U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Modular HTGR Technology and Safety Design Approach

Office of Nuclear Energy
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Course Outline

- **Modular HTGR Design Overview**
  - HTGR Historical Perspective
  - Modular HTGR Fuel
  - Vessel System
  - Reactor Building
  - Heat Removal Systems
  - Secondary Plant Alternatives
- **Modular HTGR Safety Design Approach**
  - Requirements and Objectives
  - Safety Design Approach
  - Retention of Radionuclides At Their Source
  - Control of Heat Generation
  - Remove Core Heat
  - Control of Chemical Attack
  - Functional Containment Design and Performance

Course Outline (cont.)

- **Factors That Impact Design Criteria for Modular HTGRs**
  - Need for Adapting Existing Criteria
  - Functional Containment vs. LWR Containment
  - New Criteria (70 – 72)
    - Reactor Vessel
    - Reactor Building
  - Modular HTGR Fuel Design Limits (10)
  - Safety-Related Heat Removal (34 & 35)
  - Safety Related Power Supply (17)
  - Modular HTGR Design Criteria Summary
- **Suggested Reading**
- **Q&A**

Modular HTGR Design Overview

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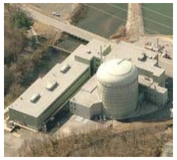
Several HTGRs Have Been Built and Operated World Wide

Power Reactors

Research Reactors






	Peach Bottom 1 U.S. 1966 - 1974	Fort St. Vrain U.S. 1976 - 1989	THTR Germany 1986 - 1989	Dragon England 1966 - 1975	AVR Germany 1967 – 1988	HTTR Japan 2000 – Present	HTR-10 China 2003 – Present
Power Level: MW(t)	115	842	750	20	46	30	10
MW(e)	40	330	300	-	15	-	-
Coolant: Pressure MPa	2.5	4.8	4	2	1.1	4	3
Inlet Temp. ºC	344ºC	406ºC	250ºC	350ºC	270ºC	395ºC	250ºC
Outlet Temp. ºC	750ºC	785ºC	750ºC	750ºC	950ºC	850ºC/950ºC	700ºC
Fuel Type	$(U\text{-}Th)C_2$	$(U\text{-}Th)C_2$	$(U\text{-}Th)O_2$	$(U\text{-}Th)C_2$	$(U\text{-}Th)O_2$	$(U\text{-}Th)O_2$	$(U\text{-}Th)O_2$
Peak Fuel Temp. ºC	~1000ºC	1260ºC	1350ºC	~1000ºC	1350ºC	~1250ºC	~1050ºC
Fuel Form	Graphite compacts in hollow rods	Graphite compacts in Hex blocks	Graphite Pebbles	Graphite Hex blocks	Graphite Pebbles	Graphite compacts in Hex blocks	Graphite Pebbles

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U.S. HTGR Licensing History

U.S Program	Licensing Period	Organization	Stage
Peach Bottom 1	1958 - 1966	Philadelphia Electric Co.	Operating License Issued Decommissioned
Fort St. Vrain (Prismatic)	1966 – 1972	Public Service Co. of Colorado	Operating License Issued Decommissioned
Summit (Prismatic)	1972 - 1975	General Atomics (GA)	Construction Permit/Limited Work Authorization Submitted
MHTGR (Prismatic)	1986 – 1995	DOE/GA	Pre-Application Review NUREG-1338
Exelon Design Certification (Pebble)	2001 – 2002	Exelon	Pre-Application Review
PBMR Design Certification (Pebble)	2006 – 2010	PBMR Pty LTD	Pre-Application Review
NGNP (Prismatic/Pebble)	2009 – 2014	DOE	Pre-Application Review NRC Assessment

Modular HTGR Designs Emphasize Low Accident Risk

- **Objective: Provide safe, economic reliable process heat & power**
- **Select compatible fuel, moderator, & coolant with inherent characteristics**
- **Design reactor with passive safety features sufficient to meet safety requirements**
- **Supplement with active features for investment protection and defense-in-depth**
- **Utilize proven technologies**

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Definition of Modular HTGR for the Design Criteria Effort

<u>modular HTGR</u>: Refers to the category of HTGRs that use the inherent high temperature characteristics of tristructural isotropic (TRISO) coated fuel particles, graphite moderator, and helium coolant, as well as passive heat removal from a low power density core with a relatively large height-to-diameter ratio within an uninsulated steel reactor vessel. The modular HTGR is designed in such a way to ensure during design basis events (including loss of forced cooling or loss of helium pressure conditions) that radionuclides are retained at their source in the fuel and regulatory requirements for offsite dose are met at the Exclusion Area Boundary.

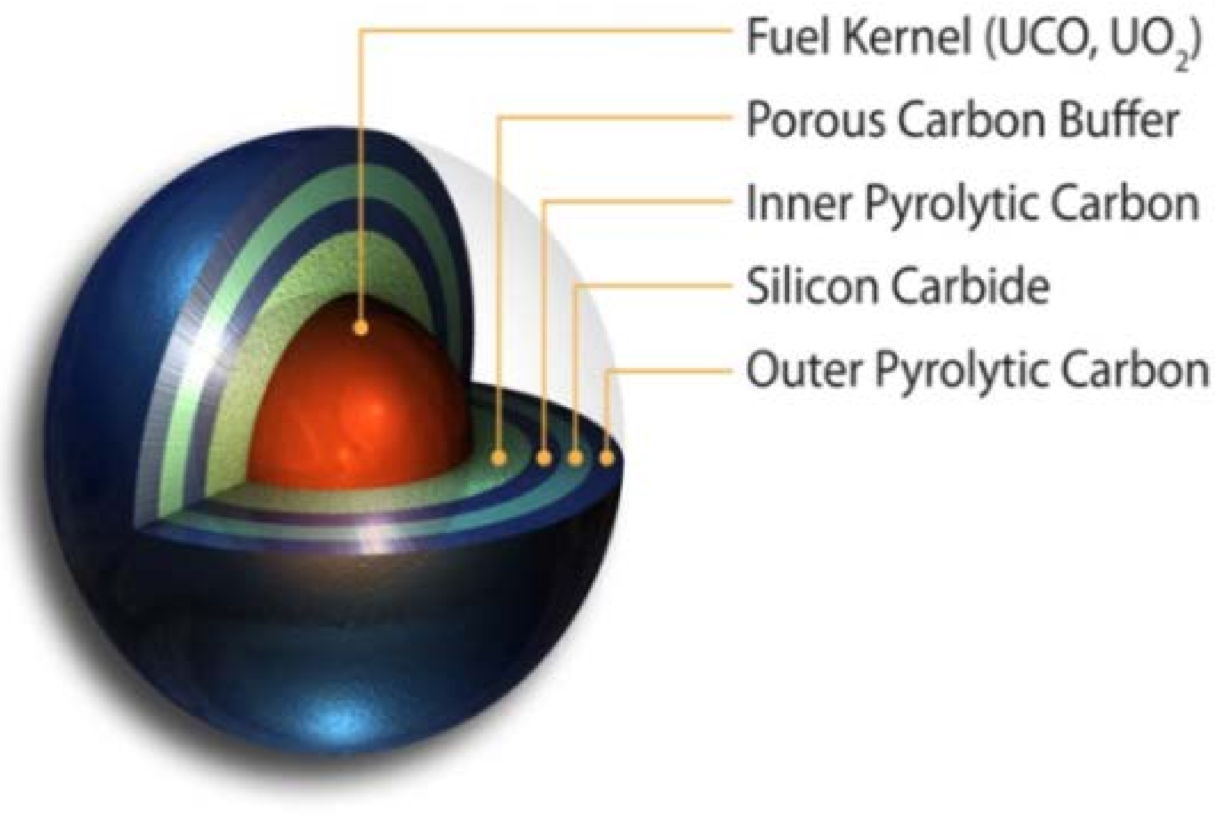
Several modular HTGR designs have been developed that are consistent with this definition.

United States	**South Africa**	**Germany**	**South Korea**
France	**Japan**	**China**	**Russia**

Design is Responsive to NRC 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 the potential for consequences of severe accidents
- Use existing technology or technology that can be satisfactorily established by commitment to a suitable technology development program

