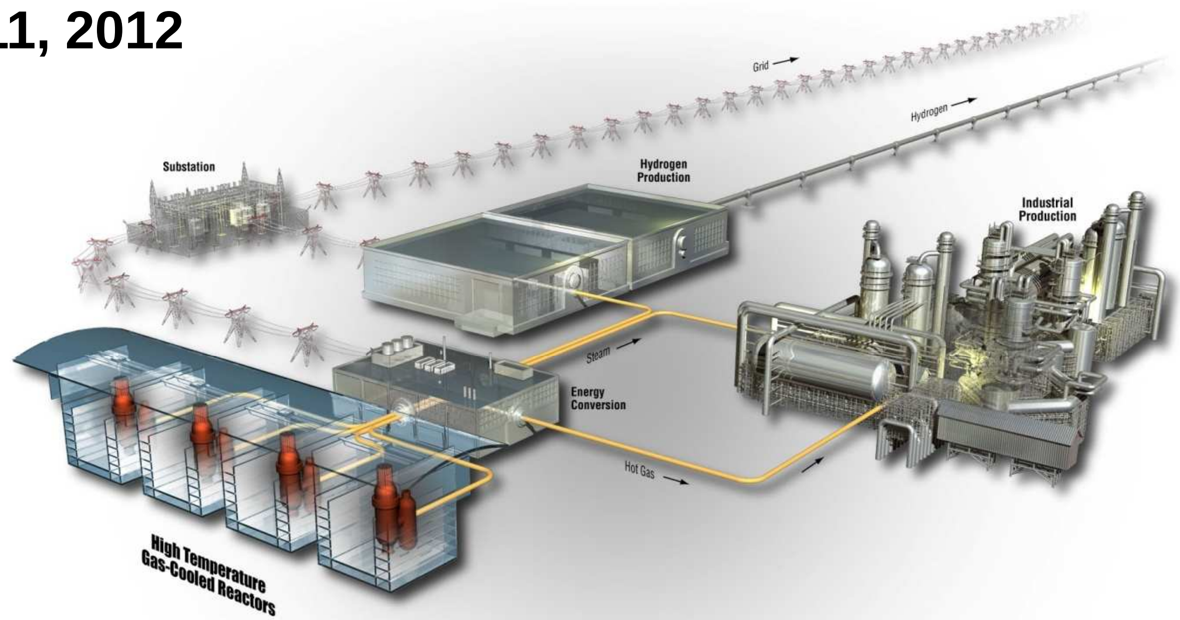
NRC Public Meeting

NGNP Functional Containment

Next Generation Nuclear Plant

July 11, 2012



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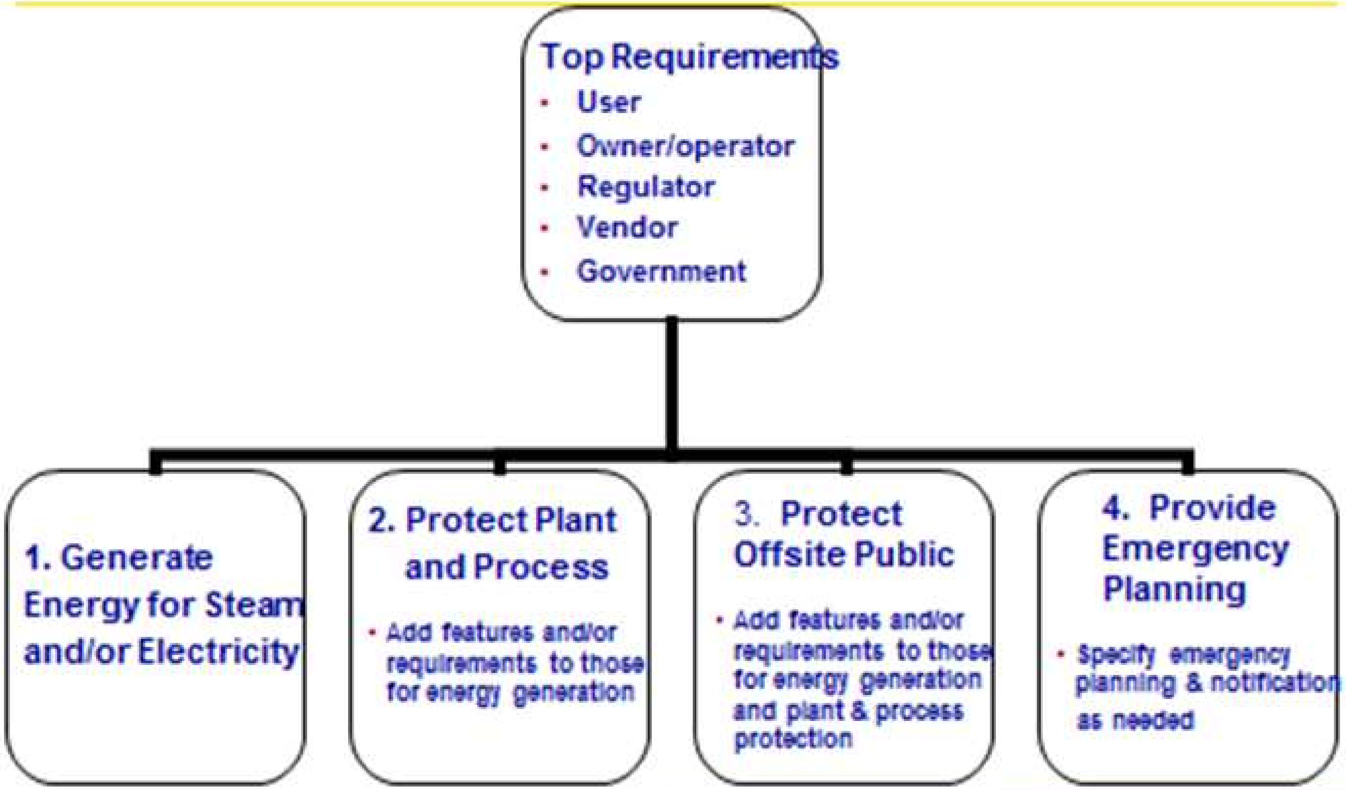
Functional Containment Presentation Outline

- HTGR Safety Design Objectives and Approach
- Functional Containment Description
- Introduction to Mechanistic Source Terms
- Functional Containment Performance
- Reactor Building Design Alternatives
- Regulatory Background
- HTGR Functional Containment Principal Design Criteria
- Next Steps

HTGR Safety Design Objectives and Approach

Top Level Objective and Goals



Modular HTGR Safety Design Objective

- Do not disturb the normal day-to-day activities of the public
    - Do not require sheltering or evacuation during plant normal operation and over wide spectrum of off-normal events
        - Meet EPA Protective Action Guidelines at the plant boundary (EAB) for event sequences to a frequency of 5×10^{-7} per plant year

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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

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

Modular HTGR Safety Design Approach (cont'd)

- Develop simple modular reactor design with passive safety
  - Retain radionuclides at their source within the 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

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

Approach is Consistent with the NRC Advanced Reactor Policy Statement

"Among the attributes which could assist in establishing the acceptability or licensability of a proposed advanced reactor design, and which therefore should be considered in advanced designs, are:

- ✓ Highly reliable and less complex shutdown and decay heat removal systems. Use of inherent or passive means to accomplish this objective is encouraged (negative temperature coefficient, natural circulation)
- ✓ Longer time constants and sufficient instrumentation to allow for more diagnosis and management prior to reaching safety system challenge and/or exposure of vital equipment to adverse conditions
- ✓ Simplified safety systems which, where possible, reduce required operator actions, equipment subjected to severe environmental conditions, and components needed for maintaining safe shutdown conditions. Such simplified systems should facilitate operator comprehension, reliable system function, and more straight-forward engineering analysis.

FR Vol. 73, No. 199, pg. 60612-60616, Oct. 14, 2008

Approach Is Consistent With the NRC Advanced Reactor Policy Statement (cont'd)

- ✓Designs which minimize the potential for severe accidents and their consequences by providing sufficient inherent safety, reliability, redundancy, diversity, and independence in safety systems
- ✓Designs that provide reliable equipment in balance of plant (or safety-system independence from balance of plant) to reduce the number of challenges to safety systems
- ✓Designs that provide easily maintainable equipment and components
- ✓Designs that reduce radiation exposure to plant personnel
- ✓Designs that incorporate defense-in-depth philosophy by maintaining multiple barriers against radiation release, and by reducing the potential for consequences of severe accidents
- ✓Design features that can be proven by citation of existing technology or which can be satisfactorily established by commitment to a suitable technology development program."

FR Vol. 73, No. 199, pg. 60612-60616, Oct. 14, 2008

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
- 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 Modular HTGR could release activity within the HPB (e.g., activity circulating in the coolant) and stay within offsite accident dose limits without consideration of retention in the reactor building
- Thus, safety design focus is on avoiding incremental releases from fuel during off-normal events

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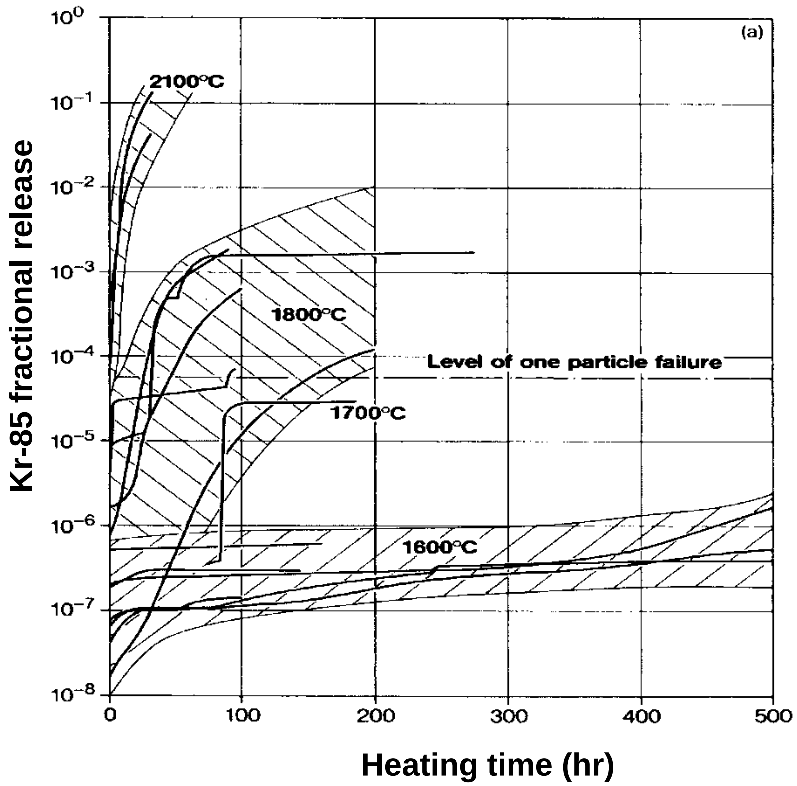
Fuel Particles Are Highly Retentive 100's of Degrees Above Normal Operation

- 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
- 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



