  - 10 CFR Part 53 – Fourth Interim Letter on Rulemaking Language and Associated Guidance
  - Draft SECY White Paper on Licensing and Regulating Fusion Energy Systems
  - Response to NRC Staff Letter on ACRS Letter Report on Draft SECY White Paper on Fusion Systems

Seventeen Reports Issued since June 2022 Meeting (Cont'd)

- Design-Specific Applications
  - SHINE Medical Technologies, LLC Operating License Application
  - Draft Safety Evaluation (SE) of KAIROS Topical Report (TR) on Graphite Material Qualification
  - Draft SE of KAIROS TR on Metallic Materials Qualification
  - Draft SE of KAIROS TR on Fuel Qualification
  - Draft SE of NuScale TR for Establishing the Technical Basis for Plume Exposure EPZ
  - SE of KAIROS Non-Power Reactor Hermes Construction Permit Application

Seventeen Reports Issued since June 2022 Meeting (Cont'd)

- Operating Fleet
  - RG 1.82 on Water Sources for Long-Term Recirculation Cooling following a LOCA
  - SECY-22-0076, Expansion of Current Policy on Potential Common Cause Failures in DI&C Systems
  - Framatome TR ANP-10353, Increased Enrichment for PWRs
  - Draft RG 1.152, Criteria for Programmable Digital Devices in Safety-Related Systems
  - Draft RG 1.250, Dedication of Commercial Grade DI&C Items
  - Safety Aspects of SLR Application Review of Oconee Nuclear Station, Units 1, 2, and 3
- Other Topics
  - White Paper on Enduring Legacy of ACRS

On-Going Reviews

- Design Centered Applications
  - NuScale Standard Design Approval
  - X-Energy Pebble Bed Gas-Cooled Reactor
  - Terrapower Natrium Sodium-Cooled Fast Reactor
  - General Atomics Fast Breeder Reactor
  - Westinghouse eVinci Microreactor
- Subsequent License Renewal Applications
- Safety-Significant Topical Reports
- Topics Identified in 2022 Research Review Report

Other ACRS Activities

- ACRS Process Improvements
  - Continued developing member guidance to promote consistent and effective review processes
    - Report writing
    - Design center reviews
    - Other knowledge transfer information
  - Continued efforts to streamline reviews and focus on risk significant activities

Other ACRS Activities (Cont'd)

- Other Beneficial Interactions
  - Continued reviews of selected staff transformation/process improvement activities
  - Resumed plant and fuel fabrication facility visits
  - Continued preparations for anticipated design center submittals
  - Conducted international interaction of nuclear regulatory advisory committees with participation by France, Finland, Japan, and the United Kingdom

SHINE Operating License Application Review

Ron Ballinger, Chair

SHINE Subcommittee

Background

- SHINE submitted operating license application on July 17, 2019
- SHINE requested a 30-year license
- Completed ACRS review in December 2022

Facility Characteristics

- The SHINE Medical Isotope Production Facility designed to provide a domestic, reliable supply of ^{99}Mo for medical applications
- ^{99}Mo produced from fission occurring in a low enriched uranium target solution in the Irradiation Facility
  - Source neutrons for fission derived from accelerator induced fusion neutrons and a neutron multiplier
- Radioisotope Production Facility consists of a series of hot cells for ^{99}Mo separation and purification

SHINE Safety Measures

- Low power density irradiation units
- Automatic shut down of irradiation process
  - Placing target solution into a safe stable passively cooled condition without immediate operator actions
- Criticality during dissolving and filling processes precluded by the engineering controls
- Criticality safe vessels or double contingency controls used for fissile solutions in the Radioisotope Production Facility

ACRS Subcommittee Engagement

- 6 Subcommittee Meetings
- Issued 19 Chapter/Topic memos
- Site visit and discussions in Janesville, Wisconsin, in August 2022
  - Enhanced understanding of facility layout; site culture; staff training, caliber and commitment

Safety Analysis Approach

- Used concept of maximum hypothetical accident (MHA) to demonstrate compliance with acceptable limits for both radiological and chemical consequences
- Performed a Hazard and Operability Analysis and Failure Modes and Effects Analysis Approach
  - Provided systematic approach to identify, evaluate, and group credible accident sequences
  - Both internal and external events considered
- Design Basis Accidents (DBAs) were identified as those events with maximum consequences for each accident sequence grouping
- DBA analysis confirmed selected MHA bounding

Observations/Comments Addressed During Review

- The importance of human factors and actions in the conduct of operations of an irradiation and radioisotope production facility
- Coordination with local community resources to respond to low-frequency hazards (e.g., fire, chemical, aircraft impact, etc.)
- Broadening of cyber security assessments to all critical digital assets

Conclusion and Recommendation

- The staff SER and SHINE OL application provide a comprehensive perspective of important safety aspects of the design and operation of the SHINE facility.

