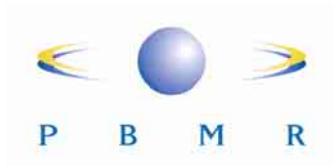


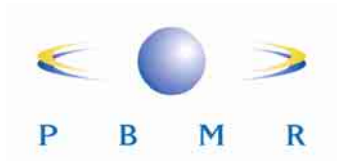
Safety Design Approach

Fred A. Silady



Presentation Objectives

- **Review safety design approach**
- **Review safety design basics**
- **Set the stage for presentations on specific event analyses**



Definition of Passive Design Features

- **Design features engineered to meet their functional requirements *without***
 - Needing successful operation of systems with mechanical actions such as pumps, valves, blowers, HVAC, sprays
 - Depending on availability of electric power
 - Relying on operator actions

PBMR passive design features utilize inherent characteristics and properties.

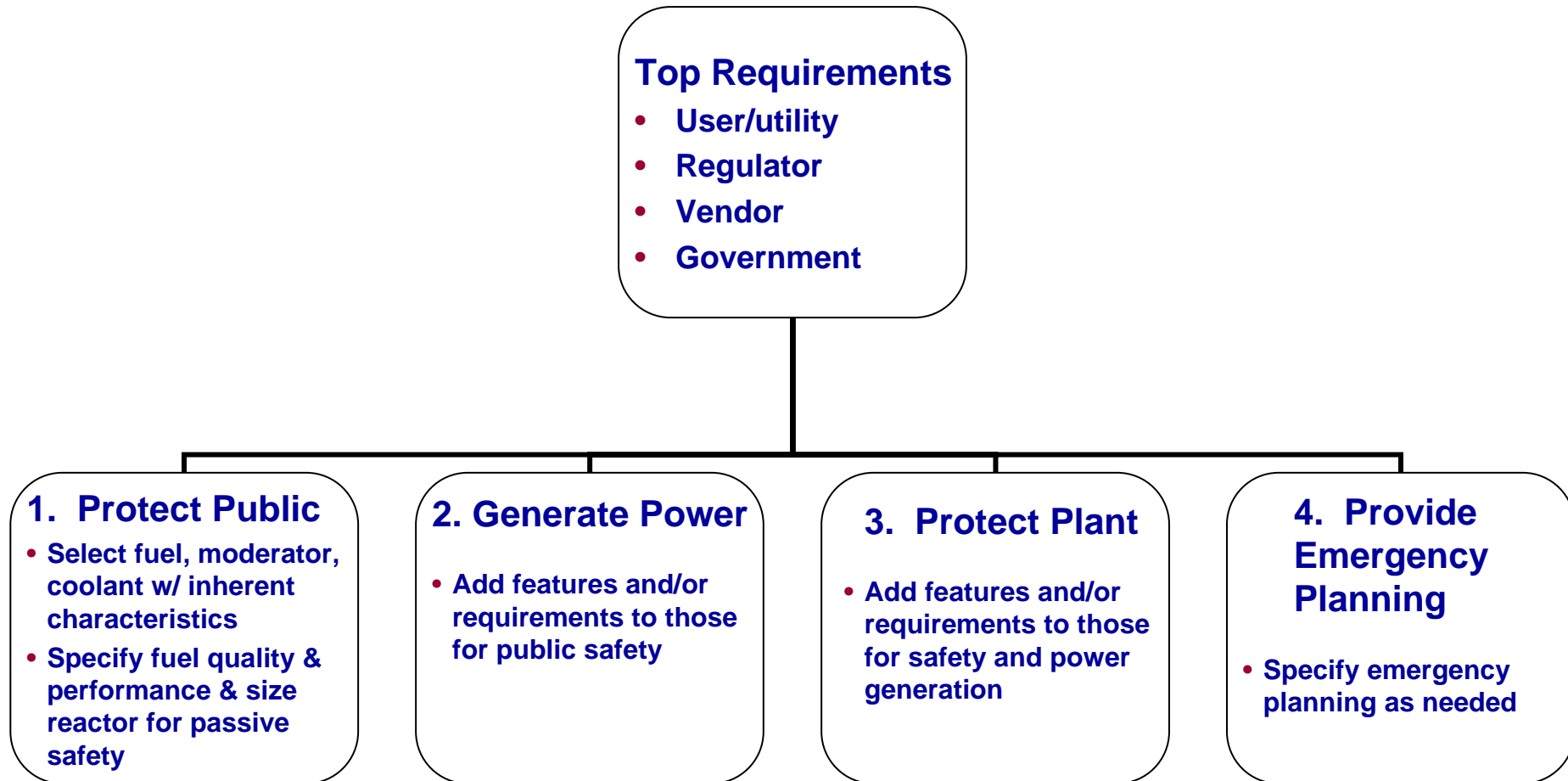


Important PBMR Paradigm Shifts

- The fuel, helium coolant, and graphite moderator are **chemically compatible** under all conditions.
- The fuel has very **large temperature margins** in normal and accident conditions.
- The safety of the PBMR is **not dependent** on the presence of the helium coolant.
- The **response times** of the reactor are very **long** (days as opposed to seconds or minutes).
- There is no inherent mechanism for runaway reactivity excursions or power excursions.
- The PBMR has three **concentric and independent** radionuclide barriers.
- Accident phenomena can be modeled mechanistically.
- An LWR-type containment is neither advantageous nor necessarily conservative.

