Modular High Temperature Gas-cooled Reactor: Licensing Experience

Advanced Reactor Technologies

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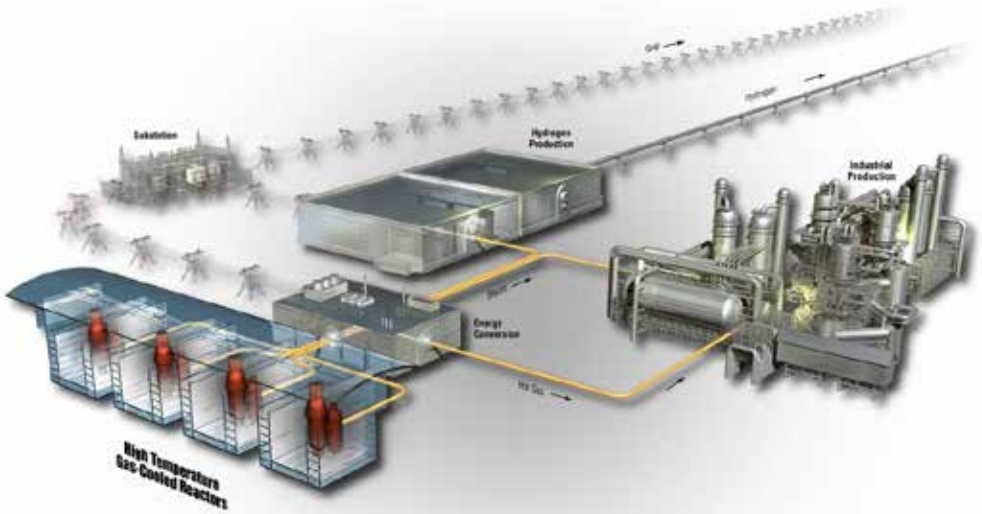
ADVANCED REACTOR TECHNOLOGIES

Past U.S. HTGRs and Licensing Approaches



US HTGR Licensing History

US Program	Licensing Period	Organization	Stage
Peach Bottom-1	1958 – 1966	PECO	OL Issued Decommissioned
Ft. St. Vrain (Prismatic)	1966 – 1972	PS Colo.	OL Issued Decommissioned
Summit (Prismatic)	1972 – 1975	GA	CP-LWA Submitted
MHTGR (Prismatic)	1986 – 1995	DOE/GA	Pre-App Review
Exelon DC (Pebble)	2001 – 2002	Exelon	Pre-App Review
PBMR DC (Pebble)	2006 – current	PBMR (Pty.) Ltd	Pre-App Review
NGNP (Prismatic/Pebble)	2009 – current	DOE	Pre-App Review

Peach Bottom Experience (1966-1974)

- Peach Bottom 1 – very successful - 40 MW(e)
  - Demonstrated variety of nuclear industry performance records
  - Average gross efficiency - 37.2%
  - Availability - 85%
  - No steam generator tube failures
  - Operator doses less than 10 man-rem/year
  - Load following demonstrated
  - Post examination of materials performed
- Lessons learned
  - Fuel element and coated particle design improvements

Fort St. Vrain Experience (1976-1989)

- Demonstrated excellent fuel performance, low operator doses, and core physics
- Demonstrated fuel handling / refueling approach
- Lessons learned
  - Helium circulator and seals leaked bearing water
  - Water cooling pump cavitation
  - Reserve shutdown malfunction
  - Hot helium bypass on control rod drives
  - Core thermal fluctuations
  - Core support floor - liner cooling system

General Atomics (GA) Modular HTGR: Pre-Application

- After Peach Bottom-1 and Ft. St. Vrain, the next major HTGR licensing effort was associated with the General Atomics Modular HTGR
- The GA design and licensing effort was based on a functional performance approach and included a number of key concepts that are similar to the current designs that are being refined and would likely be coming to NRC for review, such as:
  - Utilize inherent material properties
    - Helium coolant – neutronically transparent, chemically inert, low heat capacity, single phase
    - Ceramic coated fuel – high temp capability, high radionuclide retention
    - Graphite moderator – high temp stability, large heat capacity, long response times
  - Develop simple modular reactor design with passive safety
    - Retain radionuclides at their source within the fuel
    - Configure and size reactor for passive core heat removal from reactor vessel with or without forced or natural circulation of pressurized or depressurized helium primary coolant
    - Large negative temperature coefficient for intrinsic reactor shutdown
    - No reliance on AC-power
    - No reliance on operator action and insensitive to incorrect operator actions

