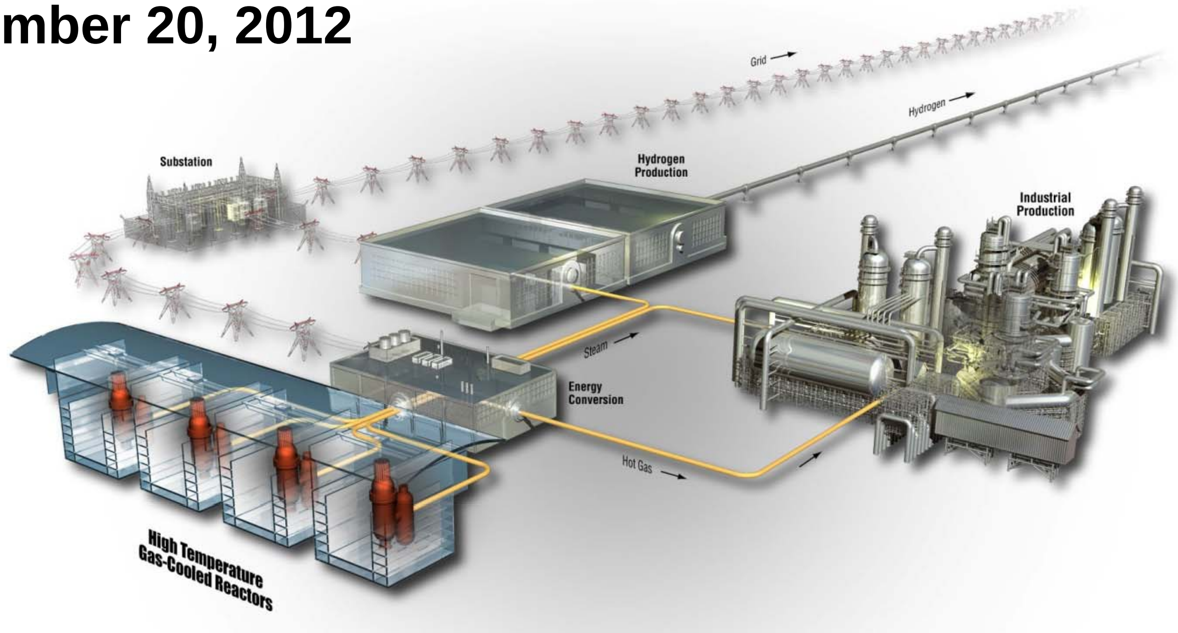
NRC Public Meeting

NGNP Siting Source Terms Approach

Next Generation Nuclear Plant

September 20, 2012



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Meeting Purpose

- To discuss with the NRC staff NGNP's approach to developing siting source terms for the HTGR, answer staff questions, and reach consensus regarding key aspects of the approach.
- To provide supporting information regarding:
    - The request in NGNP's July 6, 2012 letter to NRC, *Confirmation of Requested NRC Staff Positions*, and
    - Issue FQ/MST-19, *Determination of Bounding Source Terms*, identified from the FQ/MST working group assessment paper.

Meeting Purpose (cont.)

- The relevant requested staff positions in NGNP's July 6, 2012 letter to NRC, *Confirmation of Requested NRC Staff Positions*:

  1. Functional Containment Performance Requirements for NGNP

  - Establish a staff position to support a final determination regarding how LBEs will be considered for the purpose of plant siting and functional containment design decisions, taking into consideration previous staff positions in SECY-95-299, that improved fuel performance is a justification for revising siting source terms and containment design requirements. In particular, we request that this staff position provide an adaptation of the guidance that has generally been applied to light water reactors (LWRs) for compliance with 10 CFR 100.21.
  - Establish options regarding functional containment performance standards as requested by the Commission in the Staff Requirements Memorandum (SRM) to SECY-03-0047, "Policy Issues Related to Licensing Non-Light Water Reactor Designs," and discussed further in SECY-05-006, "Second Status Paper on the Staffs Proposed Regulatory Structure for New Plant Licensing and Update on Policy Issues Related to New Plant Licensing."

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Meeting Purpose (cont.)

- The relevant requested staff positions in NGNP's July 6, 2012 letter to NRC, *Confirmation of Requested NRC Staff Positions* (cont.):

3. Establishing Mechanistic Source Terms for NGNP

- Agree that NGNP source terms are event specific and determined mechanistically using models of radionuclide generation and transport that account for fuel and reactor design characteristics, passive features, and the radionuclide release barriers.

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Meeting Purpose (cont.)

