Gas Turbine - Modular Helium Reactor Design & Safety Approach

Presented to
Nuclear Regulatory Commission Staff
24 September 2002

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General Atomics

GENERAL ATOMICS

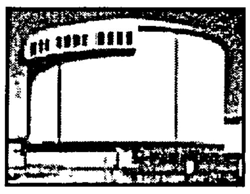
Attachment 3

U.S. AND EUROPEAN TECHNOLOGY BASES FOR MODULAR HIGH TEMPERATURE REACTORS

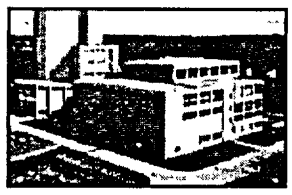
BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY

EXPERIMENTAL REACTORS

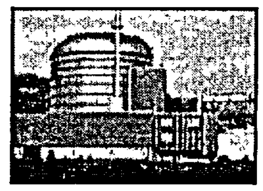
DEMONSTRATION OF BASIC HTGR TECHNOLOGY



DRAGON
(U.K.)
1963 - 76

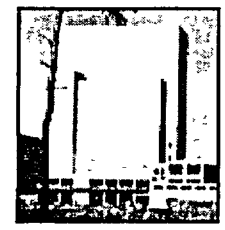


AVR
(FRG)
1967 - 1988



PEACH BOTTOM 1
(U.S.A.)
1967 - 1974

FORT ST. VRAIN
(U.S.A.)
1976 - 1989

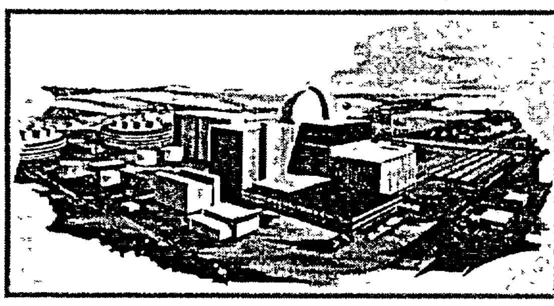


THTR
(FRG)
1986 - 1989

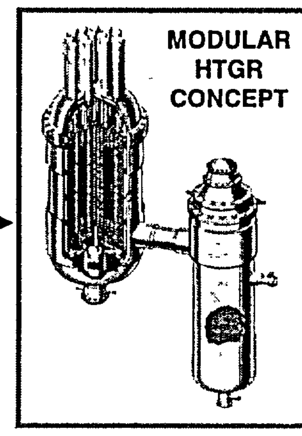
HTGR TECHNOLOGY PROGRAM

- MATERIALS
- COMPONENTS
- FUEL
- CORE
- PLANT TECHNOLOGY

LARGE HTGR PLANTS

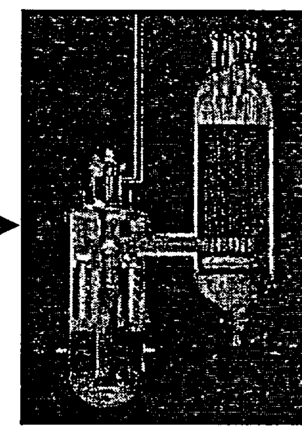


MHTGR



Steam Cycle

GT-MHR



Gas Turbine Cycle

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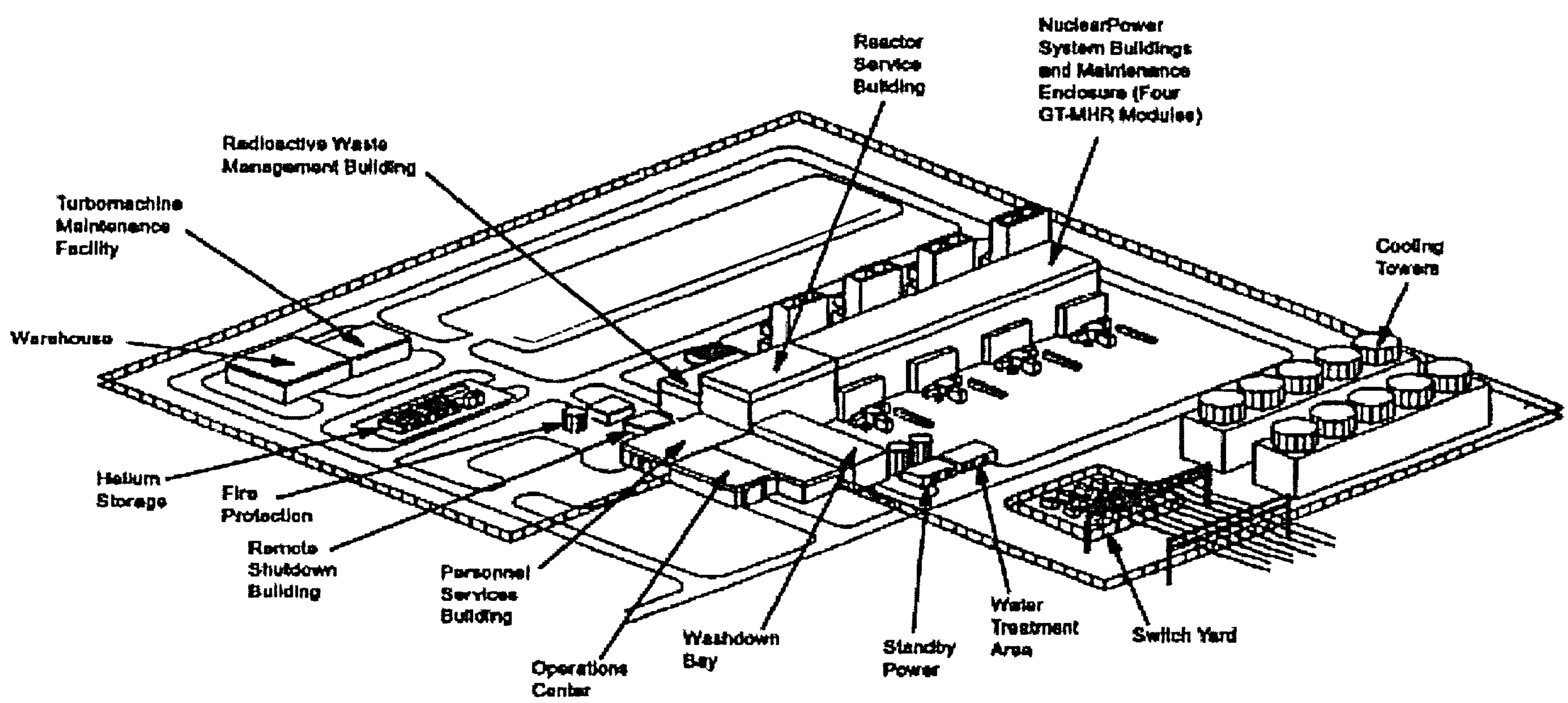
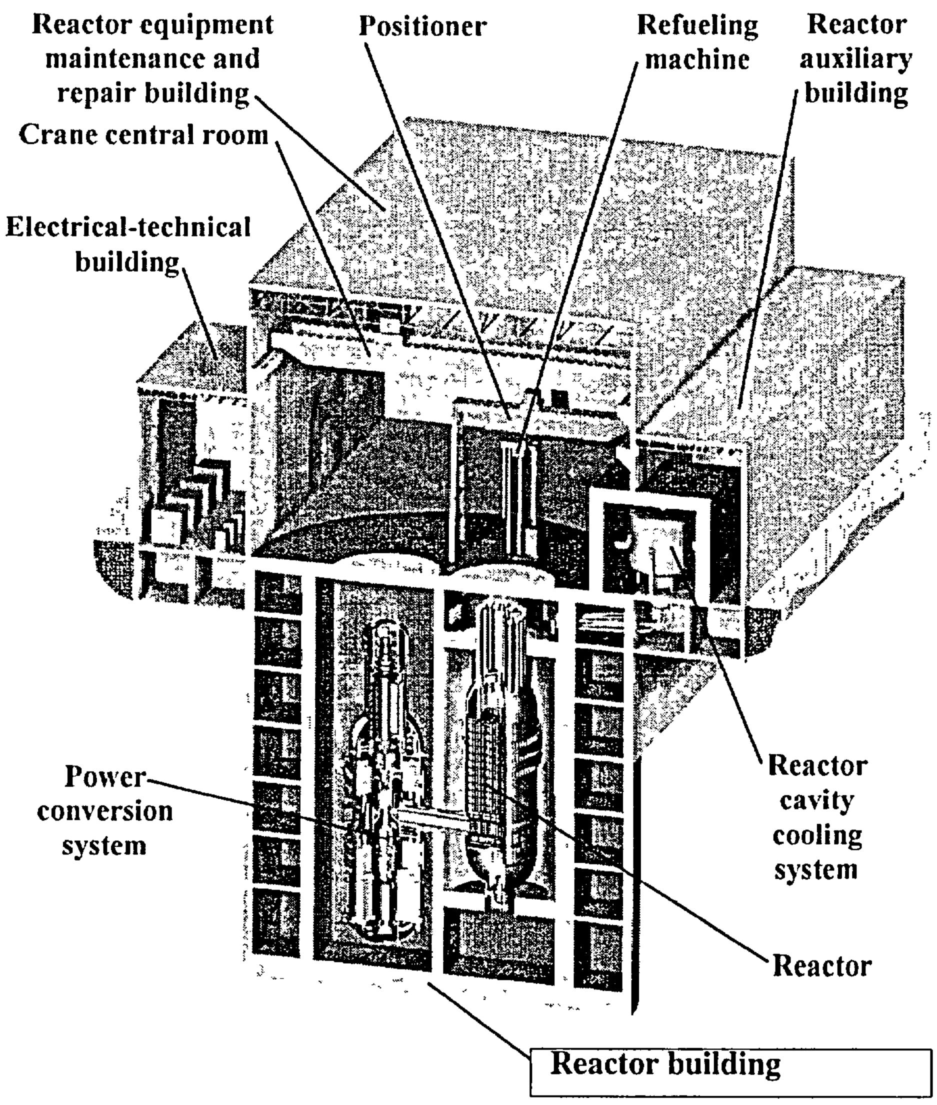
4 MODULES COMPRISE STANDARD GT-MHR PLANT