TRISO Fuel Particle



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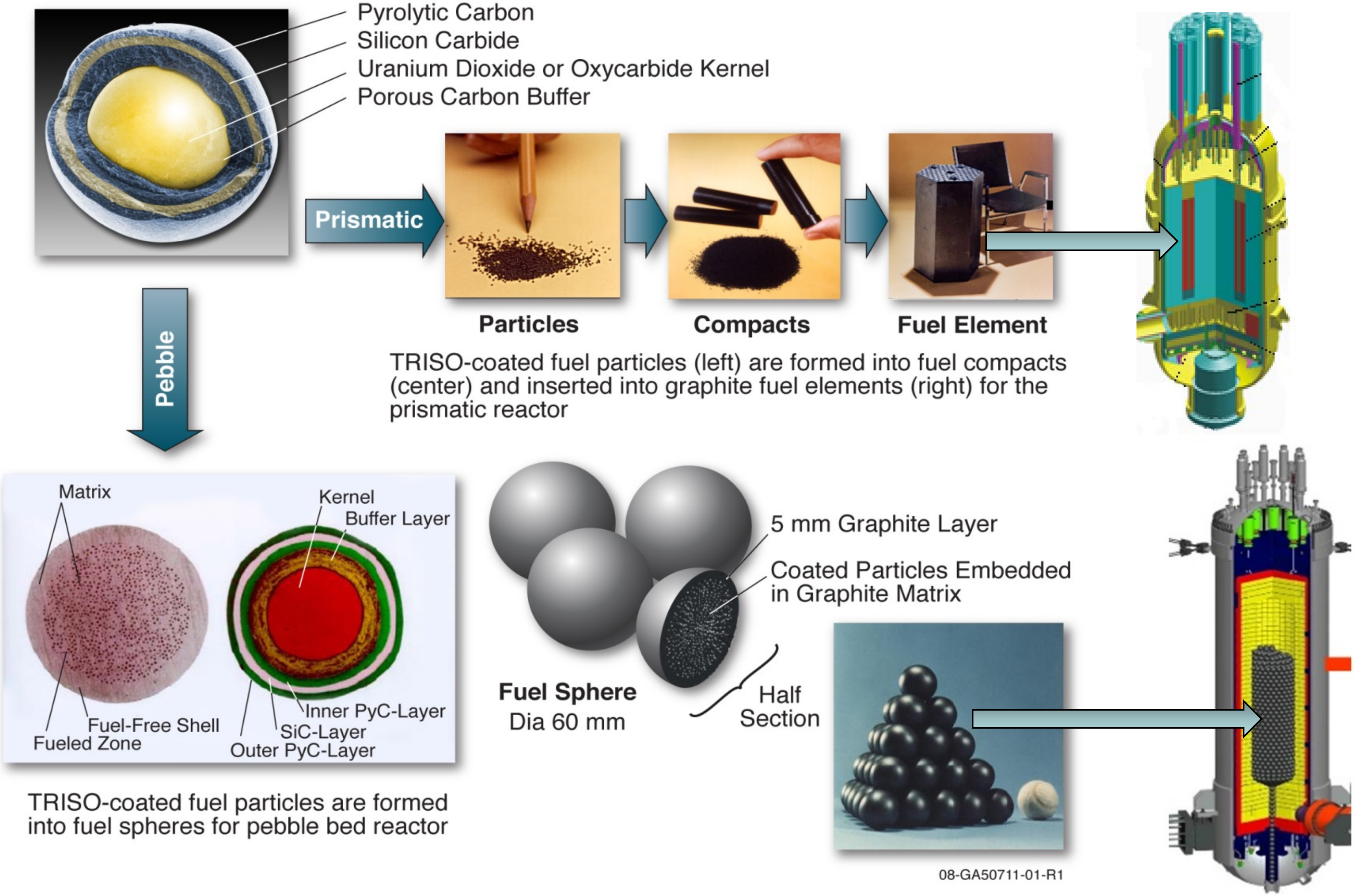
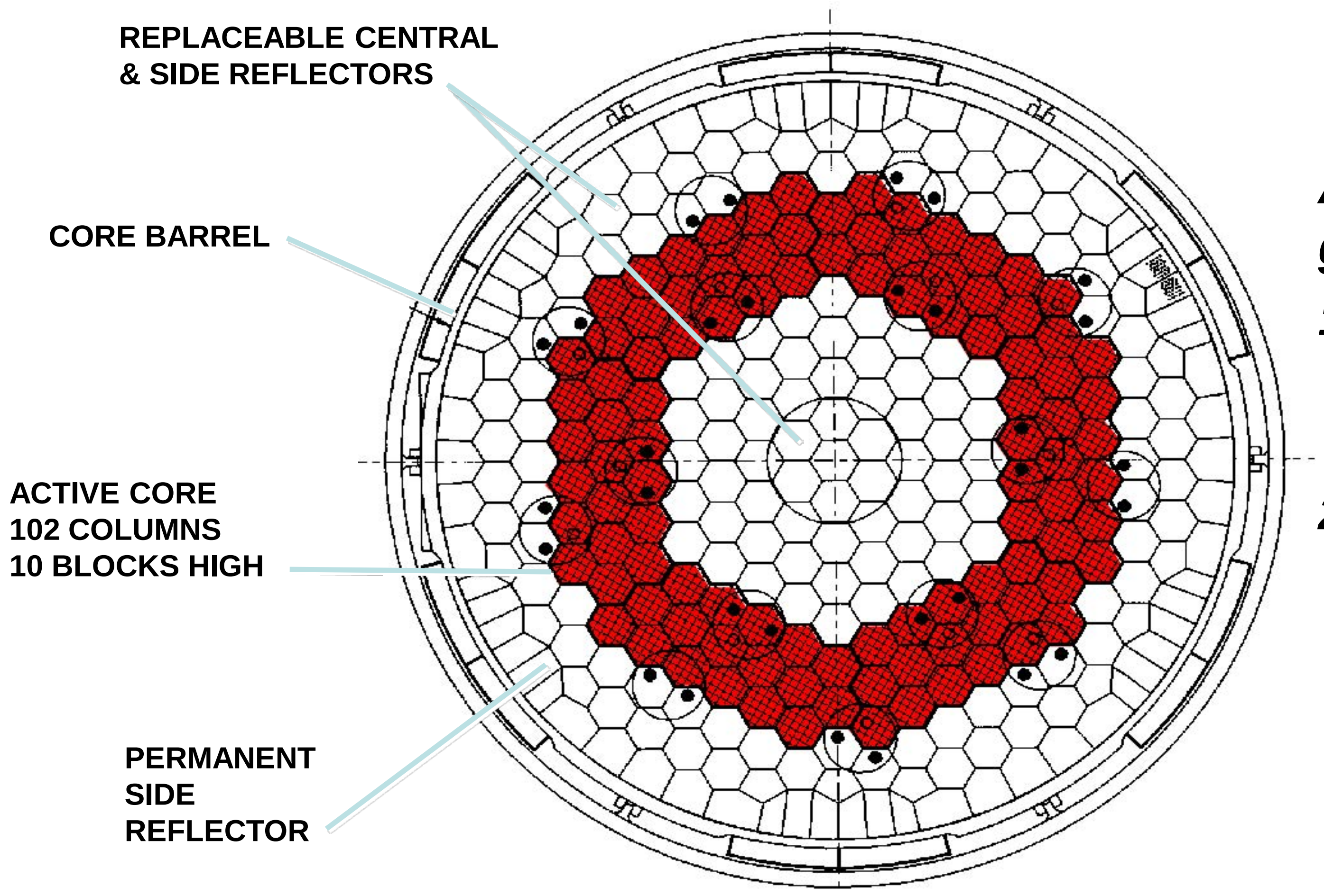
Modular HTGR Fuel



Annular Core Optimizes Passive Heat Removal



Annular core geometry:

1) Shortens heat conduction pathway

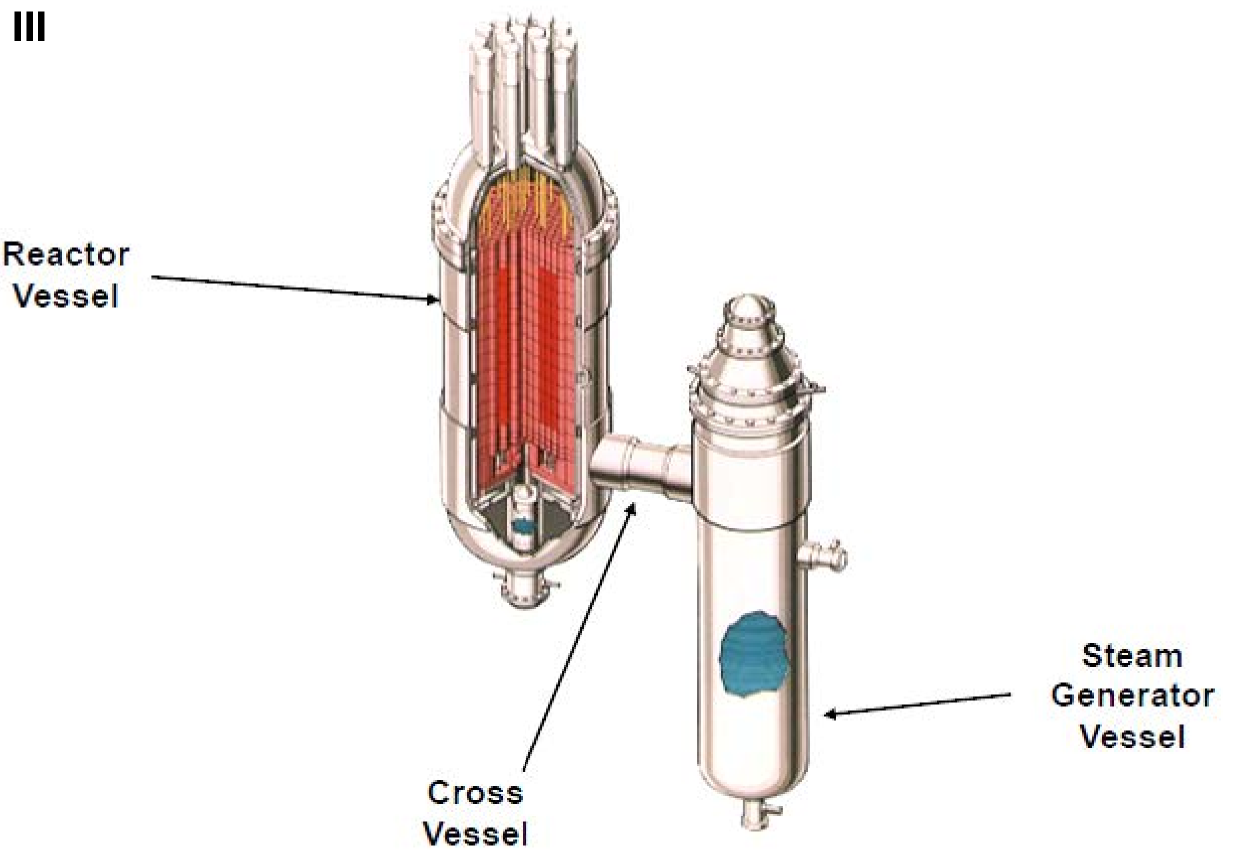
2) Enhances surface to volume ratio

Typical Modular HTGR Vessel System (Steam Cycle)