- Address issue from FQ/MST working group assessment paper, Issue FQ/MST-19 (p 27-28):
  - *Determination of Bounding Source Terms: The regulatory examination of DID capabilities (see Title 10 Code of Federal Regulations, Part 100 (10 CFR 100)) requires that a large release of radioactivity from the reactor coolant system to the reactor containment be hypothesized, consistent with expectations of a major accident at the reactor facility. This regulatory requirement is "technology neutral," predicated on the potential for severe events that could result in substantial releases of radioactivity from reactor fuel. <u>The working group believes that BDBE's significantly more severe than those considered to date in the white papers on MST and LBE selection should be evaluated for calculating bounding source terms.</u> The Project is correct in noting that the LWR oriented containment source term definition invoking a severe accident with extensive fuel melting is not applicable to modular HTGRs...*

Meeting Purpose (cont.)

- Address issue from FQ/MST working group assessment paper, Issue FQ/MST-19 (p 27-28) (cont.):
  - *…. The definition more pertinent to modular HTGRs would be the severe event induced releases to the reactor building and to the environment of <u>(a) radionuclides released from fuel elements resident in the core during the accident and (b) long-lived radionuclides that have gradually accumulated in the primary system over many years of normal operation.</u> The Project's definition of event-specific mechanistic source terms for the HTGR is generally consistent with the traditional staff definitions. However, the working group believes that appropriate consideration should be given to all available barriers in the assessment of event-specific mechanistic source terms.*

Siting Source Term Presentation Outline

- HTGR Safety Design Basis
- Regulatory Background Supporting NGNP Siting Source Terms (SSTs) Approach
- NGNP Approach to SSTs
- Adopting the NGNP SSTs Approach
- Overall Conclusions
- Discussion/Questions
- Additional Slides on HTGR Safety Design Basis

HTGR Safety Design Basis

Modular HTGR Safety Design Approach

- 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 fuel
  - Shape 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

Major Design Impact of Safety Philosophy

Emphasis on retention of radionuclides at source (within fuel particles) means:

- Manufacturing process must lead to high quality fuel
- Normal operation fuel performance must limit potential for immediate radionuclide release during off-normal conditions – coolant is continuously monitored during operation for circulating activity
- Off-normal fuel performance must limit potential for delayed radionuclide release to a small fraction of non-intact fuel particles from manufacturing and normal operation conditions

Safety Design Focus

- High fuel manufacturing quality and normal operation fuel performance aim at ensuring the HTGR could release activity outside of fuel (e.g., circulating) and stay within offsite accident dose limits

- Thus, safety design focus is on limiting incremental releases from fuel during off-normal events down to the beyond design basis event region

Safety Design Approach Summary

- Top objective is to meet the EPA PAGs at the site boundary for spectrum of events within and beyond the design basis
- Responsive to Advanced Reactor Policy
  - use of inherent or passive means of reactor shutdown and heat removal
  - longer time constants
  - simplified safety systems which reduce required operator actions
  - minimize the potential for severe accidents and their consequences
  - safety-system independence from balance of plant
  - incorporate defense-in-depth philosophy by maintaining multiple barriers against radiation release and by reducing potential for consequences of severe accidents
  - citation of existing technology or which can be satisfactorily established by commitment to a suitable technology development program
- Multiple barriers with emphasis on retention at the source within fuel

Regulatory Background Supporting NGNP SSTs Approach

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MHTGR Licensing Experience

- In the MHTGR PSID, DOE "proposed a mechanistic siting source term (SST) for site evaluations, in accordance with 10 CFR Part 100, on the basis that <u>no substantial fuel failure</u> will occur even when the reactor is subjected to the bounding events (BEs)."* (emphasis added)
- "The proposed SST [in the MHTGR PSID] is that radionuclide inventory in the primary system derived from a small amount of initially defective fuel that can be augmented to only a small degree by the occurrence of certain BEs."*

***[1989 Draft PSER, NUREG-1338, p 15-21]**

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MHTGR Licensing Experience (Cont.)

- "In its review of the DOE's mechanistic approach, the [NRC] staff has concluded that, for plant designs with long response times and the capability to withstand many low-probability events, it is acceptable and preferred to develop mechanistic bases rather than to follow the customary approach of postulating a non-mechanistic source term, which could obscure important phenomenological considerations."* (emphasis added)

***[1989 Draft PSER, NUREG-1338, p 15-21]**

MHTGR Licensing Experience (Cont.)

- “Furthermore, the mechanistic approach can be viewed as a safety enhancement in that the limits of the MHTGR's hazards would be technically defined rather than encompassed within a envelope that has not traditionally required complete technical accounting and understanding of all bounding events deemed credible.”* (emphasis added)

***[1989 Draft PSER, NUREG-1338, p 15-21]**

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MHTGR Licensing Experience (Cont.)

- "The [NRC] staff has <u>accepted</u> [DOE's proposed] source term for use in the MHTGR conceptual design review and has determined that it is in accordance with the criteria set forth in [PSER] Section 3.2.2.2, Siting-Source-Term Calculation and Use."*(emphasis added)
- "Final selection of SSTs for the MHTGR will depend mainly on factors such as the results of research programs…and further safety analysis."*

***[1989 Draft PSER, NUREG-1338, p 15-21]**

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MHTGR Licensing Experience (Cont.)