GA MHTGR Policy and Licensability Issues

- Key Policy and Licensability Issues are summarized in NRC's Pre-Application Safety Evaluation Report for the MHTGR (NUREG 1338) and include:
  - Fuel Performance
  - Fission Product Transport
  - Source Term
  - "Unconventional" Containment
  - Accident Selection and Evaluation
  - Safety Classification of Structures, Systems, and Components
  - Emergency Planning

Identification of Key Policy Issues

- Key issues for modular HTGRs have been consistently confirmed:
  - MHTGR (NRC Draft SER NUREG-1338, 1989 and 1995)
  - Exelon PBMR licensing activities (2001)
  - NRC SECY documents (various, incl. 2002)
  - PBMR US design certification program (2005)
  - Jointly developed DOE-NRC licensing strategy for NGNP (2008)
  - NRC SECY 10-0034 (2010); “Policy and Technical Issues for SMRs”

Summary of
Next Generation Nuclear Plant Experience

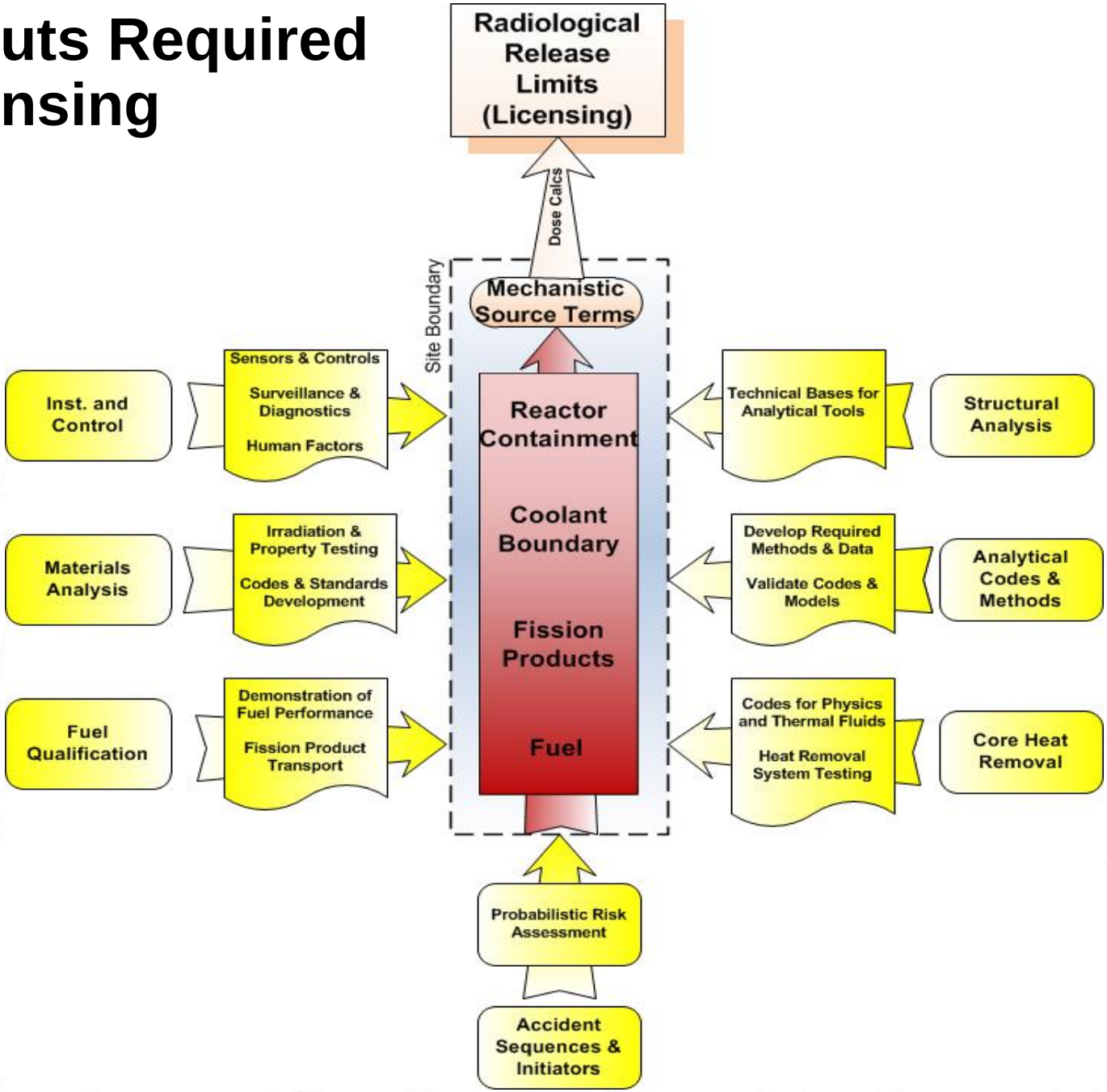
DOE-NRC Report to Congress (August 2008)