- The OL for the SHINE Medical Isotope Production Facility should be issued.

Lessons Learned

- Grouping chapters for review requires close coordination with staff and applicant to ensure the logical sequencing of topics
- Sequencing our review to align with the release of the SER with no open items allows Members to focus on important aspects of the application
- Committee flexibility is important once the review sequence is established to accommodate schedule uncertainty
- Having individual members conduct detailed review of chapters within their expertise and presenting the important safety results allows the Committee to identify and focus on cross-cutting safety issues, improving the efficiency of our review

Methodology for Establishing Plume Exposure EPZs at NuScale SMR Plant Sites

Walt Kirchner, Chair

NuScale Subcommittee

Current Emergency Planning Zone (EPZ) Size

- Generally, the EPZ size for nuclear power plants is defined by:
  - a plume exposure pathway EPZ area of about 10 miles in radius and
  - an ingestion pathway EPZ area of about 50 miles in radius
- The basis for current emergency planning (and EPZ size) was developed in NUREG-0396 (1978)
- The primary objective was to produce “dose savings” for a spectrum of accidents that could result in doses in excess of Protective Action Guidelines (PAGs)

Current EPZ Technical Basis

- Appendix I to NUREG-0396 provides the rationale for the recommended generic plume exposure pathway EPZ radius of 10 miles
- Recognizing the need for defense-in-depth, this recommendation was based on a review of the consequences of design basis accidents from operating LWRs and a spectrum of beyond design basis (or severe) accident sequences from WASH-1400

Other Considerations

- Provisions exist in 10 CFR 50.47 for sizing EPZs on a case-by-case basis for gas-cooled nuclear reactors, and for reactors ≤250 MWt
- Significant advancement in knowledge base and methods for severe accidents (i.e., post-Fukushima actions, PRAs, MELCOR, MACCS, SOARCA study)
- The concept of a consequence dose/distance EPZ size for SMRs was explored in SECY-11-0152 and elaborated upon in an NEI White Paper (2013)

NuScale Methodology

- NuScale's topical report (TR) describes a dose-consequence methodology to determine the size of the plume exposure pathway EPZ for the NuScale SMR plant sites
- The methodology is generally consistent with the technical basis and criteria in NUREG-0396
- Requires a technically acceptable, full-scope PRA, uses RELAP and MELCOR to develop source terms, and requires MACCS for consequence analysis
- Their approach is similar to that of Clinch River ESP, and meets the intent of SECY-20-0045 and the draft EP rule for SMRs

NuScale Methodology (Cont.)

- The dose criteria are essentially:
  a) total effective dose equivalent from the design basis source term is less than or equal to 1 rem;
  b) the total effective dose equivalent from less severe accidents (containment intact) is less than or equal to 1 rem; or
  c) a substantial reduction in early health effects from more severe accidents (containment failure or bypass), i.e., an acute whole-body dose less than 200 rem
- The latter criterion effectively sets the plume exposure pathway EPZ size

Staff's Seismic-Related Conditions of Use

- Revision 3 of the TR contains a proprietary screening threshold for seismic events (which likely dominate the NuScale SMR's risk profile)
- The staff's conditions of use:
  - limit the screening threshold to sites with a ground motion response spectrum (GMRS) bounded by NuScale's certified seismic design response spectrum;
  - limit the seismic event screening threshold to NuScale's high confidence of low probability of failure (HCLPF) plant-level fragility; and
  - require confirmation of the GMRS and HCLPF plant-level fragility limits at the COL application and prior to fuel loading for the as-built plant