- "In its decision on source terms for the advanced reactors policy issues…the Commission approved the use of mechanistic source terms for the MHTGR."*
- "However, the Commission criteria for use of mechanistic source terms is that the source terms had to be based on:
  - The fuel performance being well understood,
  - Fission-product transport being adequately modeled, and
  - Events considered in the development of source terms include bounding severe accidents and design-dependent uncertainties."*

***[1995 Draft PSER, NUREG-1338, p 4-8 that references the criteria in SRM for SECY-93-092 and SECY-93-092, p 7-8]**

MHTGR Licensing Experience (Cont.)

- "…there were bounding events that were chosen by the staff to establish confidence in the ability of the design to prevent accidents that could result in significant core damage or offsite release of radioactive material."*
- "The bounding events were not rigorously qualified in terms of probability and the major assumptions were the following:
  - Select worst-case plant states as initial conditions.
  - Assume non-safety-grade equipment fails.
  - Assume failure of safety-grade equipment for a period of time.
  - Allow a reasonable time (consistent with emergency planning) to recover safety-grade equipment where no plant damage has occurred.
  - Assume multiple human errors or other initiating events consistent with events that have occurred.
  - Assure at least an equivalent challenge to that applied to LWRs."*

***[1995 Draft PSER, NUREG-1338, p 5-8]**

MHTGR Licensing Experience (Cont.)

- Bounding event sequences (BES) defined by the staff were provided to DOE in PSID RAI 15-7 and revised in RAI 15-8:*
  - BES-1 Inadvertent withdrawal of all control rods without scram for 36 hours (one module).
    - With forced cooling
    - Pressurized with RCCS cooling only
    - Depressurized with RCCS cooling only
  - BES-2 Station blackout (all modules) for 36 hours.
    - Pressurized
    - Depressurized
  - BES-3 Loss of forced cooling plus RCCS for 36 hours (one module).
    - Pressurized (RCCS 25% unblocked after 36 hours)
    - Depressurized (RCCS 25% unblocked after 36 hours)

***[PSID p R 15-7-2]**

MHTGR Licensing Experience (Cont.)

- Bounding event sequences (BES) defined by the staff were provided to DOE in PSID RAI 15-7 and revised in RAI 15-8 (continued):*
  - BES-4 Steam generator tube rupture (25% of tubes) with failure to isolate or dump.
    - With forced circulation cooling (depressurized)
    - Without forced circulation cooling (depressurized)
  - BES-5 Rapid depressurization (one module): double ended guillotine break of crossduct (sic) with failure to scram (assume RCCS failed for 36 hours and 25% unblocked thereafter).
  - BES-6 External events consistent with those imposed on LWRs

***[PSID p R 15-7-2]**

Staff Requirements - SECY-03-0047 - Policy Issues Related To Licensing Non-Light-Water Reactor Designs

- "The staff should develop [containment] performance requirements and criteria working closely with industry experts (e.g., designers, EPRI, etc.) and other stakeholders regarding options in this area, taking into account such features as core, fuel, and cooling systems design." (emphasis added)

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

- Issue 6: Use of Scenario-Specific Source Terms for Licensing Decisions - The Commission approved the use of scenario-specific source terms provided that the staff understands the fission product behavior and plant conditions and performance.
- The staff proposed to use a flexible, performance-based approach to establish scenario-specific licensing source terms. The key features of this approach are as follows:
  - Scenarios are to be selected from a design-specific PRA.
  - Source term calculations are based on verified analytical tools.
  - Source terms for compliance should be 95% confidence level values based on best-estimate calculations.
  - Source terms for emergency preparedness should be mean values based on best-estimate calculations.
  - Source terms for licensing decisions should reflect scenario-specific timing, form, and magnitude of the release.

NGNP Siting Source Terms (SSTs) Approach

NGNP Approach to SSTs

- NGNP's approach to SSTs is patterned after that developed by DOE and the NRC staff in the development and review in the late 1980s and early 1990s of the MHTGR Conceptual Design documents including the PSID and PRA.
  - Develop the design consistent with the safety design approach.
  - Utilize risk insights as input to the design for the range of user and regulatory requirements.
  - Select and mechanistically evaluate risk-informed LBEs including DBEs/DBAs as well as BDBEs, against the Top Level Regulatory Criteria (10CFR20, 10CFR50.34, and Prompt QHO) and the NGNP design goal (PAG at EAB).

NGNP Approach to SSTs (Cont.)

- Mechanistically evaluate events over LBE-spectrum that have limiting dose consequences for use as mechanistic SSTs and present to the staff for their review and agreement (e.g., MHTGR DBA 6, 10, and 11 in the PSID).

NGNP Approach to SSTs (Cont.)