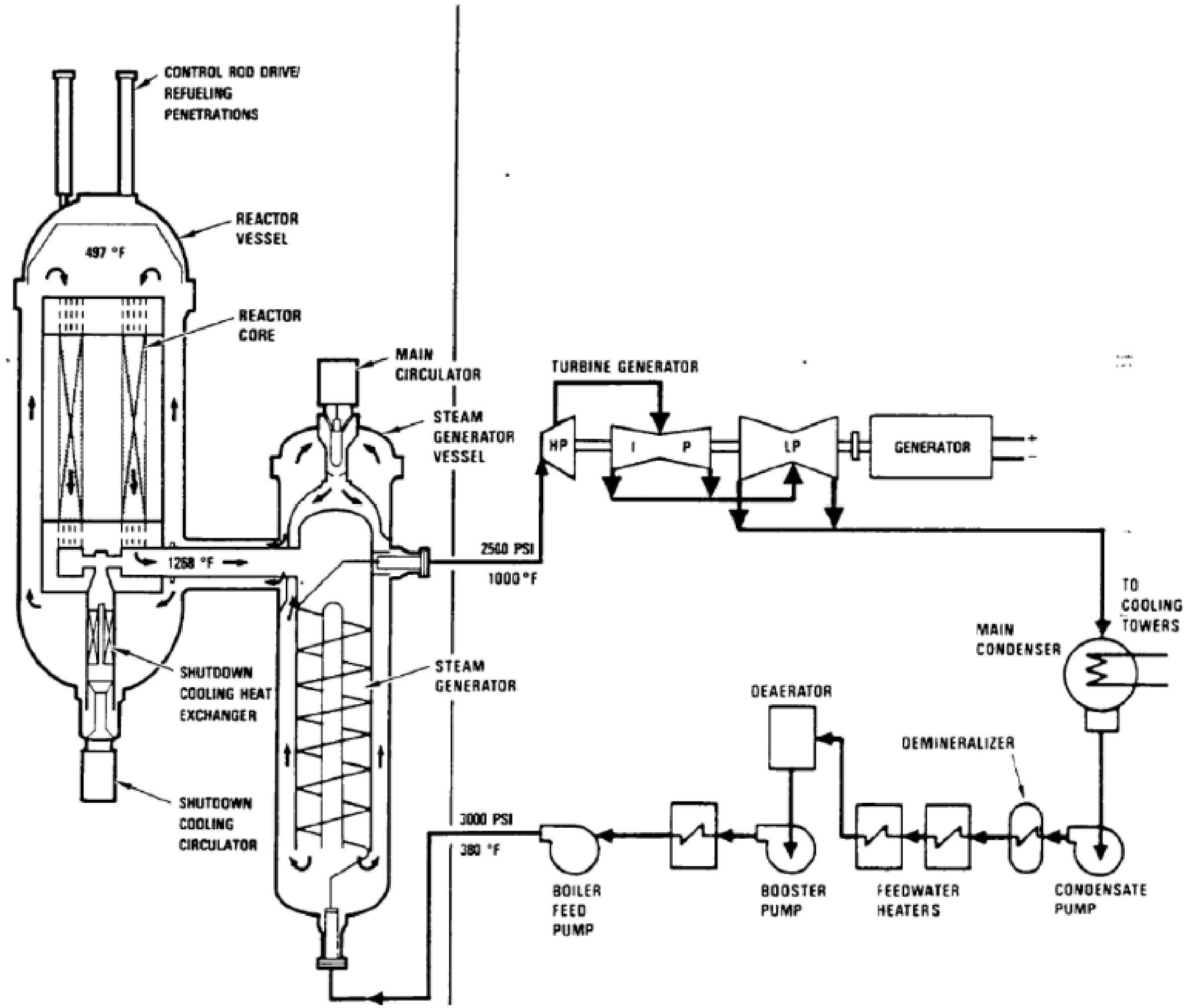
ASME B&PV Code Section III pressure vessels

Higher pressure colder helium in contact with vessels

Loss of helium pressure does not cause loss of cooling



Typical Modular HTGR Steam Cycle Schematic



Reference Embedded Reactor Building (MHTGR)

Multi-cell, reinforced concrete

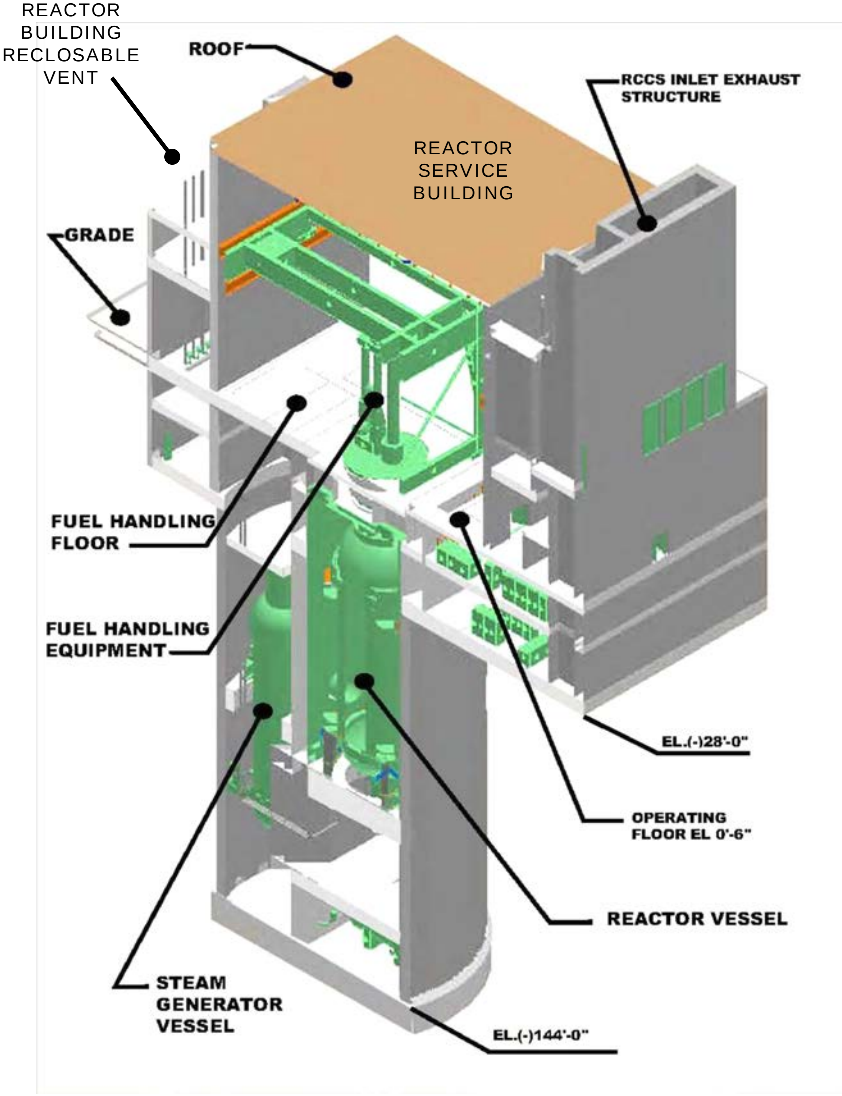
Safety Related, Seismic Category 1

External walls ~ 3 ft thick

5 ft slab between RV and SGV cavities

Slab at grade provides:
- Biological shielding
- Missile protection
- Plugs for equipment access
- Control for personnel access

Moderate reactor building leak rate (100% per day)

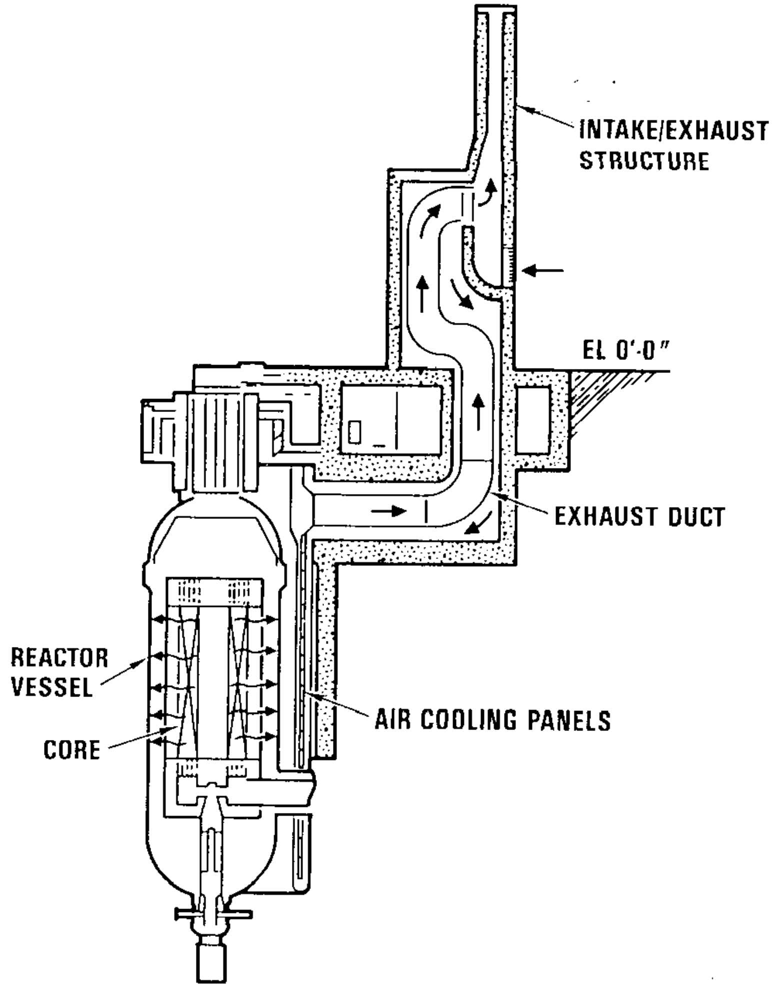


Modular HTGR Core Heat Removal

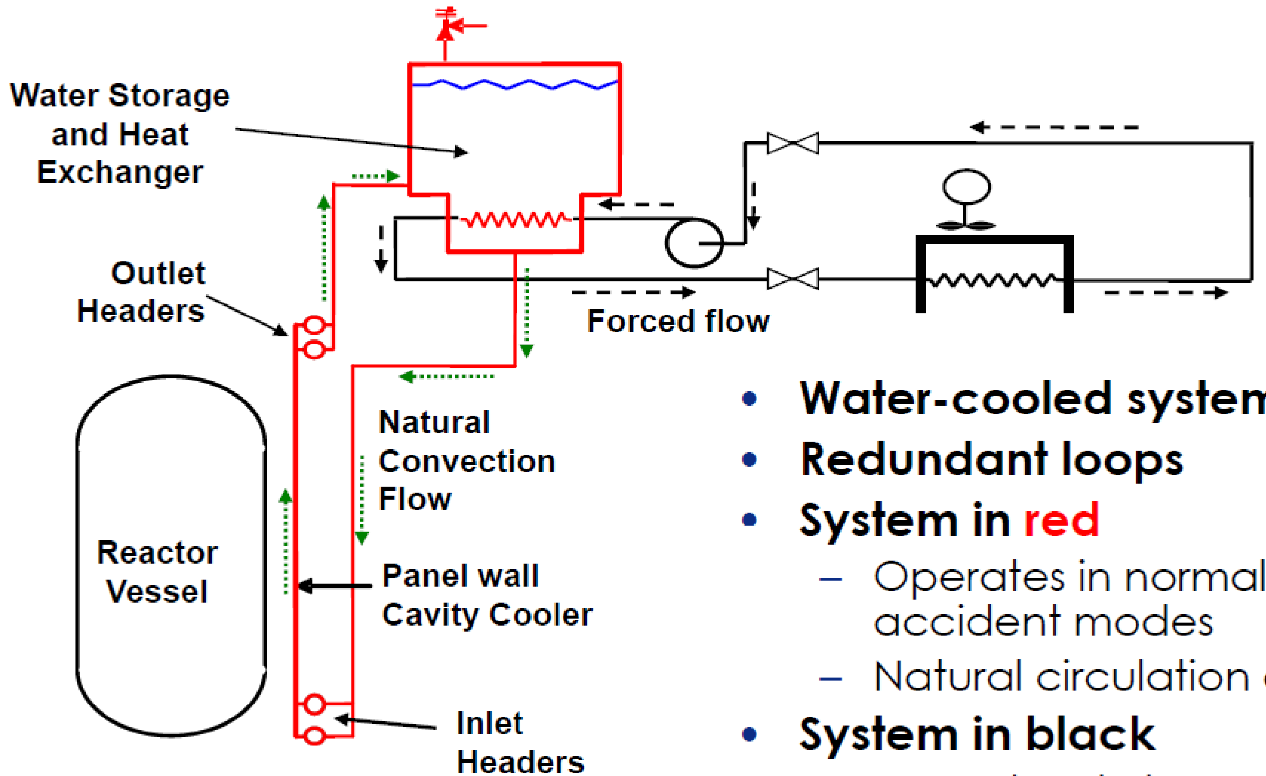
- **Typically, there are three ways to remove core heat:**
  - Heat Transport System
  - Shutdown Cooling System, and
  - Reactor Cavity Cooling System (RCCS)
- **The Heat Transport System and the Shutdown Cooling System are not safety related**
- **The RCCS:**
  - Can be active or passive during normal operation
  - Is passive during accident conditions; passive portions are safety-related and are relied upon during accident conditions
- **Passive removal of core heat under accident conditions is among the defining characteristics of a modular HTGR**