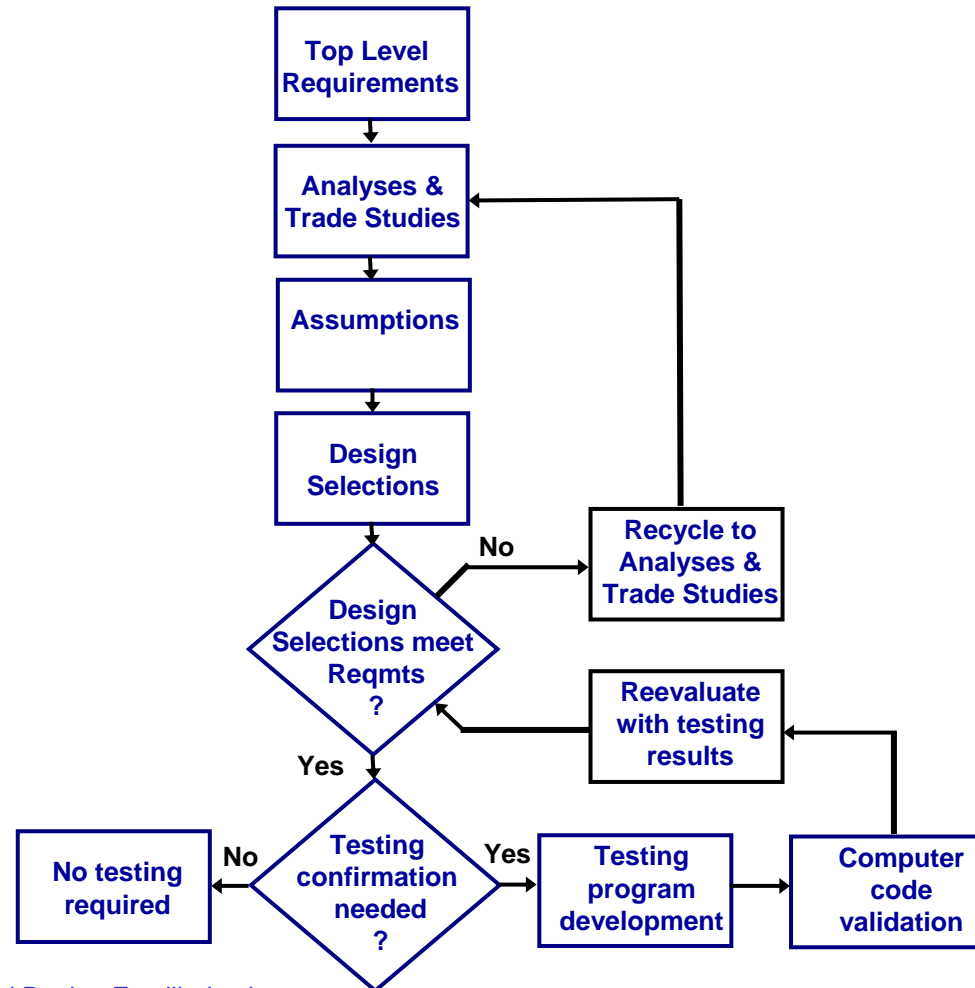


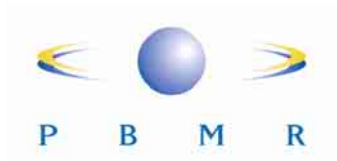
PBMR Design Process: Safety First



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

Iterative Design Approach

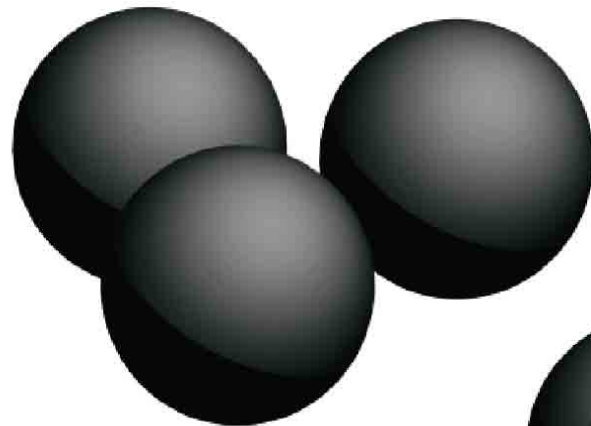




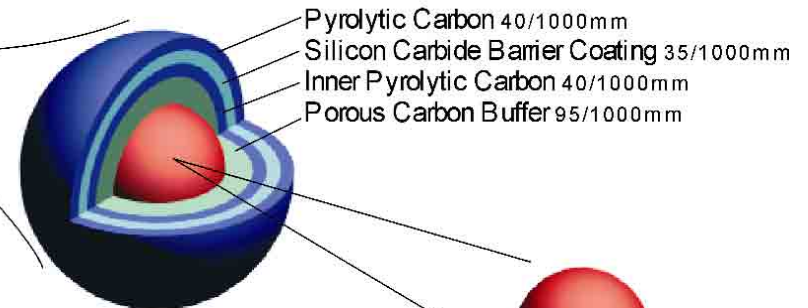
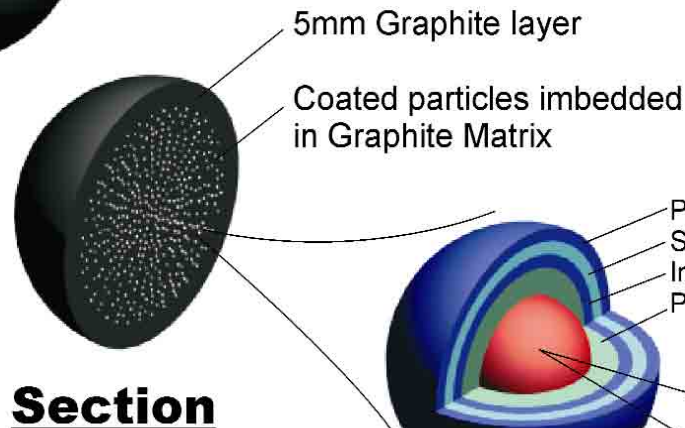
Inherent Characteristics of PBMR Fuel-Moderator-Coolant

- **Ceramic-coated Pebble Fuel**
 - High temperature capabilities
 - Chemical compatibility with coolant and moderator
- **Graphite Moderator**
 - High temperature capabilities
 - High heat capacity
 - Chemical compatibility with fuel and coolant
 - Large neutron migration length for neutron stability
- **Helium Coolant**
 - Single phase
 - Chemically and neutronically inert
 - Low stored thermal energy