- The MHTGR PSID identified 11 DBEs/DBAs and 5 BDBEs enveloped by 3 highest offsite consequence DBAs with frequencies in the DBE and BDBE regions:
  - DBA-6: Steam Generator (SG) offset tube rupture with SG isolation and immediate and indefinite loss of forced cooling leading to an early (min to hr) and a delayed (days) radionuclide release from Helium Pressure Boundary (HPB) via opening of Vessel System (VS) relief valve to the Reactor Building (RB)
  - DBA-10: VS relief line breach of HPB with immediate and indefinite loss of forced cooling leading to an early (sec to min) and a delayed (days) radionuclide release from HPB to RB
  - DBA-11: Instrument line leak in HPB with immediate and indefinite loss of forced cooling leading to an early (min to hr) and a delayed (days) radionuclide release from HPB to RB

NGNP Approach to SSTs (Cont.)

- To assure that there are no cliff-edge effects and to understand the ultimate safety capability of HTGRs, supplement the LBE-derived SSTs with insights from a best estimate mechanistic evaluation of bounding event sequences, with the understanding that:
  - Such events shall be physically plausible rather than arbitrary combinations of event parameters or end-states
  - While the bounding event sequences would not be rigorously qualified in terms of frequency it is expected that they would generally have frequencies lower than the BDBE region
  - Events and their evaluation will consider the intrinsic and passive characteristics and the safety behavior of the HTGR (e.g., six MHTGR bounding event sequences requested by NRC staff in MHTGR PSID RAIs)

NGNP Approach to SSTs (Cont.)

- Process Output
  - Ultimate product of the NGNP approach is a set of SSTs mechanistically derived from evaluation of a spectrum of limiting risk-informed LBEs supplemented with insights from credible bounding event sequences to assure no cliff edge effects.

Adopting the NGNP SSTs Approach

10CFR52.79(a) and the Footnote

- Agreement is needed on an interpretation of the 10CFR52.79(a) footnote for the NGNP HTGR technology. Current regulations:

  "The assessment must contain an analysis and evaluation of the major structures, systems, and components of the facility that bear significantly on the acceptability of the site under the radiological consequence evaluation factors identified in paragraphs(a)(1)(vi)(A) and (a)(1)(vi)(B) of this section. In performing this assessment, an applicant shall assume a fission product release [5] from the core into the containment assuming that the facility is operated at the ultimate power level contemplated."

  [5] "The fission product release assumed for this evaluation should be based upon a major accident, hypothesized for purposes of site analysis or postulated from considerations of possible accidental events. Such accidents <u>have generally been assumed</u> to result in substantial meltdown of the core with subsequent release into the containment of appreciable quantities of fission products." *(emphasis added)*

Interpretation of 10CFR52.79(a) Footnote

- NRC staff has stated that the assumptions underlying the bounding siting event for LWRs are not really technology neutral (HTGRs and their safety characteristics were not considered when the requirements were developed).*
- The wording of the footnote is clear that SST accidents have “generally” (but not necessarily always) “assumed” substantial meltdown of the core.
- It is clear that the language in the footnote recognizes that this assumption may not be appropriate in all cases, and that alternate assumptions can be used under certain circumstances.
- Therefore, a change to the regulation is not necessary for development of an interpretation of the footnote that is appropriate for use in HTGR licensing.

*NRC meeting summary (dated June 6, 2012) of April 16-17, 2012 public meeting with NGNP (p4)

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Proposed Alternative Guidance for 10CFR52.79(a) Regarding the HTGR SST

- **Existing footnote**:

  The fission product release assumed for this evaluation should be based upon a major accident, hypothesized for purposes of site analysis or postulated from considerations of possible accidental events. Such accidents have generally been assumed to result in substantial meltdown of the core with subsequent release into the containment of appreciable quantities of fission products.

- **Proposed alternative guidance**:

  The fission product release assumed for this evaluation should be based upon a major accident, hypothesized for purposes of site analysis or postulated from considerations of possible accidental events. Such accidents will be based on a spectrum of limiting, mechanistically evaluated, risk informed LBEs supplemented by insights from credible (i.e., physically plausible) bounding event sequences. Such bounding event sequences will take into account the safety behavior of the plant, and the associated fission product release will be evaluated mechanistically.

NRC Enforcement Options

- The HTGR COL holder would still comply with 10 CFR 52.79(a).
- Compliance with 52.79(a) would be documented in the FSAR and approved by the staff in an SER prior to license issuance. This analysis would become part of the plant's licensing and design basis.
- As with current LWRs, a deviation from FSAR requirements without a properly approved change would be enforceable through the conditions of the license and 10 CFR 52 FSAR change regulations.
- The fact that NGNP would utilize an HTGR-based application of the footnote in 52.79(a) would not affect NRC's ability to enforce compliance with the operating license.

Overall Conclusions

Overall Conclusions

- The NGNP SSTs approach is essentially the same as that proposed by DOE in the MHTGR PSID and accepted by the NRC staff in NUREG-1338.
- NGNP's SSTs approach supports the radionuclide containment performance requirements outlined in SRM-SECY-03-0047.
- The NGNP approach for SSTs is consistent with the approach proposed by the staff in SECY-05-0006 for scenario-specific source terms.