Conceptual Reactor Cavity Cooling System (RCCS) – Air-Based

- Air-cooled
- Natural circulation
- Redundant/multiple flow paths
- Intake/exhaust structure to mitigate external effects
- Always passive
- Air cooling panels and ducting allow transmission of heat from uninsulated reactor vessel to the atmosphere



Conceptual RCCS – Water-Based

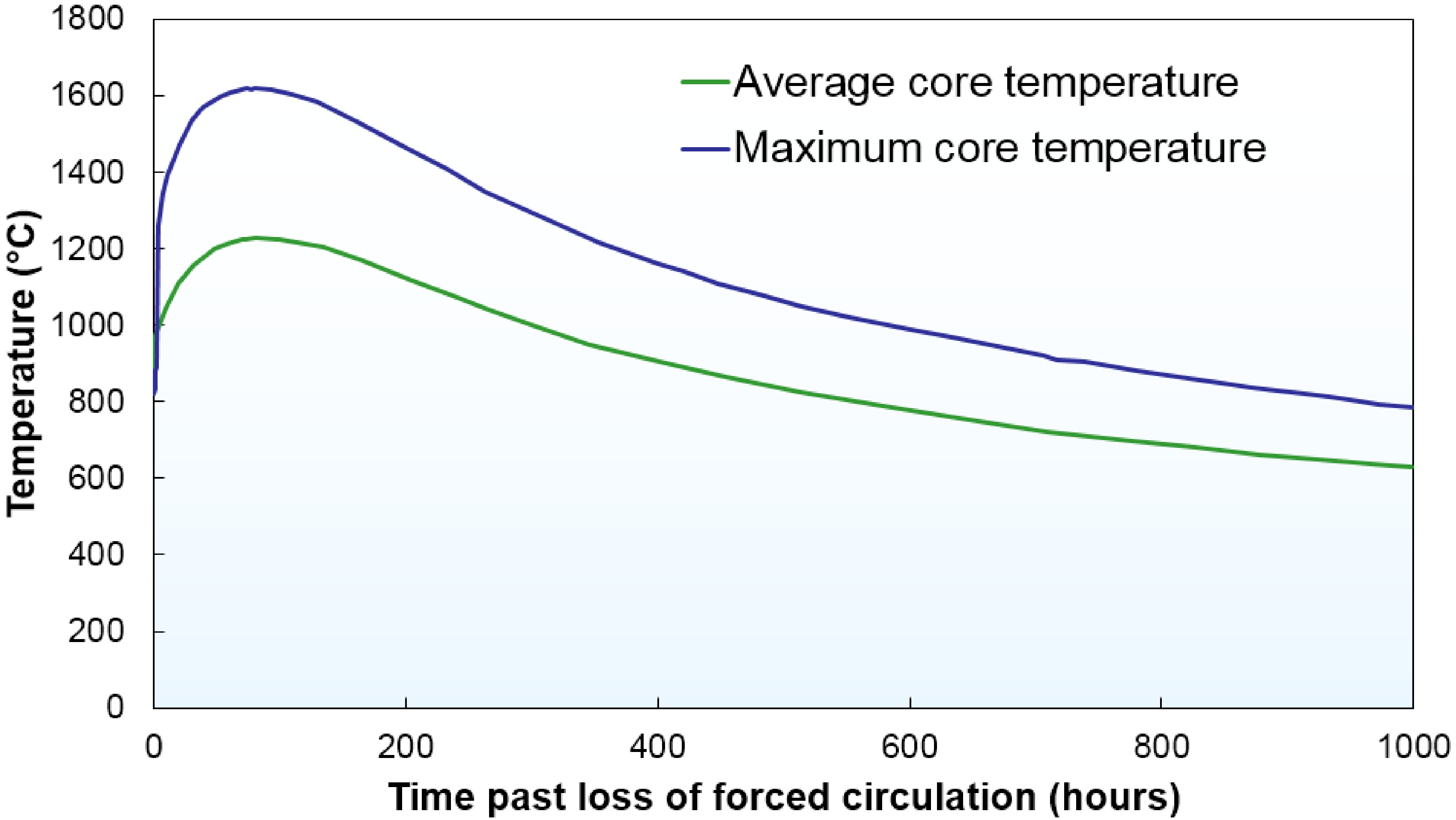


- **Water-cooled system**
- **Redundant loops**
- **System in red**
  - Operates in normal and accident modes
  - Natural circulation driven
- **System in black**
  - Operates during normal operation
  - Forced circulation

Loss of Forced Cooling Events (LOFCs) Utilize Passive Heat Removal

- **LOFCs are rare events in which the forced cooling systems are both immediately and indefinitely unavailable to remove core heat**
- **Consequently, the core gradually heats up and the heat is removed by conduction, radiation, and convection radially to the RV to the RCCS**
- **LOFCs can occur with helium under pressure or depressurized (DLOFC)**
- **DLOFCs consist of three phases that can overlap depending on the size of the leak/break in the HPB:**
  - Initial depressurization (minutes to days) – initial radionuclide release
  - Subsequent core heatup (~2 to 4 days) – delayed radionuclide release
  - Subsequent core cooldown (days) – radionuclide release ends

Typical Core Temperatures Following Depressurized Loss of Forced Cooling



Secondary Plant Alternatives (Direct, Steam, or Process Heat)

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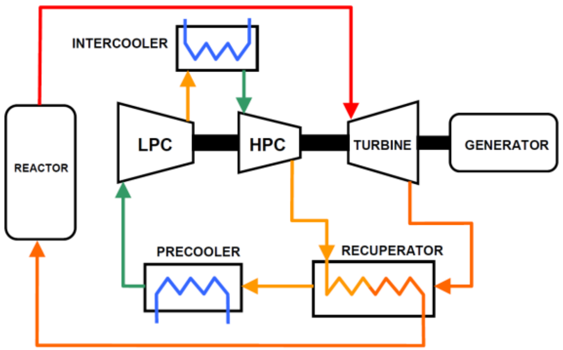
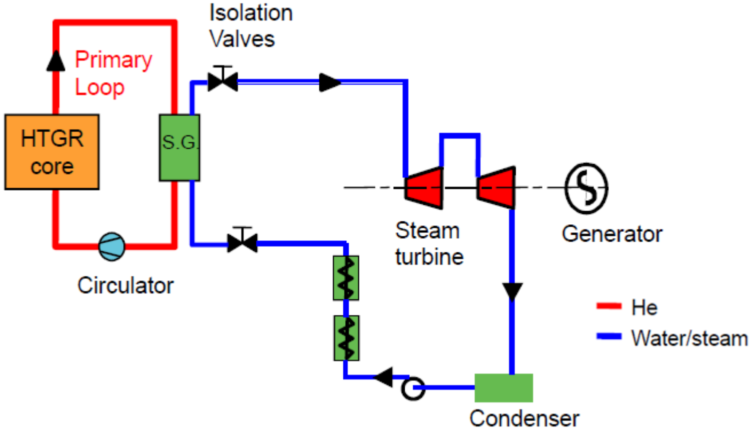
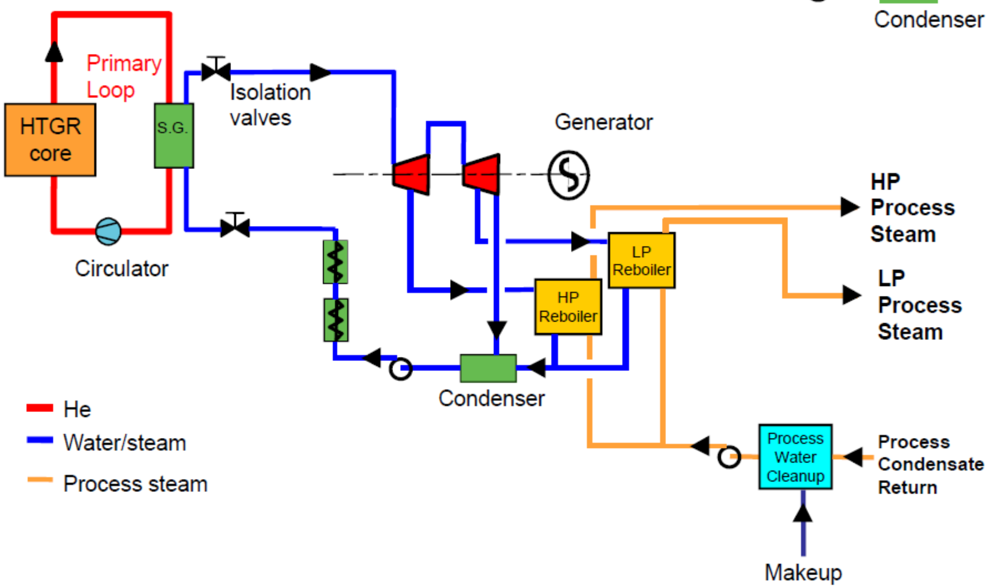
Direct Cycle



Steam Cycle



Steam Cycle + Process Heat



Modular HTGR Safety Design Approach

Modular HTGR Safety Design Requirements and Objectives

- **Meet regulatory dose limits at the Exclusion Area Boundary (EAB)**
  - 25 rem TEDE (for duration of the release) from 10 CFR 50.34 (10 CFR 52.79) at EAB for design basis accidents
  - EAB is typically estimated to be approximately 400 meters from the plant for a modular HTGR; supports co-location with industrial facilities
- **Meet safety goals for cumulative individual risk for normal and off-normal operation**
- **Meet the EPA Protective Action Guides (PAGs) at the EAB as a design goal**
  - 1 rem TEDE for sheltering
  - Design basis and beyond design basis events are considered
  - Realistically evaluated at the EAB
  - Emergency planning and protection