"It will be necessary to resolve the following NRC licensing technical, policy, and programmatic issues and obtain Commission decisions on these matters":

- Acceptable basis for event-specific mechanistic source term calculation, including the siting source term;
- Approach for using frequency and consequence to select licensing-basis events;
- Allowable dose consequences for the licensing-basis event categories;
- Requirements and criteria for functional performance of the NGNP containment as a radiological barrier

The best approach to establish the licensing and safety basis for the NGNP will be to develop a risk-informed and performance-based technical approach that adapts existing NRC LWR technical licensing requirements in establishing NGNP design-specific technical licensing requirements.

Key Inputs Required for Licensing



NGNP Licensing Working Group

- NGNP implemented a Licensing Working Group Concept
  - Provided a design-neutral licensing path that can be implemented by any modular HTGR design selected for deployment
  - Promoted a “single path” HTGR issue resolution efficiency for NRC
- Members included:
  - Three reactor vendors (AREVA, GA, Westinghouse/PBMR)
  - Representative owner-operator organization (Entergy)
  - INL - NGNP Research and Development
  - INL - NGNP Engineering
  - INL - NGNP Regulatory Affairs
- All NRC white paper submittals and follow-on interactions went through this process and represented the collaborative position of the domestic HTGR “fleet”

NGNP Licensing Framework Status – early 2012

- NRC issued two assessment reports providing the results of its working group review in the following areas:
  - Risk Informed Performance Based Approach to
    - Licensing Basis Event Selection
    - Classification of Structures, Systems, and Components
    - Defense in Depth
  - Fuel Qualification and Mechanistic Source Terms
- This NRC working group concluded: “No obvious fundamental issues that would prevent development of related licensing submittals that meet regulatory requirements…”
- NRC management clarified that the assessment reports reflected working group assessments that may not be consistent with broader NRC staff outputs

NGNP Letter – Requested NRC Staff Positions

- To achieve broader NRC staff feedback, NGNP submitted a request to NRC on July 6, 2012, to provide a description of the specific licensing framework topics where NRC staff positions are requested. Priority remains on the four key NGNP policy and technical focus areas:
  - Containment functional performance
  - Licensing basis event selection
  - Source terms
  - Emergency planning
- Work on TRISO particle fuel qualification topics also continued due to its safety case importance and close connection to the source term and functional containment topics

Fuel Qualification and Source Term White Papers

- Fuel Qualification White Paper – Purpose
  - Identify existing regulations, regulatory guidance, and licensing precedents relative to the qualification of fuel for NGNP
  - Review reactor and fuel designs and resulting fuel service conditions and performance requirements
  - Describe planned fuel fabrication, irradiation, testing activities
  - Obtain feedback from the NRC staff on the proposed approach to qualify the fuel

- Mechanistic Source Terms White Paper – Purpose
  - NGNP definition of event-specific mechanistic source terms for the HTGR is acceptable
  - Approach to calculating event-specific mechanistic source terms for HTGR technology is acceptable (subject to validation of the design methods and supporting data that form the bases of the calculations)
  - That the approach of planned fission product transport tests under the NGNP/AGR Fuel Development and Qualification Program, as supplemented by the existing irradiation and post-irradiation heating databases to validate these fission product transport analytical tools, is acceptable.

Fuel Qualification and Source Term Outcomes

White Paper	Submittal Date	NRC Public Meeting(s)
NGNP Fuel Qualification White Paper INL/EXT-10-18610	July 21, 2010	September 2, 2010 October 19, 2011 April 17, 2012
HTGR Mechanistic Source Terms White Paper INL/EXT-10-17997	July 21, 2010	July 24, 2012 September 20, 2012 November 14, 2012