Overall Conclusions (cont.)

- This presentation supports several items from the request in NGNP's July 6, 2012 letter to NRC, *Confirmation of Requested NRC Staff Positions*:

  1. Functional Containment Performance Requirements for NGNP

  - Establish a staff position to support a final determination regarding how LBEs will be considered for the purpose of plant siting and functional containment design decisions, taking into consideration previous staff positions in SECY-95-299, that improved fuel performance is a justification for revising siting source terms and containment design requirements. In particular, we request that this staff position provide an adaptation of the guidance that has generally been applied to light water reactors (LWRs) for compliance with 10 CFR 100.21.
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Overall Conclusions (cont.)

- This presentation supports several items from the request in NGNP's July 6, 2012 letter to NRC, *Confirmation of Requested NRC Staff Positions (cont.)*:

  3. Establishing Mechanistic Source Terms for NGNP

  - Agree that NGNP source terms are event specific and determined mechanistically using models of radionuclide generation and transport that account for fuel and reactor design characteristics, passive features, and the radionuclide release barriers.

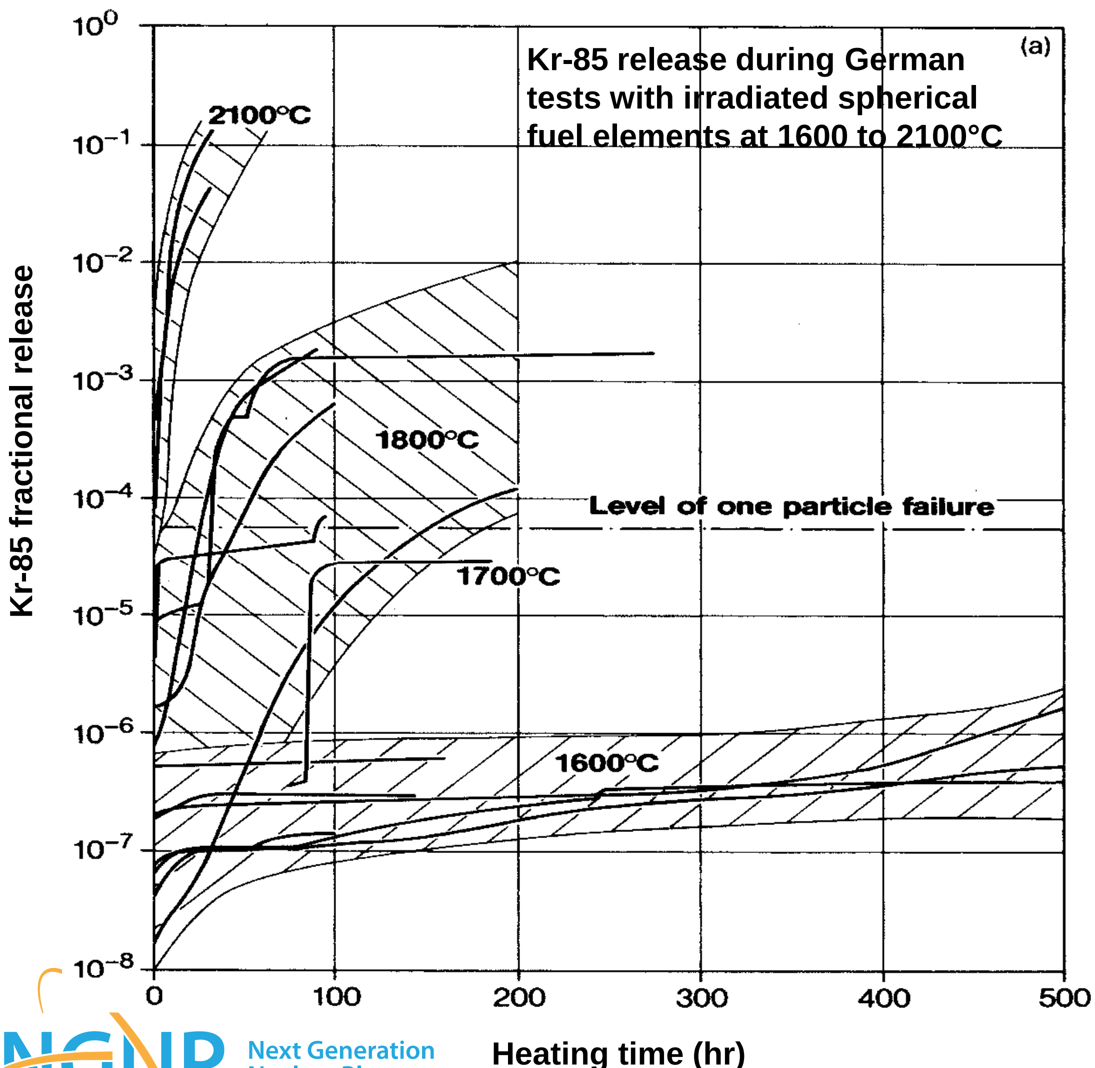
Overall Conclusions (cont.)

