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Pebble Bed HTGRs

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Joint IAEA-ICTP Workshop on the Physics and Technology of Innovative High Temperature Nuclear Energy Systems

Presentation Aim

Introduce pebble type HTGRs, explain operation, main features, systems, some advantages / challenges

Presentation Objectives

By the end of this session, participants should be able to:

- Define pebble type modular HTGRs
- Consider operation modes
- Identify design aspects that need special care
- Identify the main design considerations
- Know the main systems

Reactor Functions

- Energy production functions
  - Produce reactor energy
  - Maintain energy transfer
  - Maintain reactor shutdown

- Radionuclide control functions
  - Control radionuclide release from core
  - Retain radionuclides in the fuel particles/spheres
    - Remove core heat
    - Control heat generation
    - Control chemical attack

Reactor Operating Modes

Example PBMR400 direct cycle

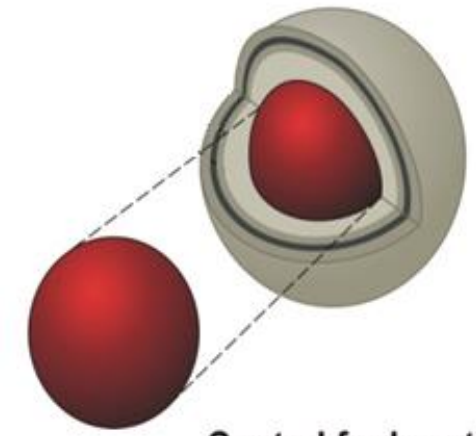
- Starting up and shutting down
  - Describe process for each in terms of manual/automatic control of flows, pressures, reactivity/sphere movement
  - Describe initial startup
- Energy production
  - Power can be adjusted by changing the mass flow rate of the coolant through the core. This can be affected by adjusting the coolant pressure (Inventory Control) or the flow rate (Circulator Speed Control)
  - Control rods are used to adjust the reactor outlet temperature
  - On-line refueling to maintain criticality
- Shutdown
  - Insert control rods to shutdown the reactor
  - Insert SAS to shutdown the reactor to cold temperatures
  - Remove decay heat with either main circuit (SG and Circulator), or with backup cooling system (SCS, CCS, HPS)

Pebble Bed Key Operating Conditions & Materials

	PBMR	LWR
Moderator	Graphite	Water
Coolant	Helium	Water
Reactor Inlet Temperature	250°C Steam Cycle 500°C Gas Turbine	
Reactor Outlet Temperature	750°C - 950°C	310°C
Structural Material	Graphite	Steel, aluminum
Fuel Clad	PyC/SiC	Zircalloy
Fuel	UO_2 / UCO	UO_2
Fuel Damage Temperature	1600 - 2000°C	1260°C
Power Density (w/cc)	3-6	58 – 105

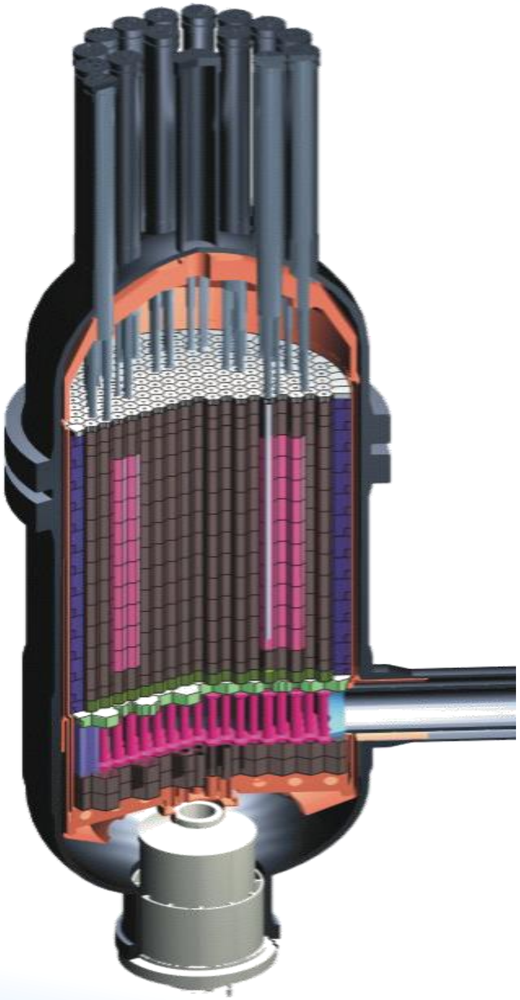
(V)HTGRs Characteristics

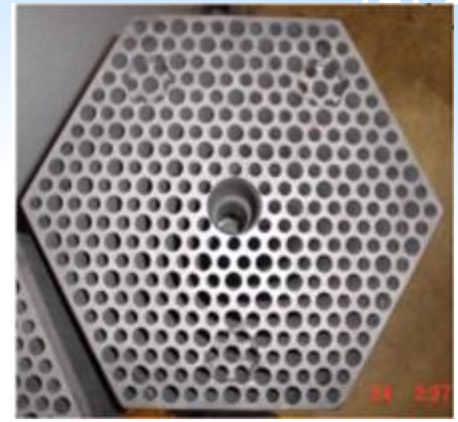
- High Temperature Gas Cooled Reactors is an advanced reactor system (part of GEN-IV) with the following main characteristics:
  - High output temperatures (750-1000ºC)
  - Use of coated particle fuel
  - Helium coolant
  - Graphite moderated
  - Small reactor units (~100 - 600 MWth)
  - To be deployed as multiple modules
  - Low power density (typically 3-6 W/cc compared to 60-100W/cc for LWRs)
  - Two basic design variations – Prismatic and pebble bed design