- NGNP team responded to approx. 140 NRC RAIs
- Fuel Qualification
  - NRC's NGNP assessment concluded that the fuel qualification approach was generally reasonable, with certain caveats and open issues to be addressed
  - Advanced Gas Reactor (AGR) Program still ongoing
  - EPRI topical report planned for 2019 submittal requesting formal NRC review
- Source Terms
  - NRC's NGNP assessment determined that the proposed event-specific mechanistic approach is reasonable, but remains subject to resolution of several follow up items. Expected to be resolved as the AGR Program and HTGR design efforts proceed to completion
  - NRC has more recently issued SECY-16-0012, expanding and clarifying the use of the mechanistic source term approach to various advanced non-LWR designs

NRC Approval of the NGNP QAPD

- NGNP's Quality Assurance Program Description (QAPD) was submitted to the NRC for review
  - Original submittal in August 2010
  - Updated submittal in May 2011
  - NGNP then engaged in a series of follow-on discussions and provided written responses to NRC questions during the review
- NRC provided its approval of the QAPD for use in NGNP technology development and high level design activities (September 2012)
  - Approval assures that data and insights gained from currently ongoing R&D activities (particularly the AGR Fuel Qualification Program) can later be used directly by designers and license applicants

Note: The NGNP program structure and submittal was the first in the nuclear industry to utilize the NRC-endorsed guidance of American Society of Mechanical Engineers Standard NQA-1-2008, with 2009 addenda

Risk-Informed and Performance Based (RIPB) Approach to Event Identification and Evaluation

- The RIPB approach was developed and proposed through a series of four NGNP white papers:
  - Licensing Basis Event (LBE) Selection
  - Classification of Structures, Systems, and Components
  - Defense-In-Depth
  - Probabilistic Risk Assessment
- The bulk of NRC interactions were associated with the LBE Selection paper, with a focus around establishing a well-defined process for selecting LBEs, including:
  - Establishing acceptable limits on event sequence consequences,
  - Establishing the kinds of events, failures, and natural phenomena to be evaluated during the analysis
  - Identification of the design basis accidents to be included in Chapter 15 of the safety analysis

RIPB Interactions with NRC

White Paper	Submittal Date	NRC Public Meeting(s)
NGNP Defense-in-Depth Approach INL/EXT-09-17139	December 9, 2009	March 8, 2010
NGNP Licensing Basis Event Selection White Paper INL/EXT-10-19521	September 16, 2010	November 2, 2010 April 16, 2012 May 16, 2012 July 10, 2012 August 22, 2012 September 19, 2012 November 14, 2012
NGNP Structures, Systems, and Components Safety Classification White Paper INL/EXT-10-19509	September 21, 2010	November 2, 2010 July 10, 2012 September 6, 2012
NGNP Probabilistic Risk Assessment White Paper INL/EXT-11-21270	September 20, 2011	April 12, 2012 September 19, 2012

Emergency Planning Interactions with NRC

White Paper	Submittal Date	NRC Public Meeting(s)
Determining the Appropriate EPZ Size and Emergency Planning Attributes for an HTGR INL/MIS-10-19799	October 28, 2010	January 26, 2011 November 14, 2012

- NGNP proposed a consequence-based approach to emergency planning
- NGNP's proposal was later followed by similar inputs from NEI on behalf of the broader advanced reactor community
- In response, NRC issued SECY-11-0152 outlining high level guidance for moving forward with the proposed approaches

Licensing Interactions – Other Topics

White Paper	Submittal Date	NRC Public Meeting(s)
High Temperature Materials White Paper INL/EXT-09-17187	June 25, 2010	September 1, 2010
Licensing Structure for Multi- Module Facilities INL/EXT-10-18178	August 10, 2010	None
NGNP Nuclear-Industrial Facility and Design Certification Boundaries INL/EXT-11-21605	July 22, 2011	None