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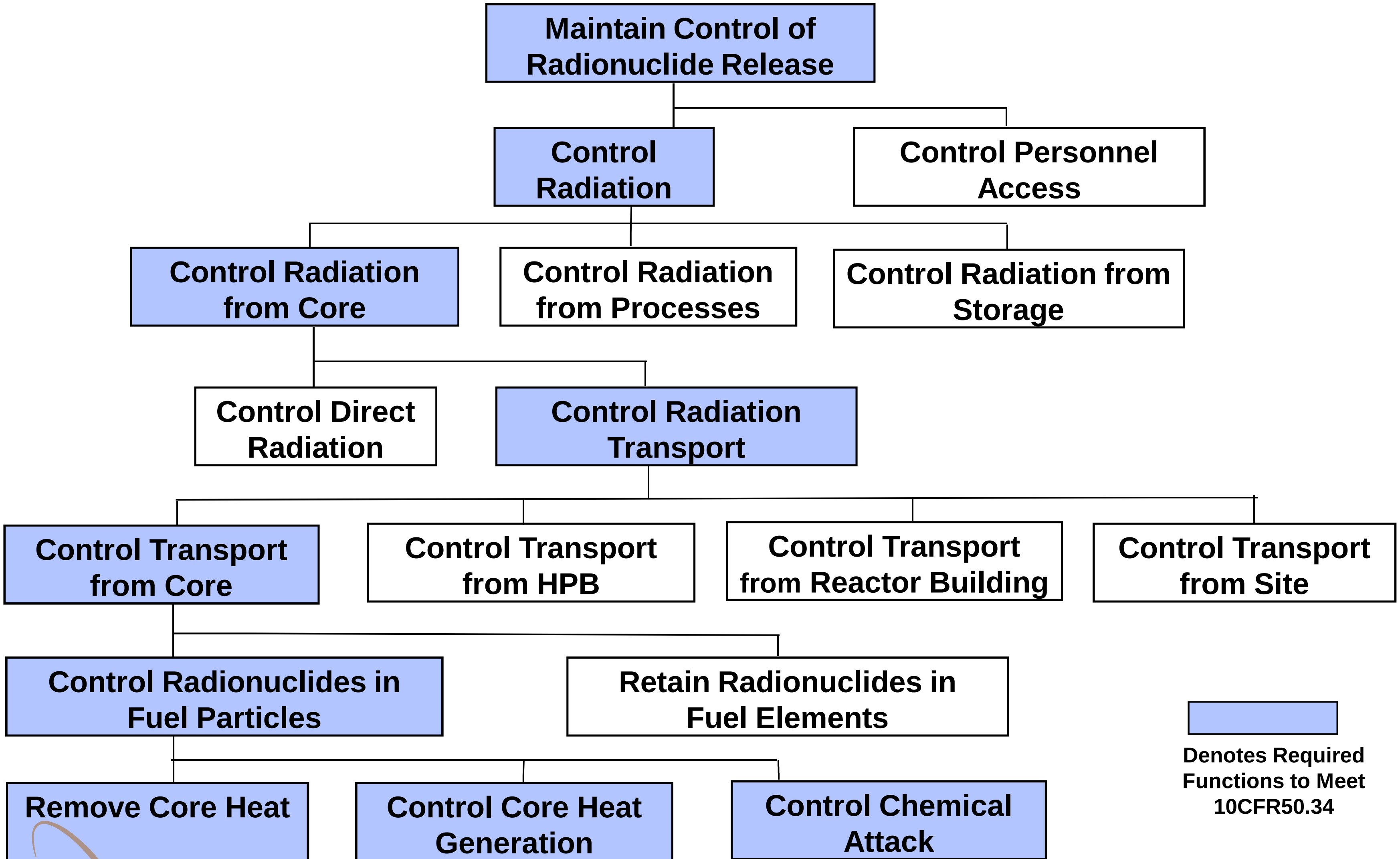
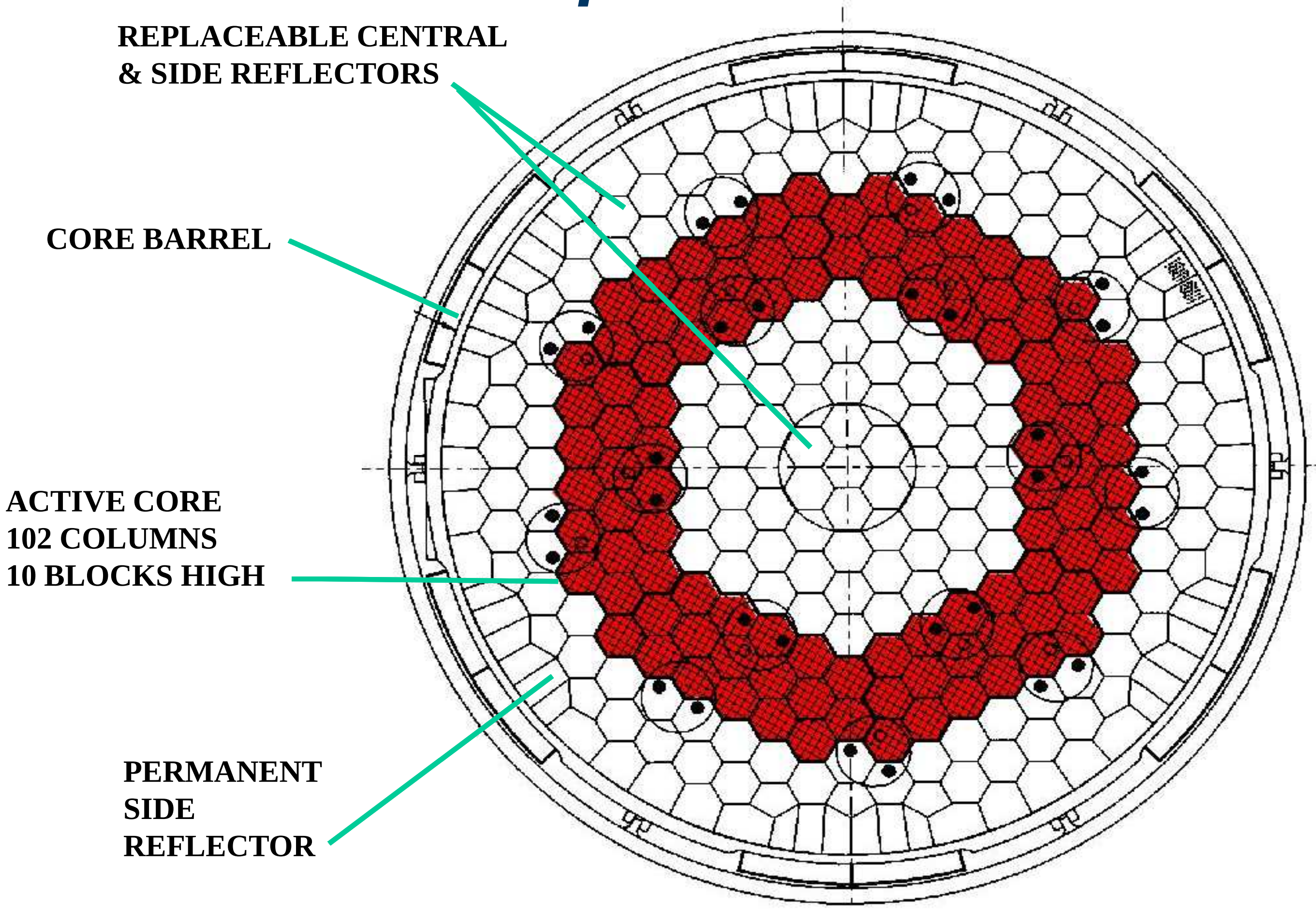
Functions for Control of Radionuclide Release



Removal of Core Heat Accomplished by Passive Safety Features

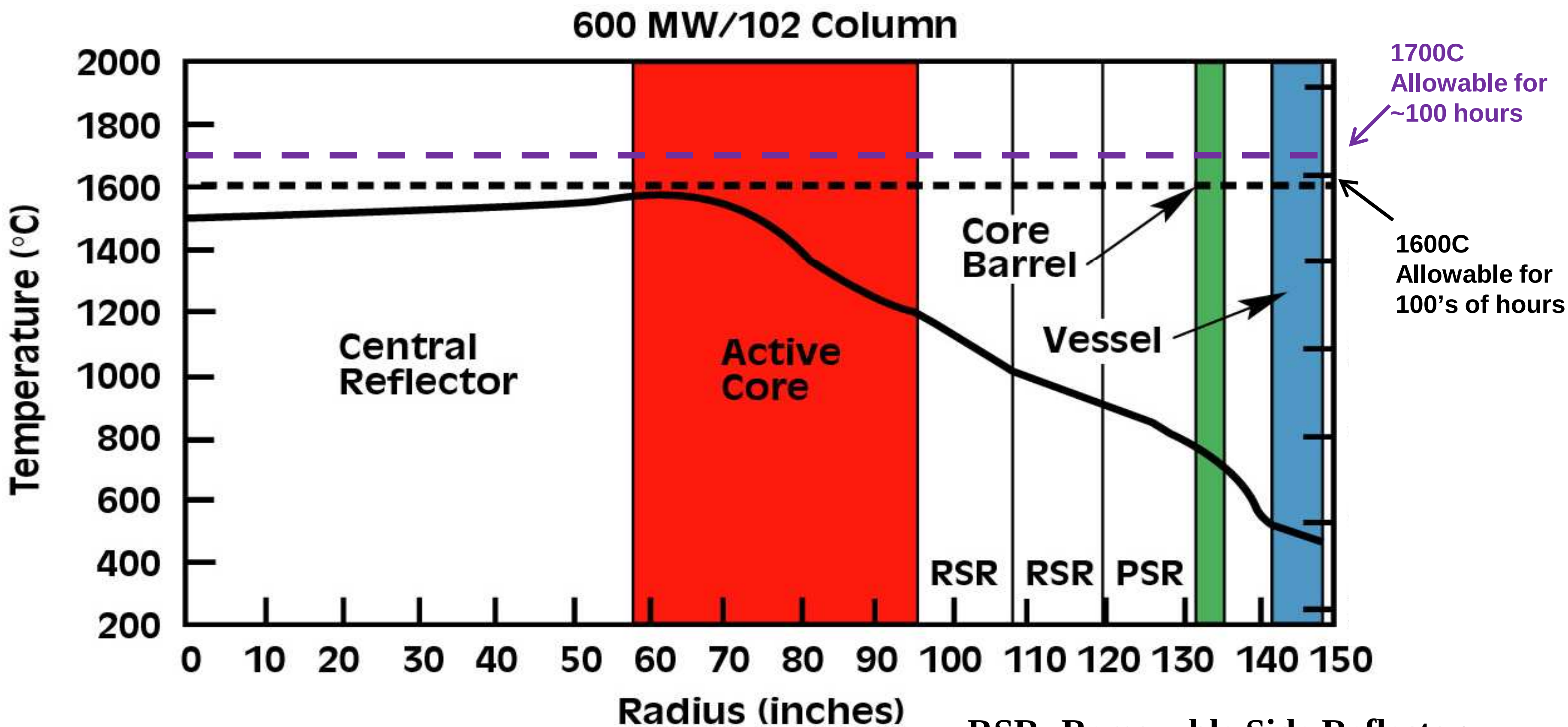
- Small thermal rating/low core power density
  - Limits amount of decay heat
  - Low linear heat rate
- Core geometry
  - Long, slender or annular cylindrical geometry
  - Heat removal by passive conduction & radiation
  - High heat capacity graphite
  - Slow heat up of massive graphite core
- Uninsulated 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

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

Reactor Cavity Cooling System

- Consists of cooling structures surrounding reactor vessel
- Removes heat transmitted from the vessel by radiation and convection
- Removes heat by natural convection air or water flow
- Provides simple and reliable means of residual heat removal
- Meets all requirements with ample margin and redundancy

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

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

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

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
- Consistent with 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
  - based on existing technology or that which can be satisfactorily established by a suitable technology development program
- Multiple barriers with emphasis on retention at the source within fuel

HTGR Functional Containment Description

What is the "Functional Containment"?

The collection of design selections that, taken together, ensure that:

1) radionuclides are retained within multiple barriers, with emphasis on retention at their source in the fuel, and

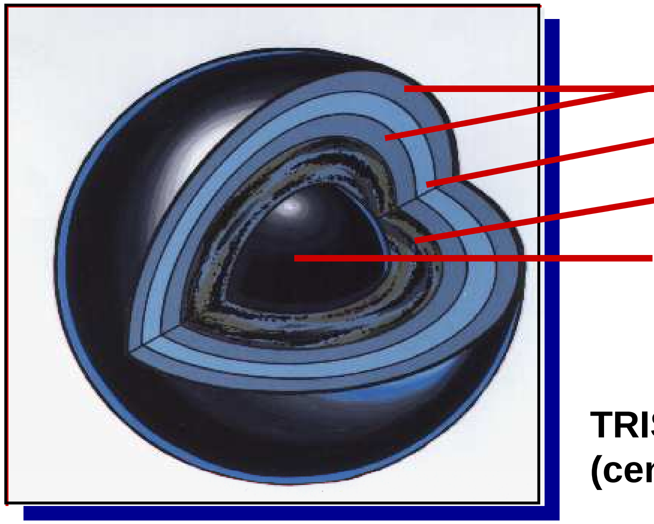
2) that NRC regulatory requirements and plant design goals for release of radionuclides are met at the Exclusion Area Boundary.