3D Arrangement of Plant



- 600 MW(t) - 285 MW(e)
- 3 vessels primary coolant system
- Power conversion system integrated in single vessel
- Below grade housing
- Continuously operating, natural circulating, air cooled reactor cavity cooling

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GT-MHR COMBINES ADVANCED REACTOR WITH SINGLE SHAFT GAS TURBINE BASED POWER CONVERSION SYSTEM

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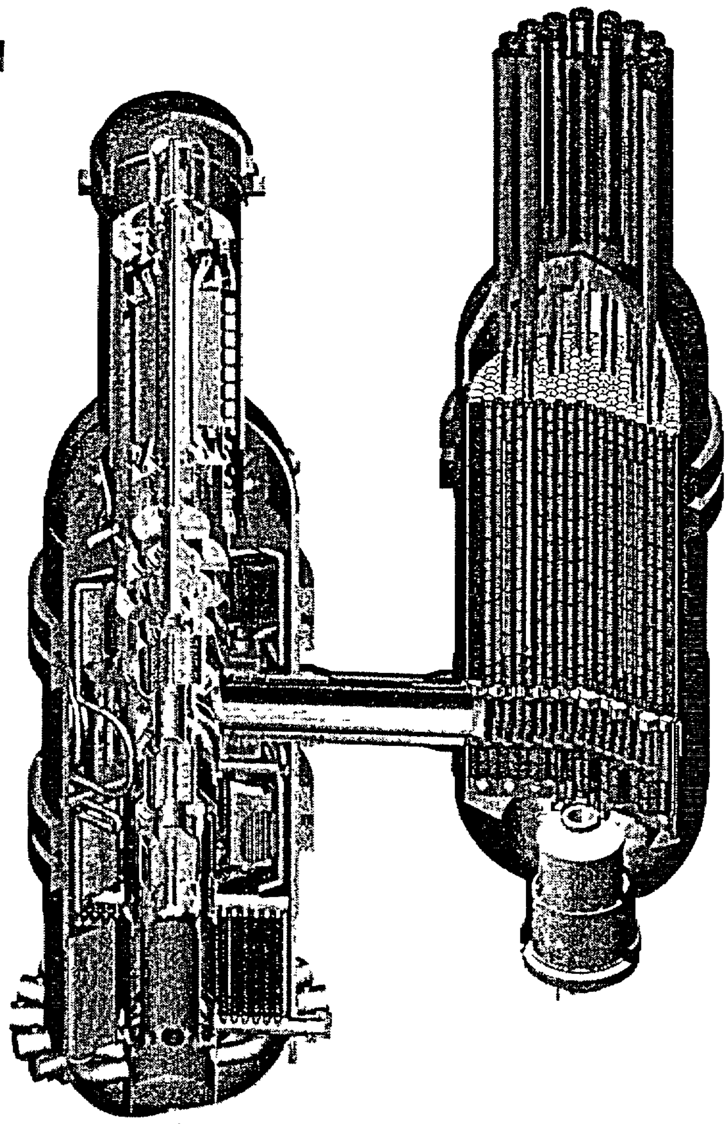
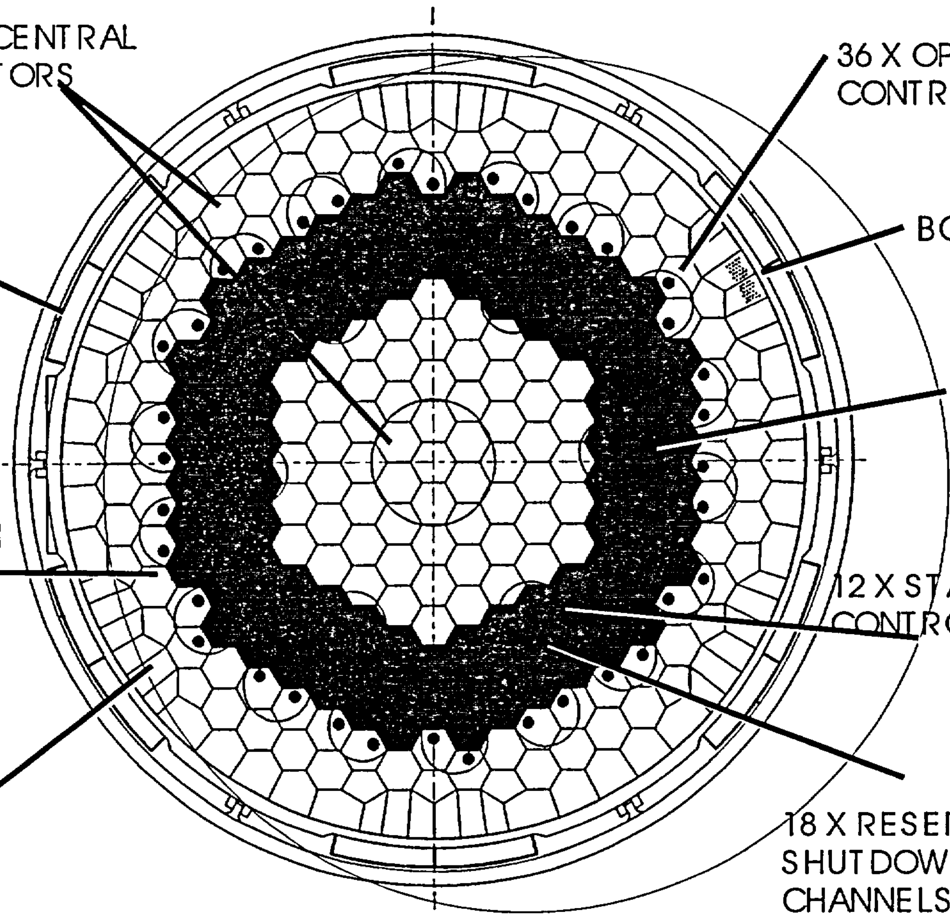