NRC Feedback – Assessment Outputs – Other Topics

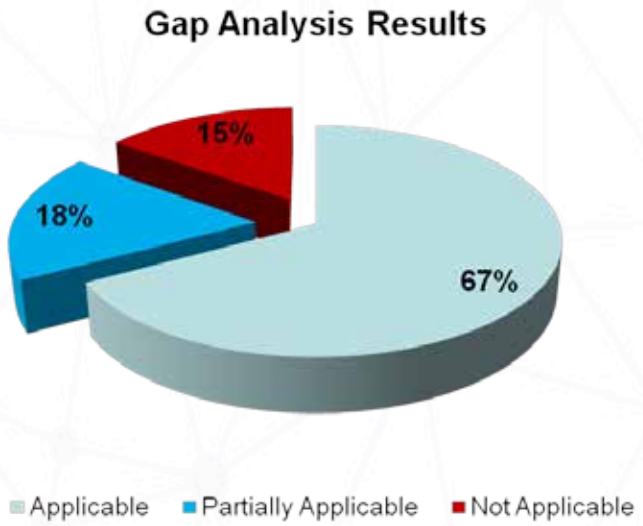
- "High Temperature Materials White Paper"
  - Principal materials proposed for NGNP primary systems were identified with approaches for regulatory compliance
  - NGNP responded to 108 NRC RAI's and NRC then issued assessment report (May, 2012)
  - NRC staff further stated an intention to not provide final conclusions regarding the design and qualification of any NGNP components, materials, or their use in the plant design, until such time as an NGNP COLA or DC application is submitted
  - White paper was updated to reflect results of NRC interactions and re-issued in August 2012
- "License Structure for Multi-Module Facilities White Paper"
  - Described the NGNP proposal regarding multi-module HTGR plant licensing with a single NRC review, hearing, and safety evaluation report
  - In response to the NGNP white paper and other related industry initiatives, the NRC issued SECY-11-0079, "License Structure for Multi-Module Facilities Related to Small Modular Nuclear Power Reactors"
- "NGNP Nuclear-Industrial Facility and Design Certification Boundaries White Paper"
  - Proposed to establish agreement regarding the boundary between a nuclear facility under NRC regulatory jurisdiction (i.e., within the scope of the DC and COLA) and the interface to energy end use facility(s) that fall outside the scope of nominal NRC authority (i.e., the industrial facility)
  - Not reviewed by NRC due to resource limitations (agreed by NGNP)

Licensing Framework Interactions with NRC (cont.)

White Paper	Submittal Date	NRC Public Meeting(s)
Modular HTGR Safety Basis and Approach INL/EXT-11-22708 (submitted for information only)	September 6, 2011	None

NGNP Regulatory Gap Analysis

- Evaluated ~2,600 individual regulatory requirements and regulatory guidance positions for applicability to modular HTGRs
- Identified 15 existing regulations that would need to be modified or otherwise addressed for HTGRs
  - 10 CFR 50 Appendix I which addresses ALARA limits for LWR effluents
  - Appendix J which describes how an LWR containment structure must be leak tested
- Confirmed overall approach of limiting rulemaking to extent possible
  - Adapt existing NRC LWR technical licensing requirements in establishing NGNP design-specific technical licensing requirements
  - NRC positions established through guides or SECY papers
- Gap analysis results summarized in INL/EXT-11-23216



NGNP Regulatory Gap Analysis (cont.)

In addition to the gap analyses results summarized in the “Applicable,” “Partially Applicable,” and “Not Applicable” categories, the analysis also identified unique modular HTGR topics that would require additional consideration, including:

- HTGR Fuel Design and Qualification
- High Temperature Ceramic Materials and Composites
- Functional Containment of Radionuclides
- Establishment of Risk Metrics (alternative to CDF and LERF)
- Passive Safety System Performance Requirements
- Helium Leak Detection
- Accident Analysis
- Classification of Structures, Systems, and Components

Summary of NRC Interactions

- DOE and NRC efforts on NGNP were aligned with the jointly developed NGNP Licensing Strategy (2008 Report to Congress)
- First phase of NRC interactions occurred late 2008 through late 2011
  - NRC working group assessment issued early 2012
- Energy Secretary suspended design/deployment efforts in October 2011, but directed that R&D and regulatory framework development should continue
- Second phase of NRC interaction focused on agreed upon priority Commission policy topics and TRISO particle fuel qualification, and resulted in August 2014 NRC Assessment Report
  - Also see draft report provided to ACRS in March 2013
- Administrative Information:
  - Assigned NRC Project (Docket) number for NGNP is: PROJ0748
  - NGNP submitted a total of 11 white papers, and responded to approximately 450 RAIs
  - There were approximately 30 public meetings associated with the NRC Staff's review of NGNP proposals

Suggested Reading

“NRC Licensing Status Summary Report for NGNP,” Rev. 1, INL/EXT-13-28205 (Nov. 2014) https://www.osti.gov/biblio/1236815-nrc-licensing-status-summary-report-ngnp

Other Key Outcomes Since NGNP Affecting HTGRs

- ARDC Reg. Guide 1.232 for developing principal design criteria
  - Result of DOE-NRC joint initiative
- SECY 18-0096 and SRM on Functional Containment Performance Requirements
- Ongoing Emergency Planning Rulemaking
- NRC Guidance on Prototype Reactors

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