PBMR Fuel Quality and Form



Dia. 60mm
Fuel Sphere

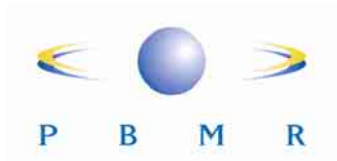


Dia. 0,92mm

TRISO
Coated Particle



Dia. 0,5mm
Uranium Dioxide
Fuel Kernel



Radionuclide Sources

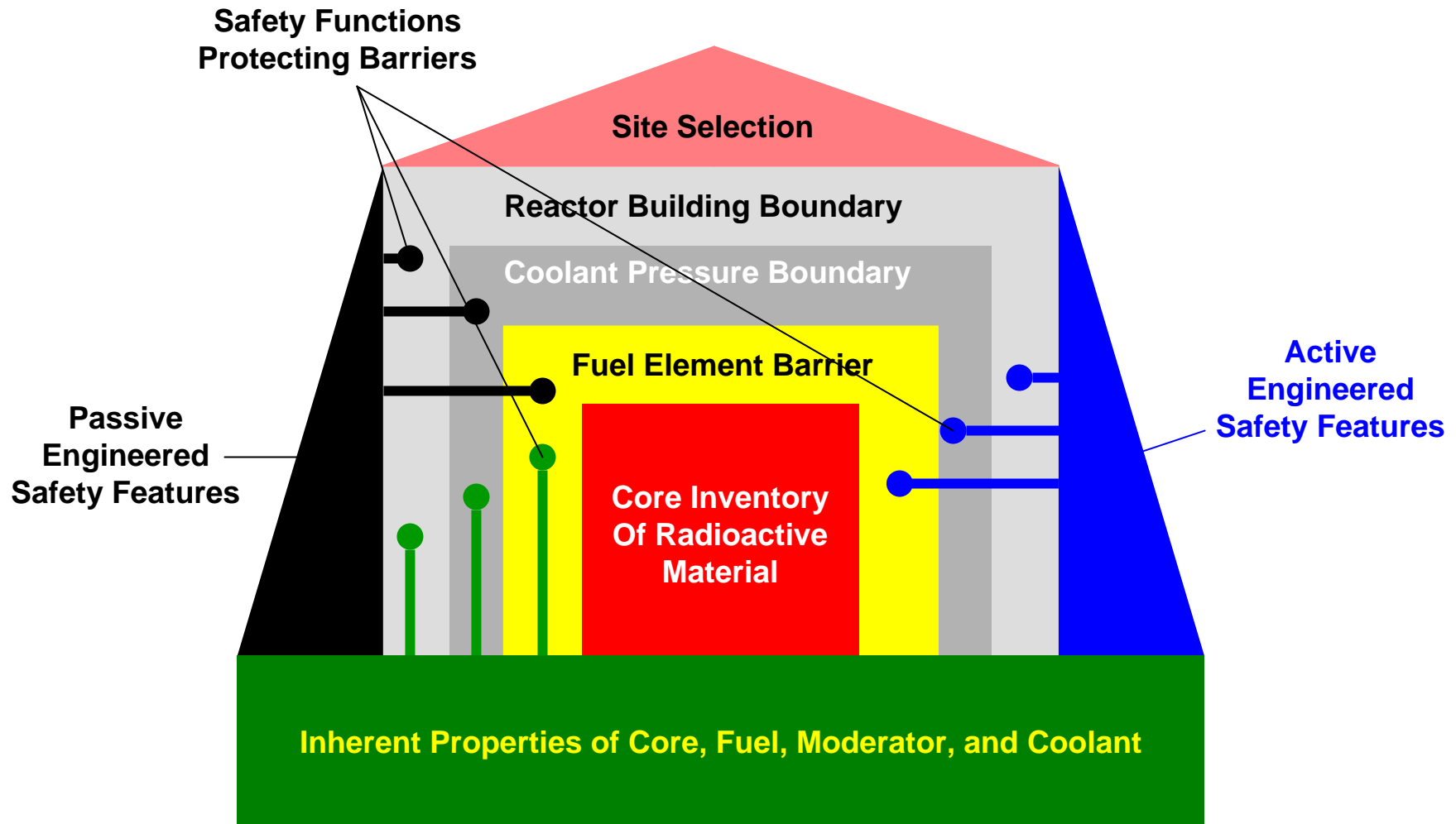
- **Sources within the MPS HPB**

- Fuel spheres in core/FHSS
 - *Intact coated particles*
 - *Failed or defective coated particles*