Modular HTGR Safety Design Approach

- **Utilize inherent material properties**
  - Helium coolant – neutronically transparent, chemically inert, low heat capacity, single phase
  - Ceramic coated fuel - high temperature capability, high radionuclide retention
  - Graphite moderator - high temperature stability, large heat capacity, long thermal response times

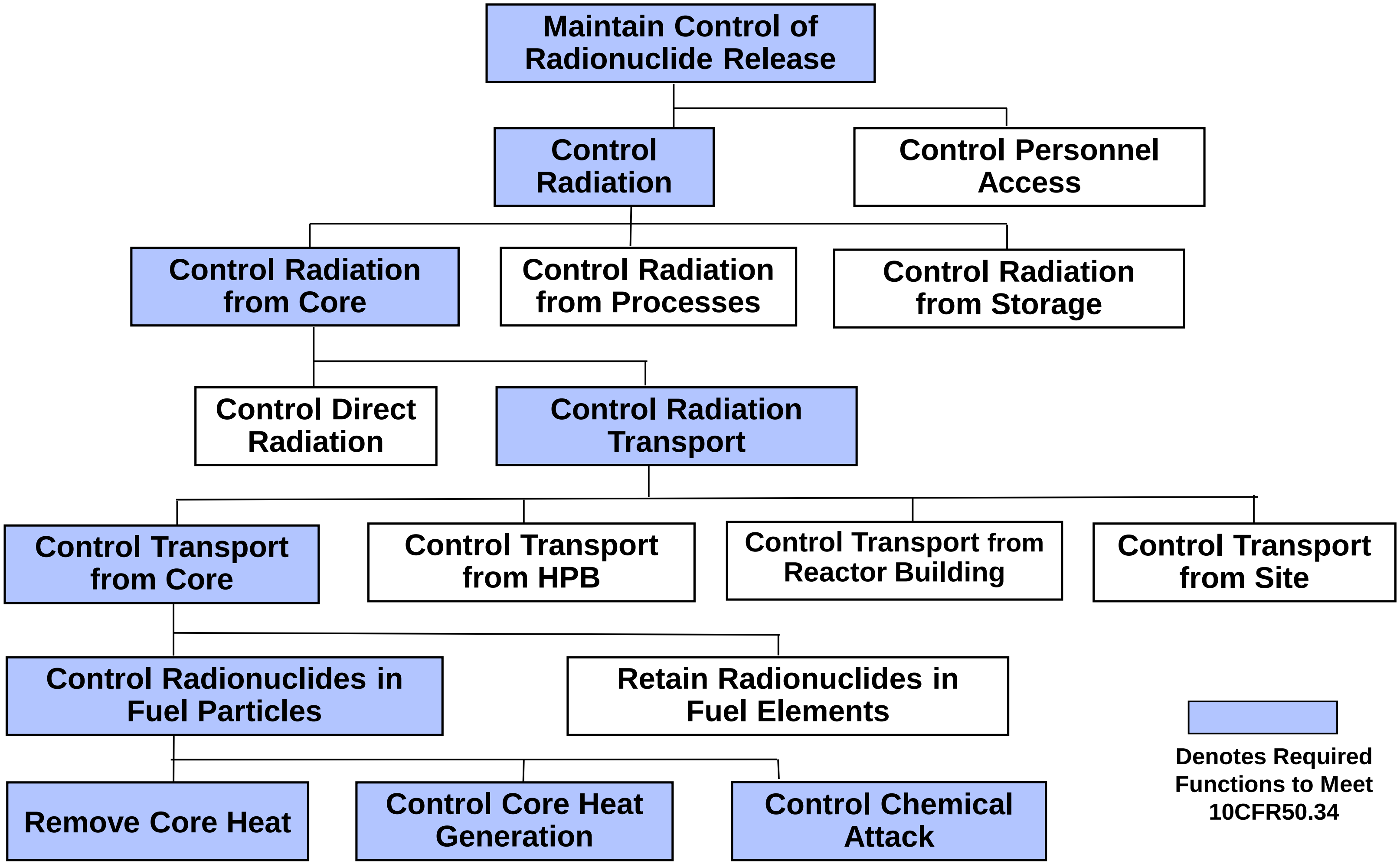
***Modular HTGR Safety Basis and Approach paper submitted for information to NRC,* INL/EXT-11-22708, September 2011, ML14174A774**

Modular HTGR Safety Design Approach (cont.)

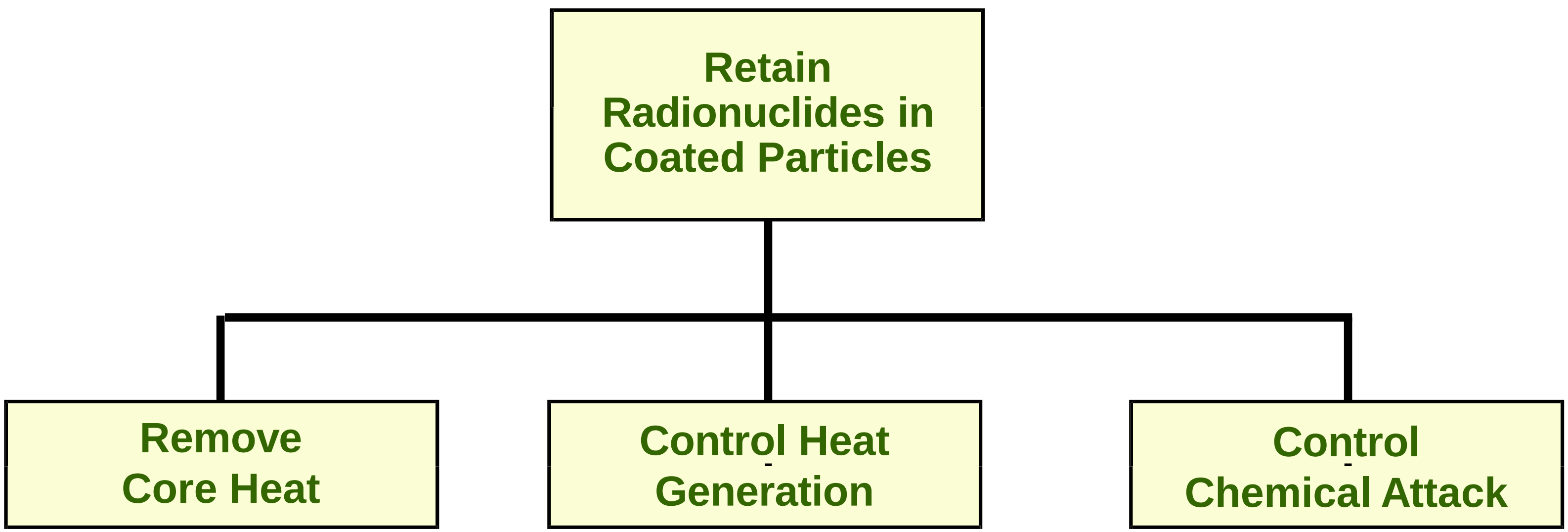
- **Develop simple modular reactor design with inherent and passive safety features**
  - Retain radionuclides at their source within the fuel
  - Shape and size of the reactor allows for passive core heat removal from the reactor core through the uninsulated reactor vessel
    - Heat is still removed if system is depressurized due to a breach in the reactor helium pressure boundary
    - Heat is radiated from the reactor vessel to the RCCS panels
  - Large negative temperature coefficient for intrinsic reactor shutdown
  - No reliance on AC-power to perform necessary safety functions
  - No reliance on operator action and insensitive to incorrect operator actions

Modular HTGR Safety Basis and Approach paper submitted for information to NRC, **INL/EXT-11-22708, September 2011, ML14174A774**

Functional Requirements for Control of Radionuclide Release



Retention of Radionuclides in the Fuel Particles Depends on Three Functions



Control of Heat Generation

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

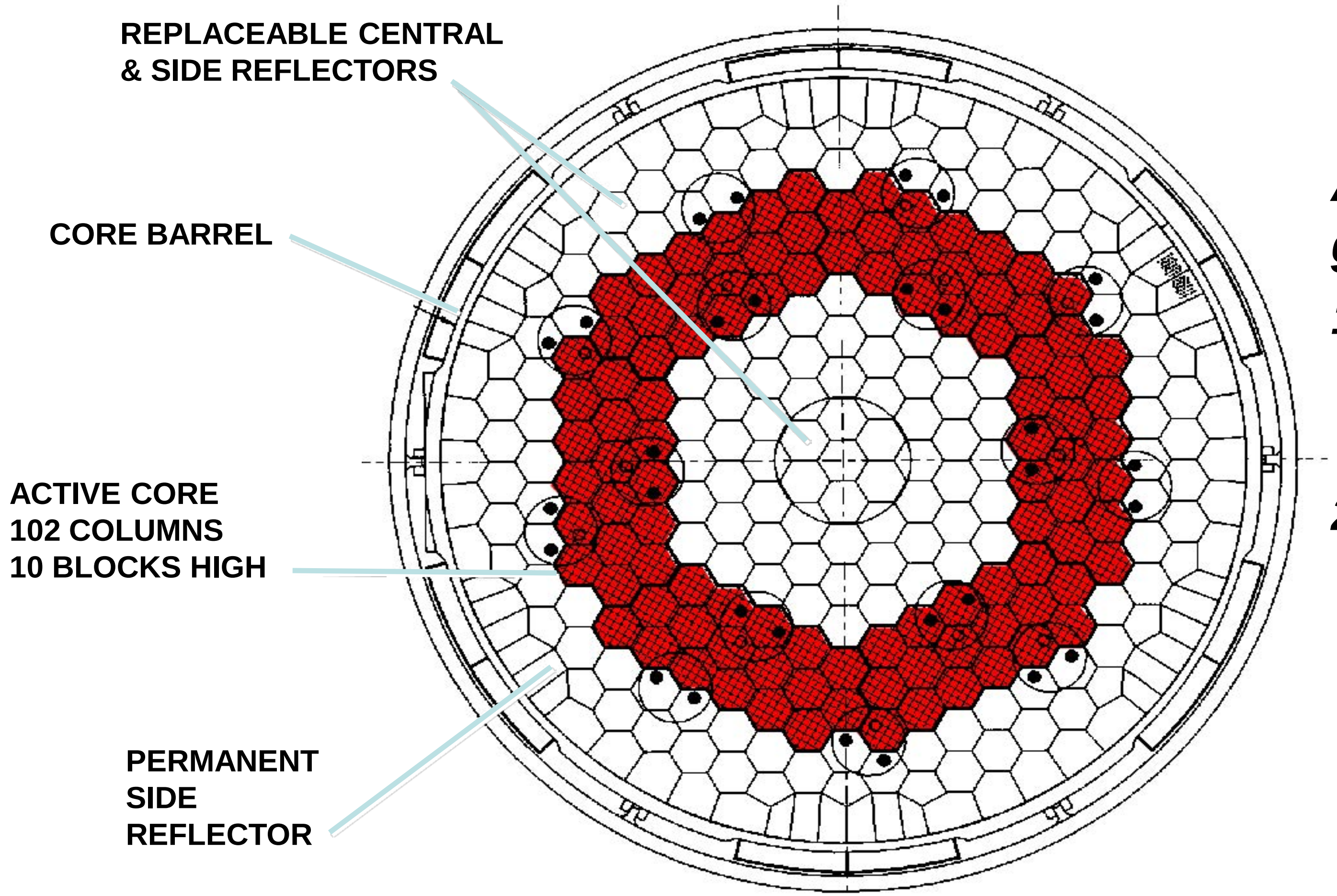
- **Large negative temperature coefficient intrinsically shuts reactor down**
- **Two independent and diverse systems of reactivity control for reactor shutdown drop by gravity on loss of power**
  - Control rods
  - Reserve shutdown system
- **Each system capable of maintaining subcriticality**
- **One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