Summary

- The NuScale TR methodology for assessing plume exposure pathway EPZ size is technically adequate
- The staff's evaluation used risk information, consequence analyses, and considerations of uncertainty and defense-in-depth in justifying the adequacy of their safety finding
- The staff should preserve the insights gained from their review in guidance that can be used in future SMR applications
- We plan to review the initial application of this TR for a NuScale COL application
- Prudent emergency planning and preparedness will still require case-by-case application of defense-in-depth considerations to protect public health and safety

Draft 10 CFR Part 53 Rulemaking Language

Dave Petti, Chair

10 CFR Part 53 Rulemaking Subcommittee

Background

- Part 53 contains two frameworks
  - Framework A builds on industry/DOE sponsored Licensing Modernization Project (LMP)
  - Framework B resulted from industry comments for the need for a more traditional deterministic approach to align with other international approaches such as IAEA
- Any approach needs to demonstrate an equivalent level of safety with current Parts 50 and 52
- Staff responses to our concerns are denoted in blue text

ACRS Findings and Recommendations (1/7)

- The Rule package and associated guidance are adequate to solicit public comments

- Framework A
  - Viable logical framework
  - A flexible technology-inclusive performance-based regulatory pathway for light water reactors (LWRs) and non-LWRs.
  - Risk informed
  - Consistent with LMP (with PRA in a ‘leading’ role)

ACRS Findings and Recommendations (2/7)

- Framework B is newer and still evolving; significant changes may still occur.
  - Substantive improvements over previous drafts
  - Risk-informed performance-based approach
    - siting
    - seismic design criteria and seismic design
  - More technology inclusive requirements
    - fire protection and
    - additional licensing basis events
  - Common language now with Framework A on human factors engineering, staffing, operator licensing, and training

ACRS Findings and Recommendations (3/7)

- Preamble provides
  - the rationale behind the two frameworks
  - a clear understanding of the depths of the differences in the requirements in the two frameworks
  - valuable context relative to assuring that a technology-inclusive performance-based framework (Framework A) yields comparable levels of safety to the existing regulatory requirements

ACRS Findings and Recommendations (4/7)

- Preamble provides an evaluation of equivalent level of safety
  - Similar to integrated assessment of plant risk using principles of integrated risk-informed decision making as described in RG 1.174
  - Cross-walked requirements in Framework A against existing set of requirements
  - Industry performed tabletop pilot studies on a variety of advanced reactor designs; results indicate the approach:
    - is flexible and workable,
    - did not set a higher regulatory bar for safety,
    - showed a way to incorporate risk insights into the design and regulatory review.

ACRS Findings and Recommendations (5/7)

- The Alternative Evaluation for Risk Insights (AERI) approach should be expanded beyond the Rule and made available for applicants to pursue under 10 CFR Parts 50 and 52.
  - Table-top exercise should be performed

- The concept of a “self-reliant mitigation facility” needs a more succinct and consistent definition given significance to operator licensing and interrelationship with AERI.
  - Staff did improve the definition
  - Staff clarified AERI entry conditions and need for operator action are separate concepts

ACRS Findings and Recommendations (6/7)

- The Rule should explicitly mention that there will always be a human being maintaining oversight of an operating reactor, providing a last line of defense independent of design features.
  - Staff stated in reconciliation letter that performance-based demonstrations or prescriptive minimum requirements would serve to ensure that there is always operator staffing overseeing facilities

ACRS Findings and Recommendations (7/7)

- The discussion of defense in depth should be amplified to address more explicitly the possible role of inherent and passive characteristics in accident prevention and mitigation.
  - Balance between prevention and mitigation is different in non-LWRs
  - These safety characteristics may have to be relied upon in combination with engineering judgement and data from a robust start-up testing to compensate for lack of applicable operating experience
  - Staff agreed with this recommendation

Additional Recommendations and Status (1/4)

- Improved discussion of safety functions (explicit in Framework A; implicit in Framework B through safety design criteria)
  - Staff anticipates changes to RG 1.232 to align design criteria to relevant safety functions for applicability to Framework B
- Streamlining the rule – shorter than Part 50 or 52 but may still be too long relative to expectations of stakeholders. Tradeoff between clarity and overall rule length.
  - The staff continues to look for areas to streamline

Additional Recommendations and Status (2/4)