 - *Uranium contamination outside coated particles*
 - *Imbedded/attached to graphite components*
- Plateout on HPB surfaces and dust
- Circulating coolant activity

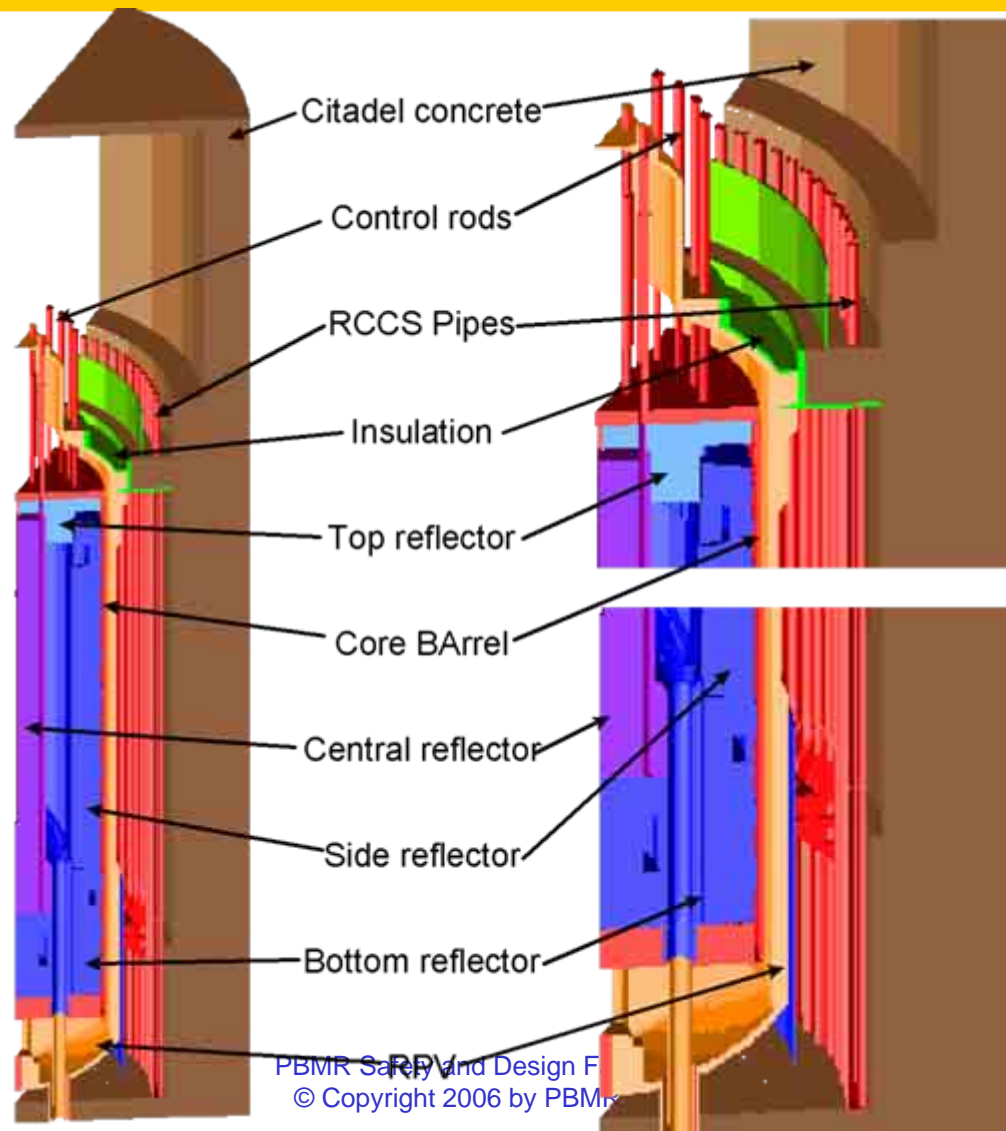
- **Sources outside the MPS HPB**

- Fuel spheres in storage systems
- HICS and HPS gas borne activity
- Solid and liquid radwaste systems