Annular Core Limits Maximum Accident Fuel Temperature



Fuel Elements

. . . ANNULAR CORE USES EXISTING TECHNOLOGY

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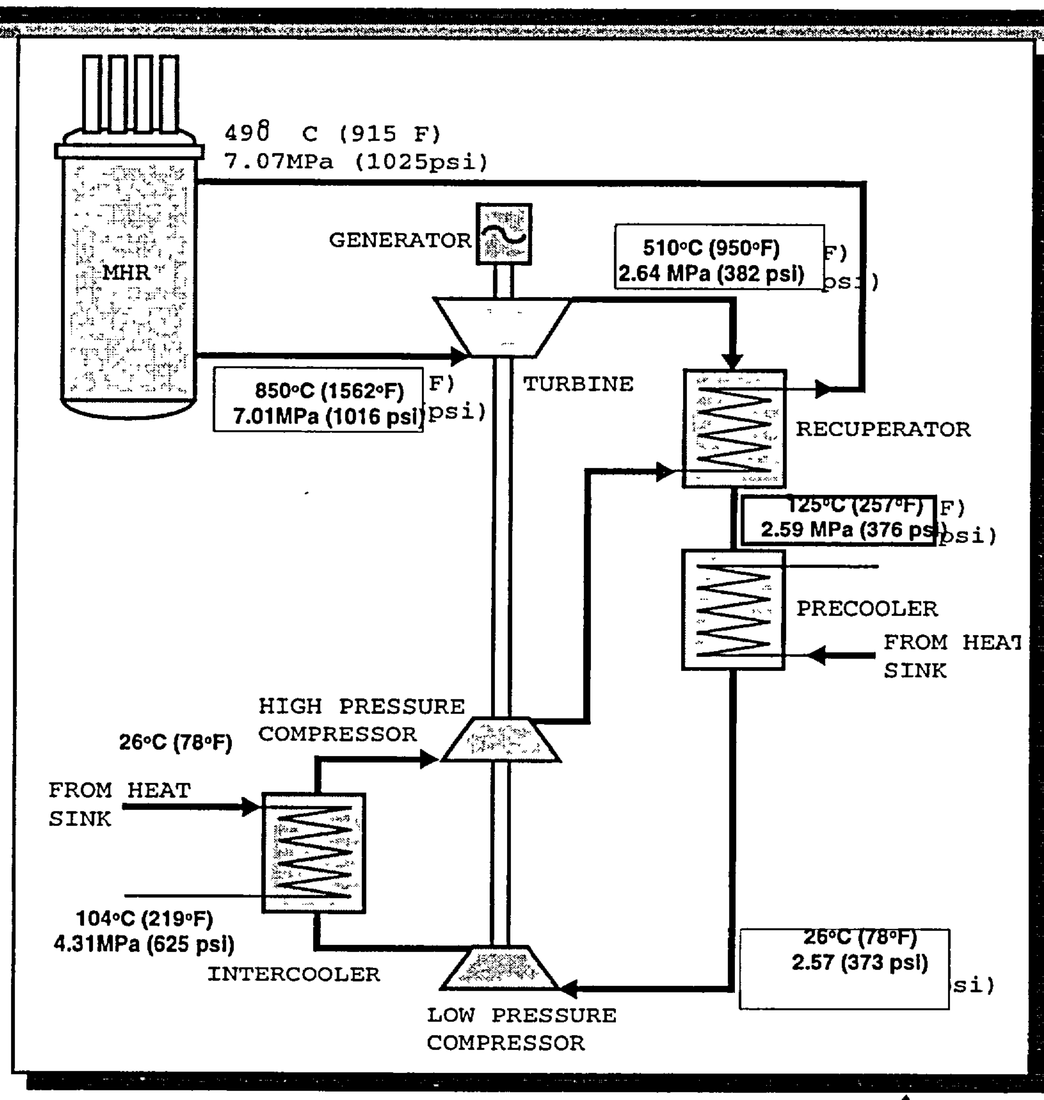
GT-MHR Power Conversion Uses High Efficiency Brayton Cycle



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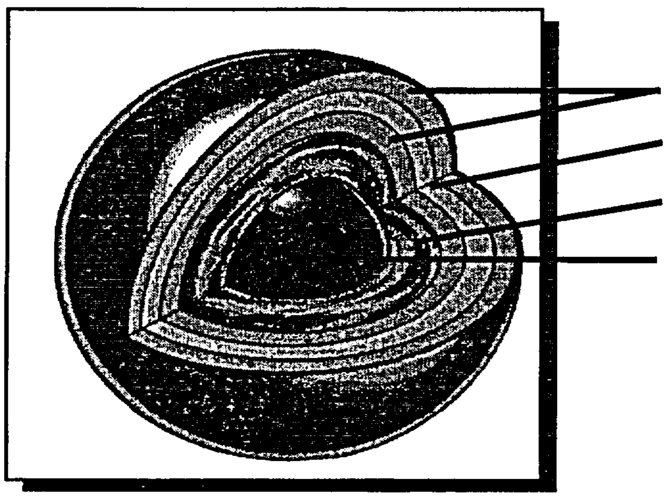
Modular Gas-Reactor Safety Approach Differs From Earlier Reactor Designs

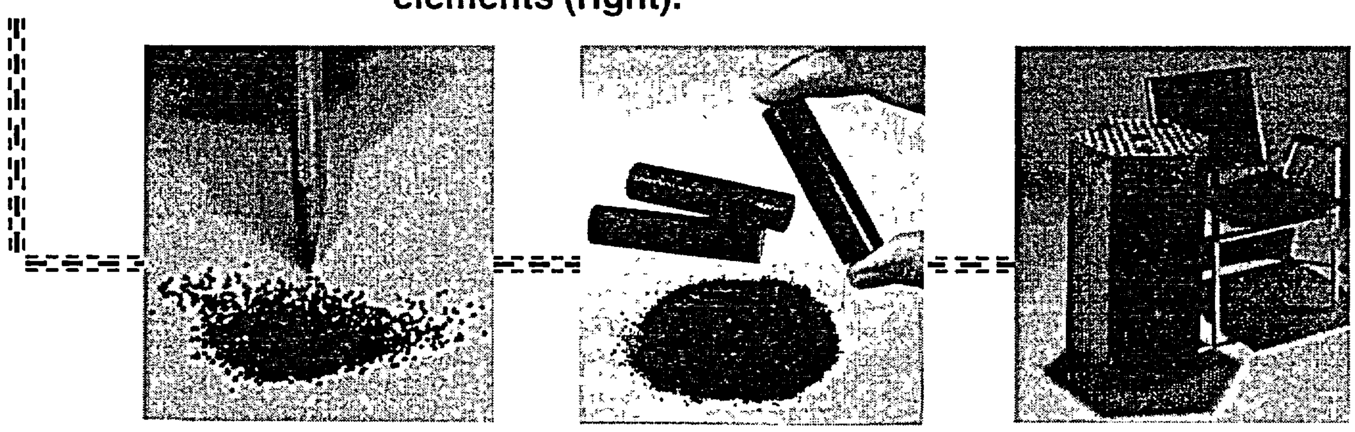
- GT-MHR safety emphasizes
  - Keeping radionuclides at source during all accidents
  - Minimizing reliance on active/complex engineered systems
- Passive safety design is based on reoptimized application of established HTGR technology
  - High temperature fuel and core
  - Single phase, chemically & neutronically inert coolant
  - Specially tailored core power and geometry