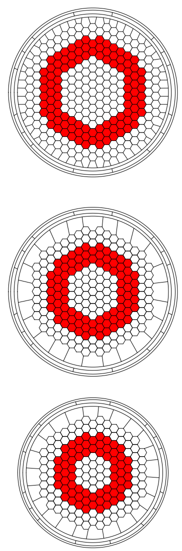


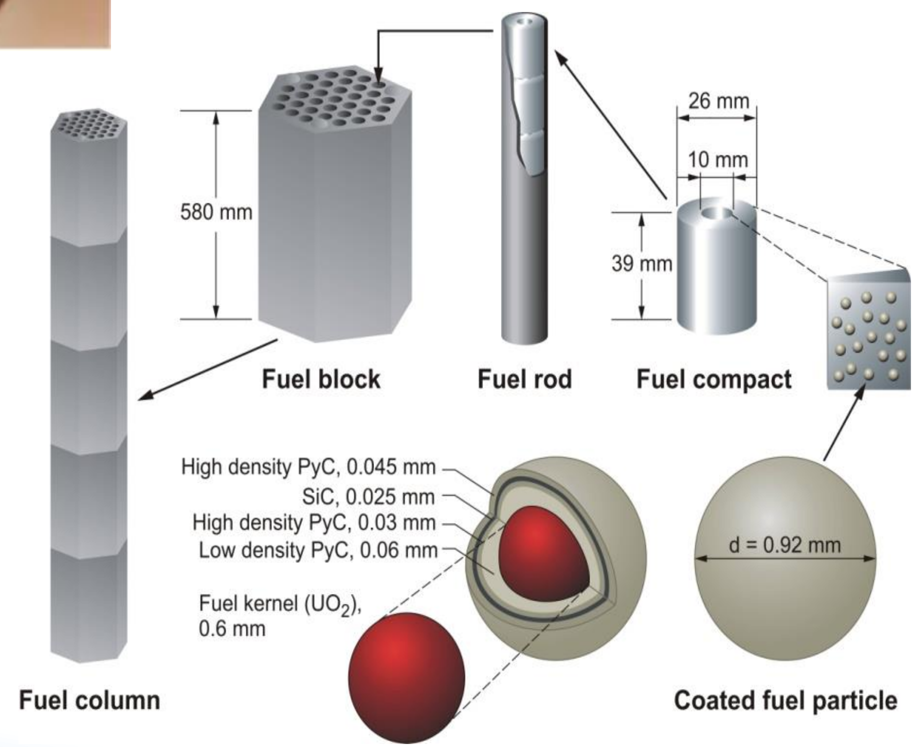
Coated fuel particle

Prismatic (block-type) HTGRs

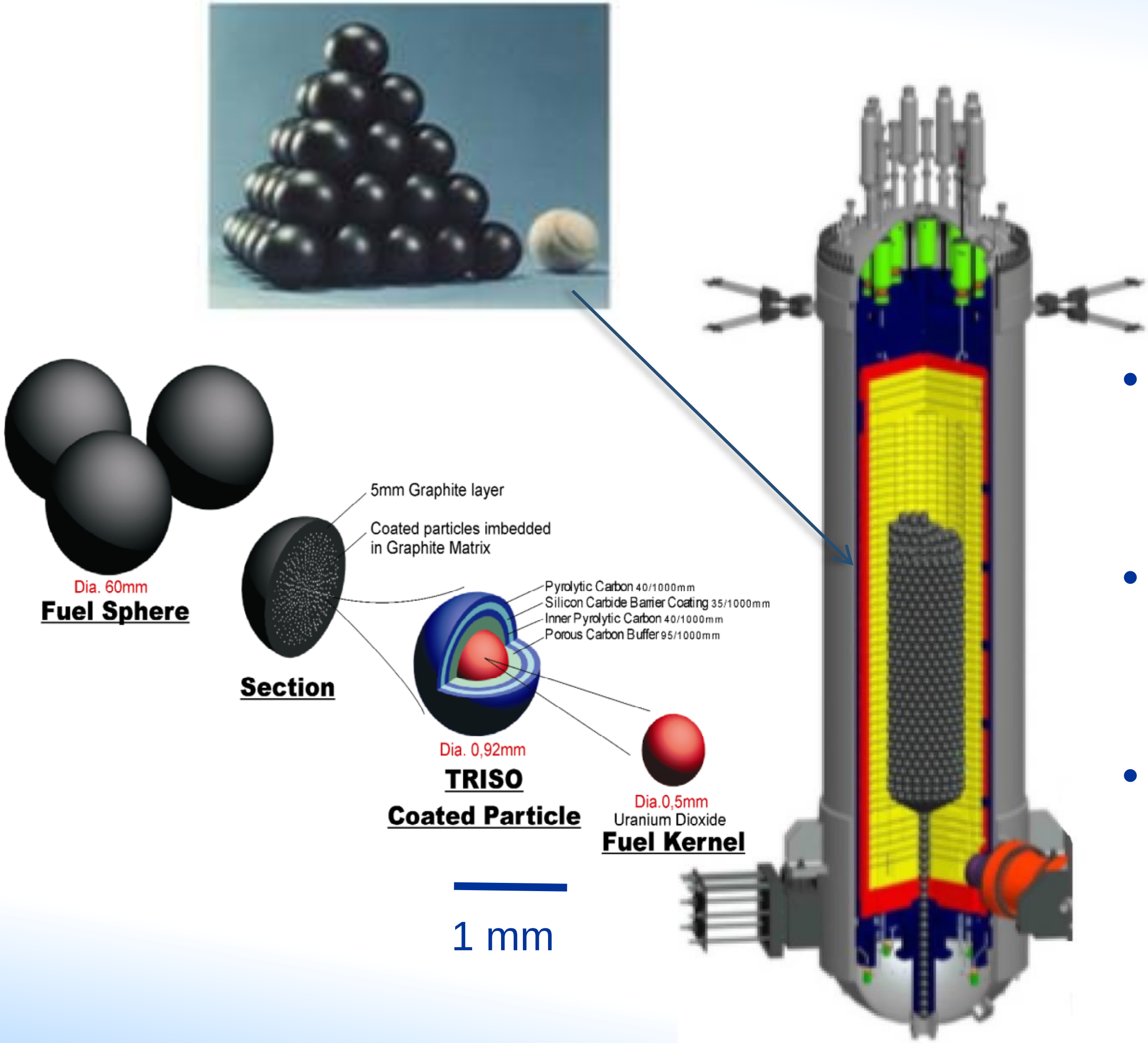








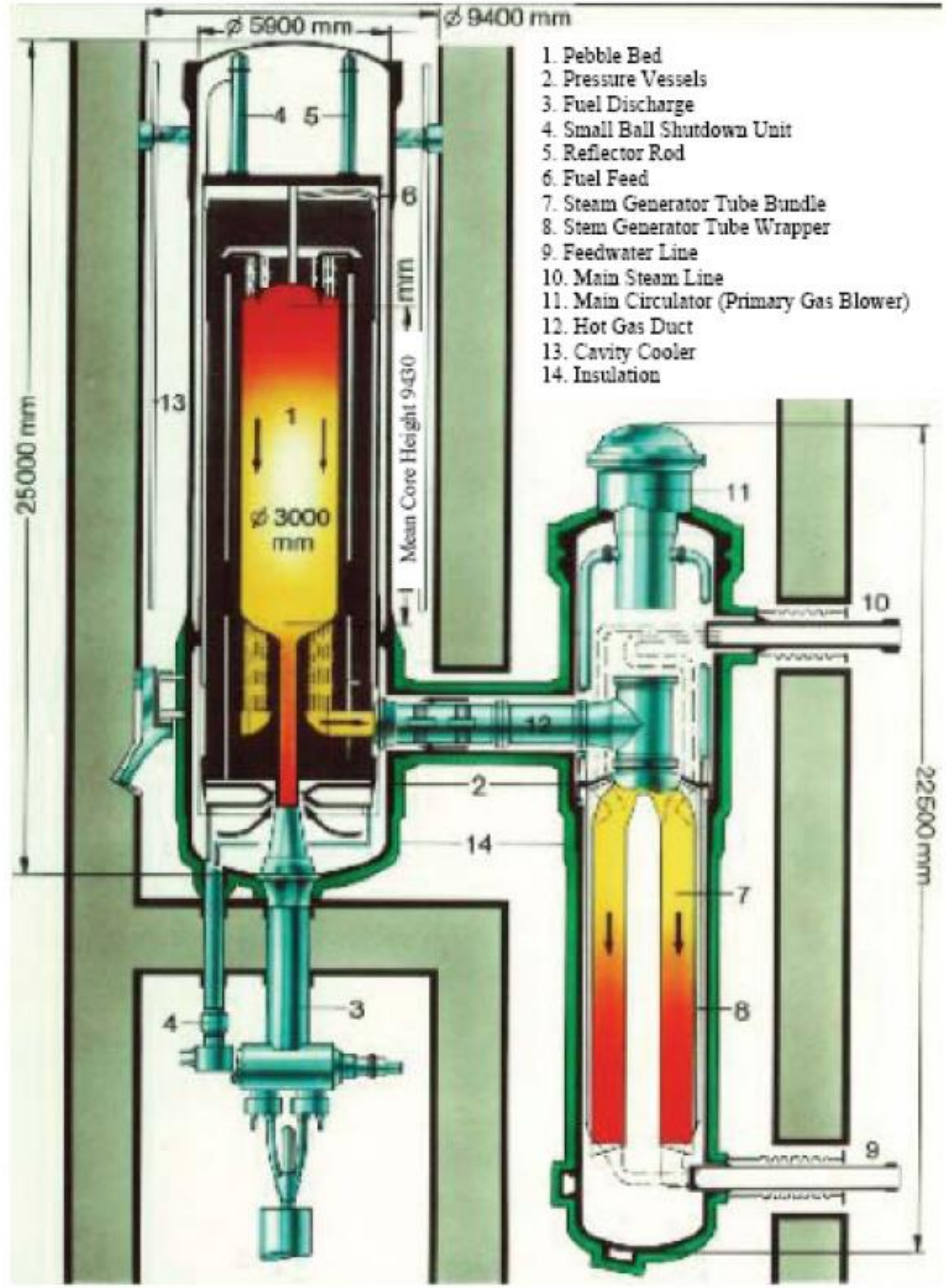
Pebble type HTGRs



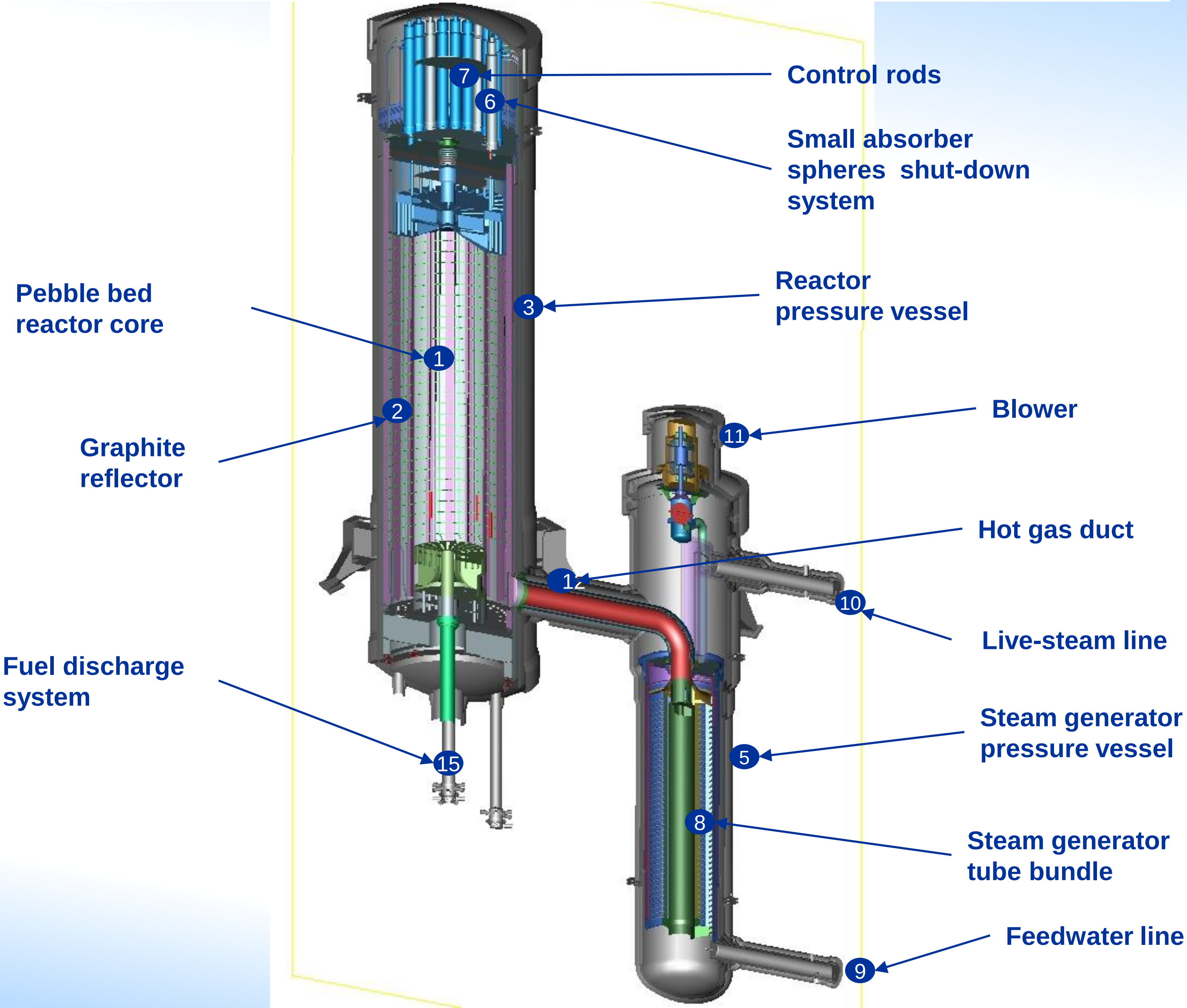
- Spherical graphite fuel element with coated particles fuel
- Fuel loaded in cavity formed by graphite to form a pebble bed
- On-line / continuous fuel loading and circulation

