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

Top Requirements

- User/utility
- Regulator
- Vendor
- Government

1. Protect Public

- Select fuel, moderator, coolant w/ inherent characteristics
- Specify fuel quality & performance & size reactor for passive safety

2. Generate Power

- Add features and/or requirements to those for public safety

3. Protect Plant

- Add features and/or requirements to those for safety and power generation

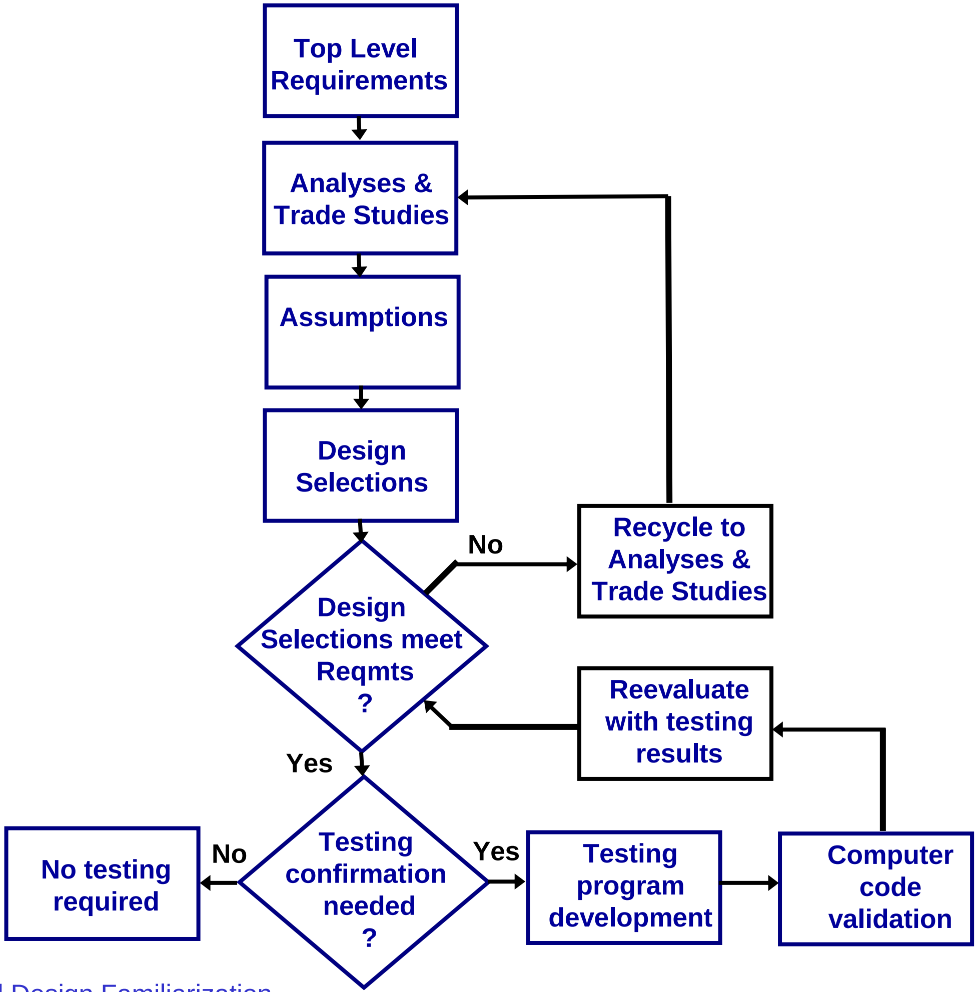
4. Provide Emergency Planning

- Specify emergency planning as needed

PBMR Design Basics

- 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