Conservative, robust design with defense-in-depth remain foundations of safety

Key to GT-MHR Safety
Multiple Ceramic Fuel Coatings

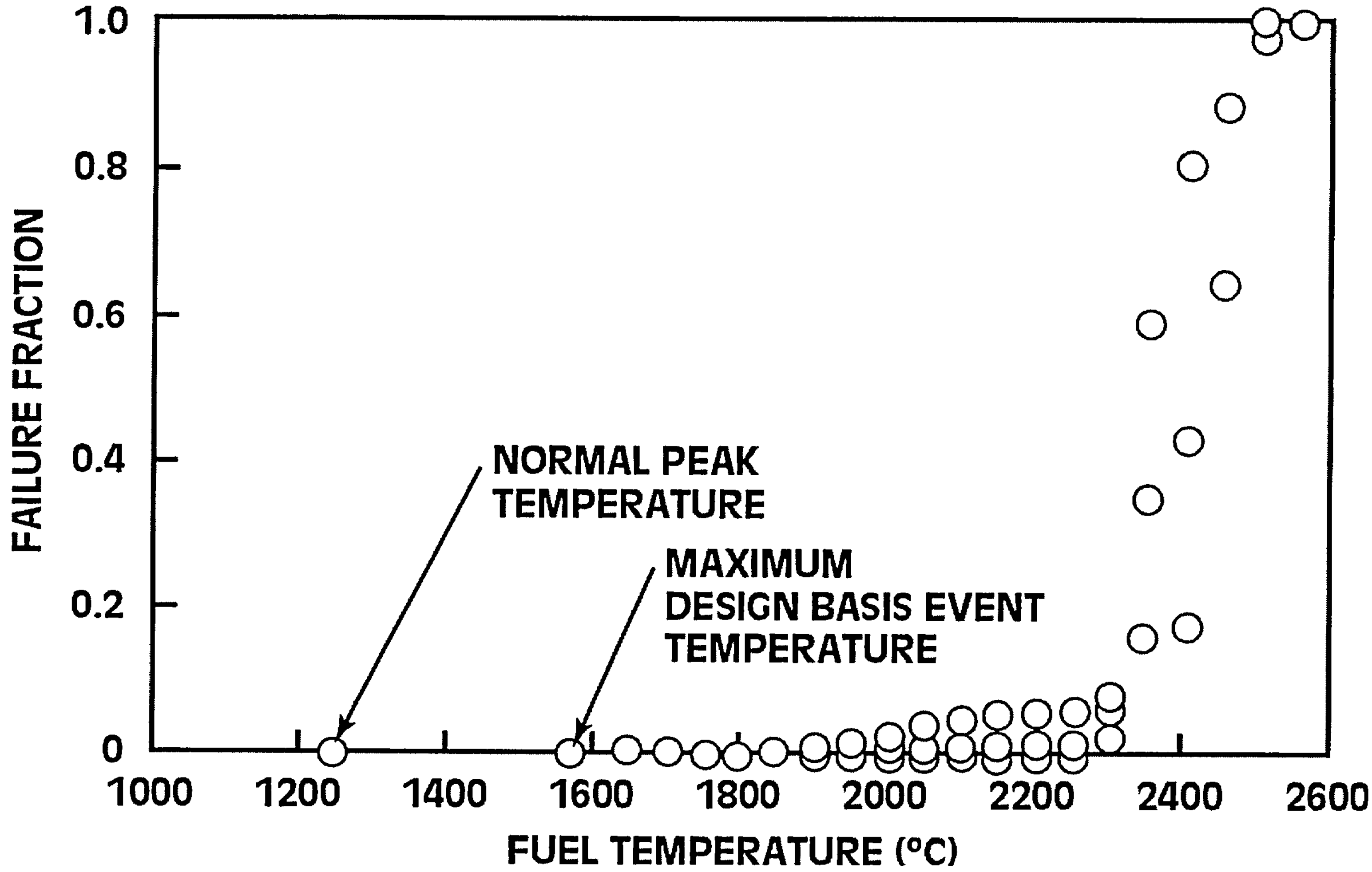


TRISO Coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right).



PARTICLES **COMPACTS** **FUEL ELEMENTS**

Coated Particles Remain Intact Even at Very High Temperatures



Safety Focused on Assured Fuel Particle Integrity

Retain Radionuclides in Fuel

Control Heat Generation | Remove Core Heat | Control Chemical Attack

- Fission (heat generation) shut down assured by
  - *Large negative temperature coefficient*
  - *Large temperature margins*

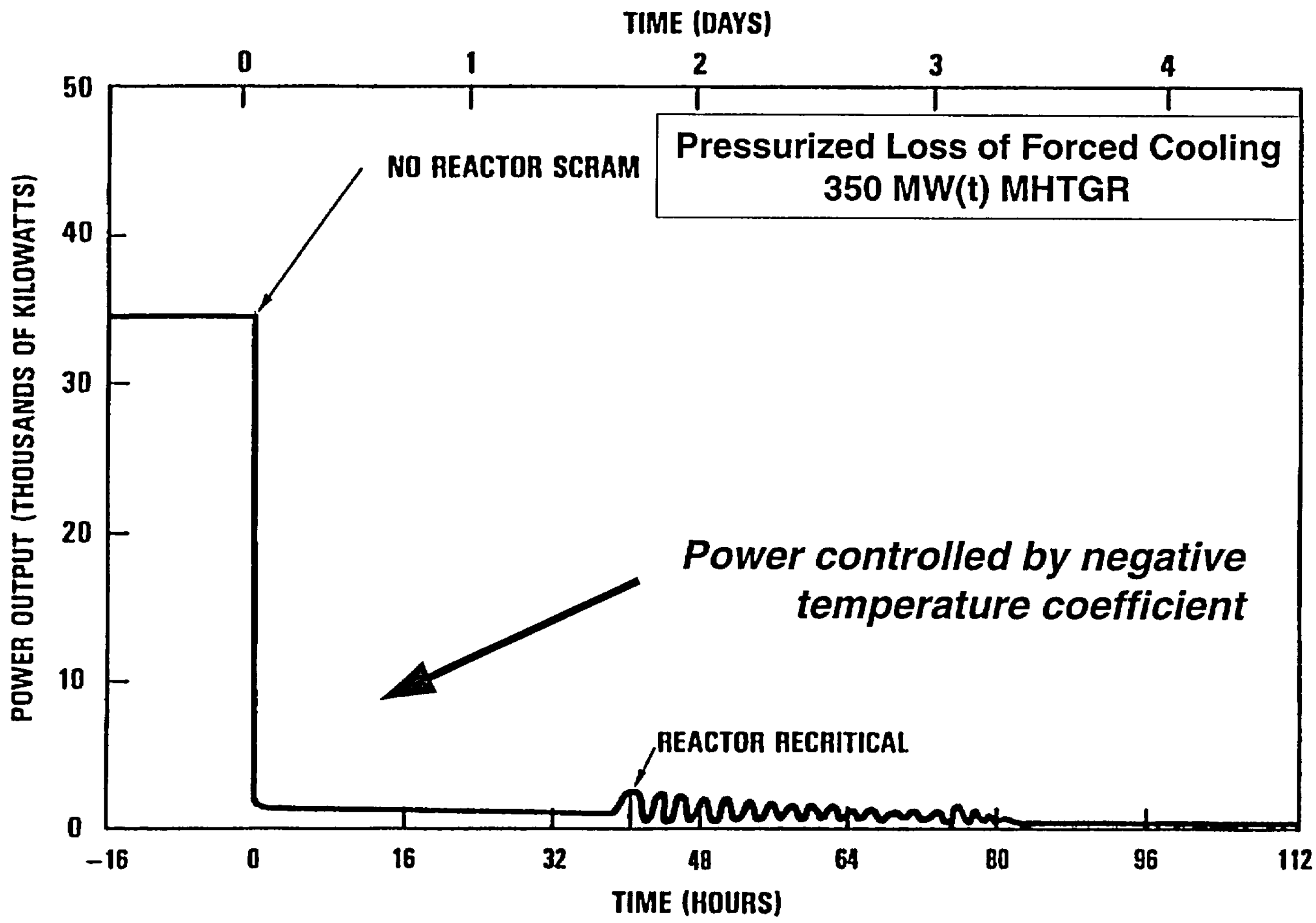
  ] *Passive Shutdown*
- Heat removal assured by
  - *Low power density & module thermal rating*
  - *Annular core and high L/D ratio*

  ] *Passive Cooling*
- Chemical attack limited by
  - Absence of high pressure water sources
  - Nuclear graphite, core geometry, and limited air availability

Multiple Means Available to Control Heat Generation

- Control rods capable of terminating fission
- Reserve shutdown system provides independent and diverse means of terminating fission
- Large negative temperature coefficient and large core temperature margins can provide passive shutdown for anticipated transient without scram