The ‘reference’ pebble bed reactor design

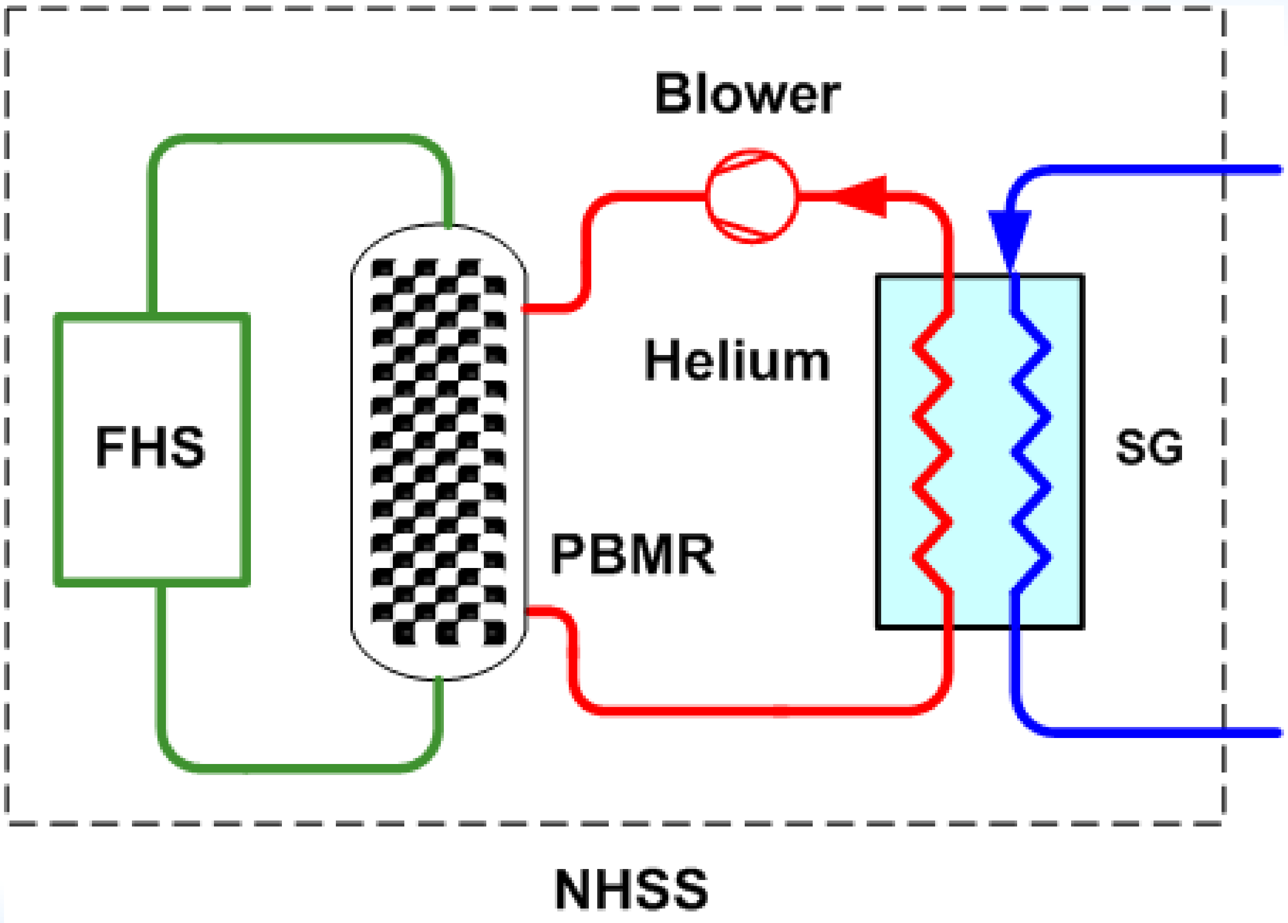
- HTR-Module
- Side-by side configuration (SG somewhat lower)



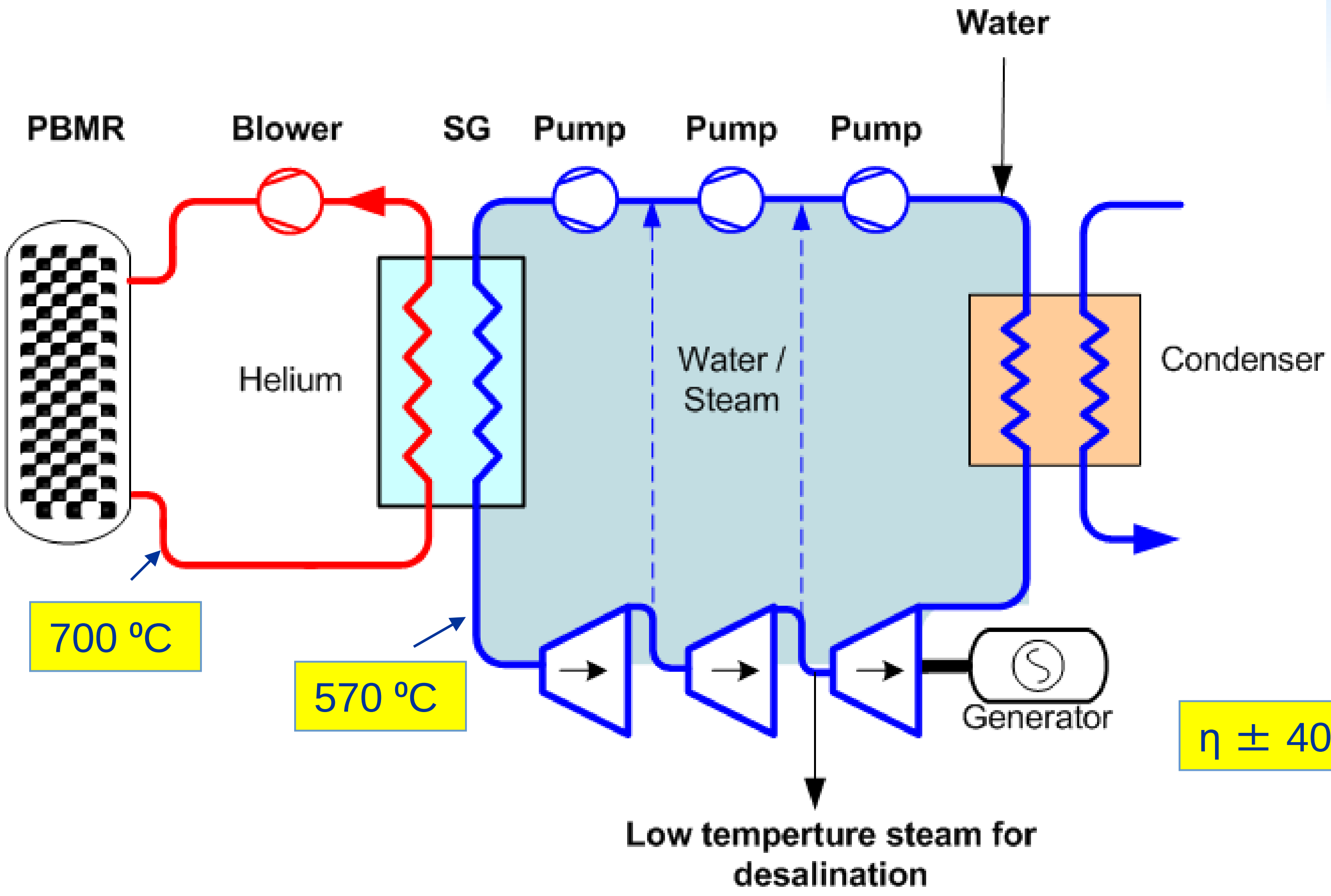
Nuclear Steam Supply System



Standardised Nuclear Heat Supply System



Demo plant – electricity plus low temperature steam for desalination

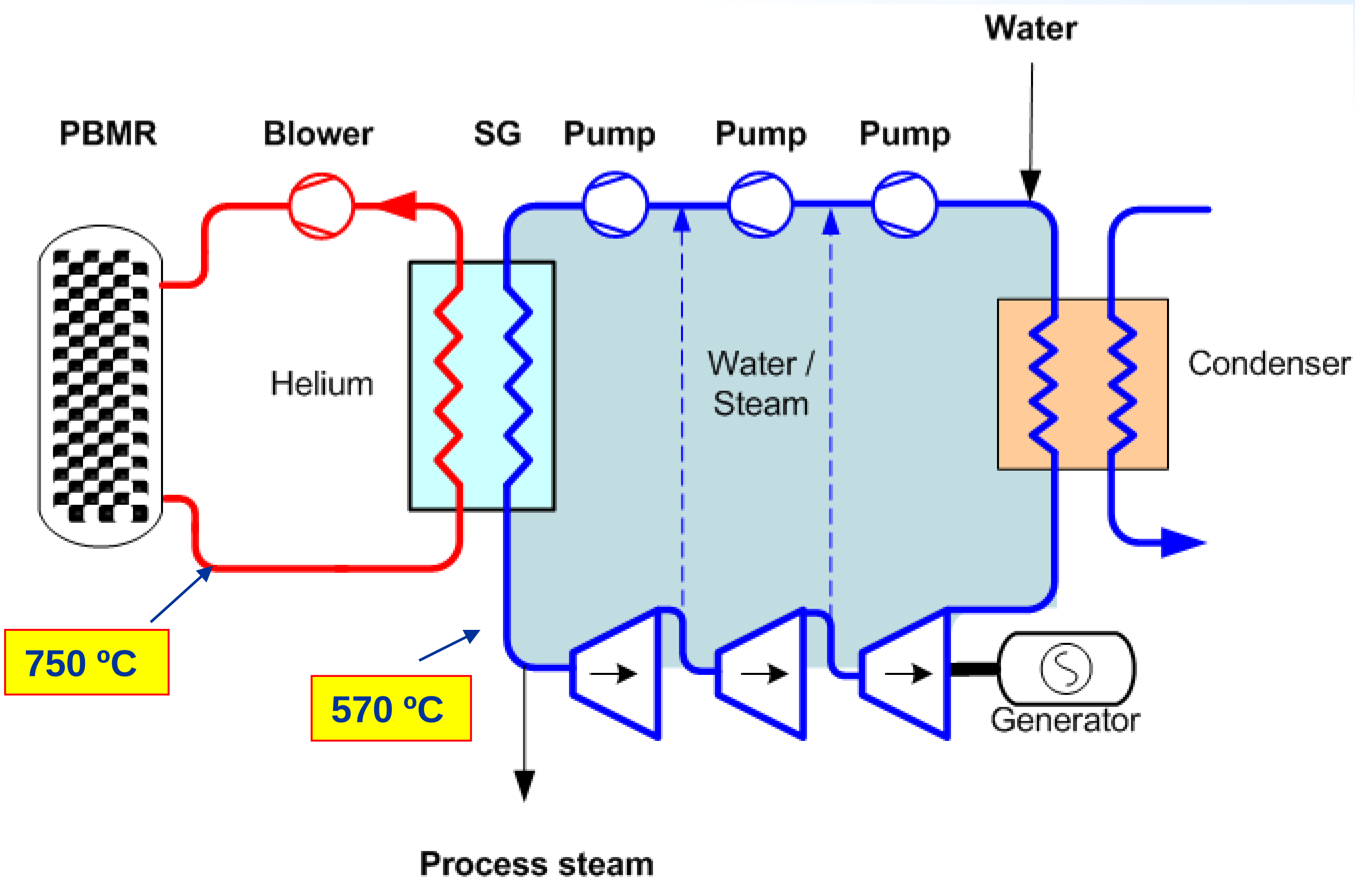


700 ºC

570 ºC

η ± 40%

Cogeneration plant - electricity plus process steam (NGNP)