- This presentation supports resolution of issue FQ/MST-19 (p 27-28) from the FQ/MST working group assessment paper:
  - *…The working group believes that BDBE's significantly more severe than those considered to date in the white papers on MST and LBE selection should be evaluated for calculating bounding source terms.*

Discussion/Questions

Additional Slides on HTGR Safety Design Basis

Fuel Particles Are Highly Retentive 100's of Degrees Above Normal Operation

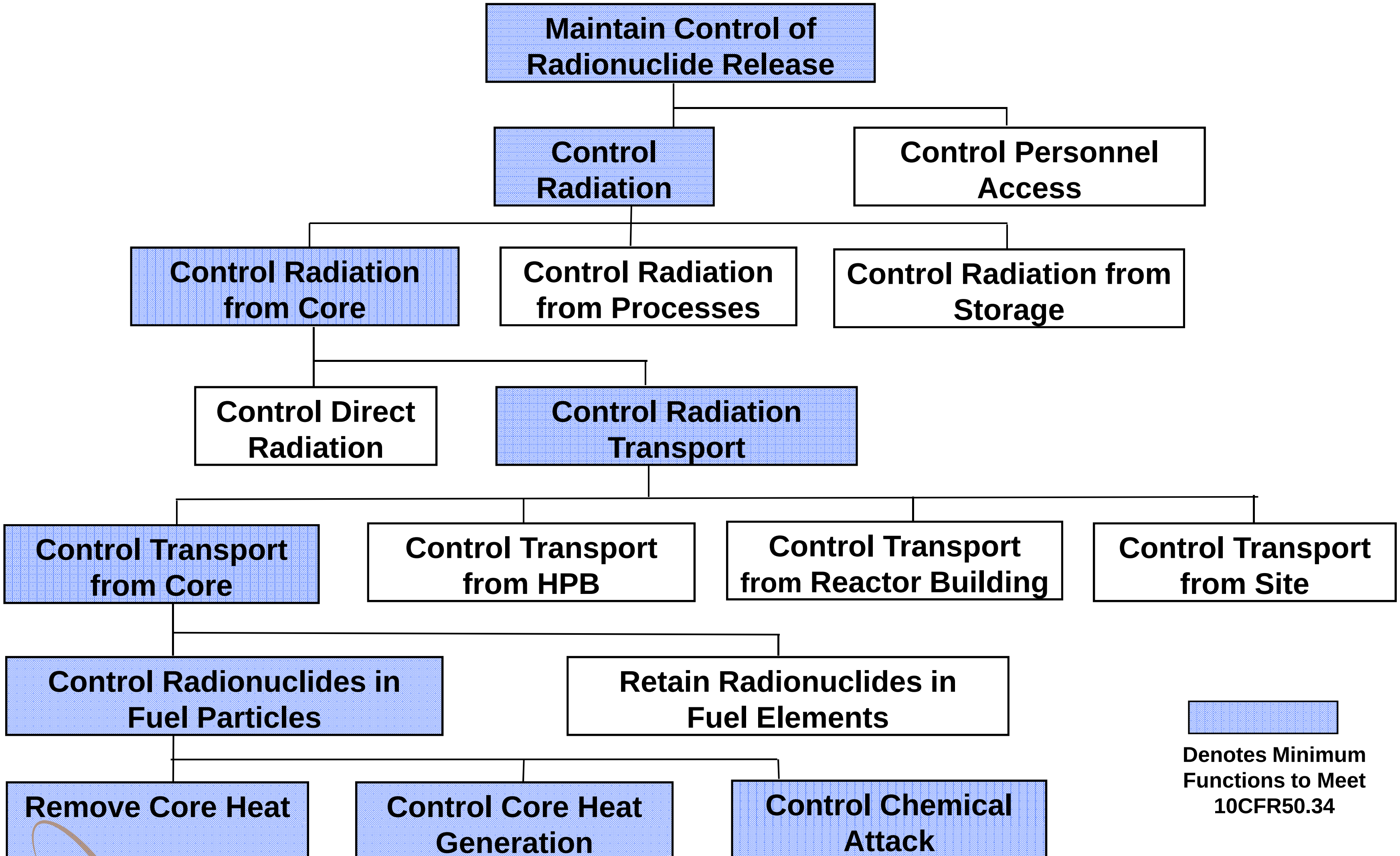


Normal operating peak fuel temperature less than 1250°C

Large temperature margins enable:

- Passive heat removal independent of coolant pressurization
- Greater use of negative temperature coefficient for intrinsic reactor shutdown

