

## Modular HTGR Safety Analysis and Licensing Challenges

### Challenges to Establishing an Acceptable HTGR Licensing Basis

- Deciding the technical approach and criteria for concluding that modular HTGRs meet the Commission's expectations for advanced reactors that they provide for enhanced margins of safety to accomplish their safety functions.
- Deciding the technical approach and criteria for concluding that the integrated risk posed by the multiple reactor modules of an HTGR modular plant at a site in meeting the Commission's safety goals.
- Developing an acceptable approach for utilizing risk information and deterministic information in establishing the plant licensing basis.
  - Utilizing event probabilities, including uncertainties and engineering judgement in selecting events to be included in the licensing basis
  - Establishing safety margin and defense-in-depth requirements to adequately accommodate uncertainties and unknowns for non-LWR plant designs which have limited operational experience, but utilize inherent characteristics and passive SSCs to reliably achieve safety functions.
  - Establishing a risk-informed approach to equipment classification where calculated dose consequences may be very low for even the most limiting design basis events and beyond the design basis events.
  - Establishing functional performance requirements for radiological barriers (e.g., whether a vented confinement would be acceptable vs a traditional low leakage containment building).
  - Establishing methodology and quality standards for the plant PRA to ensure its acceptability as a reference for establishing the licensing basis
- Establishing an acceptable basis for potential (longer-term) changes to emergency planning requirements for plants that are proposed to be built on green field sites
- Ensuring that the expectations and standards for security and physical protection are adequately integrated with the expectations and standards for safety

### Challenges to Establishing an Acceptable Technical Basis for the Plant Safety Analysis

- Nuclear, thermal-hydraulic and accident analysis computer codes to be used in the safety analysis (e.g, models, experimental data, applications) will need to be verified and validated.
- Fuel performance analysis computer codes for use in the safety analysis (e.g, models, experimental data, applications) will need to be verified and validated.
- An acceptable fuel qualification test program, together with adequate and continuing controls that ensure the safety performance of the fuel supplied over the life of the plant will need to be established.

- An acceptable basis from operating experience, experimental data and analysis methods for predicting the performance and behavior of reactor metallic components and graphite structures within the HTGR pressure boundary system operating environment will need to be established.
- An adequate data base, models and methods to use and acceptably quantify fission product transport and release for calculating the accident source term on a mechanistic basis will need to be established.
- The technical basis for licensing a highly automated multi-modular plant with significantly reduced control room staffing and significantly reduced plant staffing (compared to LWRs) will need to be established.
- Selected fuel cycle, transportation and waste issues that stem from the PBMR fuel form and, material accounting and control issues that stem from the PBMR's continuous on-line refueling, will need to be resolved.

#### Challenges to Reviewing a HTGR (e.g., PBMR) Application

- Significant safety research will be required to develop the technical tools, data and expertise need to support an effective and efficient independent NRC safety review of an HTGR application.
  - PRA models and data
  - Human performance analysis
  - Advanced Instrumentation and Controls
  - Thermal-Hydraulic and Systems Analysis
  - Accident and Severe Accident Analysis
  - Fuel Performance Analysis including Fuel Fabrication
  - Materials Performance Analysis
  - Structural Analysis
  - Fission Product Transport, Source Term and Consequence Analysis
- There are no HTGR-specific regulatory guides or HTGR-specific standard review plans. Additionally, the NRC technical staff has limited knowledge and expertise in the design, safety approach and technology of HTGRs. This will result in additional NRC challenges in conducting an HTGR safety review. Technical reviewer knowledge and capabilities will need to be developed across a range of technical review areas.
- The PBMR Pty plans to reference in the PBMR design, selected international codes and standards as well as selected US professional society code cases that have not been reviewed and endorsed by the NRC. NRC review resources will be needed to assess the acceptability of these references.
- Current LWR (e.g., Part 50) requirements either do not apply or do not address significant HTGR design features and use of new technologies. Deterministic technical and safety requirements will need to be established to address these features and technologies.