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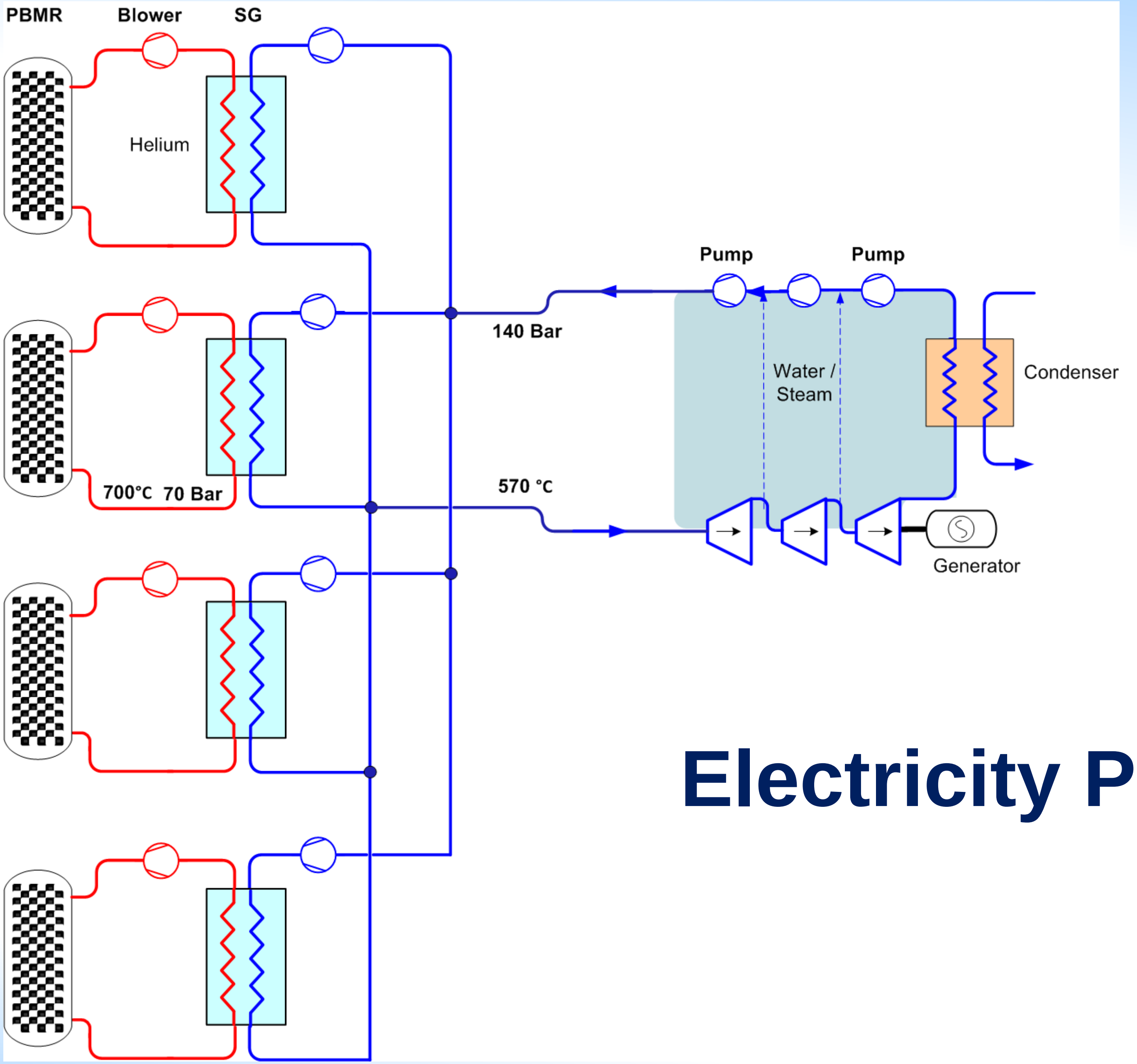
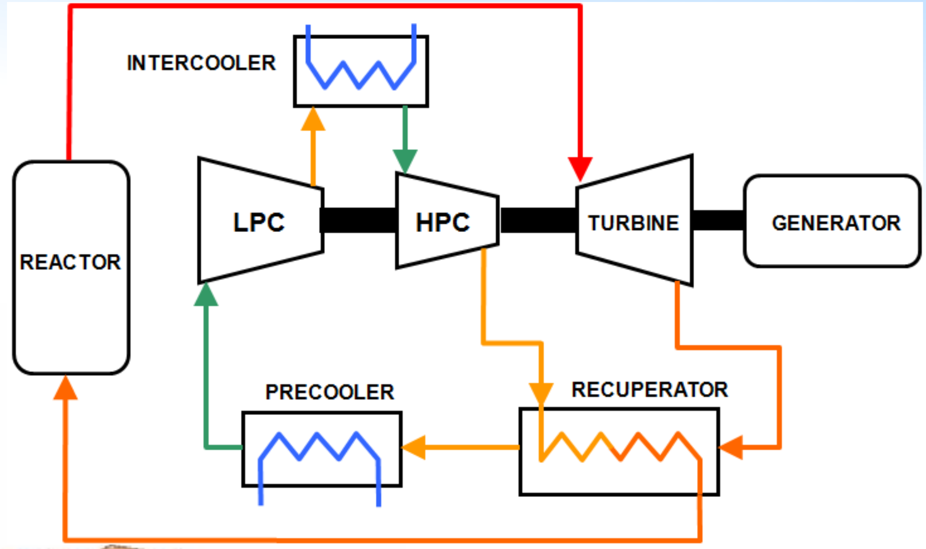
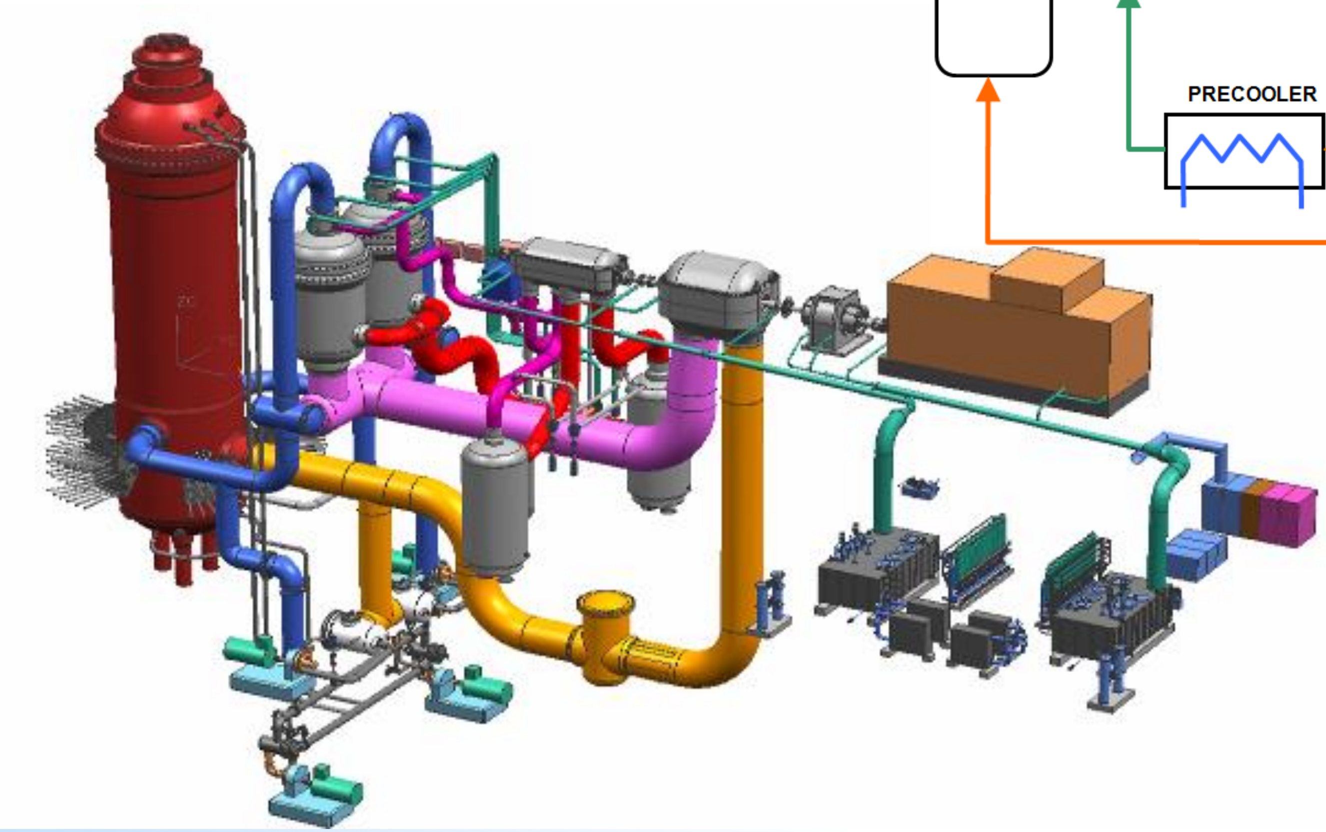