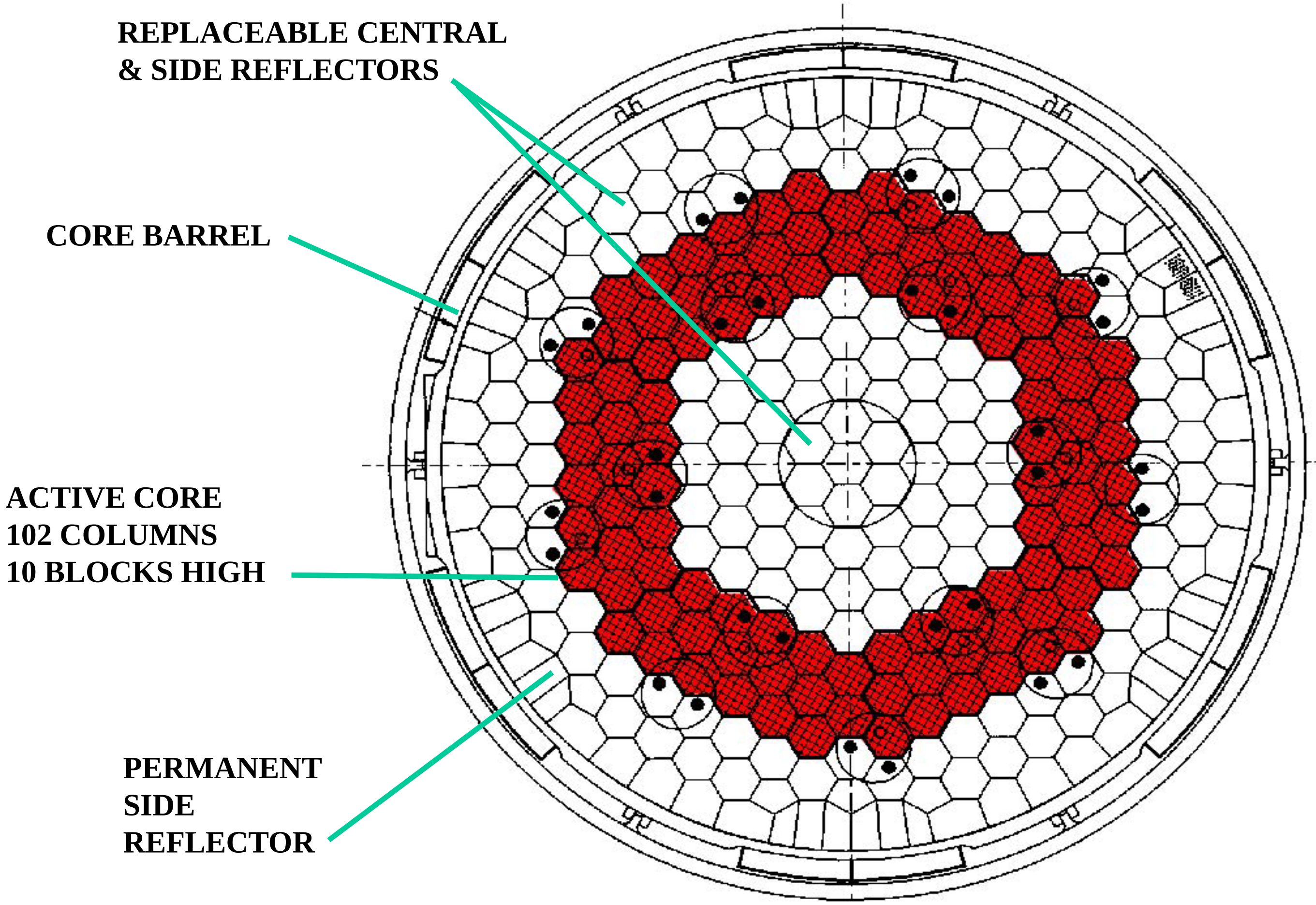
Functions for Control of Radionuclide Release



Removal of Core Heat Accomplished by Passive Safety Features

- Small thermal rating/low core power density
  - Limits amount of decay heat
  - Low linear heat rate
- Core geometry
  - Long, slender or annular cylindrical geometry
  - Heat removal by passive conduction & radiation
  - High heat capacity graphite
  - Slow heat up of massive graphite core
- Uninsulated reactor vessel
- Reactor Cavity Cooling System (RCCS)
  - Natural convection of air or water

Annular Core Optimizes Passive Heat Removal



Modular HTGR utilizes annular core geometry to 1) shorten conduction path 2) enhance surface to volume ratio