## REFERENCES

18. HTGR Licensing and Policy Issues
  - 1.A Licensing Policy Issues and PBMR Licensing Approach:
    - 1.A.1 SECY-03-0047, "Policy Issues Related to Licensing Non-light-water Reactor Designs," March 28, 2003 (ML030160002)
    - 1.A.2 SECY-04-0103, "Status of Response to the June 26, 2003, Staff Requirements Memorandum on Policy Issues Related to Licensing Non-light Water Reactor Designs" (ML041140521)
    - 1.A.3 "SECY-04-0157, "Status of Staff's Proposed Regulatory Structure for New Plant Licensing and Potentially New Policy Issues," August 30, 2004 (ML042370388)
    - 1.A.4 SECY-05-0006, "Second Status Paper on the Staff's Proposed Regulatory Structure for New Plant Licensing and Update on Policy Issues Related to New Plant Licensing," January 7, 2005 (ML043560093)
    - 1.A.5 SECY-05-0120, Security Design Expectations for New Reactor Licensing, July 6, 2005, (ML051100233)
    - 1.A.6 SECY-05-0130, "Policy Issues Related to New Plant Licensing and Status of the Technology-Neutral Framework for New Plant Licensing," July 21, 2005 (ML051670388)
    - 1.A.7 "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," March 15, 2002 (ML0208007090)
    - 1.A.8 "NRC Staff's Preliminary Findings Regarding Exelon Generation's (Exelon's) Proposed Licensing Approach for the Pebble Bed Modular Reactor (PBMR)," March 26, 2002, (ML0208600971)
    - 1.A.9 IAEA-TECDOC-xxxx, "Development of Technology Neutral Safety Requirements for Innovative Reactors." (Under development, available from IAEA)
    - 1.A.10 IAEA TECDOC 1366 "Considerations in the Development of Safety Requirements for Innovative Reactors: Application to Modular High Temperature Gas Cooled Reactors"
    - 1.A.11 IAEA-TECDOC-1362, "Guidance for the evaluation of innovative nuclear reactors and fuel cycles. Report of Phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)," Vienna, 2003. (Available from IAEA)
  - 1.B HTGR Safety and Technical Issues:
    - 1.B.1 "NRC Workshop: High-Temperature Gas-Cooled Reactor Safety and Research Issues," presentation by S. Rubin, RES to the IAEA INSAG, March 5, 2002 (not publically available in ADAMS - available from INSAG, IAEA)
    - 1.B.2 SECY-03-0059, "NRC's Advanced Reactor Research Program," April 18, 2003, (ML023310534).

- 1.B.3 IAEA TECDOC 988, High Temperature Gas Cooled Reactor Technology Development
- 1.B.4 IAEA TECDOC 1198, Current Status and Future Development of Modular High Temperature Gas Cooled Reactor Technology
- 1.B.5 IAEA TECDOC 899, Design and Development of Gas Cooled Reactors with Closed Cycle Gas Turbines
- 1.B.6 IAEA TECDOC 312, Gas-cooled Reactor Design and Safety
- 2. HTGR-Related Safety Research Results
  - 2.A PRA Models and Data
    - 2.A.1 DOE-HTGR-86-011 Rev 3 Volume 1 "Probabilistic Risk Assessment for the Standard Modular High Temperature Gas Cooled Reactor," January 1987
  - 2.B Advanced Digital Instrumentation and Controls
    - 2.B.1 NUREG-0700, Rev. 2, "Human-System Interface Design Review Guideline: Review Methodology and Procedures"
    - 2.B.1 NUREG-0711, Rev. 2, "Human Factors Engineering Program Review Model"
    - 2.B.2 NUREG-0800, Chapter 18, "Standard Review Plan - Human Factors Engineering"
    - 2.B.3 NUREG/IA-0137, "A Study of Staffing Levels for Advanced Reactors"
    - 2.B.4 NUREG/CR-5904, "Functional Issues and Environmental Qualification of Digital Protection Systems of Advanced Light-Water Nuclear Reactors"
    - 2.B.5 NUREG/CR-5941, "Technical Basis for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related I&C Systems"
    - 2.B.6 NUREG/CR-6393, "Integrated System Validation: Methodology and Review Criteria"
    - 2.B.7 NUREG/CR-6406, "Environmental Testing of an Experimental Digital Safety Channel"
    - 2.B.8 NUREG/CR-6431, "Recommended Electromagnetic Operating Envelopes for Safety-Related I&C Systems in Nuclear Power Plants"
    - 2.B.9 NUREG/CR-6436, "Survey of Ambient Electromagnetic and Radio-Frequency Interference Levels in Nuclear Power Plants"
    - 2.B.10 NUREG/CR-6579, "Digital I&C Systems in Nuclear Power Plants: Risk-Screening of Environmental Stressors and a Comparison of Hardware Unavailability with an Existing Analog System"
    - 2.B.11 NUREG/CR-6633, "Advanced Information Systems: Technical Basis and Human Factors Review Guidance"