HTGRs Have Multiple Barriers to Radionuclide Release that Provide the "Functional Containment"

- Fuel Kernel
- Fuel Particle Coatings
- Matrix/Graphite
- Helium Pressure Boundary
- Reactor Building

Fuel Element

HTGR Fuel



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

PARTICLES

COMPACTS

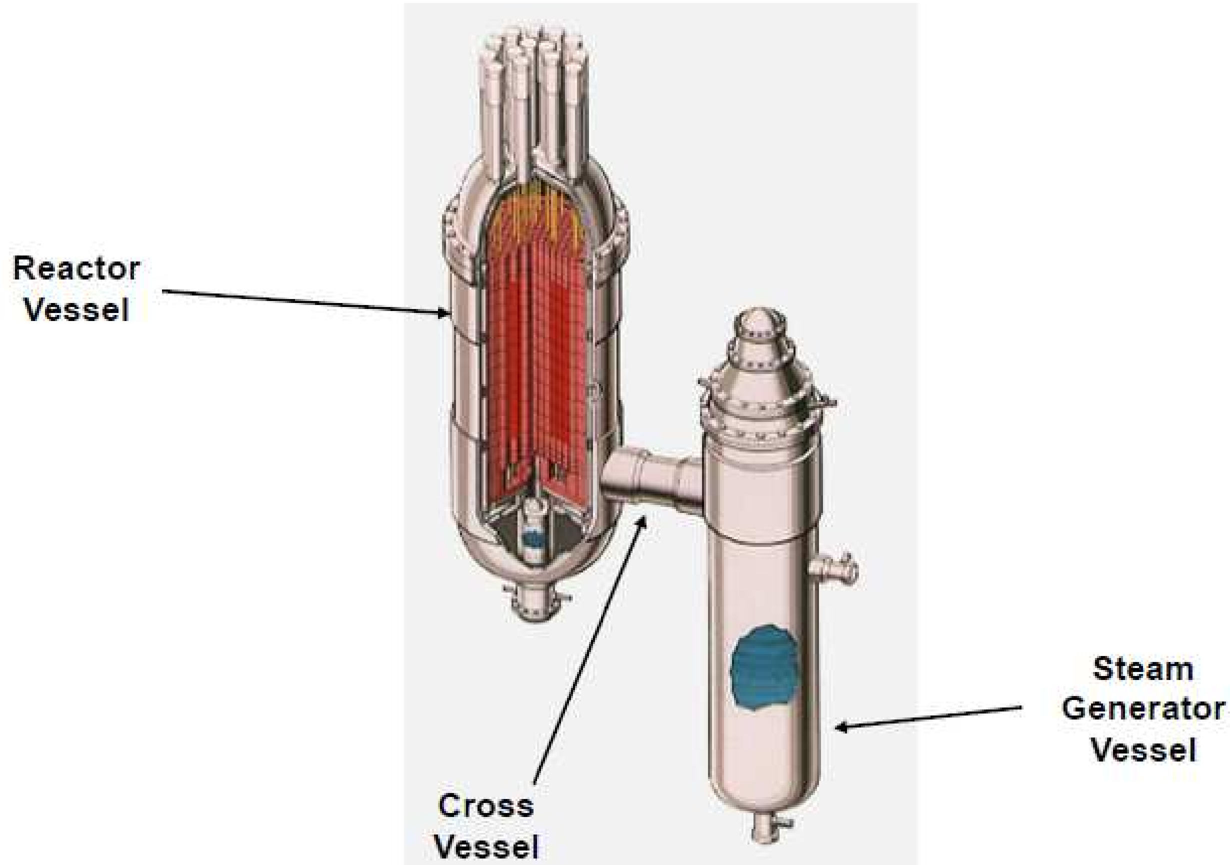
FUEL ELEMENTS

HTGR Helium Pressure Boundary (HPB) (Vessel System and Connecting Piping) (MHTGR)

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



Reference MHTGR Embedded Reactor Building

Protects pressure vessels, RCCS from external hazards, provides additional radionuclide retention, limits air ingress following HPB depressurization

Multi-cell, reinforced concrete

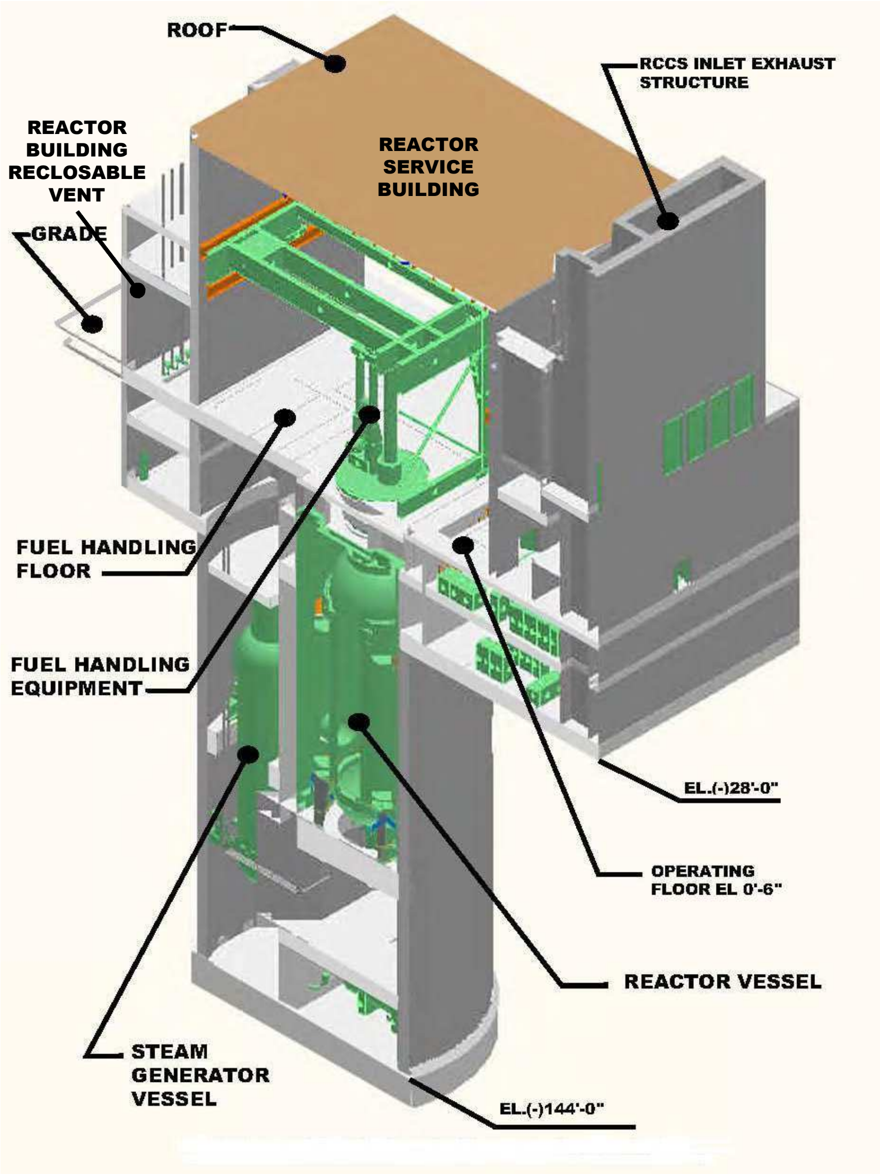
Safety Related, Seismic Category I

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 Leak Rate (100% per day)



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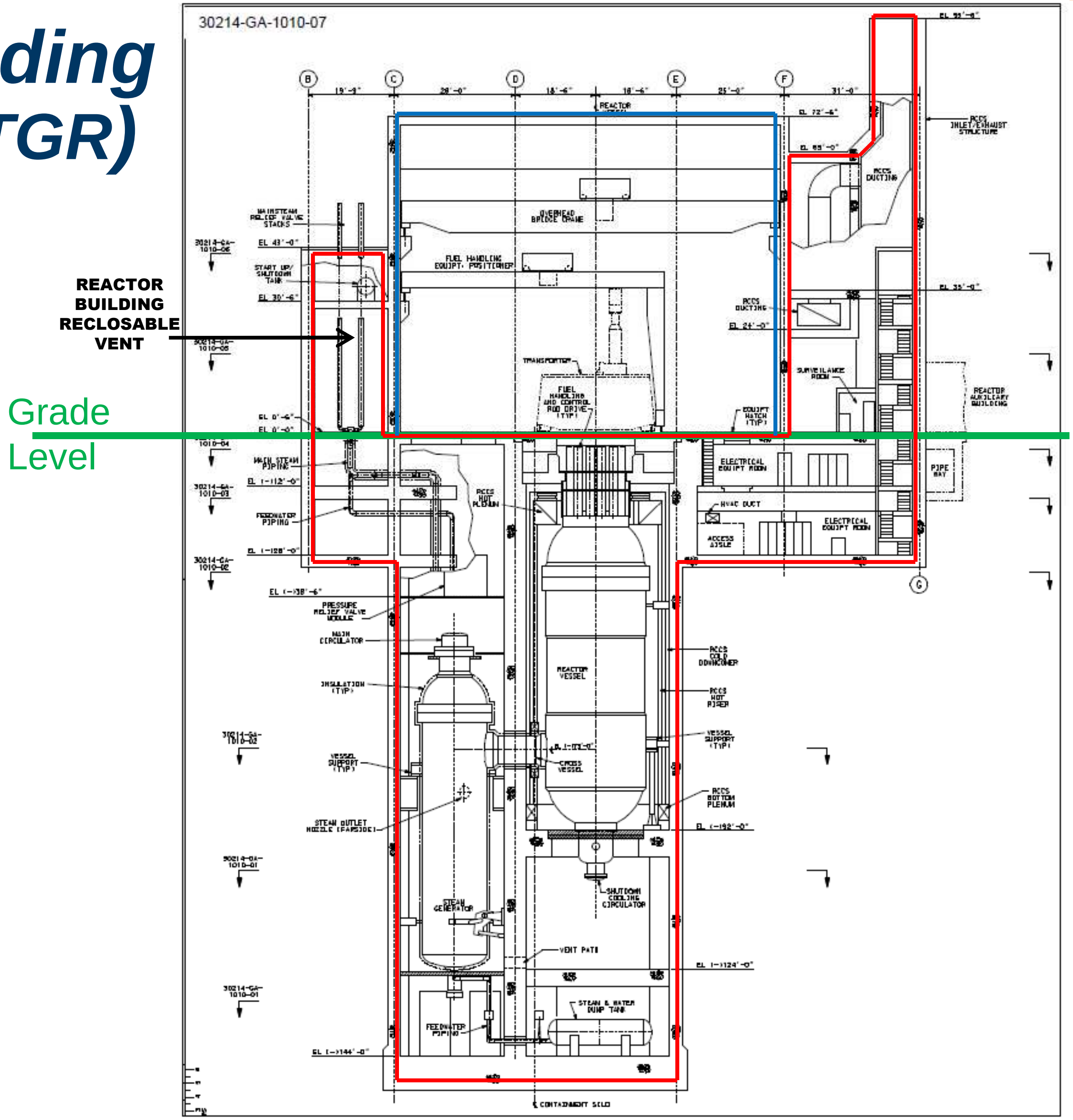
Reactor Building Section (MHTGR)



Reactor Service Building Boundary

Reactor Building Boundary

Functional Containment Manufacturing/Fabrication

- Fuel Manufacturing
  - Particles
  - Compacts
  - Elements

  Detailed specifications and product QC

- Helium Pressure Boundary Fabrication
  - ASME B&PV Code Section III

- Reactor Building Construction
  - International Building Code (IBC)
  - Multi-cell reinforced concrete - American Concrete Institute (ACI)
  - Regulatory Guide 1.142
  - American Institute of Steel Construction (AISC)

Introduction to Mechanistic Source Terms

HTGR Source Term Definition

- *Quantities of radionuclides released from the reactor building to the environment during Licensing Basis Events. This includes timing, physical and chemical forms, and thermal energy of the release.*

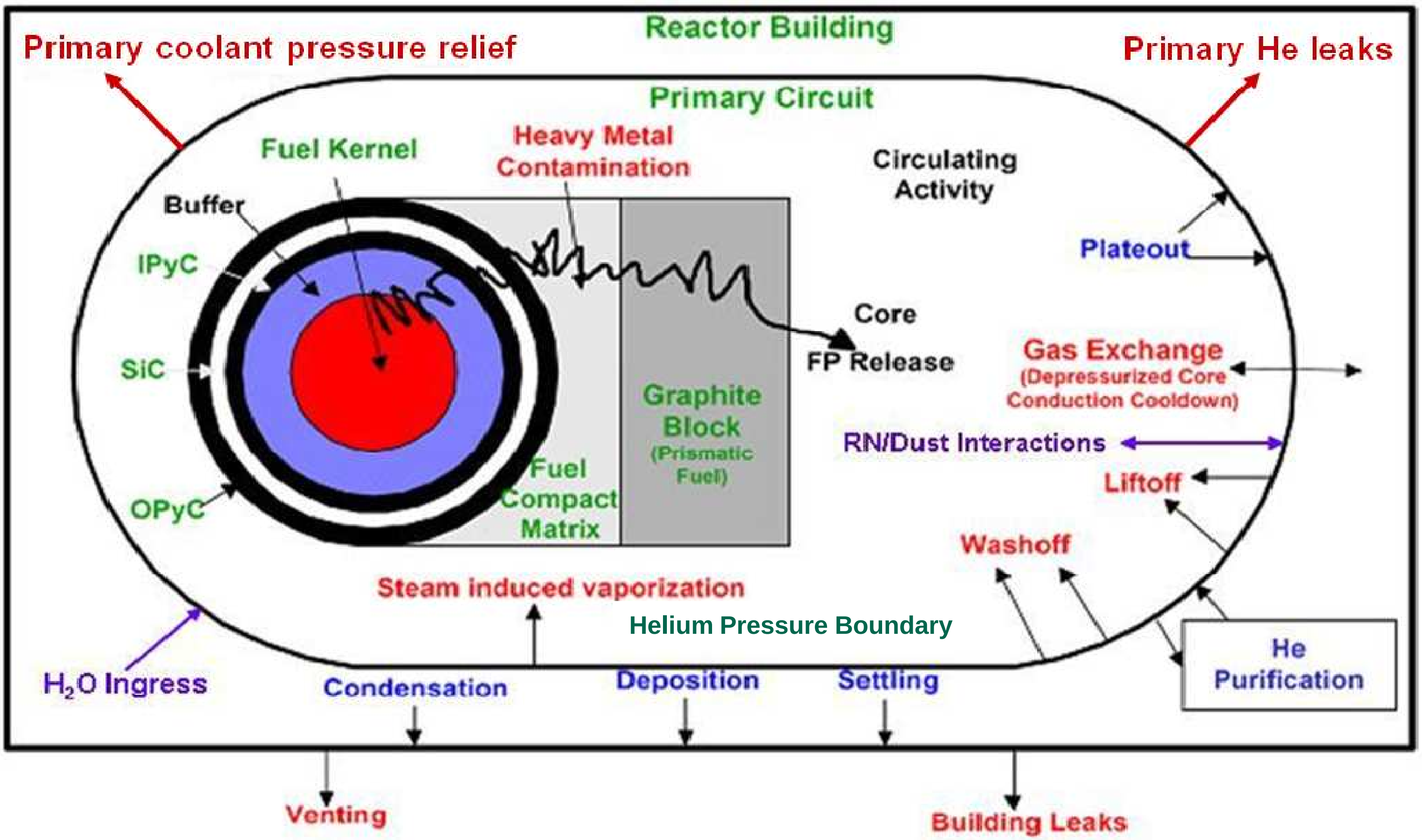
- HTGR Source Terms are:
  - Event-specific
  - Determined mechanistically using models of fission product generation and transport that account for reactor inherent and passive design features and the performance of the fission product release barriers that comprise the functional containment
  - Different from the LWR source term that is based on a severe core damage event