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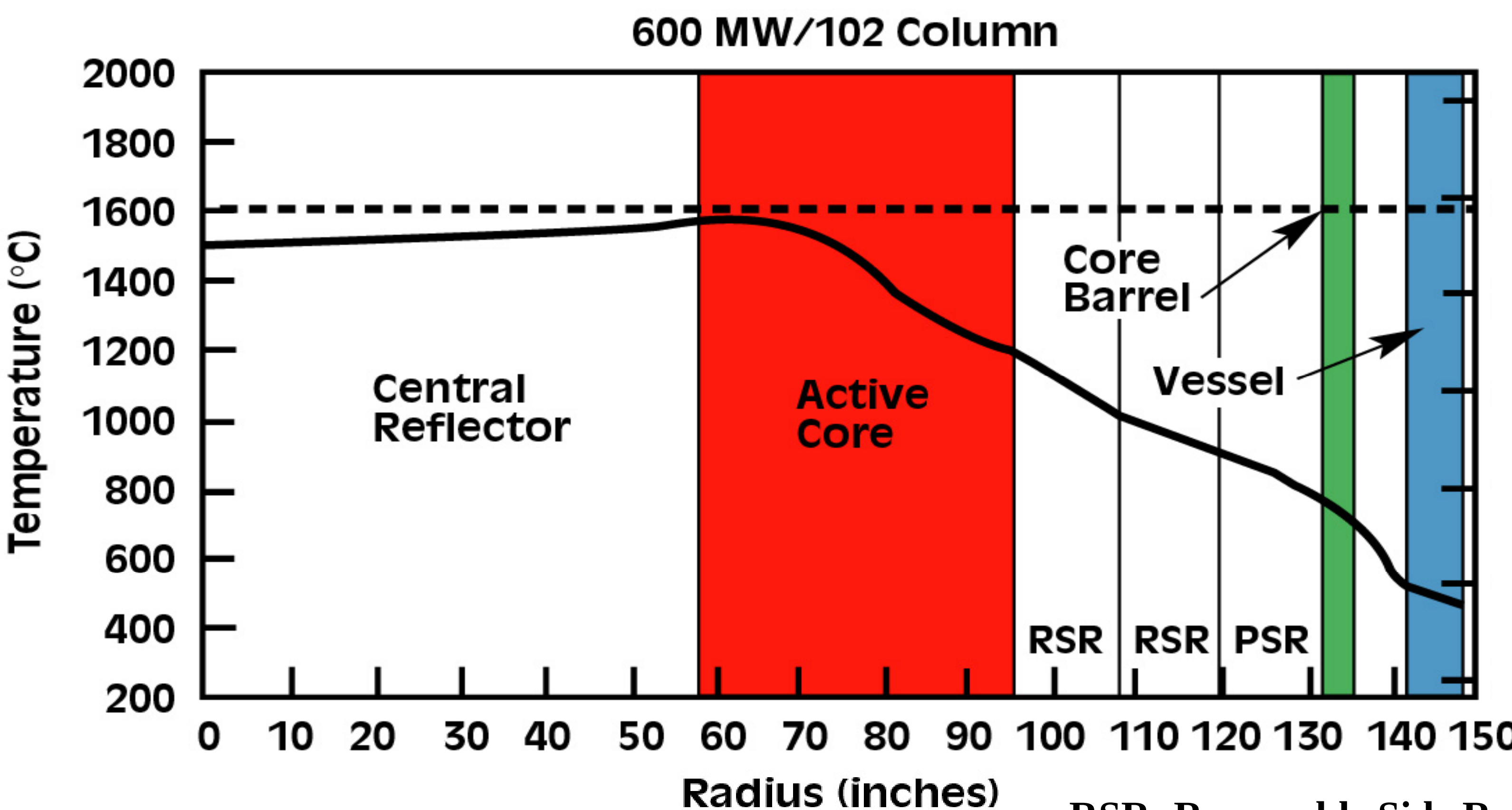
Acceptable Peak Reactor Core Temperatures at Worst Axial Location Several Days after Depressurized Loss of Forced Cooling



RSR: Removable Side Reflector
PSR: Permanent Side Reflector

Control of Heat Generation Accomplished by Intrinsic Shutdown and Reliable Control Material Insertion

- Large negative temperature coefficient intrinsically shuts reactor down
- Two independent and diverse systems of reactivity control for reactor shutdown drop by gravity on loss of power
  - Control rods
  - Reserve shutdown system
- Each system capable of maintaining subcriticality
- One system capable of maintaining cold shutdown during prismatic refueling
- Neutron control system measurement and alarms

Control of Air Attack Assured by Passive Design Features & Inherent Characteristics

- Non-reacting coolant (helium)
- High integrity nuclear grade pressure vessels make large break exceedingly unlikely
- Slow oxidation rate (high purity nuclear grade graphite)
- Limited by core flow area and friction losses
- Reactor building embedment and vents that close after venting limit potential air in-leakage
- Graphite fuel element, fuel compact matrix, and ceramic coatings protect fuel particles

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Control of Moisture Attack Assured by Design Features & Inherent Characteristics

- Non-reacting coolant (helium)
- Limited sources of water
  - Moisture monitors
  - Steam generator isolation (does not require AC power)
  - Steam generator dump system
- Water-graphite reaction:
  - Endothermic
  - Requires temperatures > normal operation
  - Slow reaction rate
- Graphite fuel element, fuel compact matrix, and ceramic coatings protect fuel particles

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