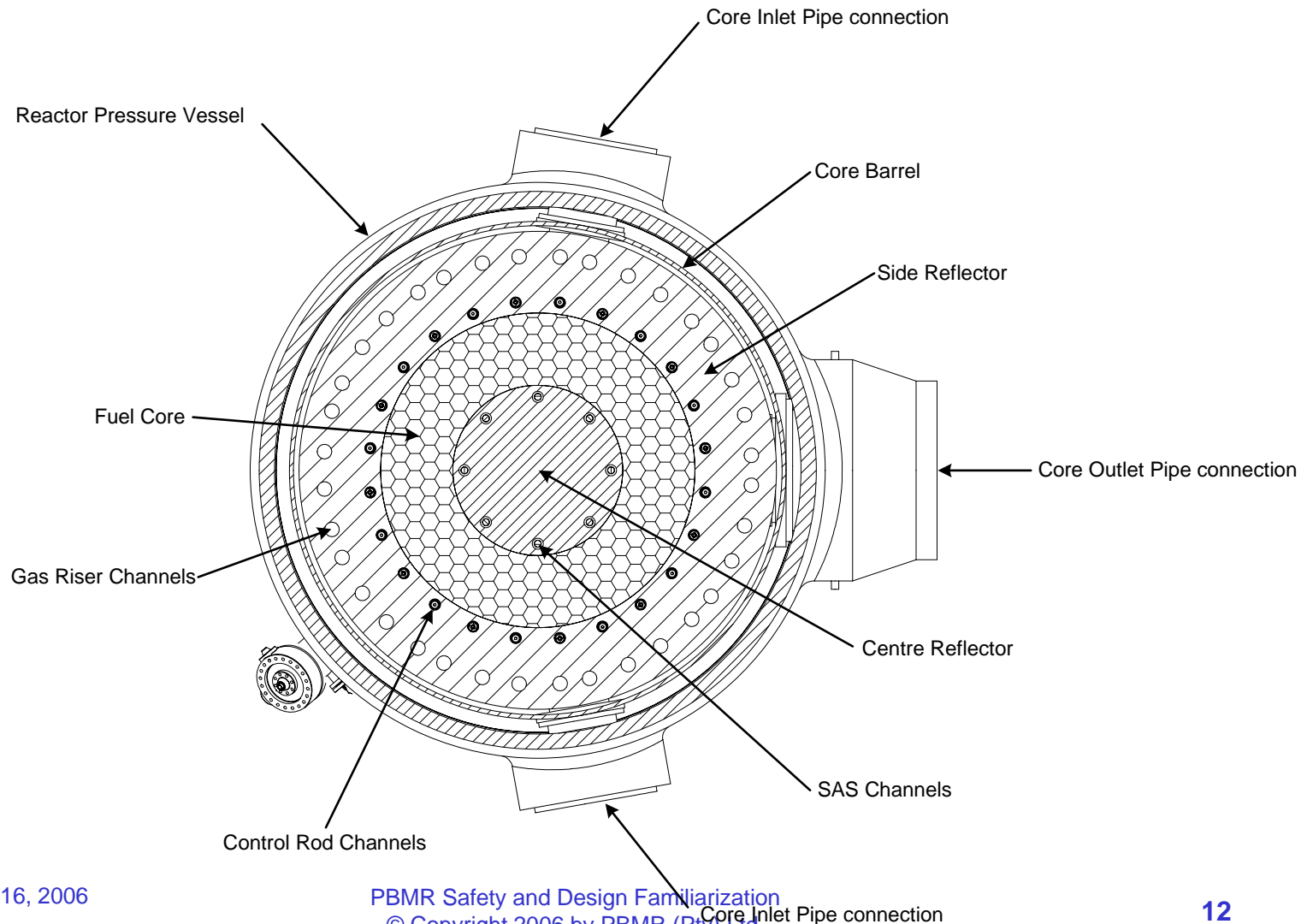
Generic Relationships of Inherent Properties and Passive & Active Features to Barrier Protection