Fission Product Transport Models Mechanistically Calculate

- Transport of radionuclides from their point of origin through the fuel to the circulating helium
- Circulating activity in the HPB
- Distribution of condensable radionuclides in the HPB (plateout and dust)
- Radionuclide release to and distribution in the reactor building
- Radionuclide release from the reactor building to the environment (source term)

IN ADDITION TO PROVIDING SOURCE TERMS THESE CALCULATIONS PROVIDE RADIONUCLIDE INVENTORIES THROUGHOUT THE PLANT

HTGR Fission Product Retention System



THE PHENOMENA ILLUSTRATED IN THIS FIGURE ARE MODELED TO DETERMINE MECHANISTIC SOURCE TERMS FOR NORMAL AND OFF-NORMAL EVENTS

Functional Containment Performance

Summary

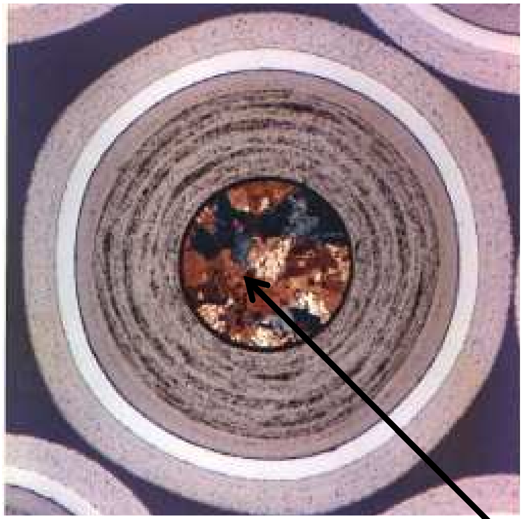
- Radionuclide retention within fuel during normal operation with relatively low inventory to HPB
- Limiting off-normal events characterized by
  - an initial release from the HPB depending on leak/break/pressure relief size
  - a larger, delayed release from the fuel
- Functional containment meets 10CFR50.34 and EPA PAGs with margin for wide spectrum of off-normal events

Coated Fuel Particle is 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)

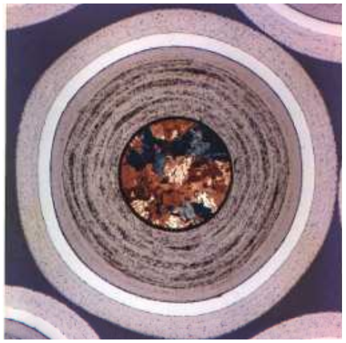
Fuel Particle Kernels

- Potential release mechanisms
  - Diffusion
  - Recoil
- Controlling parameters
  - Time-at-temperature
  - Fast neutron fluence (increased FP diffusivities for some nuclides)
- Barrier performance
  - Fractional radionuclide retention
  - Ag and Pd released by diffusion



Fuel Particle Kernel

Fuel Particle Coatings



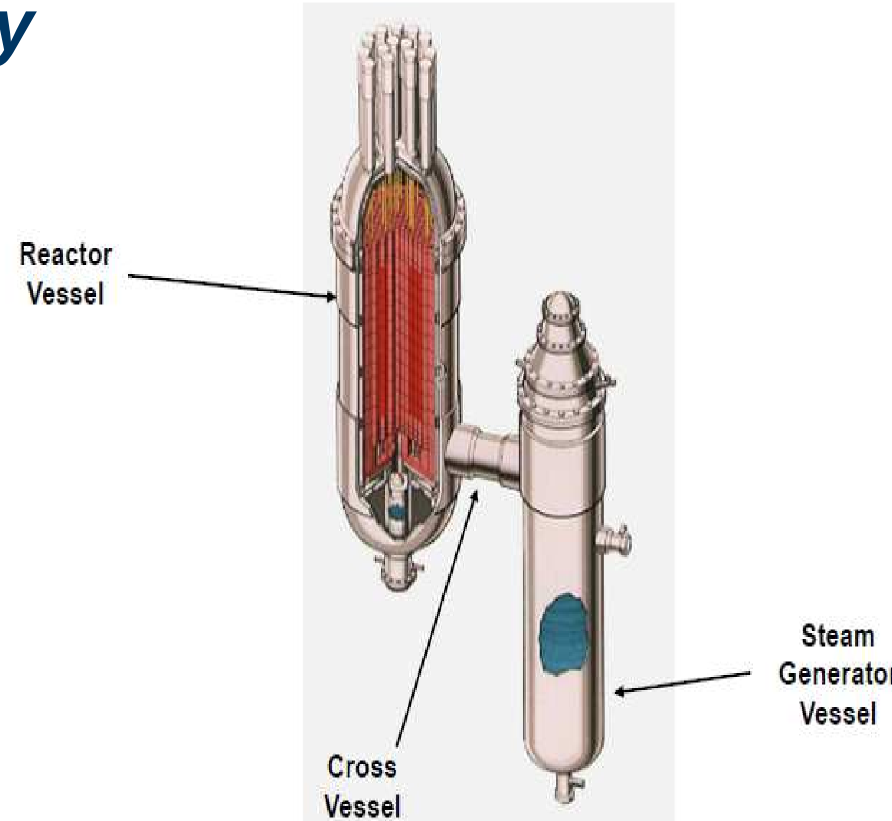
- Potential radionuclide release mechanisms
  - Diffusion through intact coatings
  - In-service coating failure
  - SiC corrosion by fission products
  - SiC thermal decomposition
- Controlling parameters
  - Time-at-temperature
  - Fast neutron fluence (increase in some FP diffusivities)
- Barrier performance
  - Radionuclide gases retained by OPyC with defective/failed SiC coating
  - Ag and Pd released by diffusion from intact particles
  - No pressure-induced failure of standard (intact) particles
  - SiC thermochemical failure function of time-at-temperature

Fuel Compacts/Elements

- Potential radionuclide release mechanisms
  - Diffusion/vaporization
  - Matrix/graphite oxidation
- Controlling parameters
  - Time-at-temperature
  - Fast neutron fluence
  - H_2O Concentration
- Barrier performance
  - Cs and Sr partially released at hotter locations
  - Released Cs and Sr partially resorb on cooler graphite
  - Sorbed metals assumed to be released by graphite oxidation

Helium Pressure Boundary

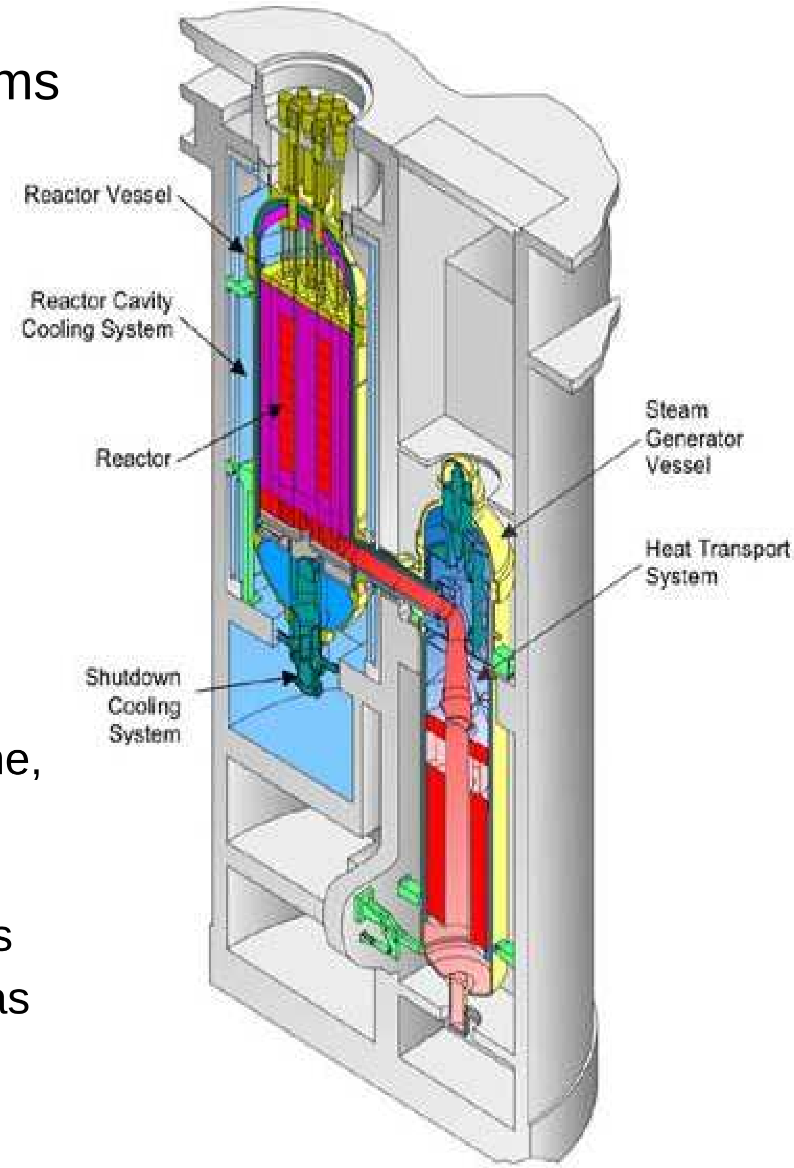
- Potential radionuclide release mechanisms
  - Primary coolant leaks
  - Liftoff (mechanical reentrainment)
  - Steam-Induced vaporization
  - Washoff (removal by liquid H_2O)
  - Primary coolant pressure relief
- Controlling parameters
  - Size/location of coolant leaks/breaks
  - Temperatures
  - Particulate matter
  - Steam/liquid H_2O 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