Heat Generation Stops During Loss of Cooling Without Rod Motion



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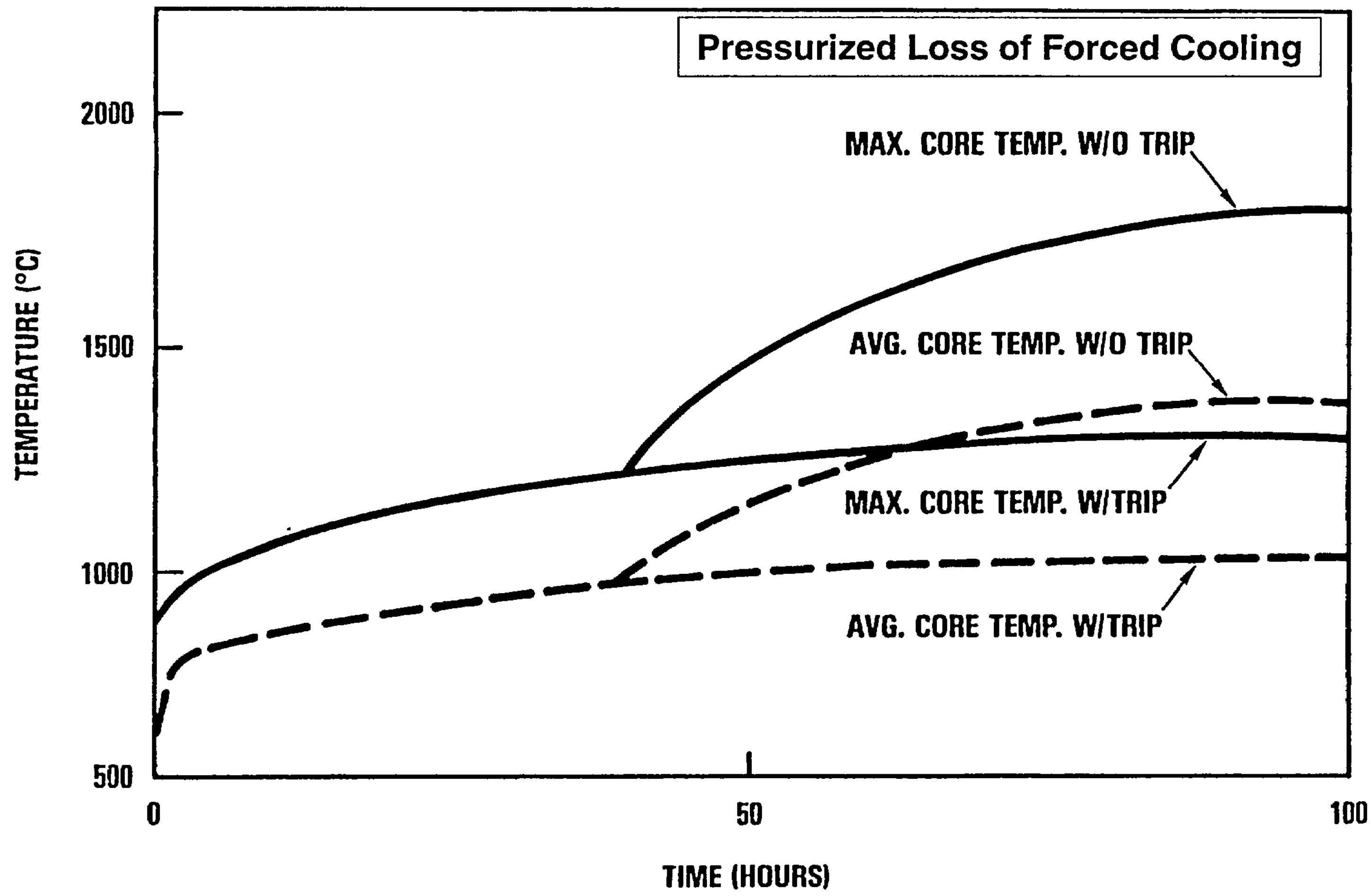
Core Temperatures Maintained at Safe Levels With and Without Reactor Trip



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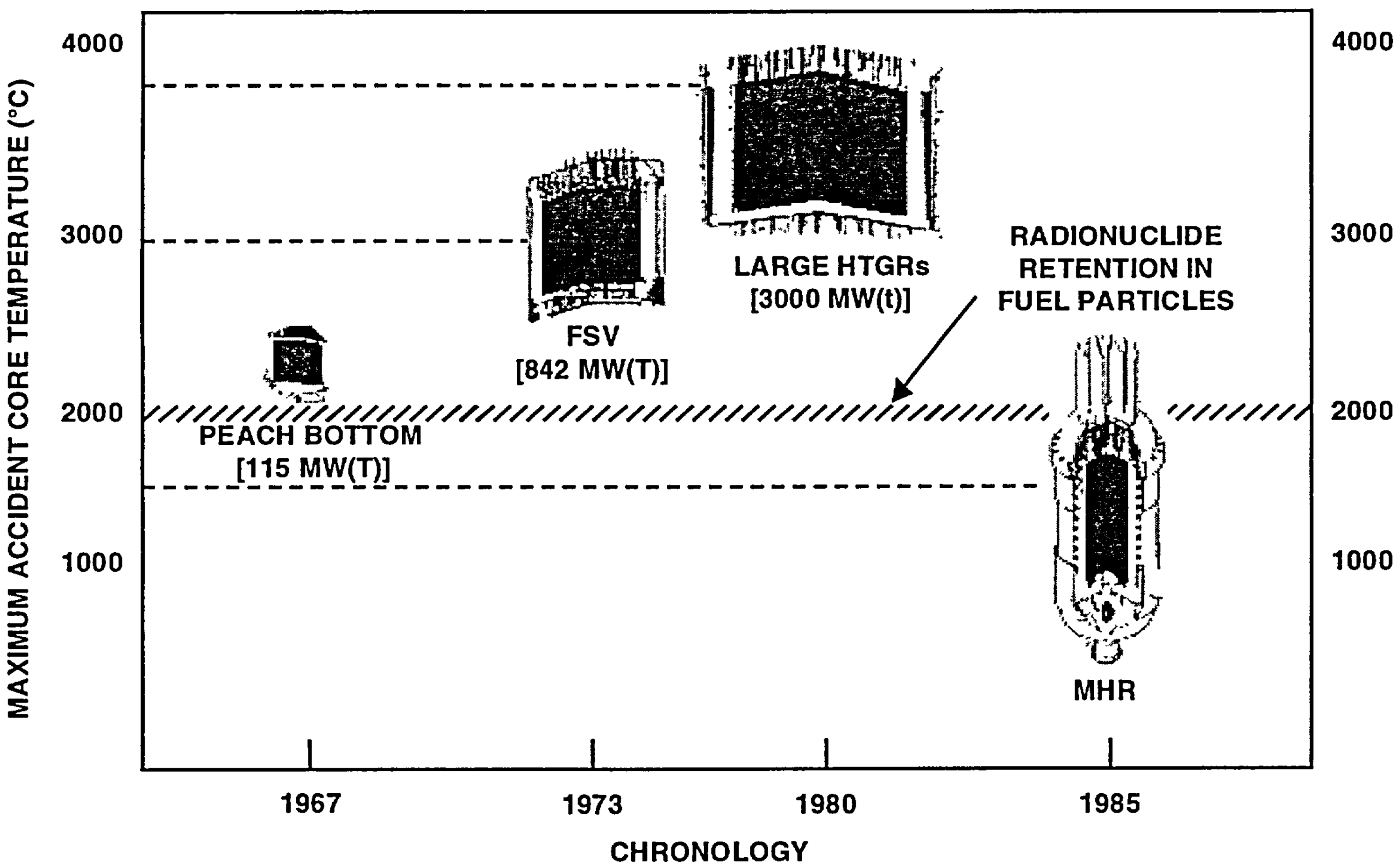
Multiple Means Available to Remove Core Heat

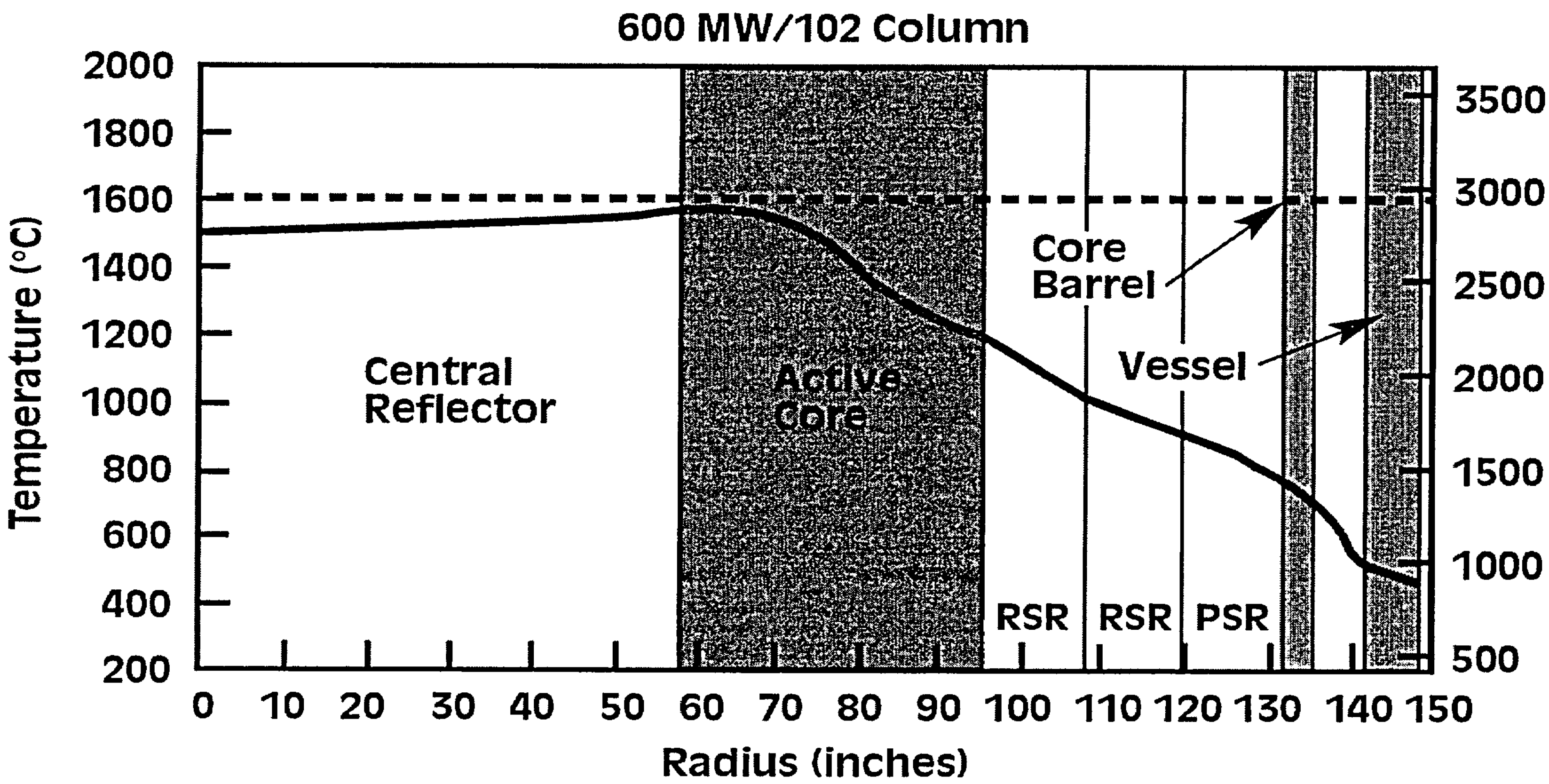
- Power conversion loop provides normal heat rejection
  - Normal operation
  - Preferred mode of shutdown cooling
  - Operates with pressurized or depressurized coolant
- Shutdown cooling system offers alternative means of forced circulation heat removal
- Passive heat rejection to Reactor Cavity Cooling assures safety for all events
- Passive heat rejection to the surroundings limits maximum consequences