Remove Core Heat

Removal of Residual 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 convective circulation of air or water during accident conditions

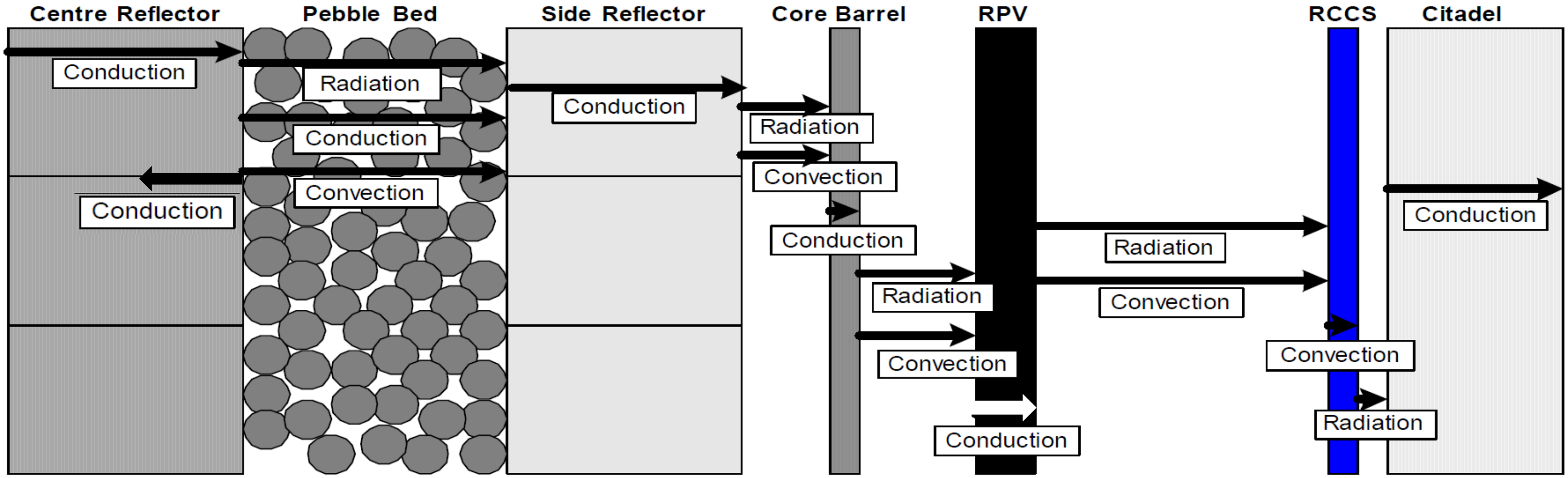
Annular Core Optimizes Passive Heat Removal



Annular core geometry:

1. ***Shortens heat conduction pathway***
2. ***Enhances surface to volume ratio***

Passive Heat Transfer Path (Example: Annular Core Pebble Bed)



Reactor Cavity Cooling System

- **Consists of cooling structures surrounding reactor vessel**
- **Removes heat transmitted from the vessel by radiation and convection**
- **The safety related portion of the system passively removes heat by natural convection air or natural circulation water flow**
- **Provides simple and reliable means of residual heat removal**
- **Meets all requirements with ample margin and redundancy**

Modular HTGR RCCS – Key Design Considerations

- RCCS maintains cavity wall and reactor vessel temperatures
- RCCS heat removal rate is similar during normal operations and accidents
- RCCS is a simple system, always passive under safety-related conditions
- Variety of possible RCCS configurations
- Concrete temperatures are a strong function of RCCS performance
- Normal operation provides confirmation of system status

Control of Chemical Attack

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

- Inert coolant (helium)
- High integrity nuclear grade pressure vessels make large break exceedingly unlikely
- Slow oxidation rate (high purity nuclear grade graphite does not "burn")
- Limited by core flow area and friction losses
- Reactor building embedment and vents that close after venting limit potential air in-leakage
- Graphite fuel form, 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 form, fuel compact matrix, and ceramic coatings protect fuel particles**

Functional Containment Design and Performance

Modular HTGR Employs a Functional Containment for Radionuclide Retention

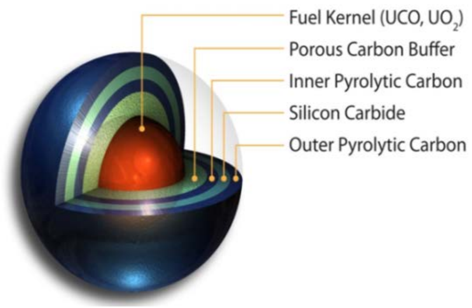
The modular HTGR functional containment consists of a collection of design selections that, taken together, ensure:

- Radionuclides are retained within multiple barriers with emphasis on retention at their source (in the fuel)
- NRC regulatory requirements (10 CFR 50.34/10 CFR 52.79) and plant design goals (PAGs) for release of radionuclides are met at the EAB

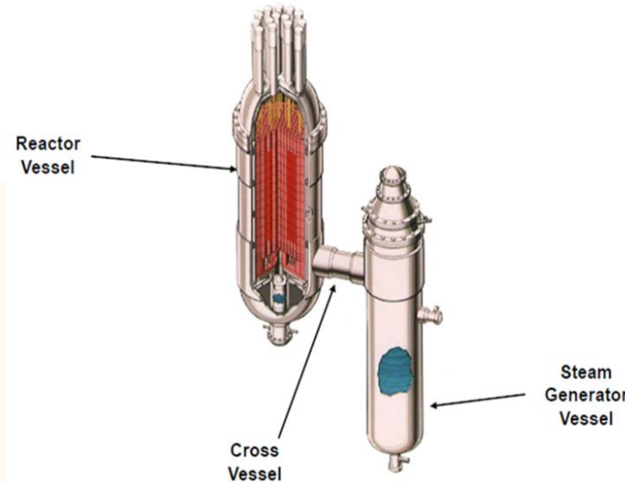
Modular HTGR Functional Containment is Five Radionuclide Release Barriers Working in Series

- **Fuel Kernel**
- **Fuel Particle Coatings**
- **Matrix/Graphite**

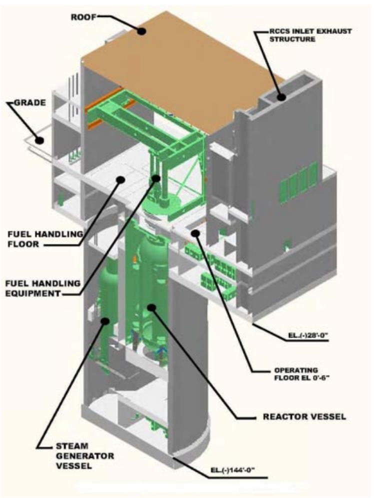
} **Fuel Element**



- **Helium Pressure Boundary**



- **Reactor Building**



Fuel Particle Coatings are the Primary Barrier to Radionuclide Release During Normal Operation and Off-Normal Events

- **Low heavy metal contamination and low initially defective fuel particles in as-manufactured fuel (~10^{-5})**
- **Minimal radionuclide release from incremental fuel failure during normal operation (<10^{-4})**
- **Minimal radionuclide release from incremental fuel failure during Licensing Basis Events (<10^{-4})**
- **Radionuclide release during LBEs dominated by exposed heavy metal (contamination and exposed fuel kernels)**

Fuel Particles Retain Radionuclides at Temperatures Well Above Normal Operation

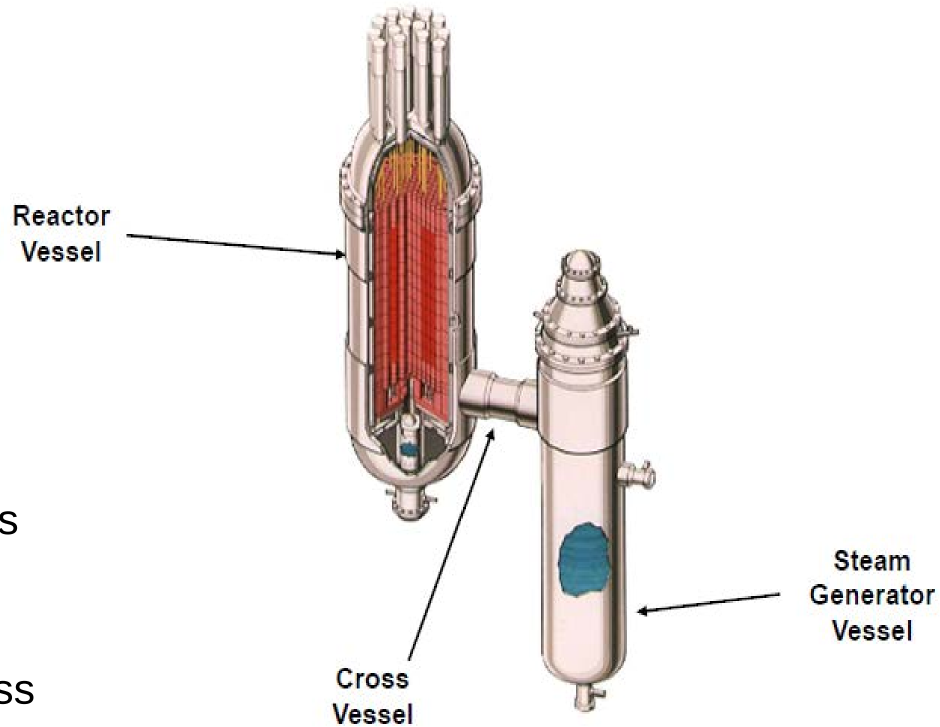
- **Normal operating peak fuel temperature less than 1250°C**
- **German fuel element test results have demonstrated retention capability for hundreds of hours at 1600°C and greater than a hundred hours at 1700°C without fuel particle failure**
- **Recent AGR-1 heat-up tests show very low releases after 300 hours at 1600 and 1700°C with no particle failures (peak burnup of 19.4% FIMA)**
- **Observed one TRISO particle failure after 270 hours at 1800°C in recent AGR-1 heat-up test for 4800 particles**
- **Large temperature margins enable:**
  - Passive heat removal independent of coolant pressurization
  - Greater use of negative temperature coefficient for intrinsic reactor shutdown