Reactor Building

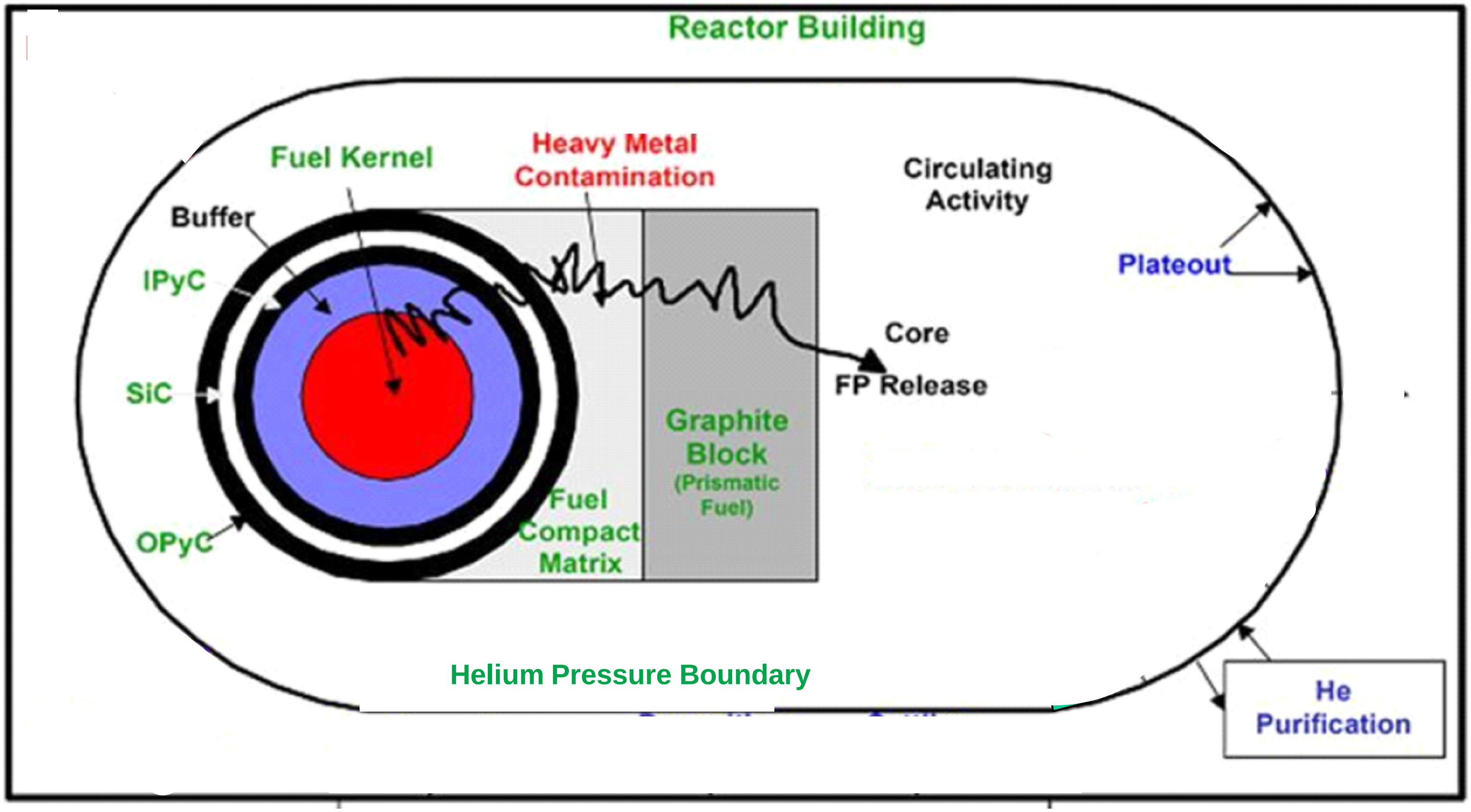
- Potential radionuclide release mechanisms
  - Building leakage
  - Venting through louvers
- Important parameters
  - Leak path(s) and rates
  - Temperatures along leak path(s)
  - Contaminated steam/liquid H_2O
  - Contaminated particulate matter
- Barrier performance
  - Noble gases decay during holdup
  - Condensable radionuclides, including Iodine, deposit
  - Contaminated steam condenses
  - Contaminated dust settles out and deposits
  - RN holdup due to thermal contraction of gas after core heatup



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 – inventory builds up over plant life)
- Concentration and distribution within HPB 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 HPB surfaces (plateout)
  - Helium purification system performance
  - Fission product contamination of dust in HPB

HTGR Radionuclide Retention and Release During Normal Operation



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Initial Radionuclide Release Mechanisms from Sources in HPB

- Circulating activity
  - Released from HPB with helium in minutes to days as a result of HPB leak/break
  - Amount of release depends on location 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.

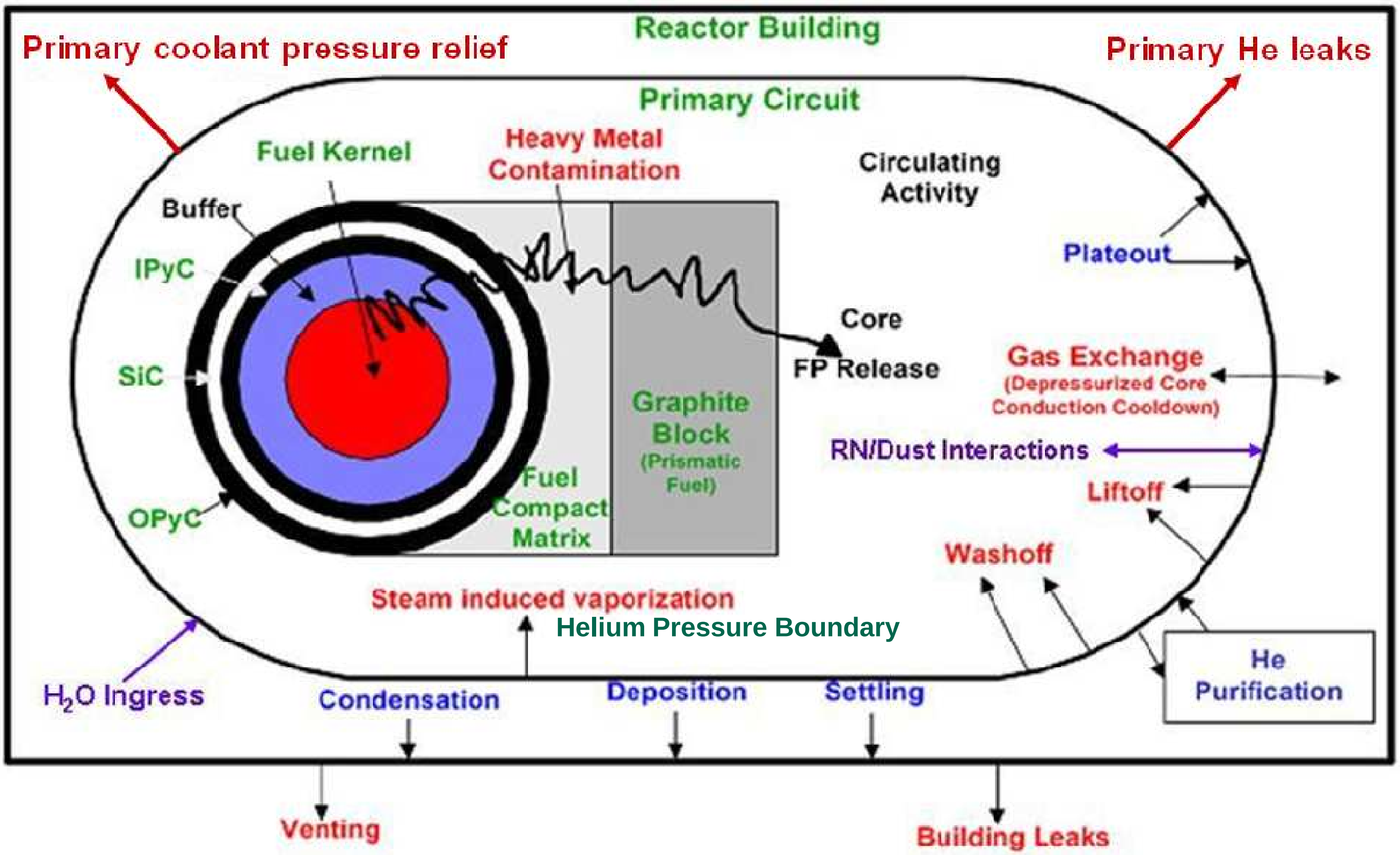
Mechanisms for Delayed Radionuclide Release from Core

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

Radionuclide Behavior During Depressurization Events with Loss of Forced Cooling

- Consists of three phases that can overlap depending on the size of the leak/break in the HPB:
  - Initial depressurization (minutes to days)
  - Subsequent core heatup (~50 to 100 hours)
  - Subsequent core cooldown (days)
- Radionuclide release during depressurization is affected by:
  - Radionuclide content of the HPB (circulating and plateout)
  - Blowdown rate and shear force ratio (size and location of HPB leak/break)
  - Liftoff of plateout
  - Release of contaminated dust
  - Fuel time-at-temperature (for slow blowdown rate)
  - Deposition of radionuclides in the reactor cavity and other RB volumes
  - RB venting
  - RB leak rate

HTGR Retention and Release During Normal Operation and Spectrum of LBEs



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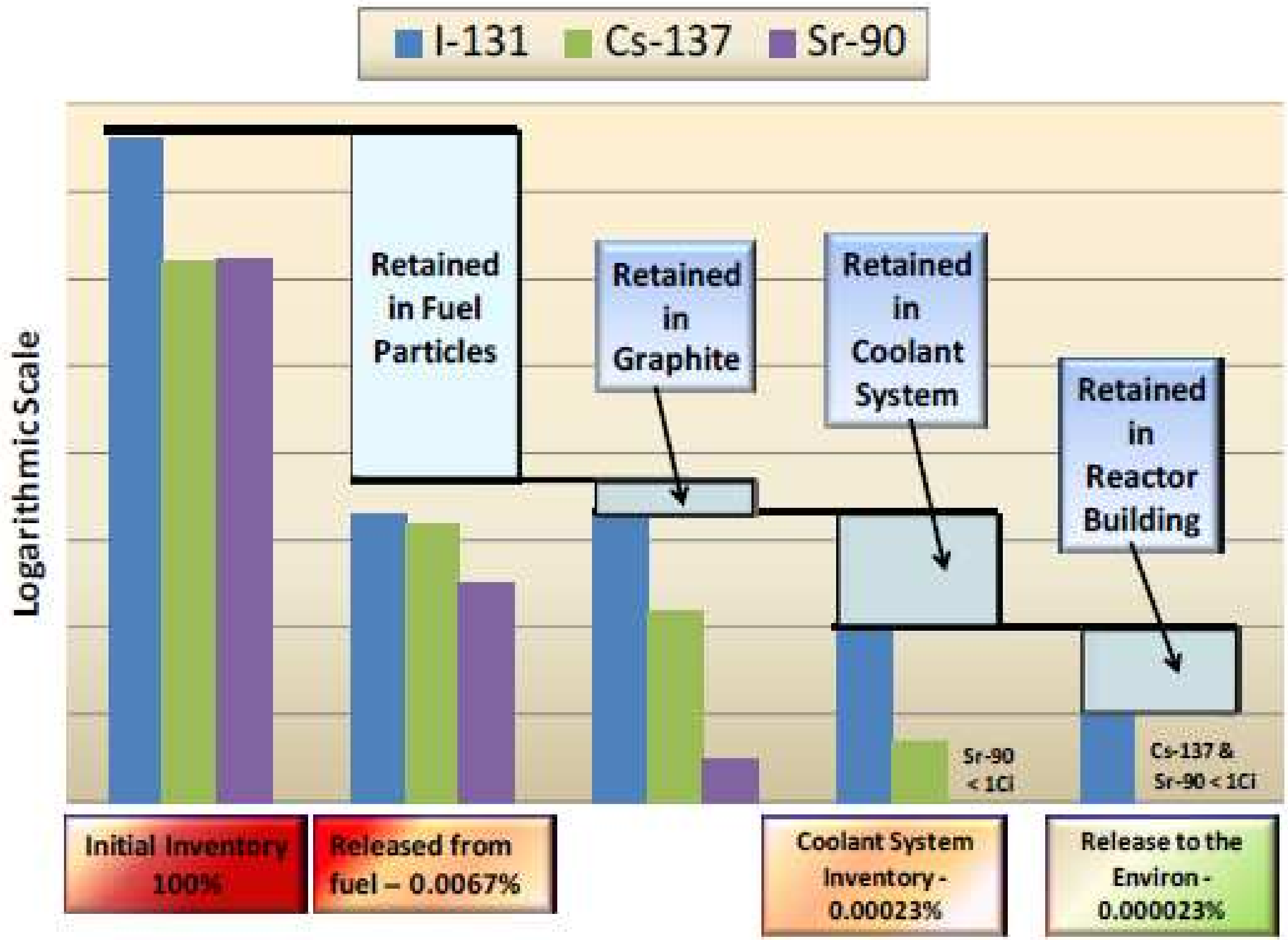
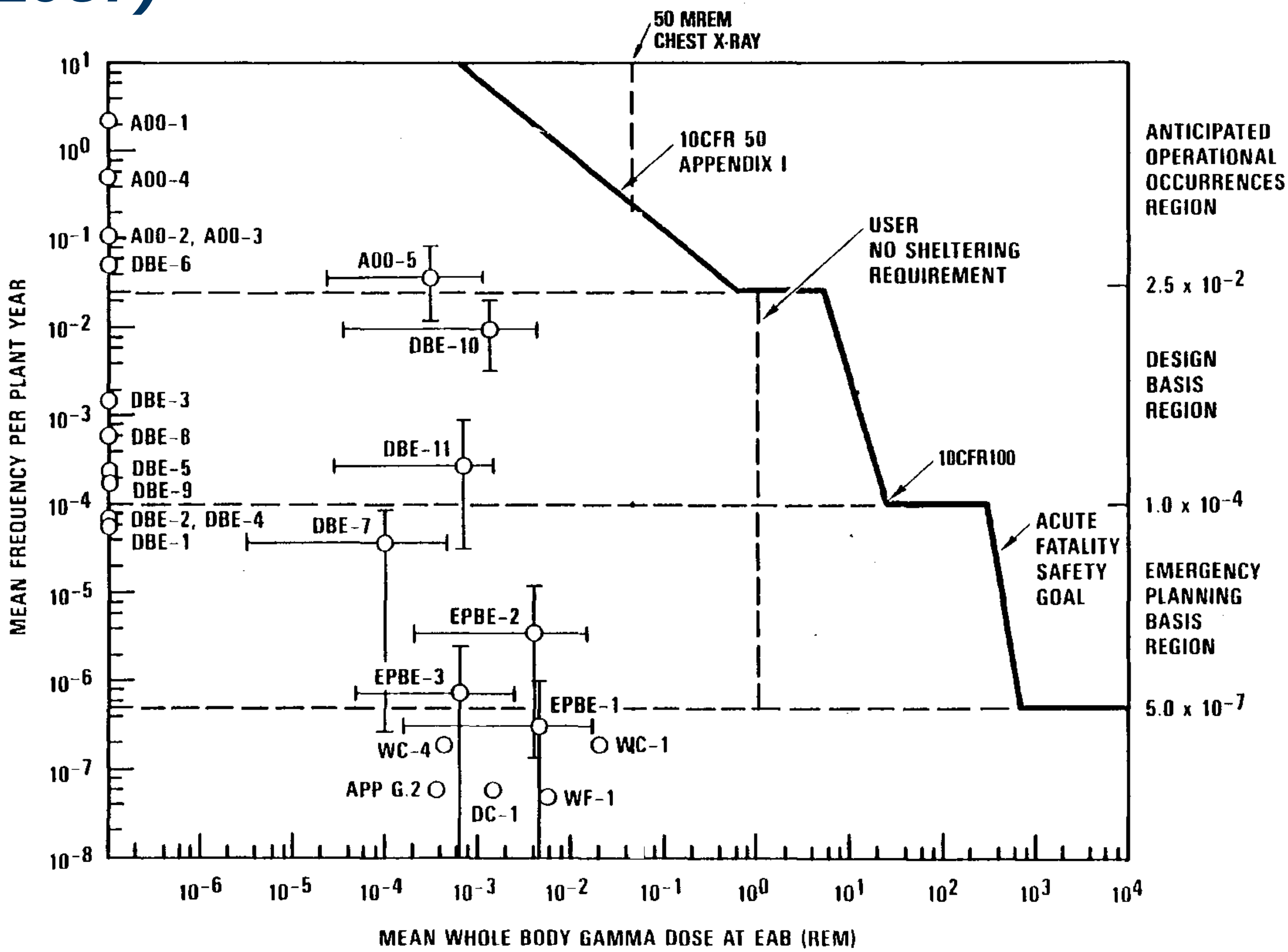
Representative Functional Containment Performance During a Depressurized Loss of Forced Cooling