- Manufacturing Licenses
  - Large changes in rule language
  - New licensing pathway for potential microreactor designs
  - Exercise prudence while more experience is gained.
- Facility Safety Program
  - Intended to improve the efficiency of NRC's licensing and reactor oversight programs at the individual facility level.
  - Should be implemented under Framework B as well as Framework A.
- Integrity Assessment Program
  - Addresses potential degradation in SSCs early in life especially in view of the historical experience with LWRs and more importantly because of the lack of operating experience with new coolants in non-LWRs.
  - Prudent addition to Part 53

Additional Recommendations and Status (3/4)

- Safety Classification: The historical process resulted in too many systems being classified as important to safety, but later found in the PRA to not have major risk significance.
- The comment was intended to optimize the “safety footprint” in a design
  - Would have major benefits for both the licensee and the regulator by keeping focus on risk significant components.
  - This is especially important for designs with new technologies and little operating experience.
  - Staff agrees with the concept and feels the Framework A and Framework B classification systems are adequate

Additional Recommendations and Status (4/4)

General Licensed Reactor Operators

- Generally, support concept of GLROs
  - Adequate level of qualification for the specific type of facility
  - Staff improved clarity in the definitions and tie between self-mitigation facility and GLRO
- Looking Ahead
  - It will be important for licensee and the GLRO to realize the weight of a certification decision
  - Licensees must diligently ensure certification requirements are met
  - NRC inspections must be thorough and frequent enough to ensure effective operator qualification programs

Closing Comments

- Industry provided comments in our meeting about their concerns with Part 53
  - Some industry support Part 53 and some do not. Achieving full consensus may not be possible
- There are valuable pieces of Part 53 being used by non-LWR applicants
  - RG 1.232 (principal design criteria for advanced reactors) and 1.233 (risk-based selection of licensing basis events, defense-in-depth evaluation)
- In addition, the two new draft reg guides will be valuable for any non-LWR applicant independent of path
  - Draft RG 1.254 – technology inclusive approach for identifying postulated accidents
  - Draft RG 1.255 – AERI - novel approach for microreactors