Radionuclide Behavior During Normal Operation

- **Most radionuclides reach a steady state concentration and distribution in the primary circuit (long lived isotopes like Cs-137 and Sr-90 are exceptions – plateout inventory builds up over plant life)**
- **Concentration and distribution are affected by:**
  - Radionuclide half-life
  - Initial fuel quality
  - Incremental fuel failure during normal operation
  - Fission product fractional release from fuel kernel
  - Transport of fission products through particle coatings, matrix, and graphite
  - Fission product sorptivity on fuel matrix and graphite materials
  - Fission product sorptivity on primary circuit surfaces (plateout)
  - Helium purification system performance

Helium Pressure Boundary (HPB) Releases

- **Potential radionuclide release mechanisms**
  - Primary coolant leaks
  - Liftoff (mechanical reentrainment)
  - Steam-Induced vaporization
  - Washoff (removal by liquid H2O)
  - Primary coolant pressure relief
- **Controlling parameters**
  - Size/location of coolant leaks/breaks
  - Temperatures
  - Particulate matter
  - Steam/liquid H2O ingress and egress
- **Barrier performance**
  - Condensable RNs plate out during normal operation
  - Circulating Kr and Xe limited by Helium Purification System
  - Plateout retained during leaks and largely retained during rapid depressurizations
  - RN holdup after core heatup due to thermal contraction of gas



Initial Radionuclide Release Mechanisms for Sources in the Helium Pressure Boundary

Circulating activity

- Released from HPB with helium in minutes to days as a result of HPB leak/break
- Amount of release depends on location of leak/break and any operator actions to isolate and/or intentionally depressurize

Liftoff of plateout and resuspension of dust

- Liftoff physical and chemical phenomena include:
  - Particulate entrainment: removal of dust, oxidic and metallic particles from surfaces
  - Desorption: removal of atoms or molecules sorbed from surfaces
  - Diffusion: transport of fission or activation products from surface inward or to and from particulates
  - Aerosol formation: mechanism by which the particulates are formed
- For large breaks, fractional radionuclide amounts released from HPB with helium relatively quickly (minutes)
- Amount of release depends on HPB break size and location
- Surface shear forces must exceed those for normal operation to obtain liftoff or resuspension

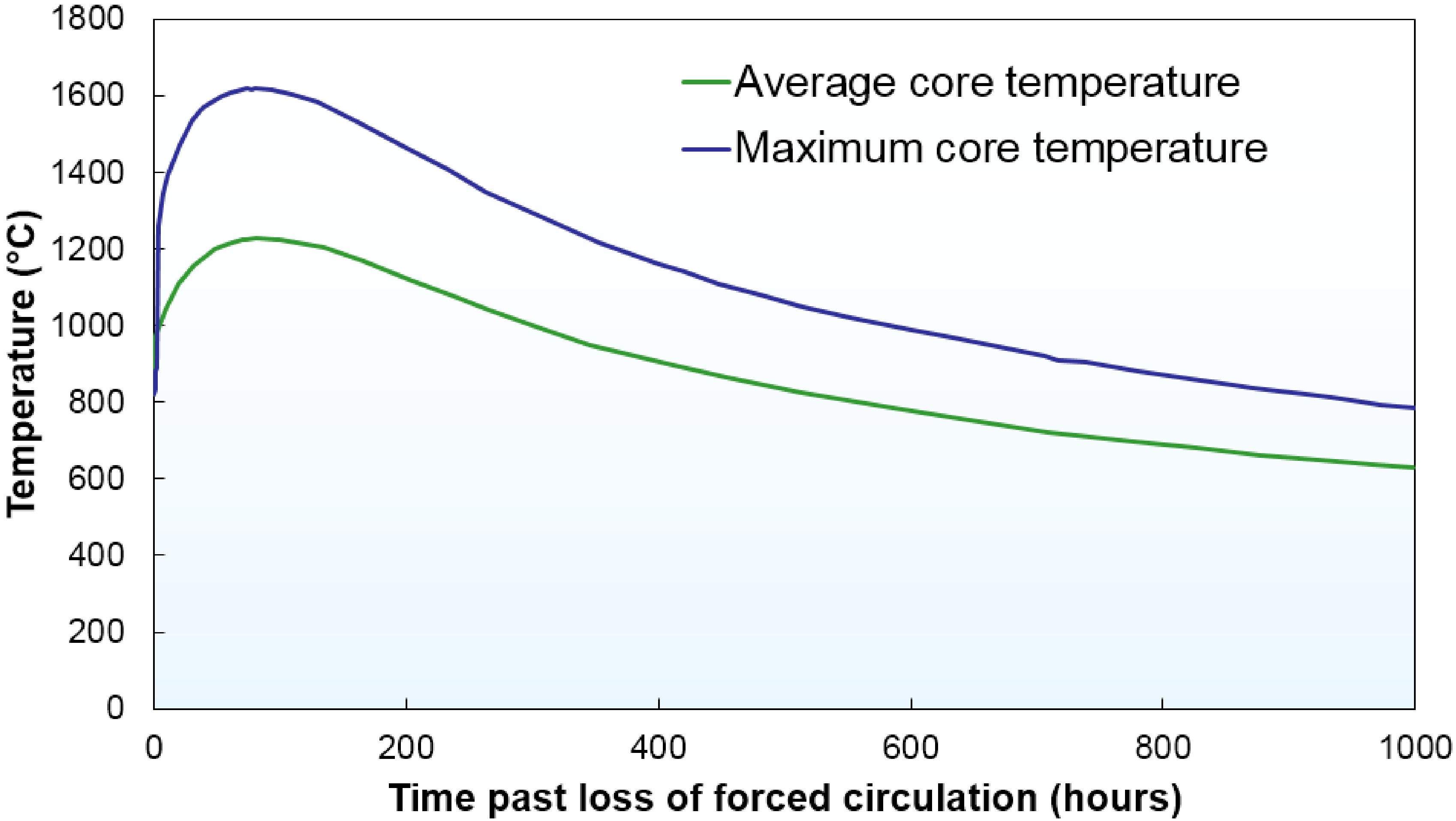
Mechanisms for Delayed Radionuclide Release from Core

- **Delayed release occurs only for accidents involving core heatup**
- **Partial release from contamination, initially failed or defective particles when temperatures exceed normal operation levels, and from particles that fail during the event**
- **Timing of release is tens of hours to days**
- **Inventory is much larger than circulating activity and liftoff**
- **Amount of release from fuel depends on fraction of core above normal operation temperatures for given times and on radionuclide volatility**
  - Governed by amount of forced cooling
  - Dependent on whether small leak or large break

Factors Affecting Delayed Radionuclide Release from the HPB

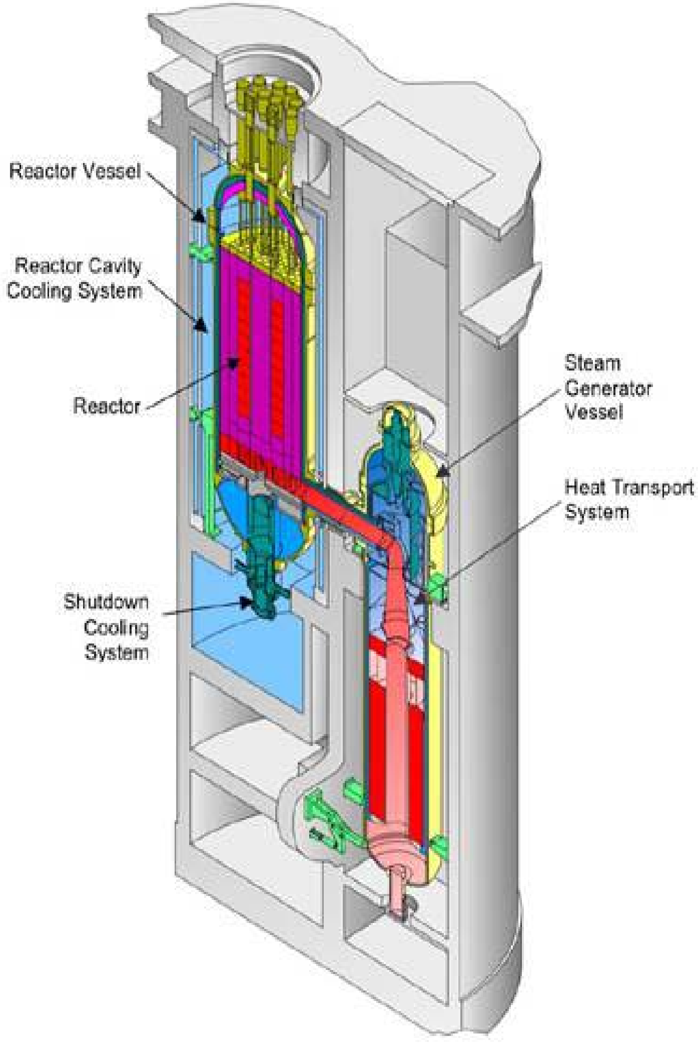
- **Amount of delayed release from HPB depends on location and size of leak/break and on timing relative to expansion/contraction of gas mixture within the HPB during a core heatup transient**
  - Small leaks have greater releases from HPB
  - Releases cease when temperatures within the HPB decrease due to core temperature cooldown