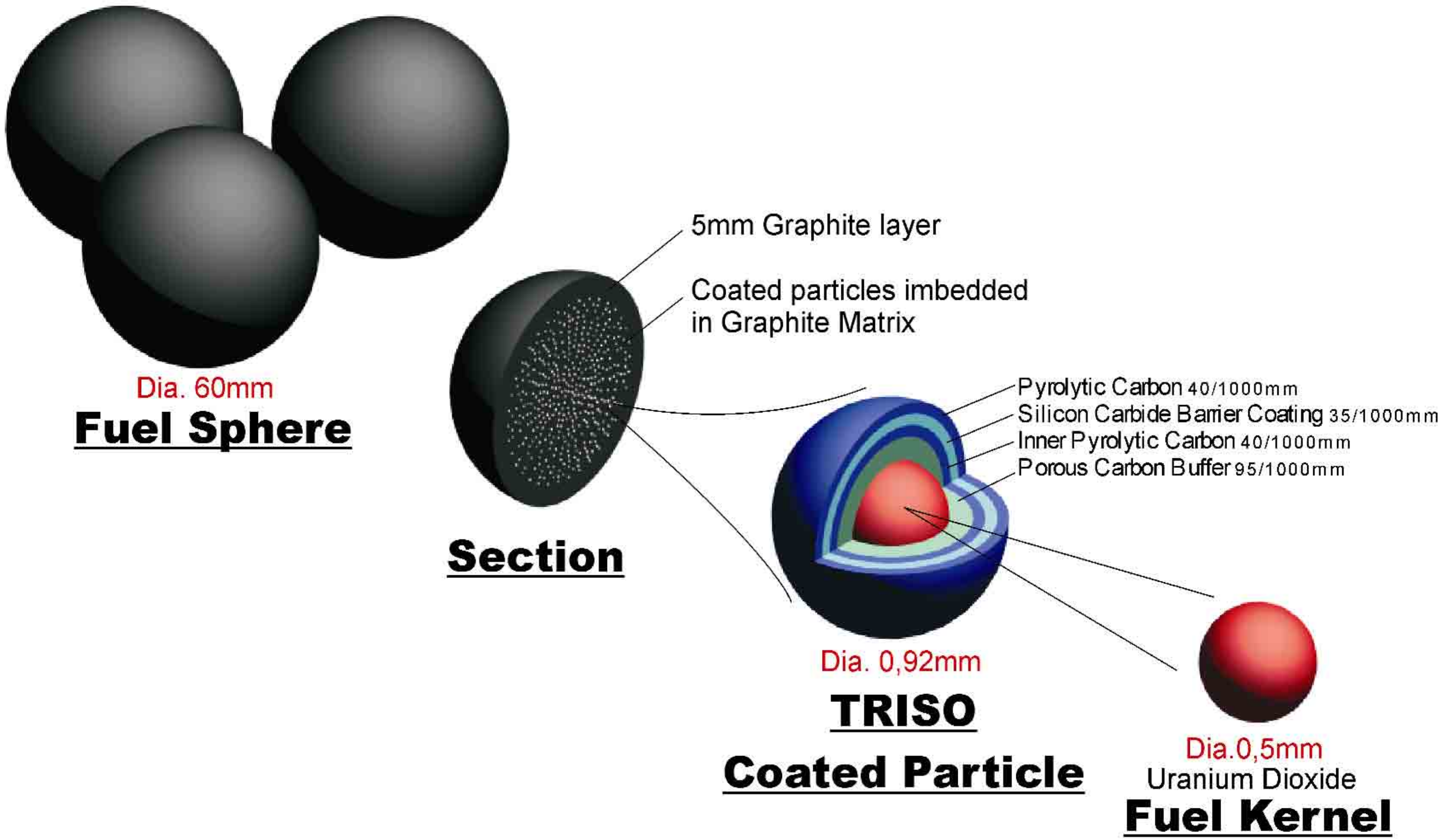
Iterative Design Approach



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**

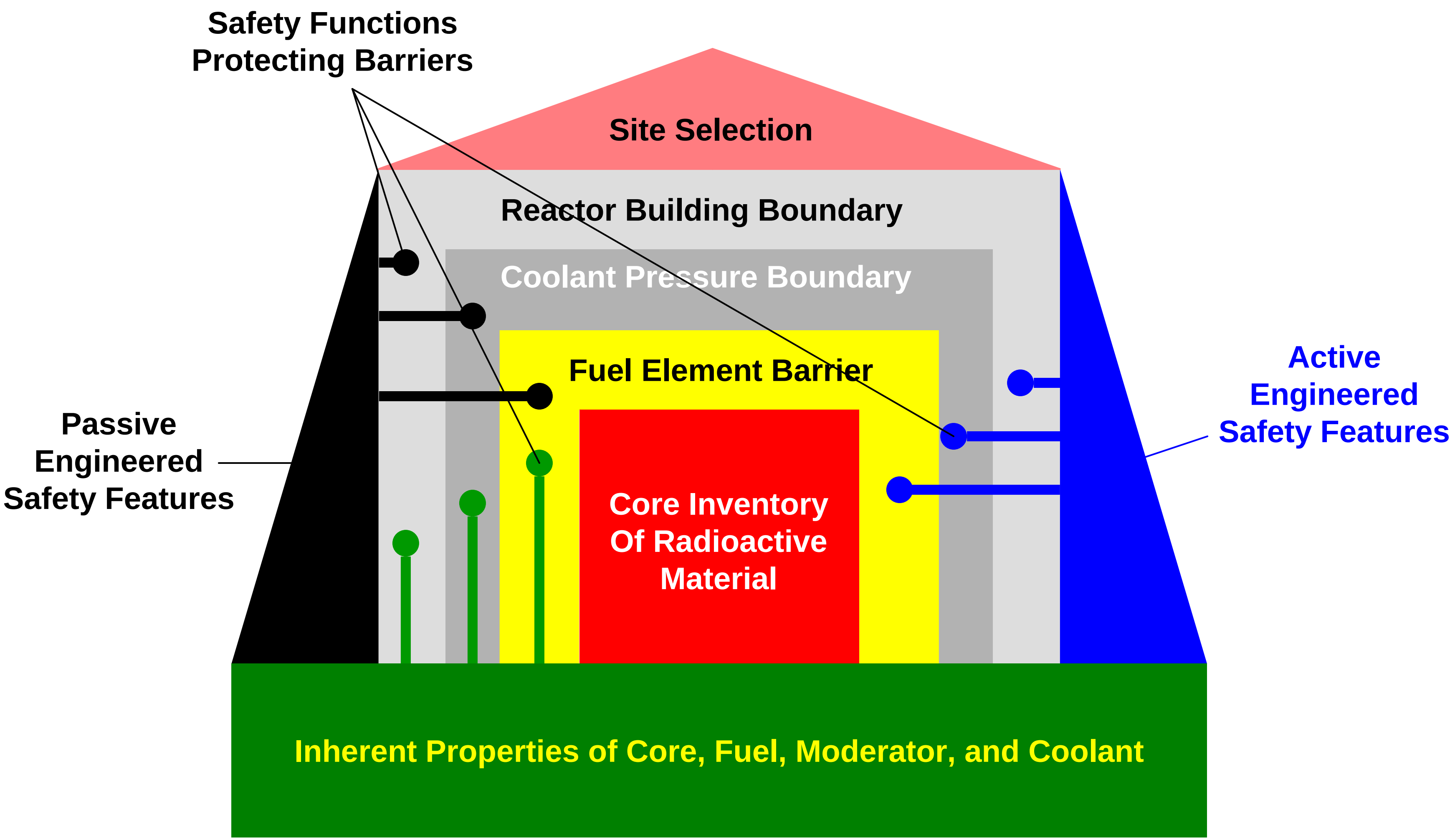
PBMR Fuel Quality and Form



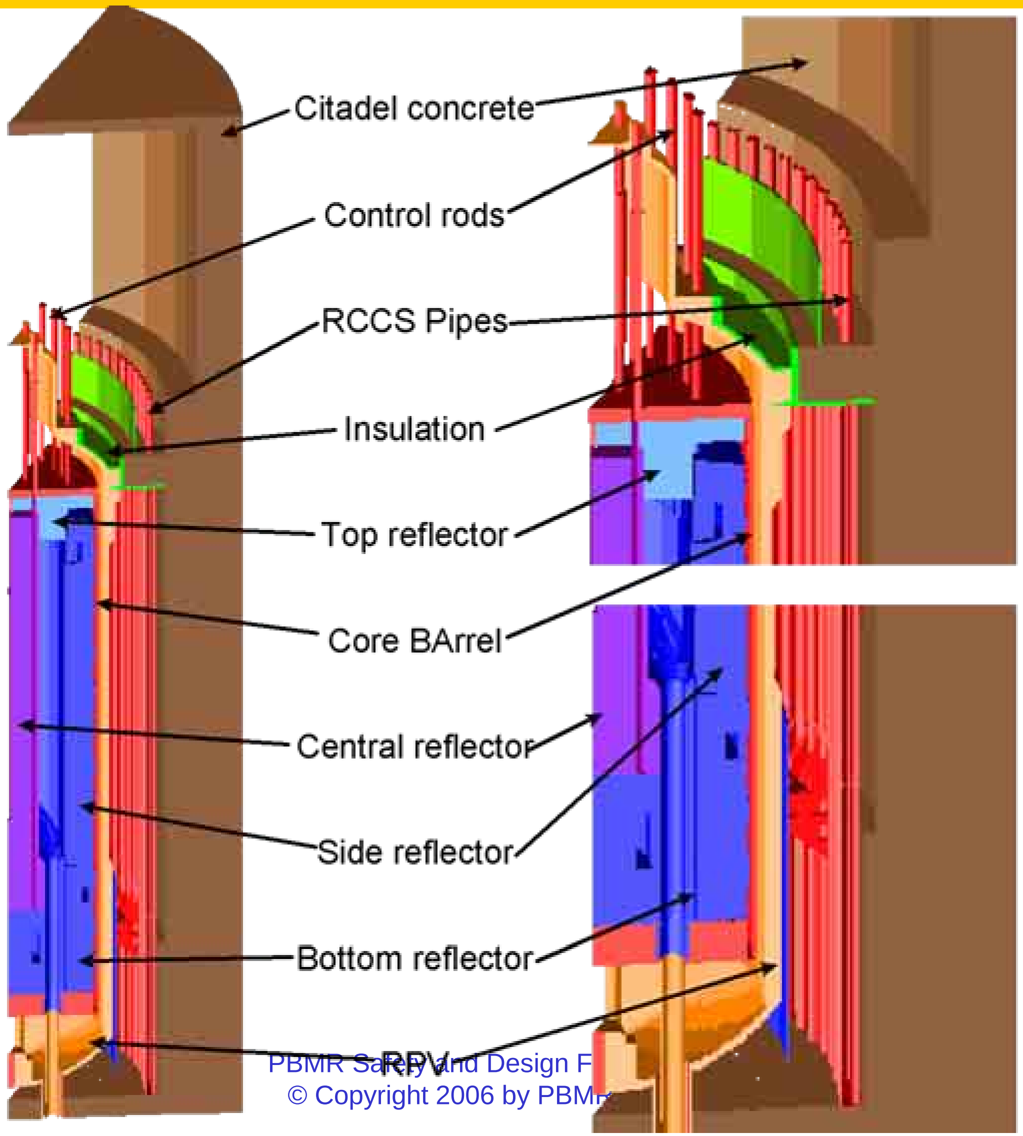