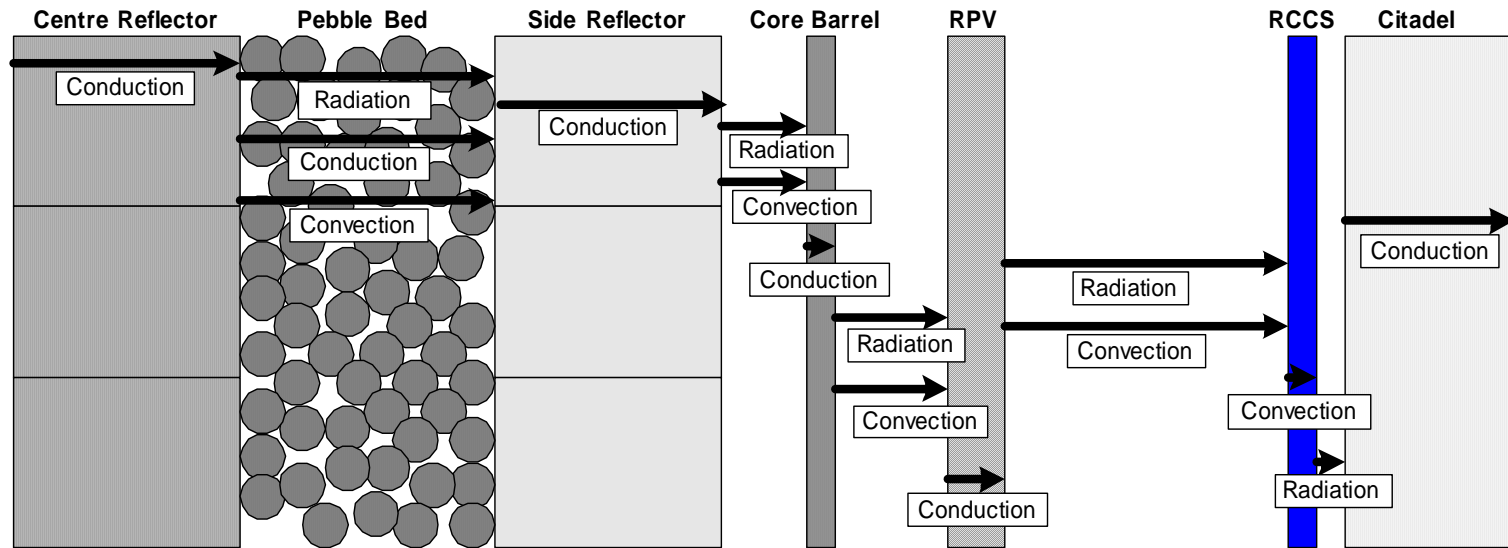
Long, Slender, Annular Core



Annular Reactor Unit Horizontal Section

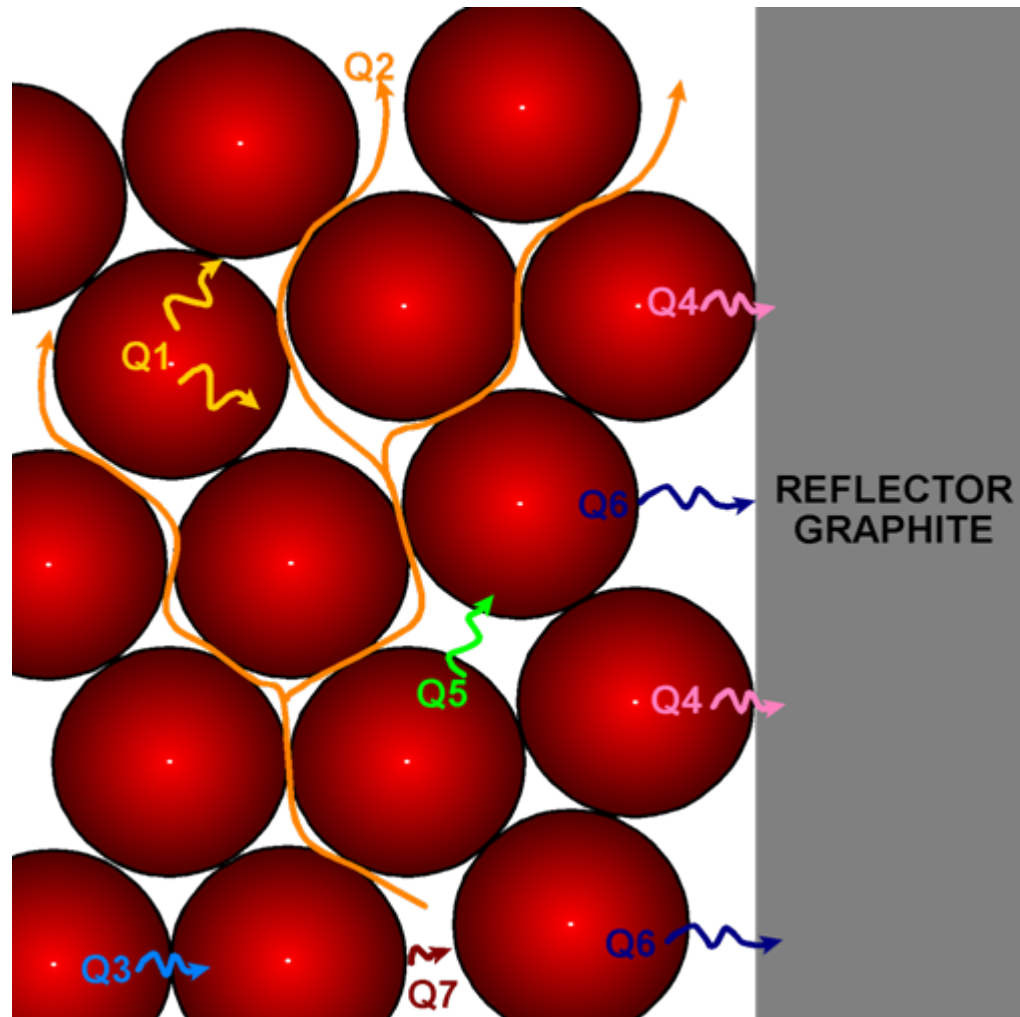


Power Level & Reactor Configuration Selected for Passive Heat Transfer



- *Heat transfer mechanisms are passive and do not require helium coolant pressure.*
- *Annular core geometry provides for short heat transfer path to the outside of RPV resulting in acceptable fuel temperatures.*
- *Relatively low thermal power compared to existing reactors.*