Passive Heat Removal Changes Reactor Design Philosophy



SIZED AND CONFIGURED TO WITHSTAND EVEN A SEVERE ACCIDENT

Temperature Gradient Provides Driving Force for Residual Heat Removal



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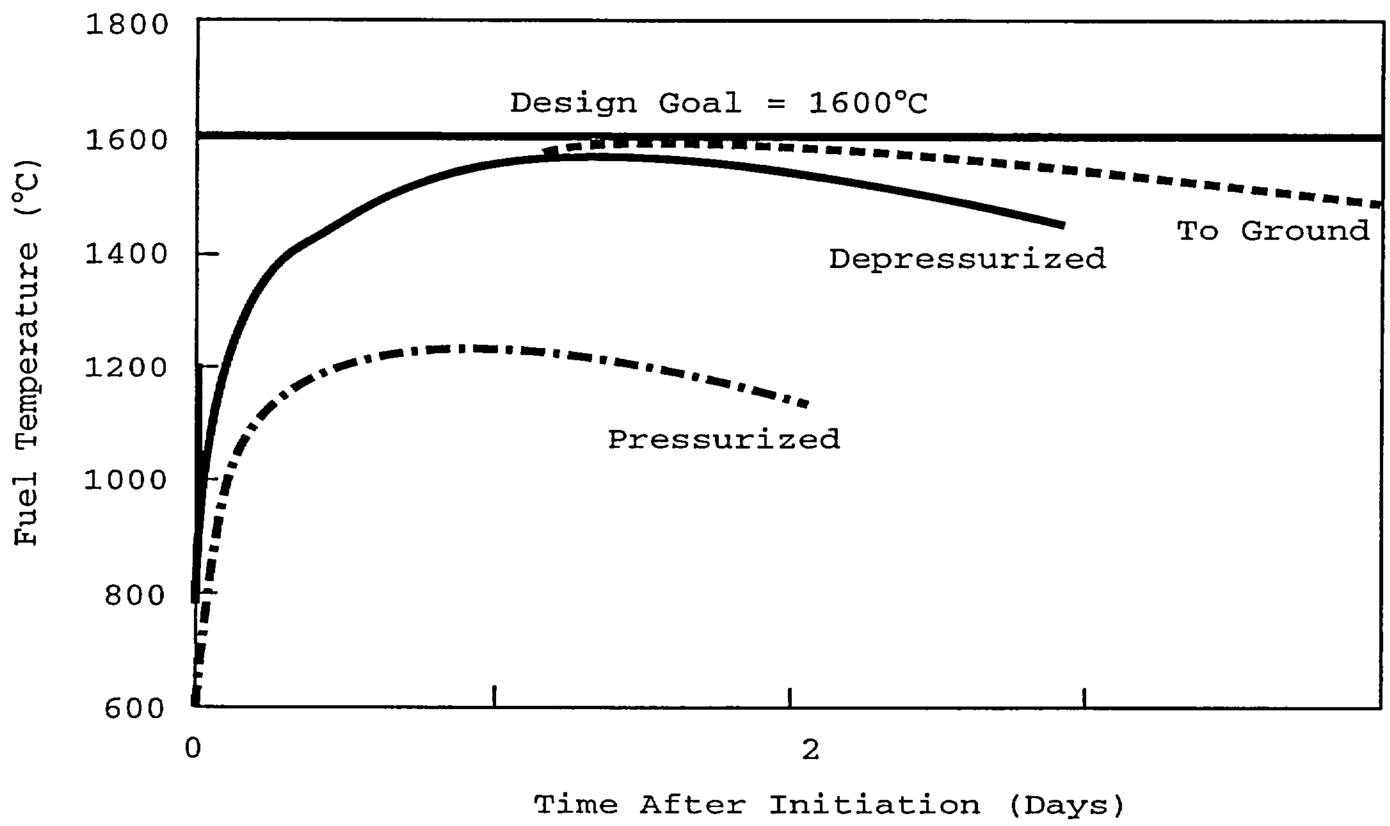
FUEL TEMPERATURES REMAIN BELOW DESIGN LIMITS DURING LOSS OF COOLING EVENTS



passive design ensures fuel remains below 1600°C

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Risk From Water Ingress Significantly Reduced in GT-MHR

- No steam generators therefore no high pressure steam source
- Precooler and intercooler water pressure below primary coolant operating pressure
- Low water pressure in heat exchangers greatly reduces potential for water ingress during normal operation
- Liquid water transport to core under depressurized conditions limited by geometry

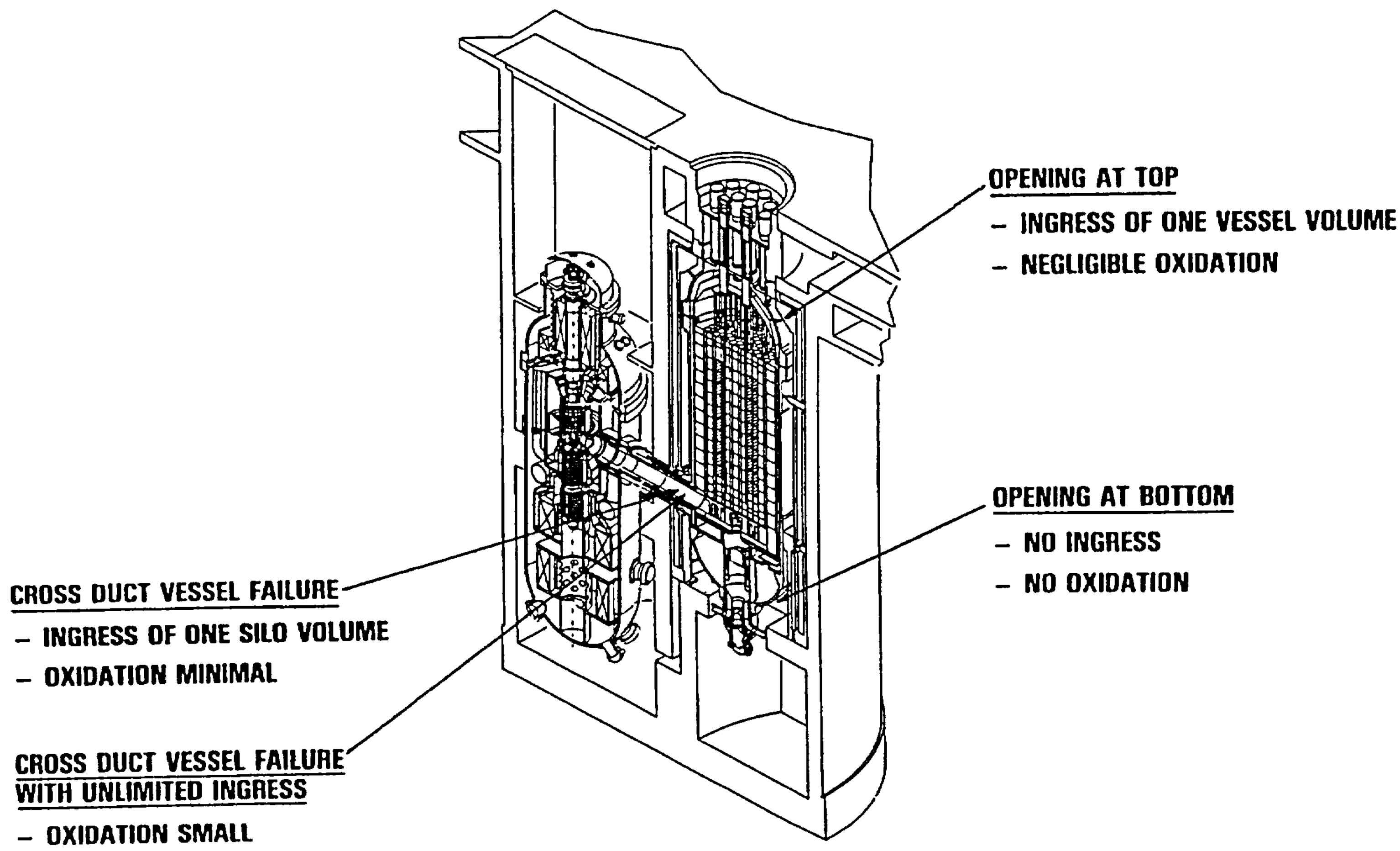
Inherent and Passive Features Control Air Attack