Typical Core Temperatures Following Depressurized Loss of Forced Cooling



Role of Reactor Building in Safety Design

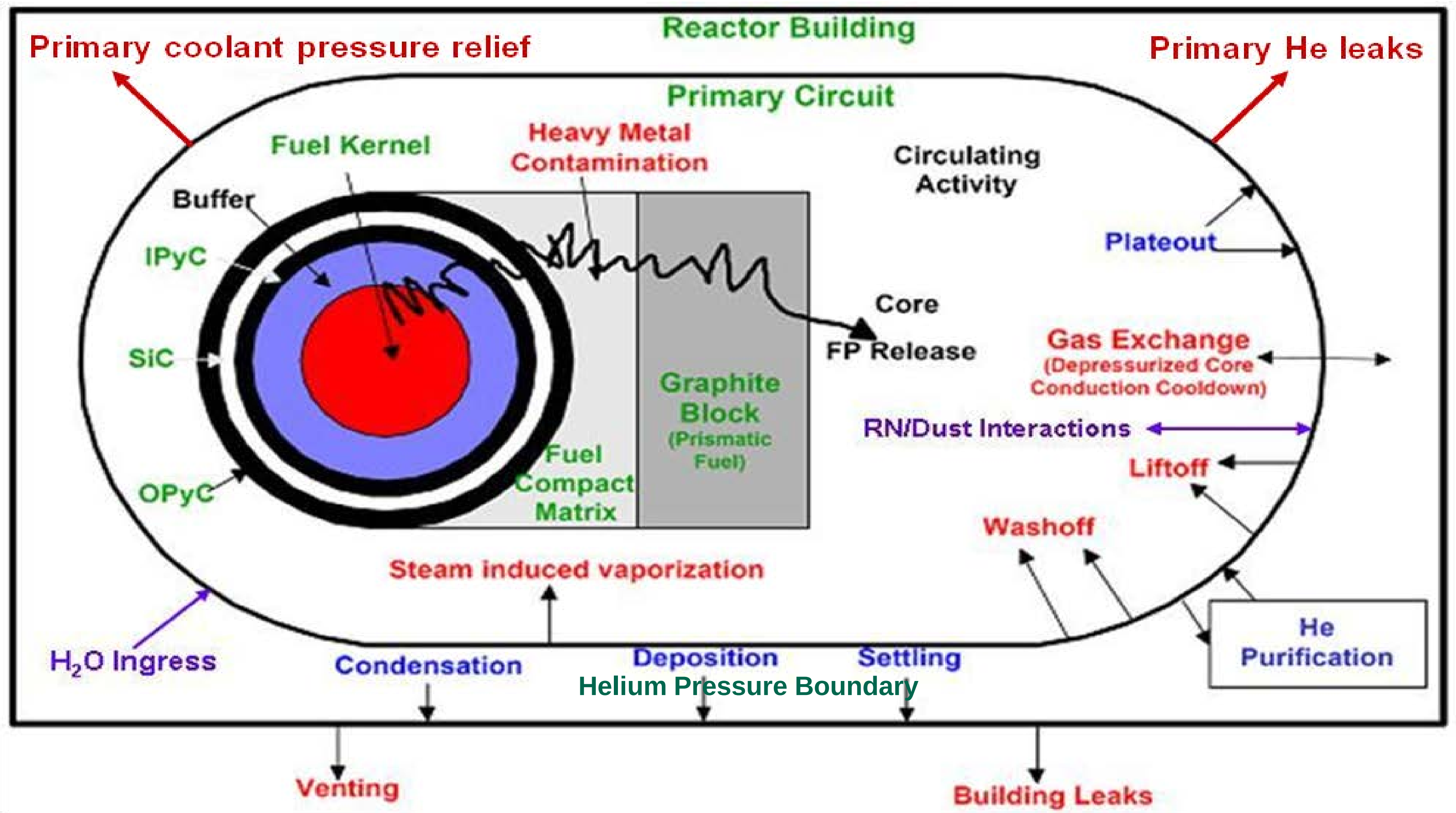
- **Structurally protects pressure vessels and RCCS from internal and external hazards, and provides additional radionuclide retention**
- **Limits air available for ingress after HPB depressurization**
- **Provides structural support for RCCS and helium depressurization pathway**
- **Is <u>not</u> relied upon for radionuclide retention to meet off-site dose regulatory requirements**



Vented Building Addresses Several Modular HTGR Specific Design Issues

- **Matched to modular HTGR accident behavior**
  - The reactor building is vented early in a helium pressure boundary break scenario when the helium circulating activity is low
  - The reactor building vent is closed later in the transient when the particle fuel experiences maximum temperatures
  - Prevents reactor building overpressure from release of non-condensing helium coolant
- **More benign environment for passive Reactor Cavity Cooling System designs**
  - Heat
  - Pressure

Modular HTGR Radionuclide Retention During Normal Operation and Licensing Basis Events



The phenomena illustrated in this figure are modeled to determine mechanistic source terms for normal and off-normal events

Functional Containment Performance Summary

- **Radionuclide retention within fuel during normal operation with relatively low inventory to HPB**
- **Limiting off-normal events characterized by**
  - An initial release from the HPB depending on leak/break/pressure relief size
  - A larger, delayed release from the fuel
- **Functional containment will meet 10CFR50.34 (10 CFR 52.79) at the EAB with margin for a wide spectrum of off-normal events without consideration of reactor building retention**
- **Functional containment (including reactor building) will meet EPA PAGs at the EAB with margin for wide spectrum of off-normal events**

Important Modular HTGR Safety Paradigm Shifts

- **The functional containment consists of multiple barriers with emphasis on radionuclide retention at the source within the fuel; barriers are nested and independent**
- **The fuel has very large temperature margins in normal operation and during accident conditions**
- **Coated particle fuel failure is a function of time at temperature; no cliff-edge effects**
- **The fuel, helium, and graphite moderator are chemically compatible under all conditions**
- **Safety is not dependent on maintaining helium circulation or pressure**

Important Modular HTGR Safety Paradigm Shifts (cont.)

- **Loss of helium pressure does not transfer large amounts of energy into reactor building**
- **Response times of the reactor are very long (days as opposed to seconds or minutes)**
- **There is no inherent mechanism for runaway reactivity or power excursions**
- **An LWR-type containment is neither advantageous nor necessarily conservative**

Factors That Impact Design Criteria for Modular HTGRs

Need for Adapting ARDC for Modular HTGRs

- **Advanced Reactor Design Criteria (ARDC) developed for advanced reactors need further adaptation to address the specifics of modular HTGRs**
- **Major drivers for ARDC adaptations for modular HTGRs:**
  - Functional Containment
  - New Criteria - Reactor Building Safety Functions
  - Modular HTGR Particle Fuel Design Limits
  - Safety Related Heat Removal
  - Effect of Passive Heat Removal on Design Criteria
  - Safety Related AC Electrical Power Is Not Required

Modular HTGR Functional Containment vs. LWR Containment

- **The functional containment focuses on retaining radionuclides within fuel under all plant conditions with relatively low inventory releases to helium pressure boundary; LWR approach assumes large source term release to containment and relies on single barrier (containment) performance**
- **Higher consequence licensing basis events characterized by:**
  - Initial release from the HPB depending on leak/break/pressure relief size
  - A larger, delayed release from the fuel once the core heats
- **Design requirements for individual constituents of the functional containment are addressed in a number of proposed modular HTGR design criteria**
  - mHTGR-DC 10: Reactor Design
  - mHTGR-DC 15: Reactor Helium Pressure Boundary
  - mHTGR-DC 16: Containment Design
  - mHTGR-DC 34: Passive Heat Removal
  - mHTGR-DC 70: Reactor Vessel and Reactor System Structural Design Basis
  - mHTGR-DC 71: Reactor Building Design Basis

New Criteria (70 – 72) – Reactor Vessel & Reactor Building

- **Reactor vessel and reactor system (internals) structural design ensure that geometry for passive heat removal is maintained during postulated accidents (70)**
  - RCCS provides passive removal of residual heat from the reactor core to the ultimate heat sink
  - Allow insertion of the neutron absorbers to effect reactor shutdown
- **Heat removal geometry issues specific to the modular HTGR are not addressed in other criteria (71 & 72)**
- **Reactor building safety functions**
  - Protect risk-significant SSCs from internal, external, and security events
  - Physically support risk-significant SSCs
  - Provide pathway for release of reactor helium from the building in the event of depressurization accidents
- **Regulatory offsite dose requirements (10 CFR 50.34/10 CFR 52.79) can be met without taking credit for radionuclide retention by the reactor building during design basis events**

Modular HTGR Particle Fuel Design Limits (10)

- **The LWR-specific specified acceptable fuel design limit (SAFDL) has no meaning relative to modular HTGR particle fuel; replaced with Specified Acceptable Core Radionuclide Release Design Limit (SARRDL) – not to be exceeded during normal operations or AOOs**
  - Coated particle fuel performance is a function of time at temperature; there is no cliff-edge temperature above which rapid fuel failure occurs
  - Residual heat removal is not dependent on helium pressurization or forced circulation, so LWR LOCA considerations do not apply
  - Core radionuclide release is measurable, tied directly to fuel particle failure, and directly linked with off-site dose consequences for off-normal events
- **Modular HTGR designers use core radionuclide release as the final fuel and core design parameter; is taken into account in setting plant Technical Specifications**

Safety Related Heat Removal (34 – 35)

- **Maintaining modular HTGR particle fuel integrity during design basis accidents**
  - Does not rely on helium pressurization or forced circulation to transport heat from the core
  - Heat is passively transmitted from the core through the reactor vessel and to the RCCS panels that surround the reactor vessel
  - The RCCS is the conduit to the ultimate heat sink (the atmosphere)
- **Separate system similar to an LWR's Emergency Core Cooling System (ECCS) is not needed**
  - Helium is not used to remove core heat under these conditions; no need to "inject" a cooling medium to maintain fuel integrity
  - Appendix A GDC related to ECCS are not needed for modular HTGRs; that function is provided by the RCCS

Safety Related Power (17)

- **Modular HTGR designs rely on passive means of removing heat from the core during design basis accidents**
- **Passive heat removal SSC are designed to eliminate reliance on AC electrical power during a wide spectrum of design basis accidents**
  - Natural Circulation used by safety related RCCS
  - Safety related power is provided by DC power sources (batteries); ensures plant safe shutdown by supplying power to safety-related electrical loads

Modular HTGR Design Criteria Summary

- **Modular HTGR design criteria are derived from ARDC**
- **Most of the adaptations made to the ARDC relate to:**
  - Functional Containment
  - New criteria for Reactor Building
  - Particle fuel design limits
  - RCCS
- **Modular HTGR design criteria can serve as guidance for development of Principal Design Criteria for a future modular HTGR license application**

Suggested Reading

- **NUREG-1338 – "Draft Preliminary Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor," 1989**
- **INL/EXT-11-22708 – "Modular HTGR Safety Basis and Approach," September 2011, ML11251A169**
- **"NGNP - Assessment of Key Licensing Issues," ML14174A774**
- **NGNP White Papers**
  - NGNP Fuel Qualification - ML102040261
  - Mechanistic Source Terms - ML102040260
  - NGNP Licensing Basis Event Selection - ML102630246

Questions?