Radionuclide Sources

- **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

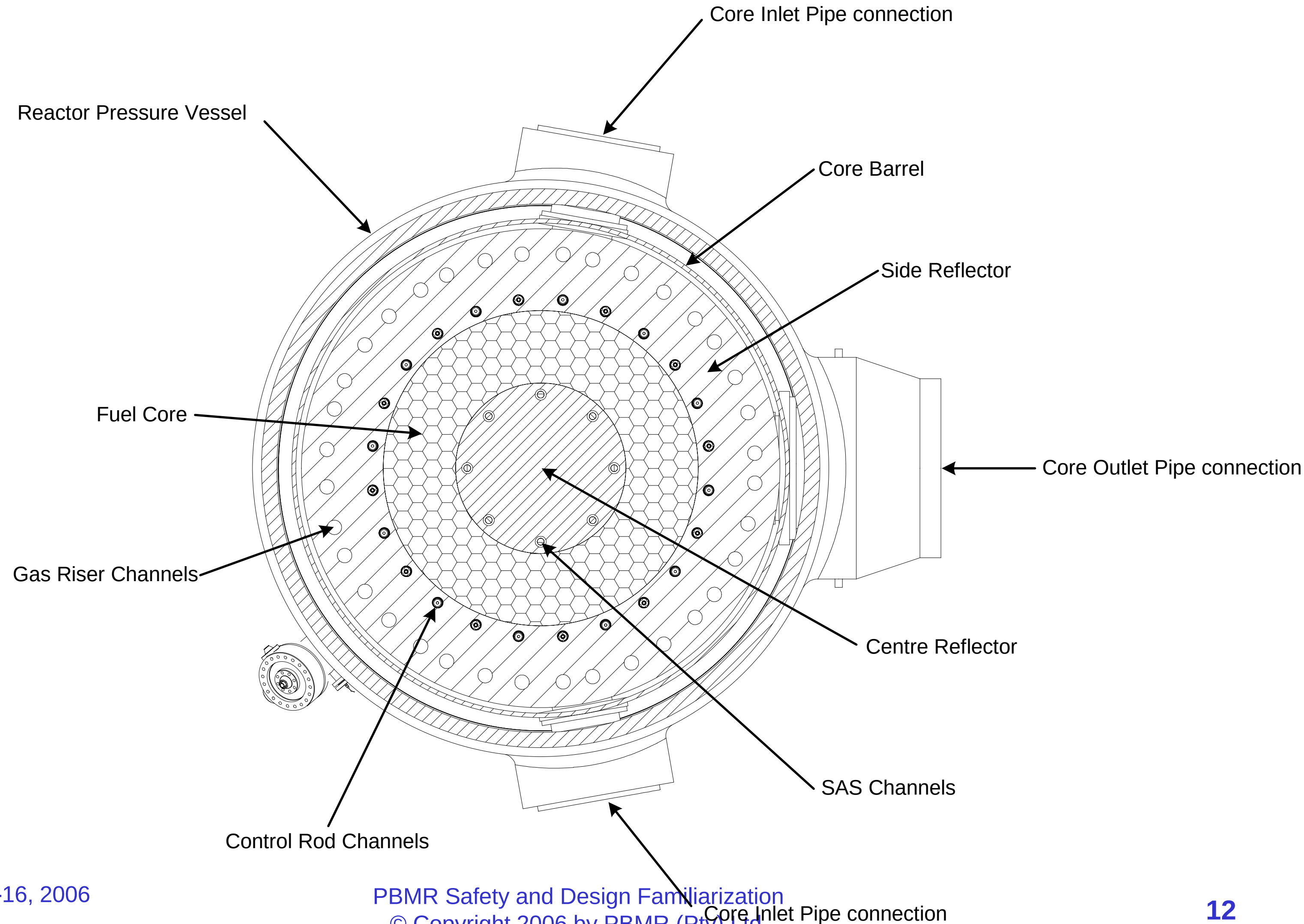
Generic Relationships of Inherent Properties and Passive & Active Features to Barrier Protection