- Non-reacting coolant (helium)
- Embedded ceramic coated particles
- Air ingress limited (requires failure of Class 1 vessels)
- Below grade, closed reactor silo (isolation)
- Air flow rate limited by core flow area (L/D > 700)
- Slow oxidation rate (nuclear grade graphite)

Low Potential for Graphite Fires

- Test results successfully compared favorably to computer code (AIP) predictions
- Extremely low probability of burning graphite
  - requires temperatures above those during operation or accidents, and
  - requires large quantities of air
- MHTGR analyses show introduction of air results in limited, decay heat driven oxidation

Graphite Oxidation Limited by Available Air



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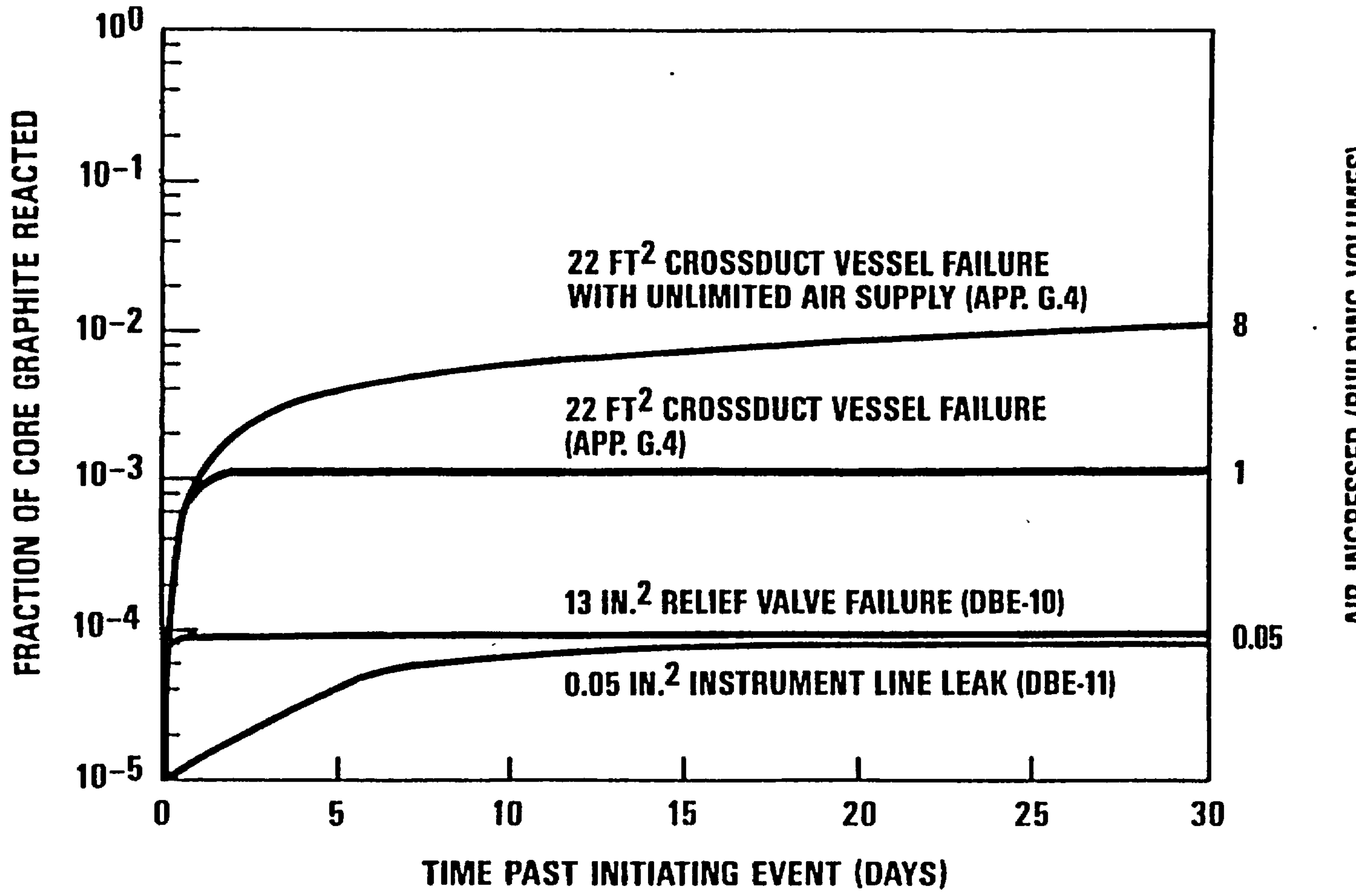
Mass Transfer, Core Temperature, & Graphite Purity Limit Oxidation Rate



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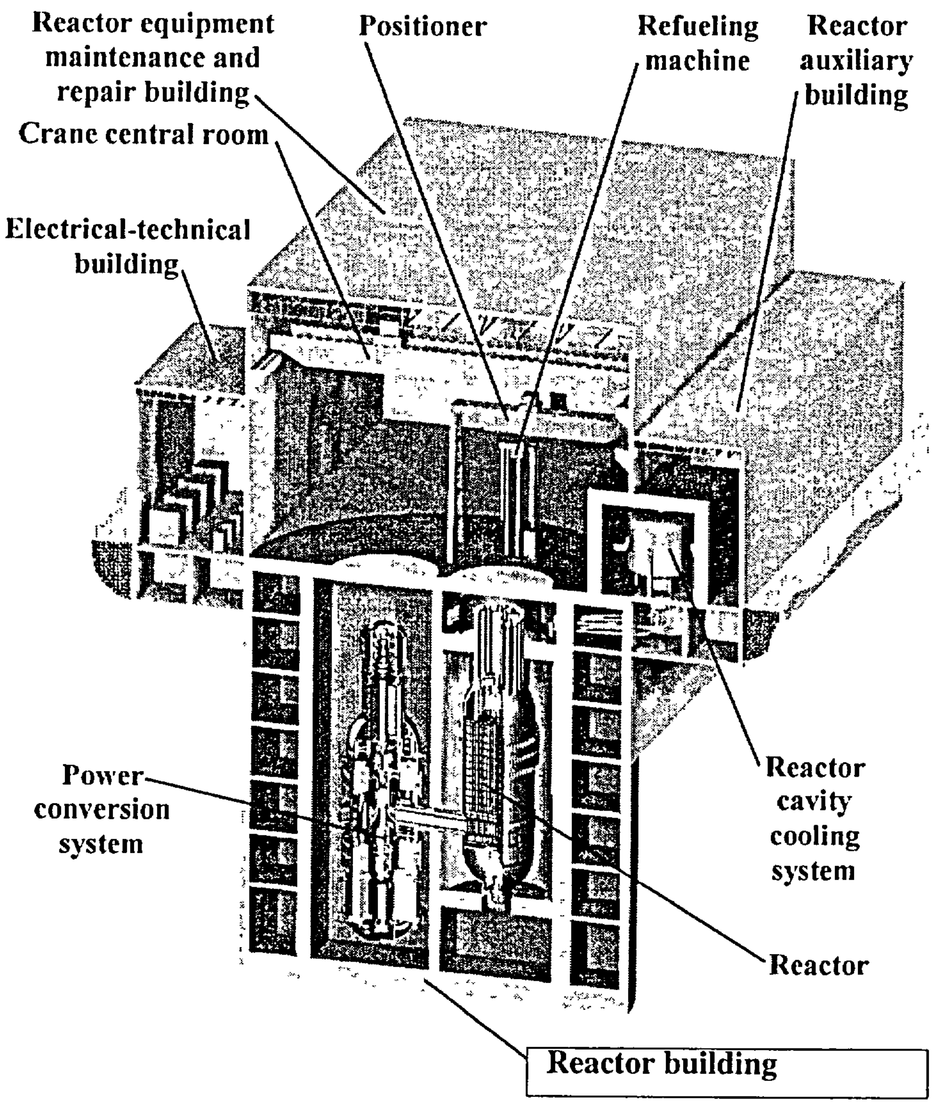
With Fuel Damage Precluded, Accident Releases Limited to Lesser Sources