- 2.B.12 NUREG/CR-6634, "Computer-Based Procedure Systems: Technical Basis and Human Factors Review Guidance"
- 2.B.13 NUREG/CR-6635, "Soft Controls: Technical Basis and Human Factors Review Guidance"
- 2.B.14 NUREG/CR-6636, "Maintenance of Digital Systems: Technical Basis and Human Factors Review Guidance"
- 2.B.15 NUREG/CR-6637, "Human Systems Interface and Plant Modernization Process: Technical Basis and Human Factors Review Guidance"
- 2.B.16 NUREG/CR-6690, "The Effects of Interface Management Tasks on Crew Performance and Safety in Complex, Computer-Based Systems"
- 2.B.17 NUREG/CR-6691, "The Effects of Alarm Display, Processing and Availability on Crew Performance"
- 2.B.18 NUREG/CR-6734, "Digital Systems Software Requirements Guidelines"
- 2.B.19 NUREG/CR-6749, "Integrating Digital and Conventional Human-System Interfaces: Lessons Learned from a Control Room Modernization Project"
- 2.B.20 NUREG/CR-6812, "Emerging Technologies in Instrumentation and Controls"
- 2.B.21 NUREG/CR-6842, "Advanced Reactor Licensing: Experience with Digital I&C Technology in Evolutionary Plants"
- 2.B.22 NUREG/CR-6848, "Preliminary Validation of a Methodology for Assessing Software Quality"
- 2.B.23 NUREG/GR-0019, "Software Engineering Measures for Predicting Software Reliability in Safety Critical Digital Systems"
- 2.B.24 NUREG/GR-0020, "Embedded Digital System Reliability and Safety Analyses"
- 2.C Human Performance Analysis
  - 2.C.1 NUREG/CR-6400, "HFE Insights for Advanced Reactors Based Upon Operating Experience"
  - 2.C.2 NUREG-1624, Rev 1, "Technical Basis and Implementation Guidelines for a Technique fo Human Event Analysis (ATHENA)"
  - 2.C.3 NUREG/CR-6690, The Effects of interface Management Tasks on Crew Performance and Safety in Complex, Computer-Based Systems"
- 2.D Thermal-Hydraulic Analysis and Systems Analysis
  - 2.D.1 IAEA TECDOC 1382, "Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to Initial Testing of the HTTR and HTR-10"

- 2.D.2 IAEA TECDOC 1163, "Heat Transport and Afterheat Removal for Gas Cooled Reactors under Accident Conditions"
- 2.D.3 IAEA TECDOC 1043, "Technologies for Gas Cooled Reactor Decommissioning, Fuel Storage and Waste Disposal"
- 2.E Accident and Severe Accident Analysis
  - IAEA TECDOC 757, "Decay Heat Removal and Heat Transfer under Normal and Accident Conditions in Gas Cooled Reactors"
- 2.F. Fuel Performance Analysis and Fuel Fabrication
  - 2.F.1 NUREG/CR-6844, "TRISO-Coated Particle Fuel Phenomena Identification and Ranking Tables (PIRTs) for Fission Product Transport due to Manufacturing, Operations and Accidents"
  - 2.F.2 IAEA TECDOC 978, "Fuel Performance and Fission Product Behavior in Gas Cooled Reactors"
- 3. Reviewing an HTGR Application
  - 3.1 Staff Readiness for New Nuclear Plant Construction and the Pebble Bed Reactor, COMJSM-00-0003, October 31, 2000
  - 3.2 Staff Requirements Memorandum (SRM) for COMJSM-00-0003, "Staff Readiness for New Nuclear Plant Construction and the Pebble Bed Modular Reactor, February 9, 2001
  - 3.3 SECY-01-0188, Future Licensing And Inspection Readiness Assessment, October 12, 2001, and subsequent semiannual FLIRA SECY reports
  - 3.4 Advisory Committee on Reactor Safety Meeting on Advanced Reactors (Workshop on Regulatory Challenges for Future Nuclear Power Plants), June 4, 2001
  - 3.5 DOE-HTGR-86-024 , Volumes 1 through 6, "Preliminary Safety Information Document for the Standard Modular High Temperature Gas-Cooled Reactor"
  - 3.6 NUREG-1338, Preapplication Safety Evaluation Report for the Modular High Temperature Gas -Cooled reactor (MHTGR) September, 1995