Heat Transfer in the Pebble Bed



Q1: Conduction from the centre of the pebble to the surface

Q2: Convection from the pebble surface to the gas

Q3: Point contact conduction between the pebble surfaces that are in contact with one another

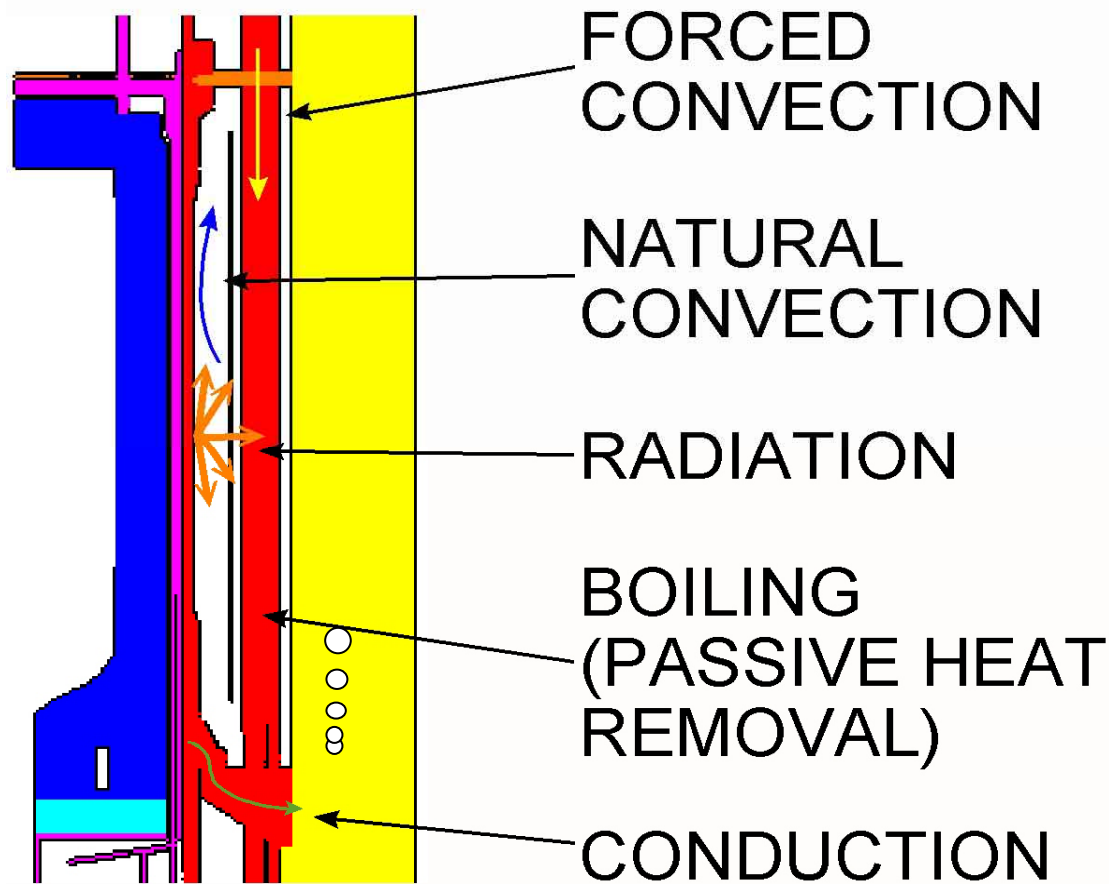
Q4: Point contact conduction between the pebble surfaces that are in contact with the reflector