- Fission products within particles with initially defective coatings (as-manufactured defect fraction)
- Fission products within particles experiencing in-service particle failure
- Fission products associated with Uranium contamination of graphite
- Activity in primary coolant
- Activity "plated-out" on coolant boundary surfaces during normal operation

Below-Grade Siting Augments Enhanced Safety



- Reduced seismic response
- Effective heat sink using surrounding earth
- Robust structure
  - Additional containment of accident releases
  - Limited vulnerability of core and key safety features to surface events
  - Limits oxidant ingress

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GT-MHR Optimization of Established Gas Reactor Features Provides

- Enhanced, easily understood safety
- Assured accomplishment of safety functions with simple, passive features
- Limited consequences, even for beyond design basis accidents

Cost of passive features offset by design simplicity and modularity

GT-MHR
Project Update
and
Pre-Application Objectives

Presented to NRC Staff
24 September 2002

Walter Simon
Senior Vice President, Power Reactor Division
General Atomics

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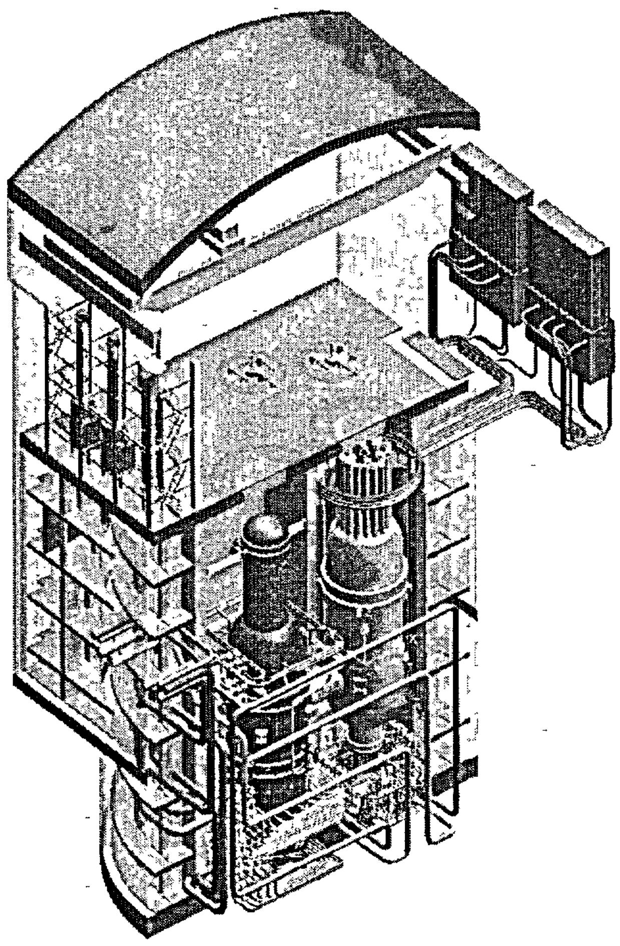
Attachment 4

GT-MHR Design Development
An International Program



- Engineering in Russia under joint US/RF agreement for destruction of surplus weapons Plutonium

- Sponsored jointly by US (DOE) and RF (Minatom) with support from provided by Japan and EU

ornl

ОКБМ

МИНАТОМ РОССИЯ

РНЦ "Курчатовский институт"

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Preliminary Design Completed

- System design requirements and component specifications established
- System configurations and component layouts developed
- Nuclear, thermal, and structural analyses prepared
- Technology development plans in-place
- Test articles, test facilities and rigs are being developed
- Bench-Scale fuel facility construction initiated
- Subcontractors selected in key areas and assisting with hardware development

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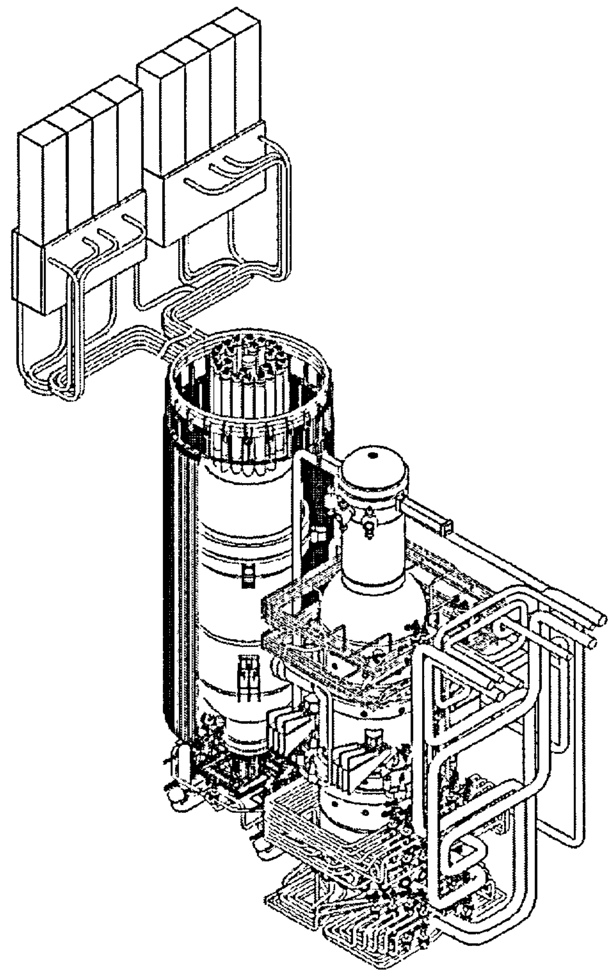
Design Effort is 40% Complete

- More than 1800 work products (10,000 pages) completed.
- Includes more than 300 drawings, 80 development test plans & 100 analysis reports.
- More than 30 meetings of US and Russian engineers to discuss design details held
- Detailed schedule with more than 6000 activities prepared.



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Final Design Begun
Major Items in Next Phase Planning

- Continue final design of systems and components
- Initiate reactor and Power Conversion Unit (PCU) development tests
- Continue structural material development for vessel, reactor, and Power Conversion Unit components
- Perform validation of computer codes
- Start physics validation tests
- Complete Bench-Scale Fuel Facility & test fuel
- Complete initial plot plan, plant layout, building arrangements and auxiliary system designs
- Initiate reactor irradiation tests of fuel, graphite, and carbon-carbon composites

U.S. Effort Aimed at Commercializing Russian Developed Design

- GT-MHR industrial consortium for US deployment being pursued
- Potential users of GT-MHR
  - Providing input on design
  - Supporting very long lead activities (e.g., licensing)

GT-MHR Utility Advisory Board (UAB) includes 35% of US nuclear capacity

NMC Entergy Dominion OPPD Omaha Public Power District Constellation Nuclear Progress Energy PSEG

- DOE / National Labs supporting generic gas cooled reactor technologies

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Objective & Expectations for GT-MHR Pre-Application Interaction

- Familiarize staff with GT-MHR technology
- Identify and resolve key, GT-MHR specific, licensing issues as early as possible
- Leverage ongoing DOE and NEI activities for GT-MHR applicability
- Candid dialogue between NRC staff and design team
- Receive NRC feedback on GT-MHR approach to safety assurance

Prepare way for commercialization of GT-MHR

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Key Areas Seen As...

- GT-MHR Source Term
  - Coated particle fuel
  - Use of mechanistic release model
  - GT-MHR containment system including reactor building
- Import of non-US technology including use of test data from outside US
- Licensing approach and unique aspects of modular reactor licensing

Ideally, pre-application aimed at GT-MHR specific subtopics not covered by DOE & NEI efforts

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