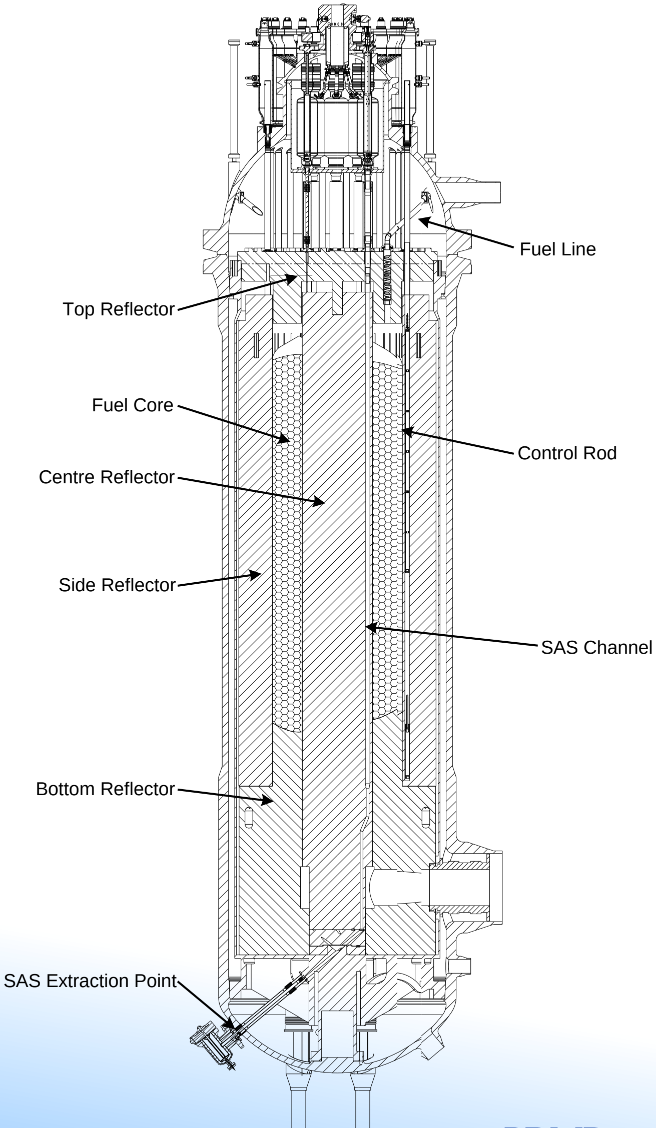
Electricity Plant

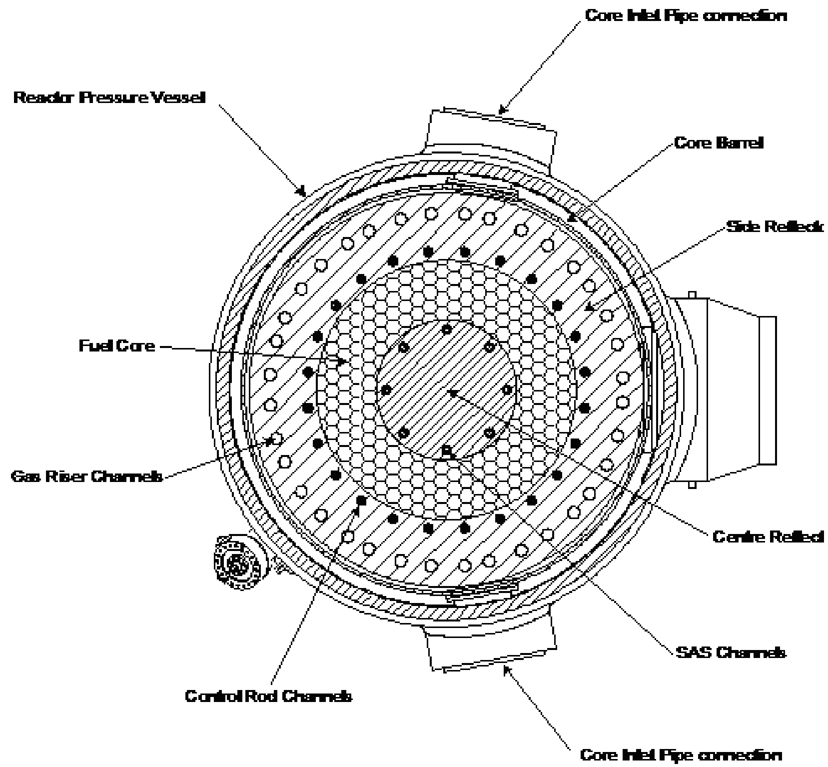
Direct Brayton Cycle – Horizontal Layout



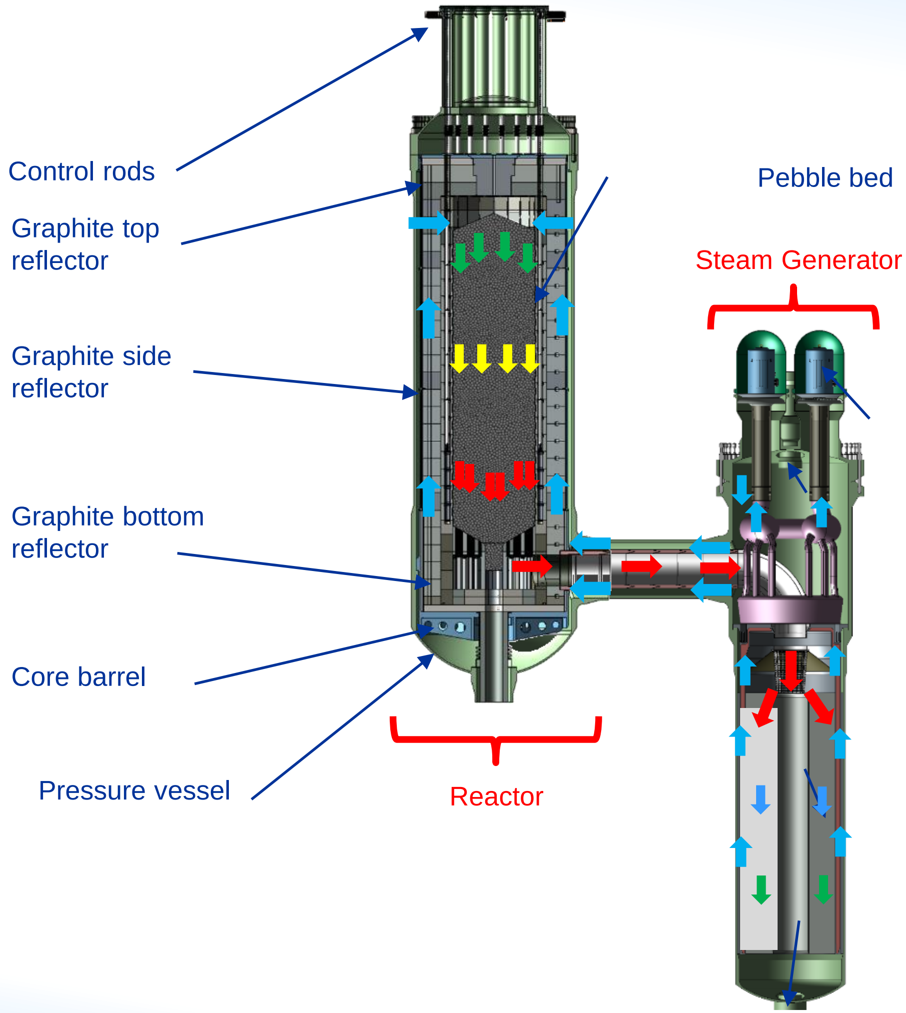


Reactor Layout





Xe-100 Reactor

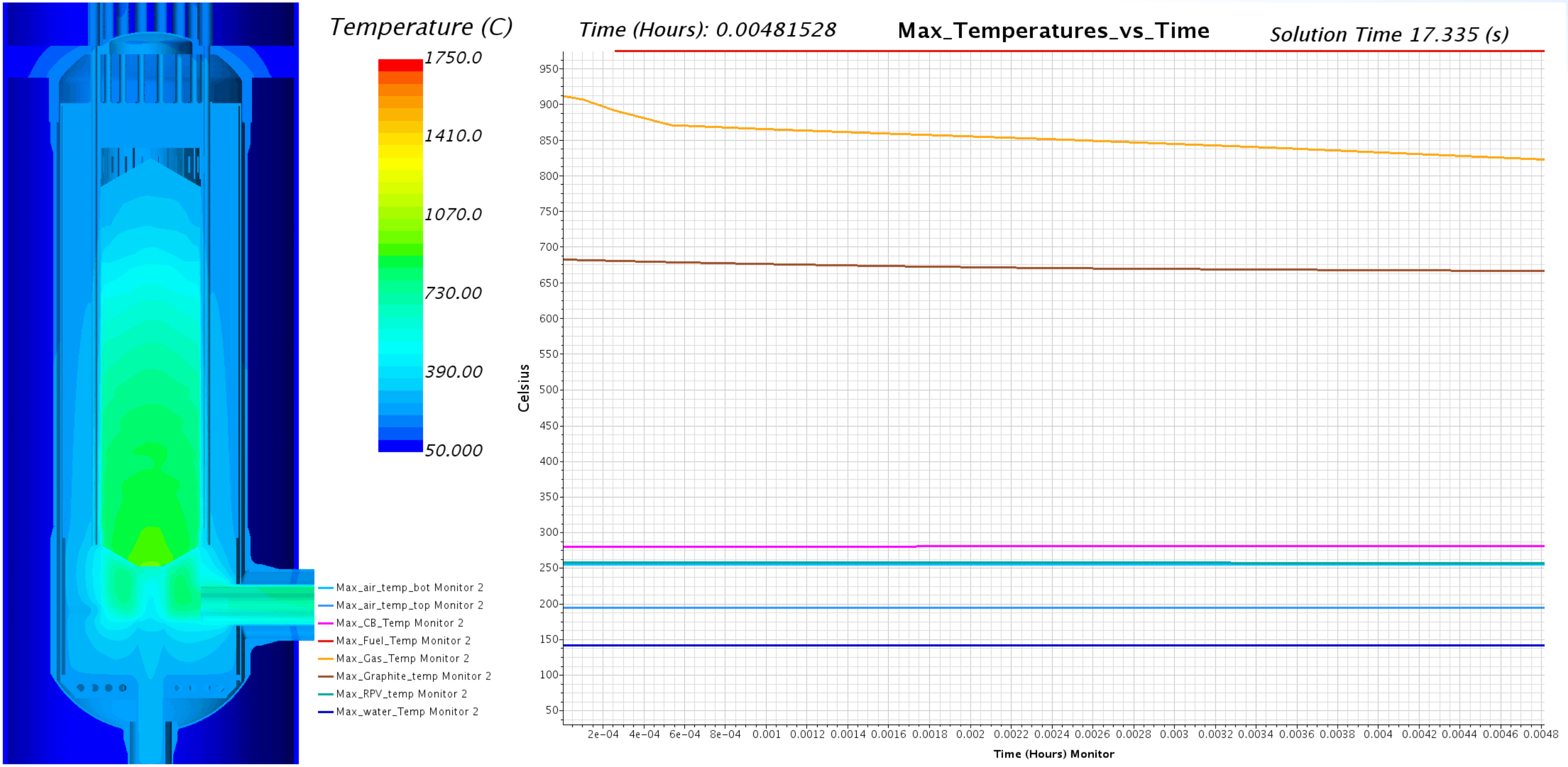


Key Technical Specifications:

- 200MWt / 75MWe
- Rankine Cycle
- Helical steam generator at 565°C / 16.5MPa
- Multi pass fuel cycle

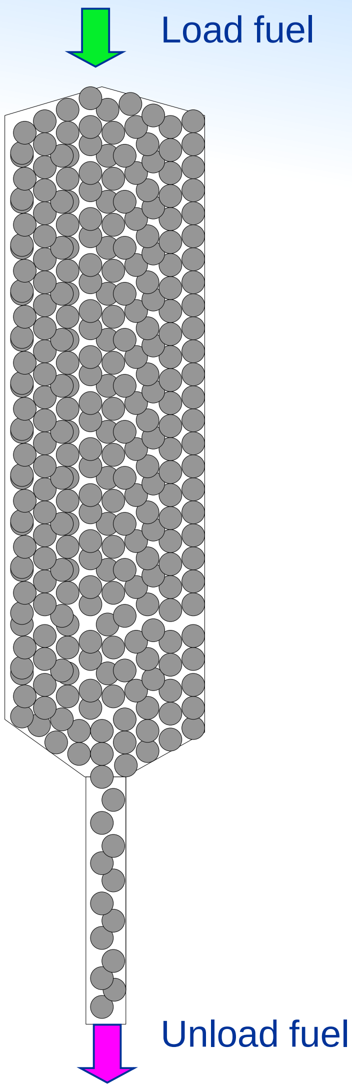
Depressurized Loss of Forced Coolant

Long transient accident analysis ≈ 120 hours



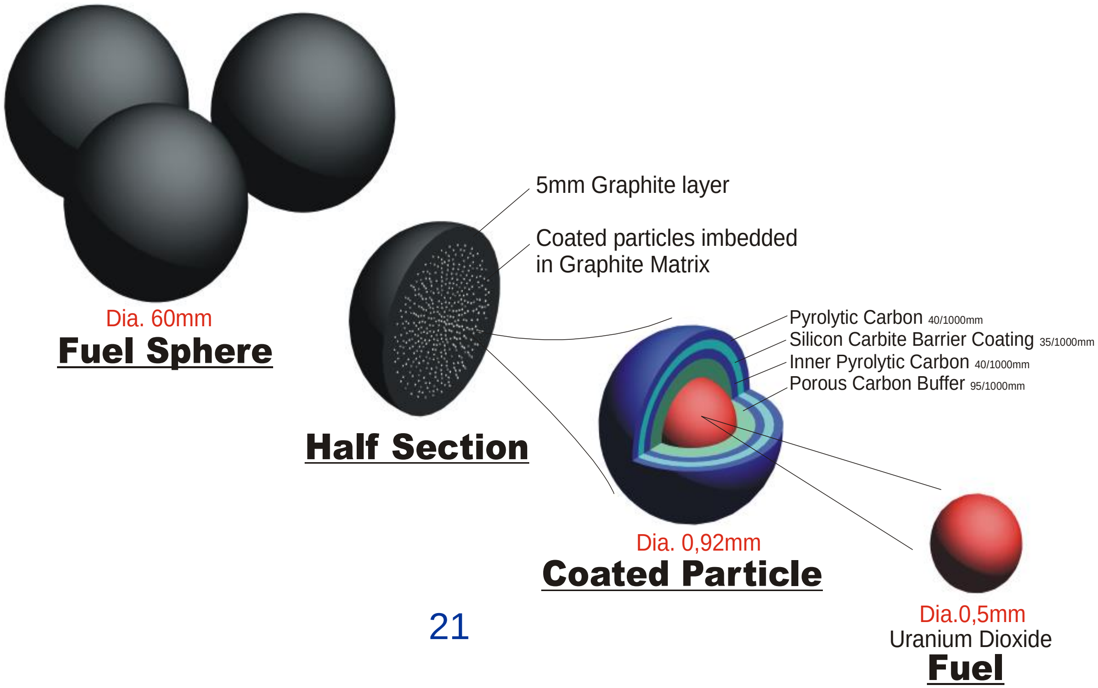
Pebble Bed Description

- A pebble bed core is a loosely packed bed of spherical fuel elements
- Fuel spheres are added from the top and extracted at the bottom
- Fuel can be recycled a number of times to flatten the power profile
- Core volume is large to limit the power density to 4-6 MWt/m^3



Pebble Fuel Description

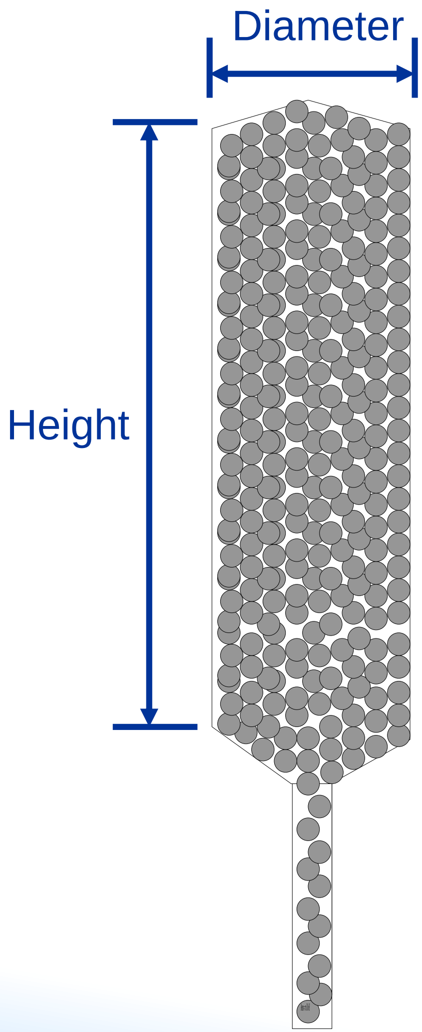
- Mostly graphite material
- Contains ~14 000 coated fuel particles (CFP)
- The number of CFP can be changed to adjust the heavy metal loading in the core
- Various spheres can be introduced in to the core (e.g. different enrichments, graphite only spheres, UO_2, UCO)



Fuel Characteristics

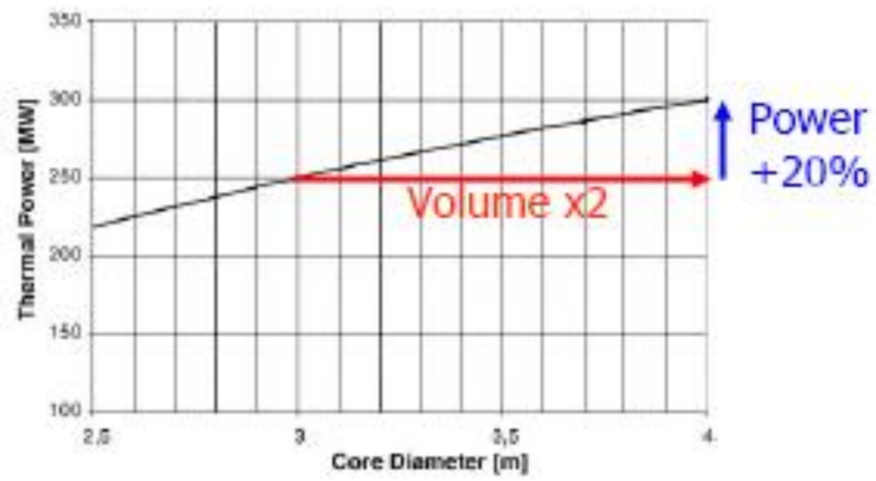
- Manufacturing failures < $6*10^{-5}$
- Fission products largely retained in UO_2 itself
- Coating (=cladding) of fuel does not suddenly fail
- No measurable damage up to 1600 ºC
- Very limited damage between 1600 ºC and 1800 ºC
- Measurable damage between 1800 ºC and 2000 ºC
- Large scale coating failure above 2200 ºC
- SiC very resistant to oxidation up to 1200 ºC
- No damage from high energy pulses (up to 2000J/g)

Core Shape



- Core shape is tall and slender to allow for increased heat transfer area from the fuel to the environment
- This results in increased neutron leakage
- Core diameter is constrained by the heat transfer path for removal of decay heat (i.e. accident fuel temperatures)

Core Power



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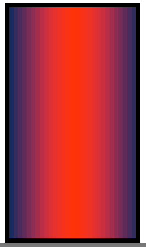
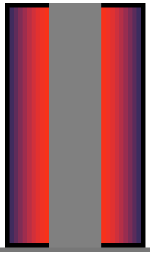
- Increasing the core diameter does not proportionally increase the power
- This limits the reactor power from a cylindrical core to ~250 MWth
- This can be increased by using an annular or two-zone core

Core Topology

Design				
Core height [m]	11		11	
Inner core diameter [m]	-		2	
Outer core diameter [m]	3		3.7	
RPV outer diameter [m]	5.7		6.4	
Variant	*Brayton*	*Rankine*	*Brayton*	*Rankine*
Inlet temperature [°C]	500	250	500	250
Outlet temperature [°C]	900	750	900	750
Thermal power [MW]	**220**	**250**	**425**	**464**
Mean power density [MW/m^3]	2.83	3.21	5.07	5.54
Helium mass flow rate [Kg/s]	105.9	96.24	204.5	178.6
Pressure drop over the core [bar]	1.27	0.84	3.55	2.18