Q5: Thermal radiation between the pebble surfaces

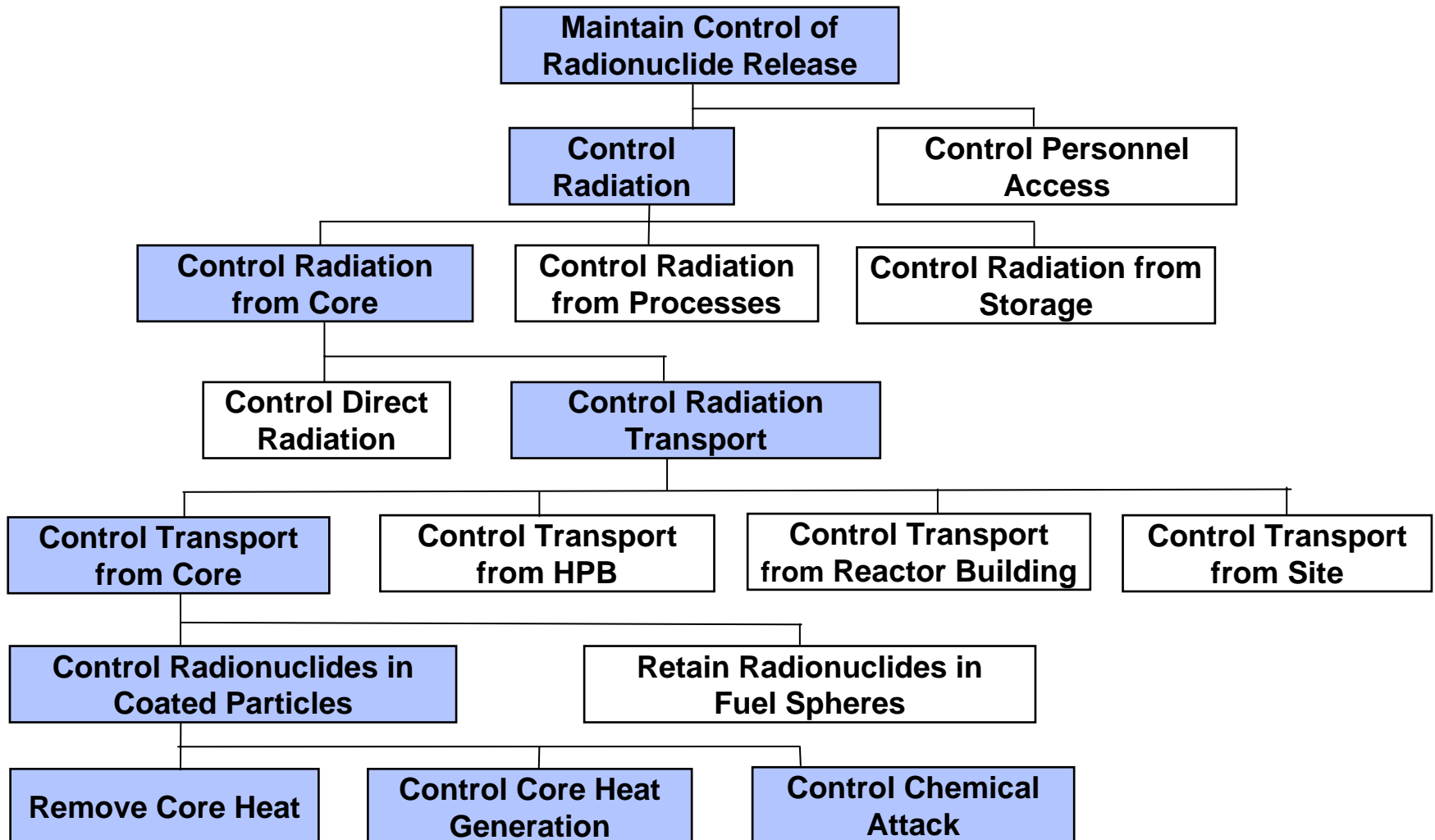
Q6: Thermal radiation between the pebble surfaces and the reflector

Q7: Conduction in the gas

Heat Removal Mechanisms in Reactor Cavity



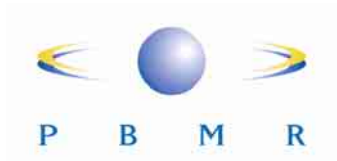
PBMR Safety Functions





Role of Active Design Features

- **Additional engineered active design features provided in order to:**
 - Meet plant reliability, availability and investment protection requirements
 - Provide prevention and mitigation roles as part of the design defense-in-depth
- **Examples of engineered active features**
 - Diverse and redundant forced cooling systems for the core and fuel storage
 - Active elements of reactivity control systems
 - MPS and Reactor building pressure relief systems
 - Reactor building HVAC filtration systems
 - Helium purification and inventory control systems



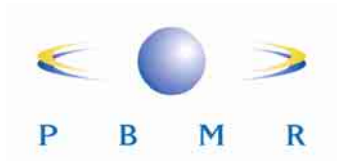
SSCs Supporting Core Heat Removal

- **Inherent and passive capabilities**

- Low power density
- Large thermal heat capacity of core
- Long, slender annular core,, annular geometry
- Uninsulated reactor vessel and reactor cavity configuration
- Passive Reactor Cavity Cooling System (RCCS)

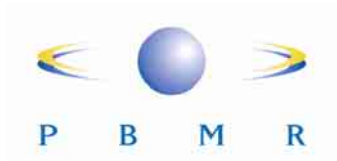
- **Active systems**

- Main Power System (MPS)
- Core Conditioning System (CCS)
- Active Reactor Cavity Cooling System (RCCS)



SSCs Supporting Control of Heat Generation

- **Inherent and passive capabilities**
 - Large negative temperature coefficient of reactivity
 - Low excess reactivity due to on-line fueling
 - Core height limited for xenon stability
 - Annular core provides azimuthal xenon stability
 - Self-regulating behavior due to close fluid-neutronic coupling
 - Gravity insertion of control rods and small absorber spheres (SAS)
- **Active systems**
 - Control and protection systems
 - *Operational Control System (OCS)*
 - *Equipment Protection System (EPS)*
 - *Reactor Protection System (RPS)*
 - Reactivity control systems
 - *Reactivity Control System (RCS) trip release of control rods*
 - *Reserve Shutdown System (RSS) release of small absorber spheres (SAS)*



SSCs Supporting Control of Chemical Attack

- **Inherent and passive capabilities**
 - High purity inert helium coolant
 - HPB high reliability piping and pressure vessels
 - Minimum of large penetrations in top of reactor vessel
 - All interfacing systems at lower pressure than MPS during operation
 - Lack of MPS pressurization mechanisms to open MPS pressure relief system valves
- **Active systems**
 - Rupture discs protect against MPS HX water leaks.
 - Isolation valves in MPS interfacing water systems
 - Reactor building exhaust duct dampers limit air ingress potential.