MHTGR Design Basis Events

DBE	Design Basis Events
DBE-1	Loss of Main and Shutdown Forced Cooling
DBE-2	Main Loop Transient w/o Control Rod Trip
DBE-3	Control Rod Withdrawal w/o Main Loop Cooling
DBE-4	Control Rod Withdrawal w/o Forced Cooling
DBE-5	Earthquake
DBE-6	Moisture Inleakage
DBE-7	Moisture Inleakage w/o Forced Cooling
DBE-8	Moisture Inleakage with Moisture Monitor Failure
DBE-9	Moisture Inleakage with SG Dump Failure
DBE-10	Moderate Primary Coolant Leak w/ Forced Cooling
DBE-11	Small Primary Coolant Leak w/o Forced Cooling

MHTGR LBEs with Uncertainties vs. TLRC (circa 1987)



Summary

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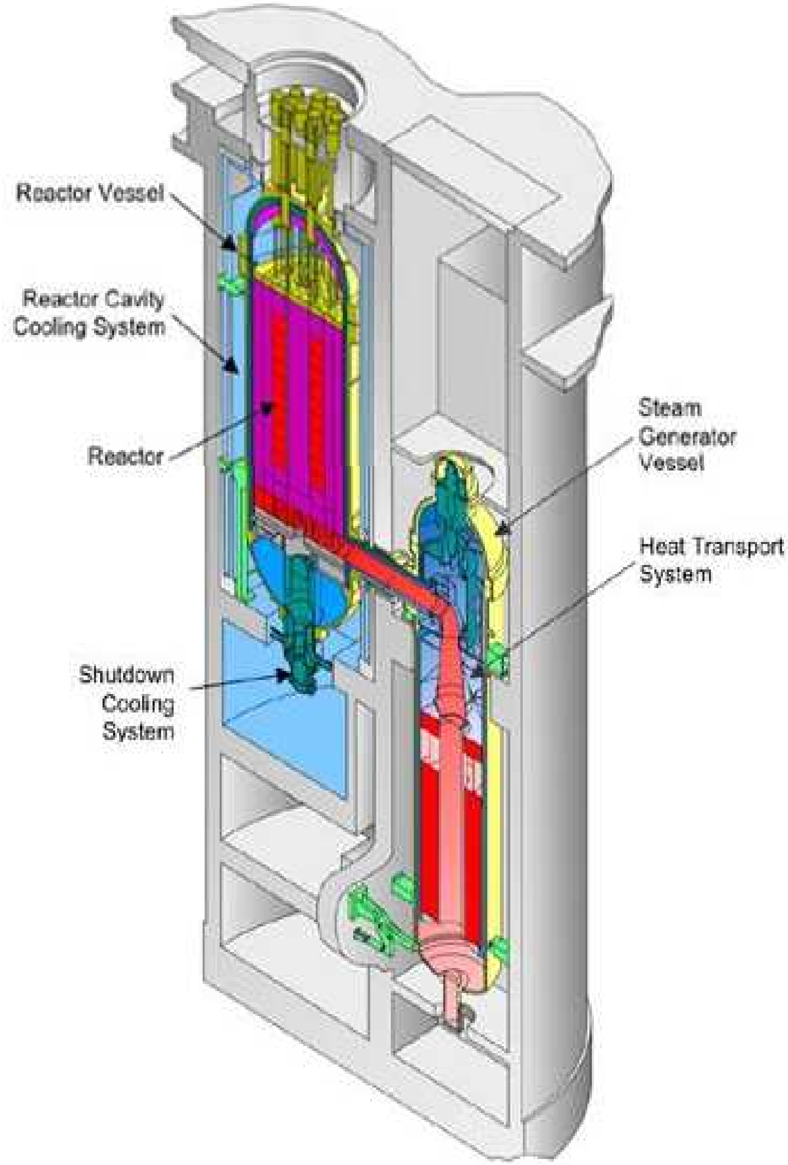
  - an initial release from the HPB sources (e.g., circulating activity) depending on leak/break/pressure relief size
  - a larger, delayed release from the fuel
- Functional containment meets 10CFR50.34 and EPA PAGs with margin for wide spectrum of off-normal events

Reactor Building Design Alternatives

Role of Reactor Building in Safety Design

- Required safety function of RB is to structurally protect heat removal from Reactor Vessel to RCCS from internal and external events and hazards

- RB provides additional radionuclide retention and limits air available for ingress after HPB depressurization



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Reactor Building Design Considerations

- Decrease in vent flow causes:
  - Increase in peak transient pressure
- Decrease in building leak rate causes:
  - Increase in peak transient pressure
  - Increased complexity of penetrations
  - Increased difficulty in designing systems that operate across building boundary (RCCS, SHTS, HVAC)
- Increase in peak transient pressure causes:
  - Increased loads on walls and slabs
- Increase in wall and slab loads causes:
  - Increase in wall and slab thickness, or
  - Change to curved walls and slabs (round building)

Vented Building Addresses Several Modular HTGR Specific Design Issues

- Matched to non-condensing helium coolant
- Matched to modular HTGR accident behavior
  - Vented early in transient when radionuclides released are low
  - Closed later in transient when fuel sees maximum temperatures
- More benign environment for passive Reactor Cavity Cooling System designs

Reference MHTGR Embedded Reactor Building

Multi-cell, reinforced concrete

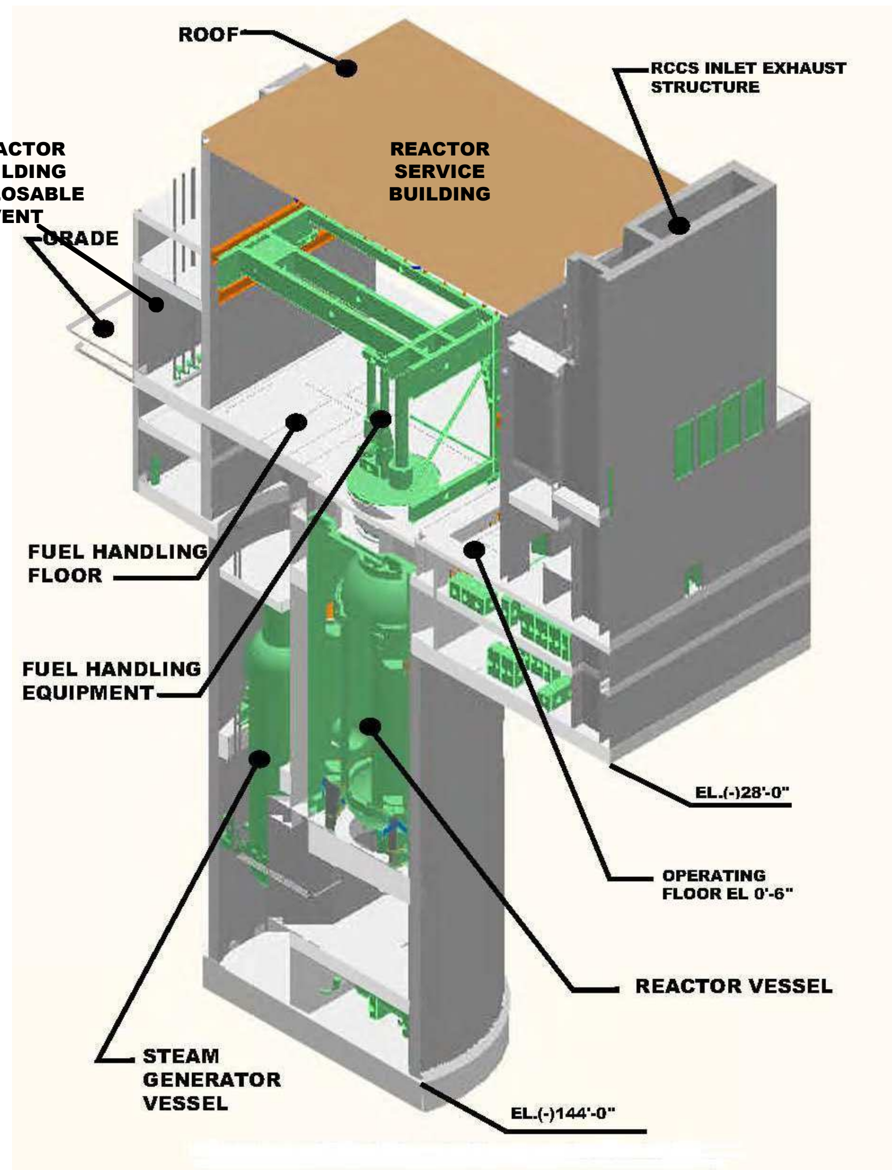
Safety Related, Seismic Category I

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 Leak Rate (100% per day)