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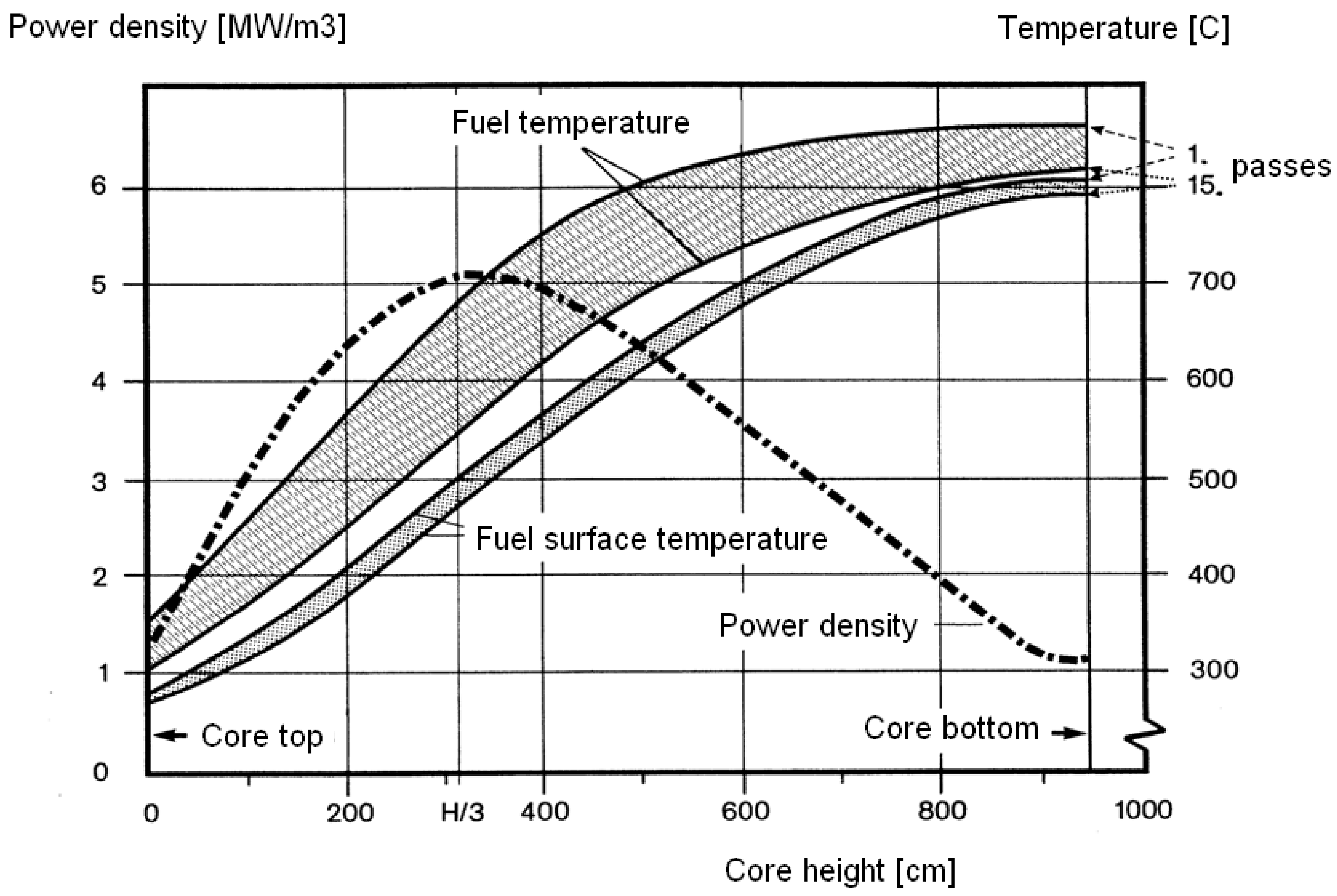
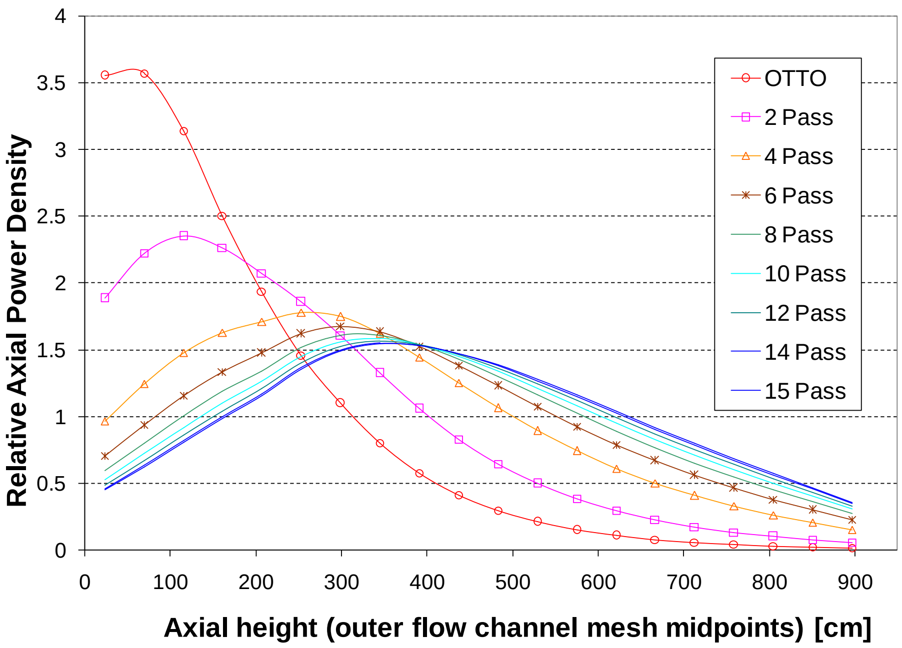
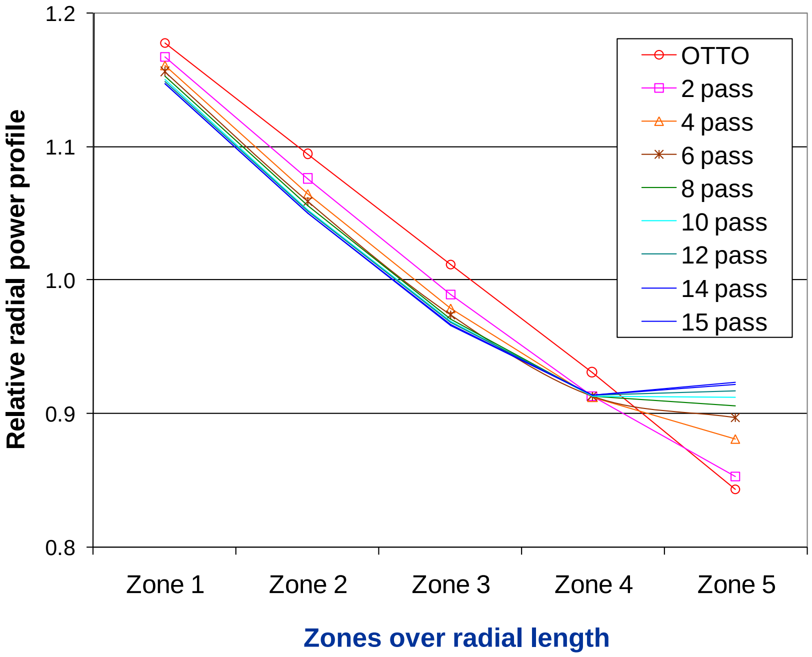
Pebble bed multi-pass principle



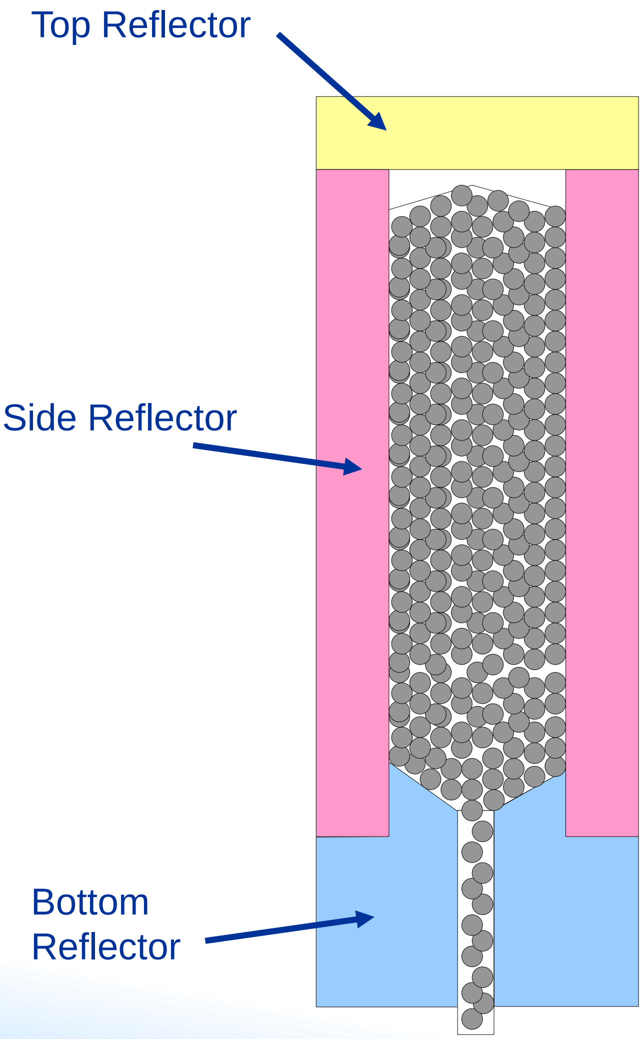
HTR Module – Power profile results

- For an optimal core design it is required to achieve a flattened power distribution over the core.
- Fresher fuel mixture causes peaking at the top of the core (in the low pass numbers)
- Radial power profile impact is limited (small benefit for multiple passes)