Kairos Power, LLC, Construction Permit Application for Hermes

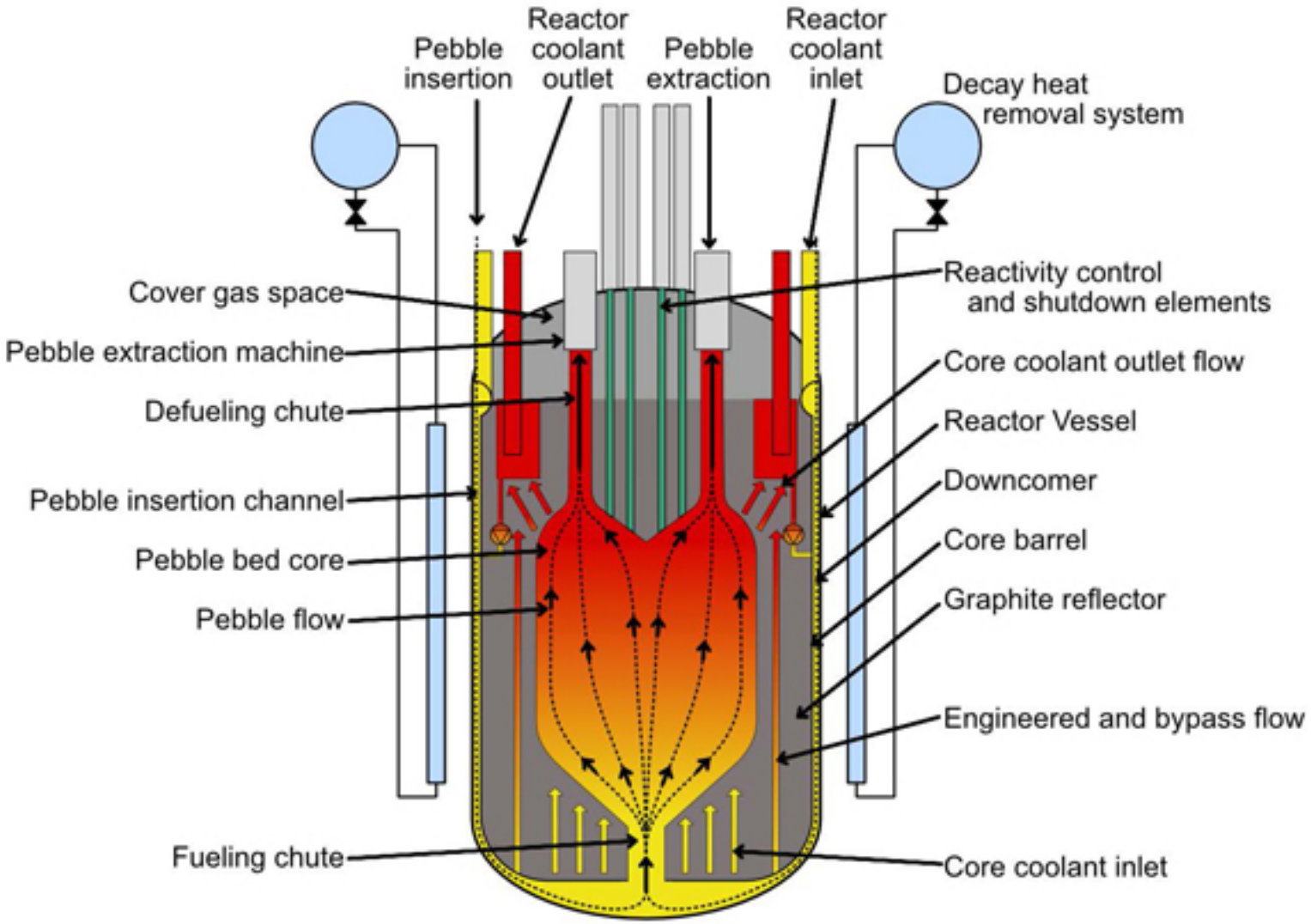
Dave Petti, Chair

Kairos Subcommittee

Preface

- Letter structure reflects our evolving approach for advanced reactor reviews and
  - Builds on lessons from NuScale and SHINE reviews
  - Top-down focus
    - ❖ Novel features
    - ❖ Key safety functions: what are they, how are they implemented and how do they work
    - ❖ Principal design criteria, SSC classification and Defense in Depth
    - ❖ Postulated event selection, safety analysis and safety margin
    - ❖ Operational reliability
    - ❖ Worker safety
    - ❖ Technology development required

Hermes Test Reactor



Novel Aspects of Hermes Design

- First nuclear reactor application of functional containment
- First application of ASME, Section III, Div 5 for high temperature materials
- Buoyancy of the fueled pebbles and graphite in the Flibe coolant
- A spherical shell of TRISO particles in a pebble that is smaller than that used in German and Chinese high temperature reactors
- Anti-siphon features to limit loss of coolant inventory in event of pipe break
- Four fluidic diodes to enable natural circulation when forced circulation is lost
- Pebble handling system that provides for handling, sorting, and storing fuel and moderator pebbles

Conclusions and Recommendations (1/3)

- Key attributes of the Hermes design include:
  - low thermal power of the reactor,
  - use of TRISO fuel and Flibe coolant as an effective functional containment, and
  - passive heat removal capability.
- The overall design results in projected dose consequences with large margins to regulatory siting criteria, allowing a unique approach to the safety classification of components.

Safety Functions

- Limit Release of Radionuclides
  - Use of Functional Containment
- Control Heat Removal
  - Heat is transferred by conduction through fueled pebbles, natural circulation of the Flibe coolant and then by conduction through vessel
  - Fluidic Diode to enable natural circulation of Flibe in the vessel
  - Passive Decay Heat Removal System: Four independent trains. Three are sufficient to remove heat
  - Testing planned to verify operational aspects of the system
- Control Reactivity
  - Two sets of control elements: four elements in the reflector to control reactivity and three shutdown elements in the pebble bed to shutdown the reactor
  - Only two of three shutdown elements needed to shutdown reactor
  - Testing planned to confirm operation
  - Strong inherent negative temperature coefficient of the fuel, coolant and moderator

No AC power or operator action needed to mitigate a DBE

Functional Containment

- Two inherent robust barriers
  - TRISO fuel
  - Flibe
- Unique combination results in a very small source term from fission products
  - Fuel failure assumed to be 100 x greater than found in DOE TRISO fuel qualification program
- Projected doses are 100 x below regulatory siting criteria
- Doses dominated by tritium generated in Flibe and Ar-41 from activation of argon cover gas and air trapped in graphite porosity, not fission products