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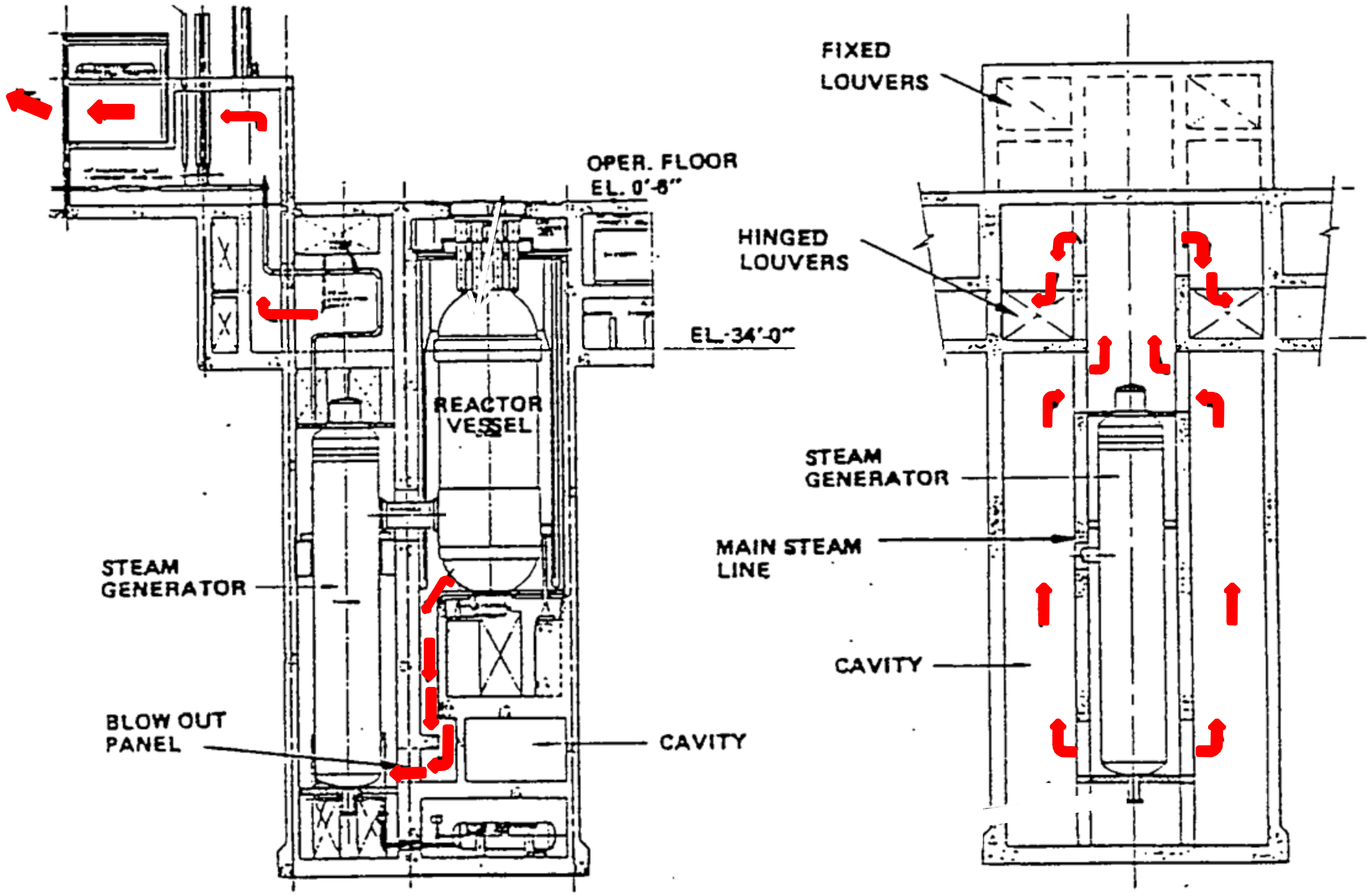
Reactor Building Vent Path from Reactor or Steam Generator Cavities



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*Alternative RBs Considered in Containment Study for MHTGR**

1. Vented, moderate leakage (100%/day) (Reference)
2. Vented, filtered, moderate leakage (100%/day)
3. Vented, filtered, low leakage (5%/day)

4A. Unvented, moderate pressure, low leakage (5%/day) air RCCS

4B. Unvented, moderate pressure, low leakage (5%/day) water RCCS

5A. Unvented, low pressure, low leakage (5%/day)

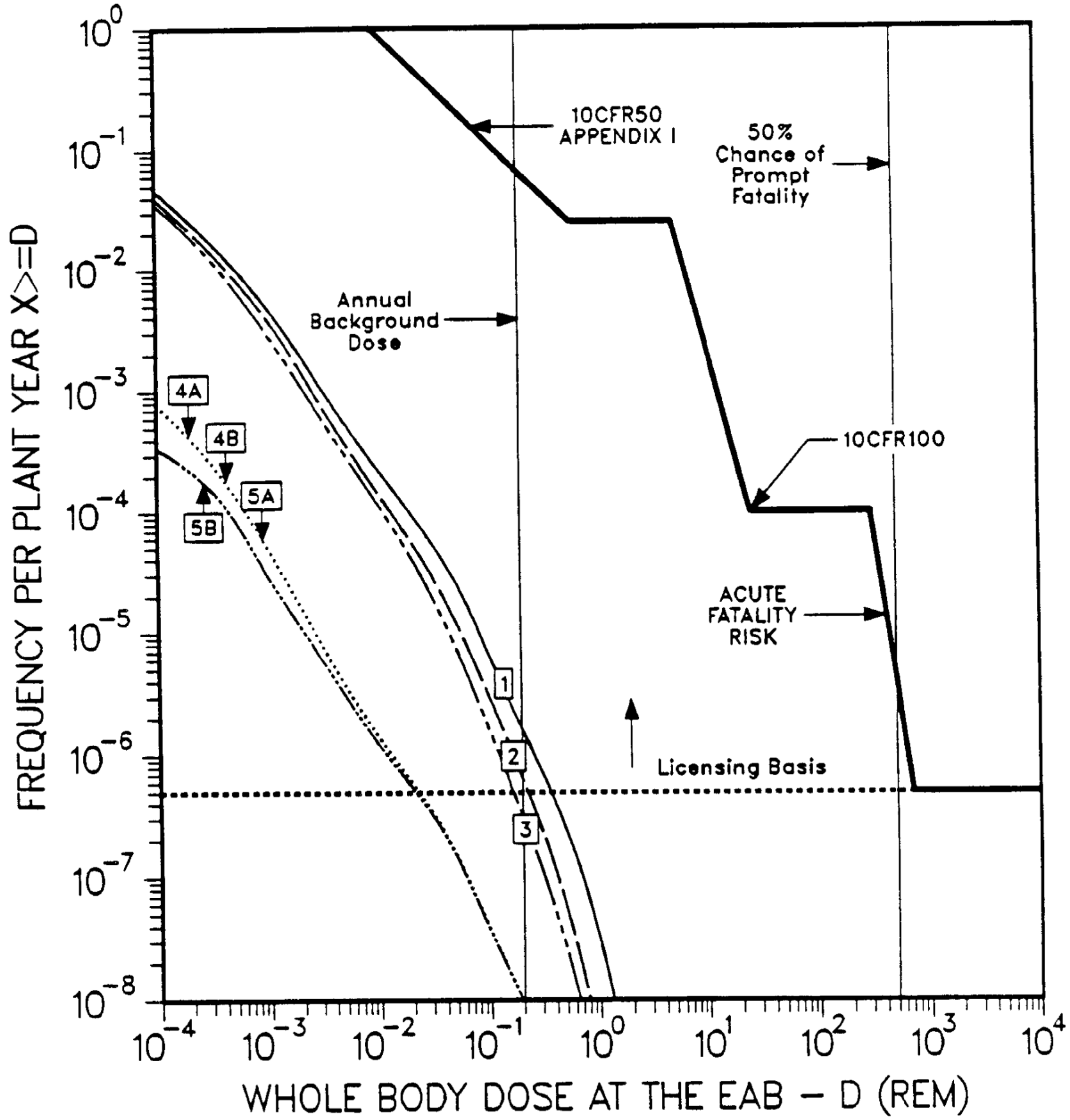
5B. Unvented, low pressure, low leakage (1%/day)

*** "Containment Study for MHTGR," General Atomics Report , DOE-HTGR-88311, November 1989**

Results from MHTGR Reactor Building Study

Alternative	Advantage	Disadvantage
1. Vented, moderate leakage	- Provides acceptable level of public safety - Maximizes reliance on simple, passive features - Simplest design	- Depends on successful completion of technology development (fuel, RCCS, etc.)
2. Vented, filtered, moderate leakage	- Provides acceptable level of public safety	- Increases cost; may not meet economic goal - Increases RN retention complexity - Depends on successful completion of essentially same technology development as Alt 1
3. Vented, filtered, low leakage	- Provides acceptable level of public safety	- Adds substantial cost; not likely to meet economic goal - Increases RN retention complexity
4. Unvented, moderate pressure, low leakage	- Provides acceptable level of public safety	- Prohibitive cost; reduced plant availability; does not meet economic goal - Reduces module independence - Introduces enhanced RN transport mechanisms in low frequency events
5. Unvented, high pressure, low leakage	- Provides acceptable level of public safety	- Prohibitive cost; reduced plant availability; does not meet economic goal - Decreases reliability of long term heat removal - Introduces enhanced RN transport mechanisms in low frequency events

Risk Plot for Alternative RBs Considered for MHTGR

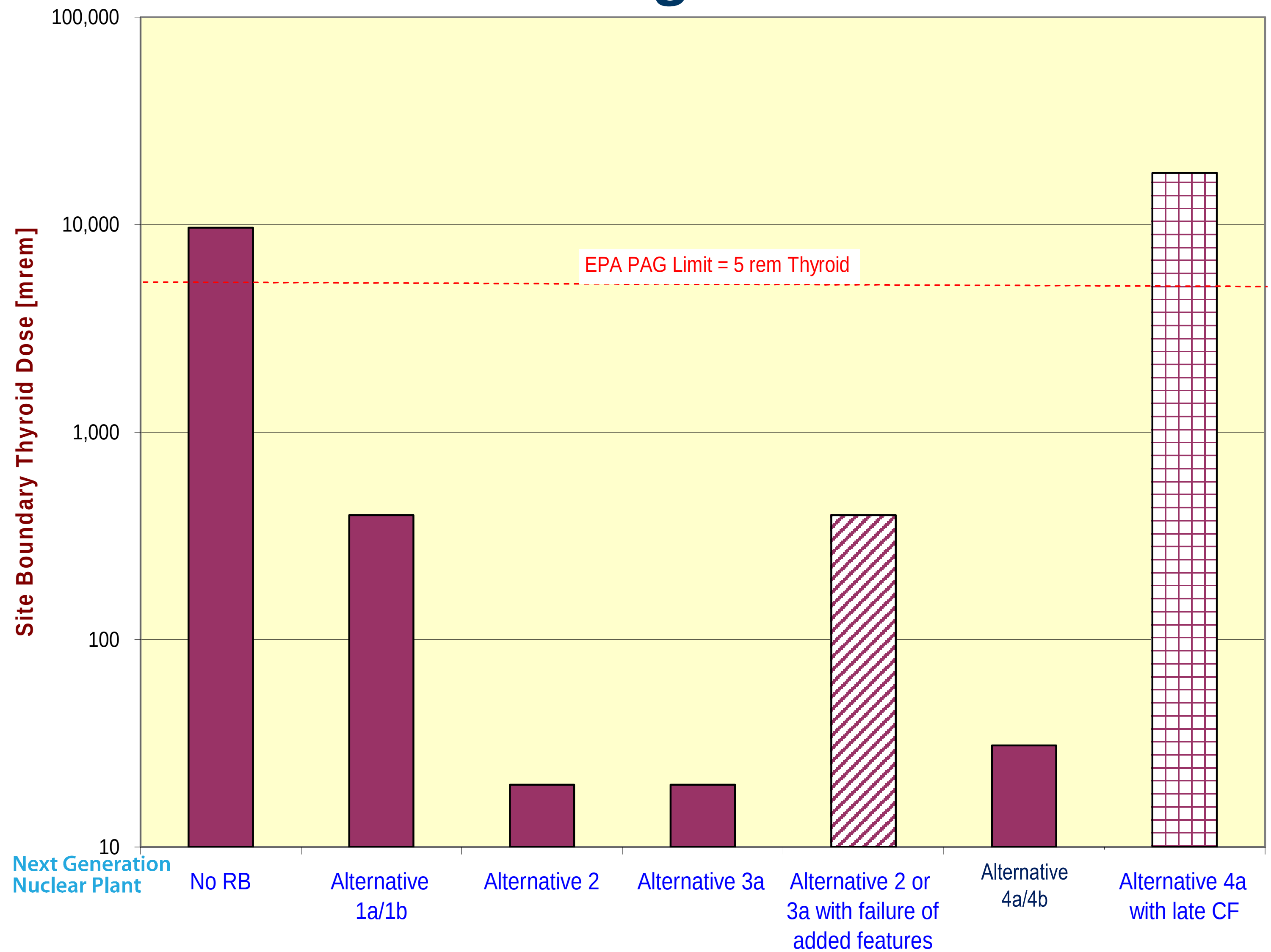


Alternative PBMR RB Design Configurations*

No.	Design Description	Pressurized Zone Leak Rate Vol % /day	NHSB Boundary Leak Rate Vol%/day	Pressure Relief Design Features	Post blow-down re-closure of PRS shaft?	Radionuclide Filtration	
						Blow-down phase	Delayed fuel release phase
1a.	Unfiltered and vented	50-100	50-100	Open vent	No	None	Passive
1b	Unfiltered and vented with blowout panels	50-100	50-100	Internal + External blowout panels	No	None	Passive
2	Partially filtered and vented with blowout panels	25-50	50-100	Internal + External blowout panels	Yes	None	Active HVAC
3a	Filtered and vented with blowout panels	25-50	50-100	Internal + External blowout panels	Yes	Passive	Active HVAC
3b	Filtered and vented with blowout panels and expansion volume	25-50	50-100	Internal + External blowout panels + expansion volume	Yes	Passive	Active HVAC
4a	Pressure retaining with internal blowout panels	0.1-1	50-100	Internal blowout panels	N/A	Passive	Passive
4b	Pressure retaining with internal blowout panels and expansion volume	0.1-1	50-100	Internal blowout panels + expansion volume	N/A	Passive	Passive

*** "Reactor Building Functional and Technical Requirements and Evaluation of Reactor Embedment," NGNP-NHS 100-RXBLDG, Rev 0, Westinghouse PBMR Team Report , September, 2008.**

Comparison of PBMR NGNP RB Alternatives to Best Estimate PAG Sheltering Dose at EAB



Common Findings from MHTGR and PBMR Alternative RB Evaluations

- Vented building provides best match for modular HTGR characteristics and passive design
- Limited value of added active systems that may not be available for low frequency events
- High pressure, low leakage LWR containment designs increase radionuclide release in low frequency events
- Confirmed decision to place emphasis on retention at the source within the fuel
- More detail can be found in the response to RAI FQ/MST-82 and in its references.