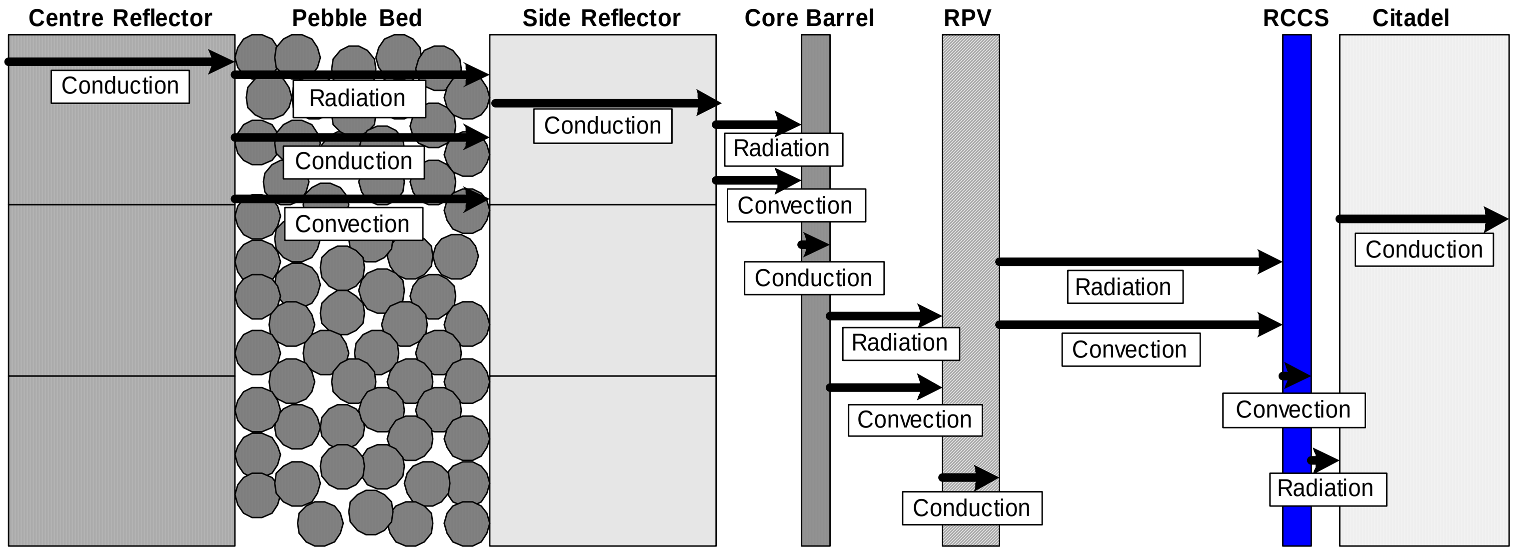
Long, Slender, Annular Core



Annular Reactor Unit Horizontal Section

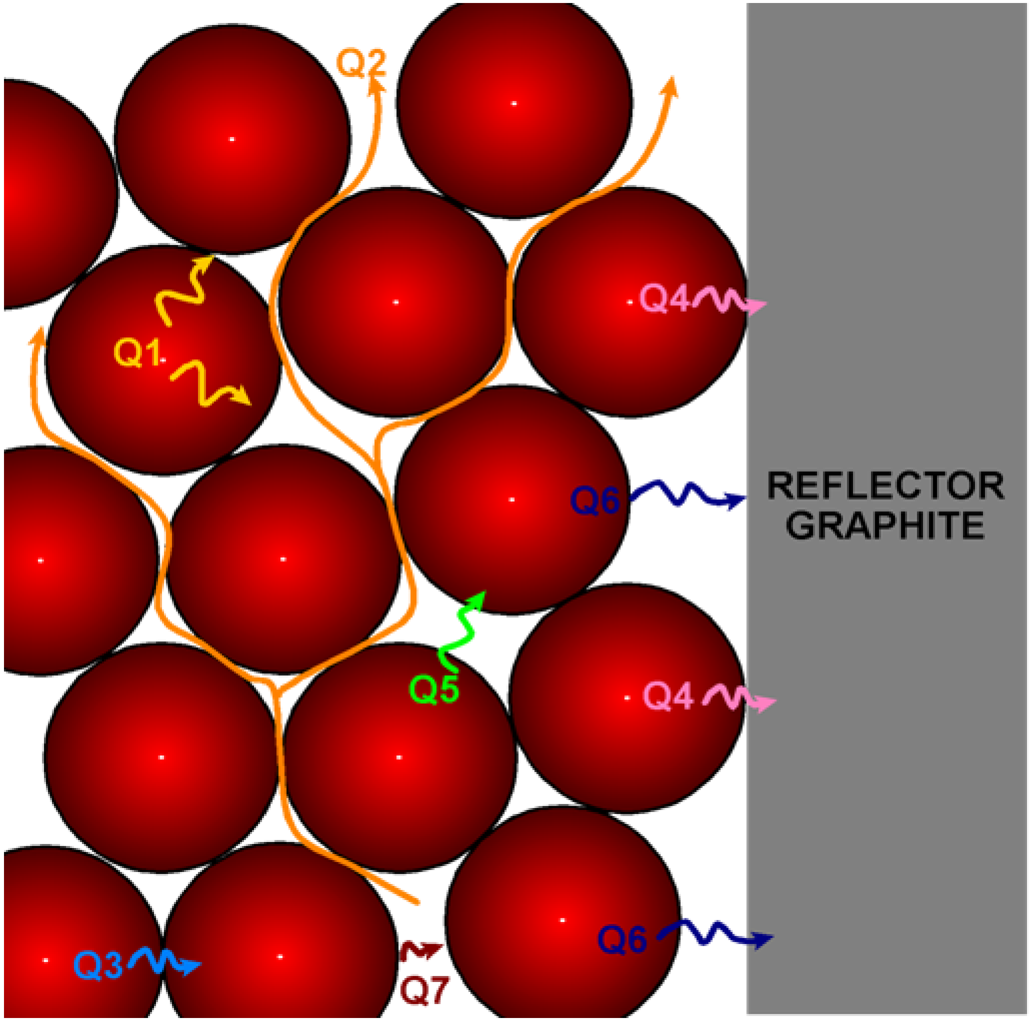


Power Level & Reactor Configuration Selected for Passive Heat Transfer



- *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

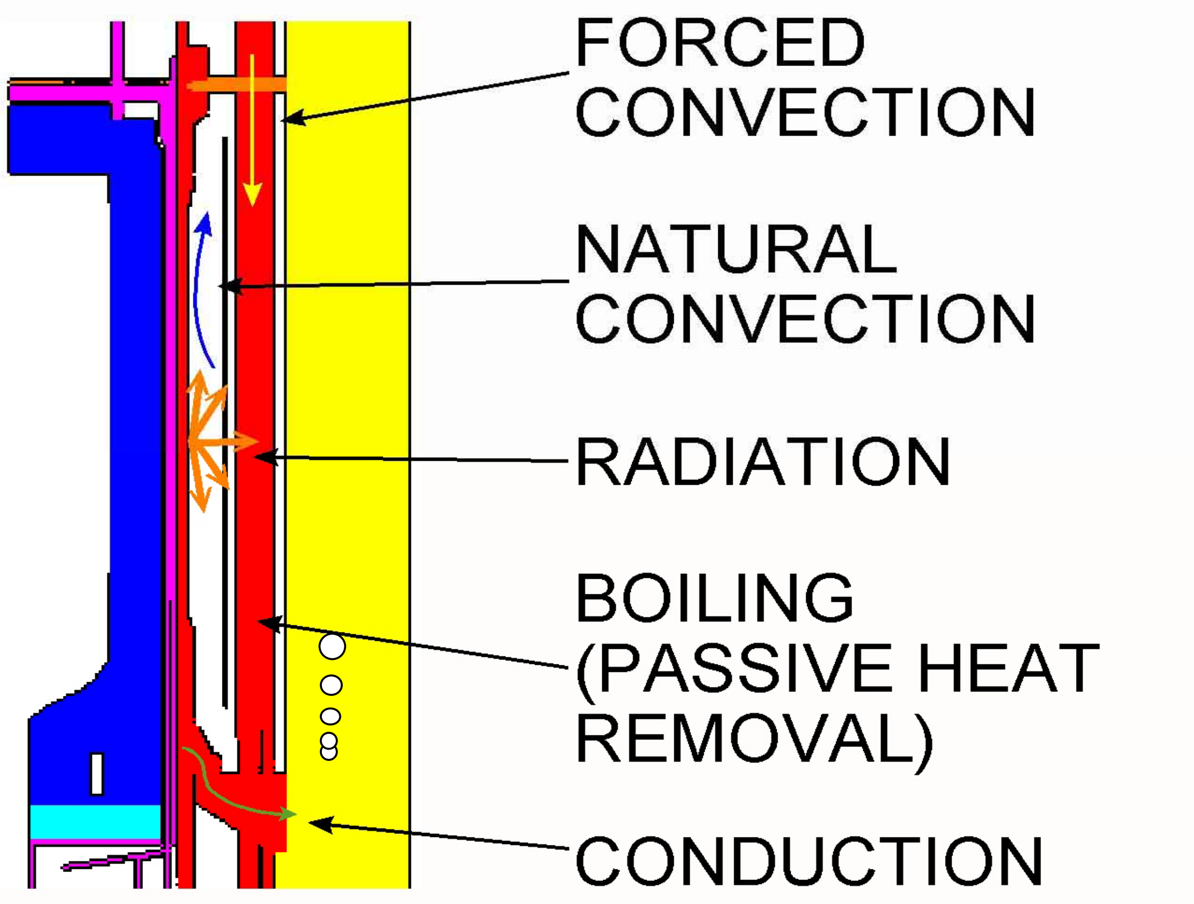
Q4: Point contact conduction between the pebble surfaces that are in contact with the reflector

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

- Maintain Control of Radionuclide Release
  - Control Radiation
    - Control Radiation from Core
      - Control Direct Radiation
      - Control Radiation Transport
        - Control Transport from Core
          - Control Radionuclides in Coated Particles
            - Remove Core Heat
            - Control Core Heat Generation
            - Control Chemical Attack
          - Retain Radionuclides in Fuel Spheres
        - Control Transport from HPB
        - Control Transport from Reactor Building
        - Control Transport from Site
    - Control Radiation from Processes
    - Control Radiation from Storage
  - Control Personnel Access

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.