Impact of Functional Containment and Safety Margin on Safety Classification

- Reactor vessel is safety-related but attached piping is non-safety related
  - Historical practice and defense in depth suggest piping should be safety related
  - Safety analysis takes no credit for piping
  - Flibe does not react with air, thus piping does not prevent chemical reaction as it does in a sodium reactor
  - Large safety margin to dose limits
- In this case, safety margin outweighs historical practice, but design specific evaluations required

We anticipate other types of departures from historical practice for advanced reactors and plan to understand the rationale for the departure as part of our evaluation of the relevant safety issue

Conclusions and Recommendations (2/3)

- Because of the first-of-a-kind nature of the FHR technology, there are performance uncertainties that can be most directly addressed during Hermes operation
  - A scaled demonstration plant like Hermes will be valuable to test key technical elements, design features, safety functions, and equipment performance for this technology
  - A key concern is the management of airborne beryllium and tritium in the facility to stay below relevant regulatory limits and protect the safety of workers

Performance uncertainties most directly addressed by operation of Hermes

- Control of chemical potential in salt coolant under irradiation and in a thermal gradient
- Control of Flibe near eutectic composition to limit viscosity changes
- Effect of impurities in the salt on fuel performance

In addition, the presence of uranium impurities and fission products in the Flibe produces a mixed waste. Kairos has identified a disposition path for the Flibe.

Conclusion and Recommendations (3/3)

- As noted by the staff in their SE, there is confidence that the facility can be constructed in accordance with relevant regulations and the design bases outlined in the PSAR.
  - Detailed design, analysis, and technology qualification will be completed prior to the Operating License review.
  - Combustible gas generation, associated with graphite oxidation, should be included in these evaluations.
- The construction permit for Hermes should be approved

Remaining Technology Development

- Necessary to confirm adequacy of the design of SSCs to resolve safety questions
  - Fuel pebble behavior
  - High temperature metal and graphite qualification and surveillance
  - Oxidation of graphite
  - Validation of computer codes
  - Development of fluidic diode
  - Justification of thermodynamic and vapor pressure correlations used in source term analysis
  - Development of process sensor technology for reactor coolant chemical monitoring instrumentation
- Kairos stated these activities will be finished before completion of construction
- Staff has noted these items in their review and tracking them to closure

Acronyms

- AC – Alternating Current
- ACRS – Advisory Committee on Reactor Safeguards
- AERI – Alternative Evaluation for Risk Insights
- ASME – American Society of Mechanical Engineers
- CFR – Code of Federal Regulations
- COL – Combined License
- DBA – Design Basis Accident
- DBE – Design Basis Event
- DI&C – Digital Instrumentation and Control
- DOE – Department of Energy
- EP - Emergency Plan
- EPZ – Emergency Planning Zone
- ESP – Early Site Permit
- FHR – Fluoride Salt Cooled, High Temperature Reactor
- Flibe – Mixture of Lithium Fluoride and Beryllium Fluoride
- GLRO – Generally Licensed Reactor Operator
- GMRS – Ground Motion Response Spectrum
- HCLPF – High Confidence of Low Probability of Failure
- IAEA – International Atomic Energy Agency
- LBE – Licensing Basis Event
- LMP – Licensing Modernization Project
- LOCA – Loss of Coolant Accident
- LWR – Light Water Reactor
- MACCS – MELCOR Consequence Code System
- MELCOR – Methods for Estimation of Leakages and Consequences of Releases
- MHA – Maximum Hypothetical Accident
- MWt – Megawatts thermal
- OL – Operating License
- NRC – U.S. Nuclear Regulatory Commission
- PAGs – Protective Action Guidelines
- PRA – Probabilistic Risk Assessment
- PSAR – Preliminary Safety Analysis Report
- PWR – Pressurized Water Reactor
- RELAP – Reactor Excursion and Leak Analysis Program
- RG – Regulatory Guide
- SER – Safety Evaluation Report
- SLR – Subsequent License Renewal
- SMR – Small Modular Reactor
- SOARCA – State of the Art Reactor Consequence Analyses
- SSCs – Systems, Structures and Components
- TR – Topical Report
- TRISO – Tri-structural Isotropic