Regulatory Background

Outline

- SECY Positions on Containment Functional Performance in Non-LWRs
- Other NRC Documents on Containment Functional Performance
- Significant LWR Regulatory Requirements Applicable to LWR Containments
- Significant Technology Neutral Regulatory Requirements Applicable to Containments
- Summary

SECY Positions on Containment Functional Performance in Non-LWRs

- SECY-93-092, "Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and Their Relationship to Current Regulatory Requirements“
  - *The staff proposes to utilize a standard based upon containment functional performance to evaluate the acceptability of proposed designs rather than to rely exclusively on prescriptive containment design criteria.*
  - *Containment designs must be adequate to meet the onsite and offsite radionuclide release limits for the event categories to be developed as described in Section A to [SECY-93-092] within their design envelope.*

SECY Positions on Containment Functional Performance in Non-LWRs (cont'd)

- SECY-95-299 "Issuance of the Draft of the Final Pre-application Safety Evaluation Report (PSER) for the Modular High-Temperature Gas-Cooled Reactor (MHTGR)" [NUREG-1338]
  - *If the overall safety of a plant design is improved … by reducing the requirements on the containment and increasing the integrity of fuel on an advanced reactor design, then there is an incentive to improve the fuel and there is a basis for accepting a different containment design.*
  - *…the Commission decided that a conventional LWR, leaktight containment should not be required for advanced reactor designs. It approved the use of containment functional design criteria for evaluating the acceptability of proposed containment designs rather than the use of prescriptive design criteria.**
  - *[The] position regarding containment allows the acceptance of containments with leak rates that are not "essentially leak tight" as described in GDC 16 for LWRs.**

* In reference to the SRM for SECY-93-092

SECY Positions on Containment Functional Performance in Non-LWRs (cont'd)

- SECY-03-0047, "Policy Issues Related to Licensing Non-light-water Reactor Designs"
  - *Issue 6: Under what conditions can a plant be licensed without a pressure retaining containment building (i.e., a confinement building instead of a containment)?*
  - *In an SRM to SECY-03-0047, the Commission disapproved the staff's recommendation related to the requirement for a pressure-retaining containment building, stating that there was insufficient information for the Commission to prejudge the best options and make a decision on the viability of a confinement building, but directed the staff to pursue the development of functional performance standards taking into account such features as core, fuel, and cooling systems design and then submit options and recommendations to the Commission on this issue.*

SECY Positions on Containment Functional Performance in Non-LWRs (cont'd)

- SECY-05-006, "Second Status Paper on the Staff's Proposed Regulatory Structure for New Plant Licensing and Update on Policy Issues Related to New Plant Licensing"
  - *The safety philosophy is to assure the fuel containment barrier rather than to allow significant fuel failures and then have to rely extensively on either backup barriers (such as a containment) or other mechanistic barriers associated with the core graphite structures or reactor coolant pressure boundary.*
  - *In this regard, preventing significant releases of fission products from the fuel is consistent with the ultimate objective of the Commission's advanced reactor policy which expects advanced reactor designs to minimize the potential for severe accidents.*
  - *Of the options evaluated, the staff endorsed the position that the containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories and have the capability to establish controlled leakage and controlled release of delayed accident source term radionuclides.*

NGNP Next Generation Nuclear Plant

SECY Positions on Containment Functional Performance in Non-LWRs (cont'd)

- SECY-05-006, "Second Status Paper on the Staff's Proposed Regulatory Structure for New Plant Licensing and Update on Policy Issues Related to New Plant Licensing" (cont'd)
  - *The staff has concluded that the function of containment has a direct or supporting role in the following accident prevention and mitigation safety functions:*
    - *Protecting risk-significant SSCs from internal and external events*
    - *Physically supporting risk-significant SSCs*
    - *Protecting onsite workers from radiation*
    - *Removing heat to prevent risk-significant SSCs from exceeding design or safety limits*
    - *Providing physical protection (i.e., security) for risk-significant SSCs*
    - *Reducing radionuclide releases to the environs and limiting core damage*

Other NRC Documents on Containment Functional Performance

- Advanced Reactor Policy Statement (FR Vol. 73, No. 199, Oct 2008)
  - *Among the attributes that could assist in establishing the acceptability or licensability of a proposed advanced reactor design, and therefore should be considered in advanced designs, are:*
    - *Designs that incorporate defense-in-depth philosophy by maintaining multiple barriers against radiation release, and by reducing the potential for consequences of severe accidents*

In contrast to:

- *50.34(a)(1)(ii)(D)* (50.34 footnote originally contained in Part 100 pre-1975)
  - *Special attention must be directed to plant design features intended to mitigate the radiological consequences of accidents…an applicant shall assume a fission product release from the core into the containment…*
    - *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.*

Other NRC Documents on Containment Functional Performance *(cont'd)*

- NUREG-1860, "Feasibility Study for a Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing"
  - 4. Defense-in-depth: Treatment of Uncertainties
    - (5) The plant design has containment functional capability to prevent an unacceptable release of radioactive material to the public.
      - …even if the mechanistic source term calculations indicate that releases from the fuel and RCS are small enough to meet release criteria, other means need to be available to prevent uncontrolled releases to the environment.
      - …each design needs to have the capability to establish a controlled low leakage barrier if plant conditions result in the release of radioactive material from the fuel and the reactor coolant system in excess of anticipated conditions. The specific conditions for the barrier leak tightness, temperature, pressure, and time available to establish the low leakage condition will be design-specific.
      - The design of the controlled leakage barrier should be based upon a process that defines a hypothetical event representing a serious challenge to fission product retention in the fuel and the coolant system.

Significant LWR Regulatory Requirements Applicable to LWR Containments

- § 50.34 Contents of applications; technical information;
  - (f) Additional TMI-related requirements…LWR specific
    - (xiv) Provide containment isolation systems (II.E.4.2)
    - (xv) Provide a capability for containment purging/venting (II.E.4.4)
    - (xxvi) Provide for leakage control and detection in the design of systems outside containment that contain (or might contain) accident source term radioactive materials following an accident. (III.D.1.1)
- § 50.44 Combustible gas control for nuclear power reactors
  - (d) Requirements for future non water-cooled reactor applicants and licensees…need to evaluate whether accidents involving combustible gases are technically relevant
- Appendix J to Part 50—Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors*

  *These test requirements may also be used for guidance in establishing appropriate containment leakage test requirements in technical specifications or associated bases for other types of nuclear power reactors.

Significant Technology Neutral Regulatory Requirements Applicable to Containments

- 50.150 Aircraft impact assessment
  - Assessment requirements - Each applicant…shall perform a design-specific assessment of the effects on the facility of the impact of a large, commercial aircraft. Using realistic analyses, the applicant shall identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions:
    - (i) The reactor core remains cooled, or the containment remains intact; and
    - (ii) Spent fuel cooling or spent fuel pool integrity is maintained.

Significant Technology Neutral Regulatory Requirements Applicable to Containments (cont'd)

- *Part 73— Physical Protection of Plants and Materials*
  - *The licensee shall locate vital equipment only within a vital area, which, in turn, shall be located within a protected area such that access to vital equipment requires passage through at least two physical barriers.*
    - *Vital area means any area which contains vital equipment.*
    - *Vital equipment means any equipment, system, device, or material, the failure, destruction, or release of which could directly or indirectly endanger the public health and safety by exposure to radiation. Equipment or systems which would be required to function to protect public health and safety following such failure, destruction, or release are also considered to be vital.*
    - *Physical barriers - protect against the design basis threat of radiological sabotage.*

Summary

- Minimizing radionuclide release from the fuel and allowing use of alternate, less prescriptive containment functional requirements is consistent with:
  - The Commission's Advanced Reactor Policy Statement
  - Numerous staff positions contained in SECY papers written over the last twenty years
- The 50.34 footnote and some aspects of NUREG-1860 appear to differ from the above.
- The HTGR functional containment is consistent with many technology-neutral containment regulations.

HTGR Functional Containment Principal Design Criteria

Background

- 10CFR50 Appendix A provides General Design Criteria (GDCs) for Nuclear Power Plants that
  - Establish minimum *requirements* for Principal Design Criteria (PDCs) for water-cooled nuclear power plants similar to previously licensed plants
  - Are considered generally applicable to other types of nuclear power plants and provide *guidance* for Principal Design Criteria for such other plants
- PDCs Must be Included in Applications (CP, DC, COL, ML, etc.)
  - Establish necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety
- NGNP Regulatory Gap Analysis (RGA) Addressed Applicability of GDCs to HTGR
  - Applicable, Not Applicable, or Partially Applicable
  - Subject to ongoing evaluation
- Modular HTGR PDC Development Effort Takes the Next Step

HTGR PDCs Were Approached from Two Directions

- Modify GDCs to create PDCs
- Derive PDCs from functional requirements
- Combine the two efforts to obtain complete PDCs

PDC 16 *Functional* Containment Design

~~Reactor~~ A functional containment ~~and associated systems~~ shall be provided to establish an essentially leak-tight set of barriers against the uncontrolled release of radioactivity to the environment and to assure that the functional containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

- Address five barriers vs. LWR containment building. (For DBAs, only the first three or four barriers are relied upon to meet regulatory requirements for off site dose at the EAB. For meeting EPA PAGs at the EAB for DBEs and BDBEs, all five barriers are taken into account.)

- Treat the functional containment as an integrated entity with one PDC. Individual barriers are addressed in other PDCs.

PDC 50 Reactor Building Design Basis

~~The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.~~

The design, fabrication, operation, and maintenance of the reactor building shall be such that during postulated accidents it structurally protects the geometry for passive removal of residual heat from the reactor core to the ultimate heat sink to maintain the specified acceptable core radionuclide release design limits.

PDC 50 Reactor Building Design Basis *(cont'd)*

- "Containment" is replaced by the "reactor building" for the purposes of this PDC.
- The reactor building primary safety function is to protect geometry for passive residual heat removal. This PDC reflects this required safety function only.
- PDC 16 covers the safety role of the reactor building as one element of the Functional Containment for radionuclide retention.

PDC 53 Provisions for Reactor Building Inspection and Surveillance

The reactor ~~containment~~ building shall be designed to permit (1) appropriate periodic inspection of all important structural areas~~, such as penetrations~~ and (2) an appropriate surveillance program~~, and (3) periodic testing at containment design pressure of the leaktightness of penetrations which have resilient seals and expansion bellows~~.

- "Containment" is replaced by the "reactor building" for the purposes of this PDC.
- Specific reference to penetrations and testing of their leaktightness is deleted due to intentional venting of reactor building at high pressure.
- Inspection and surveillance of reactor building is focused on fundamental structural integrity for protection of passive heat removal.

The Following LWR Containment GDCs Are Not Applicable to the Modular HTGR

- GDC 38: Containment Heat Removal
- GDC 39: Inspection of Containment Heat Removal System
- GDC 40: Testing of Containment Heat Removal System
- GDC 41: Containment Atmosphere Cleanup
- GDC 42: Inspection of Containment Atmosphere Cleanup Systems
- GDC 43: Testing of Containment Atmosphere Cleanup Systems
- GDC 51: Fracture Prevention of Containment Pressure Boundary
- GDC 52: Capability for Containment Leakage Rate Testing
- GDC 54: Systems Penetrating Containment
- GDC 55: Reactor Coolant Pressure Boundary Penetrating Containment
- GDC 56: Primary Containment Isolation
- GDC 57: Closed Systems Isolation Valves

Next Steps

Requested NRC Staff Positions – Functional Containment

- Confirm plans being implemented by the Advanced Gas Reactor Fuel Development and Qualification Program are generally acceptable and provide reasonable assurance of the capability of coated particle fuel particles to retain fission products in a controlled and predictable manner.

- Establish options regarding functional containment performance standards

- Establish a staff position regarding how LBEs will be considered for the purpose of plant siting and functional containment design decisions:

  - Adaptation of the guidance that has generally been applied to LWRs in association with 10 CFR 100.21 and 10 CFR 50.34 (i.e., assumption of a substantial meltdown of the core with the subsequent release of appreciable quantities of fission products.)