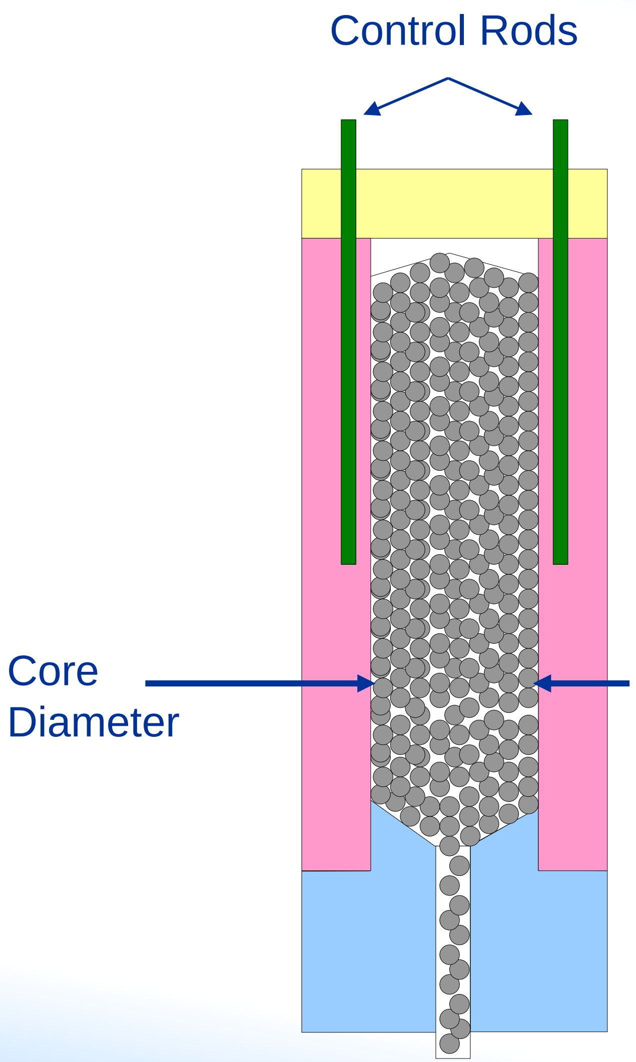


Reflectors Description



- Reflectors are added around the core to reduce the neutron loss
- Reflectors are made of high purity graphite
- The reflectors also form the core cavity and provide structural support to the fuel elements
- Typical reflector width is 1 meter

Control Rods

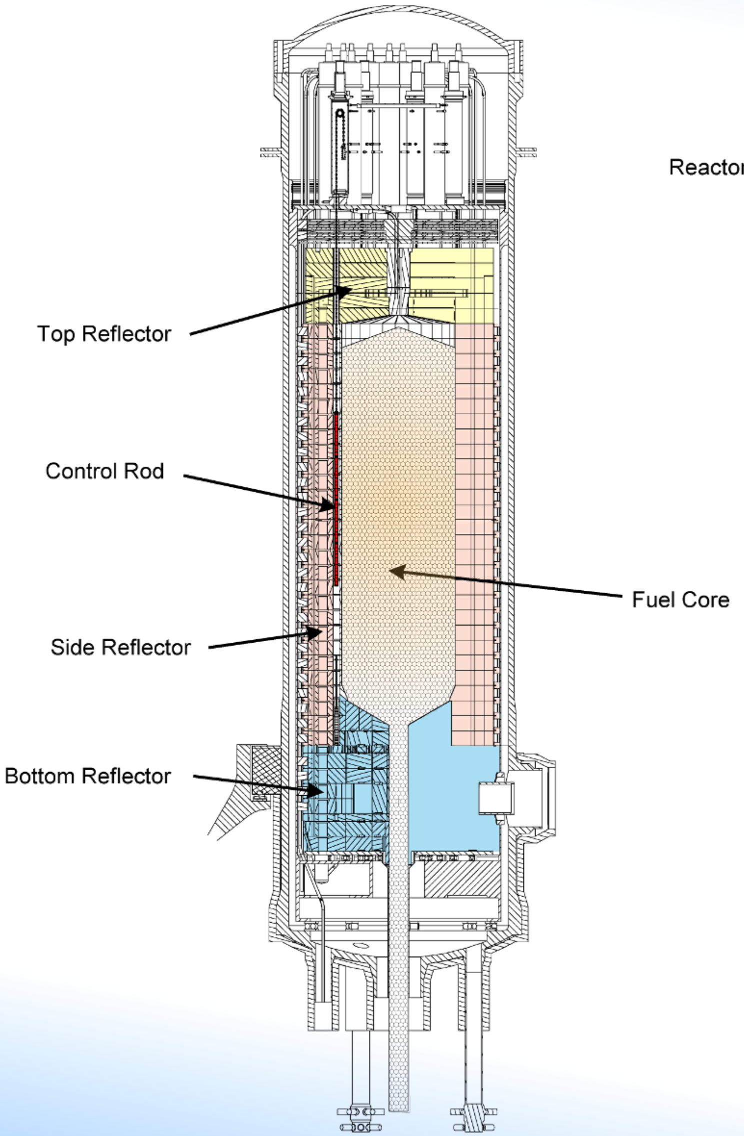


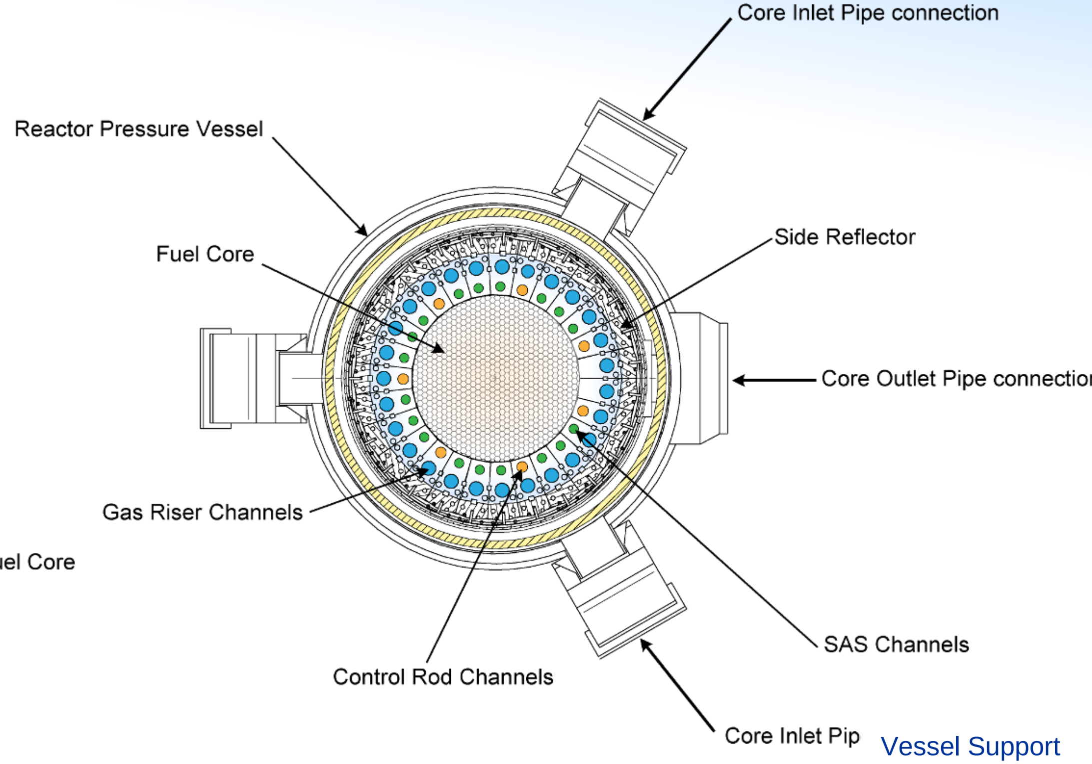
- Control rods are added to control the reactivity of the core by absorbing neutrons
- Control rods are located in channels in the side reflector
- The effectiveness of the control rod limits the maximum core radius (~1.5 meter)
- Core diameter may also be constrained by RPV diameter

Other Components

- Other components of a pebble bed reactor include:
  - Core Barrel to support the reflectors
  - Reactor Vessel to contain the coolant
  - Secondary shutdown system to shutdown the reactor in case the control rods are not available
  - Coolant flow paths and connections
  - Core loading device to add spheres to the top of the core
  - Core unloading device to extract the spheres from the bottom of the reactor

Typical Reactor Layout





Vessel Support

Reactivity Control System

Stepper motor scram test setup

Prototype Control Rod Drive Mechanism to be tested in HTF

Secondary shock absorber drop tests

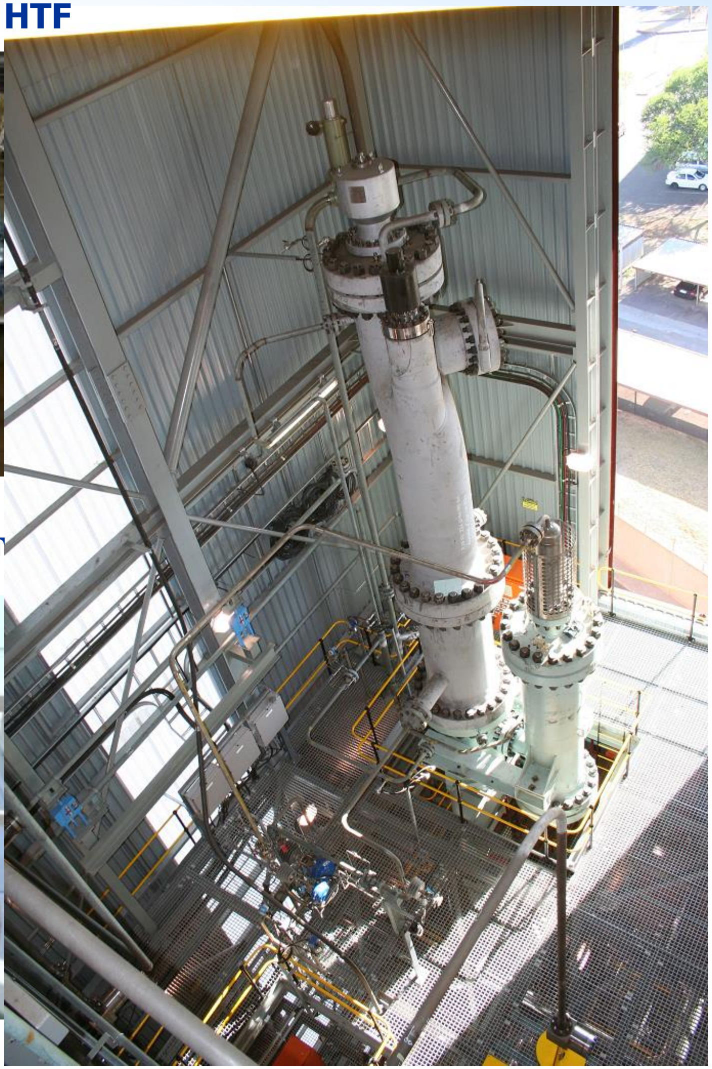
Prototype Control Rod Drive Mechanism chain test setup

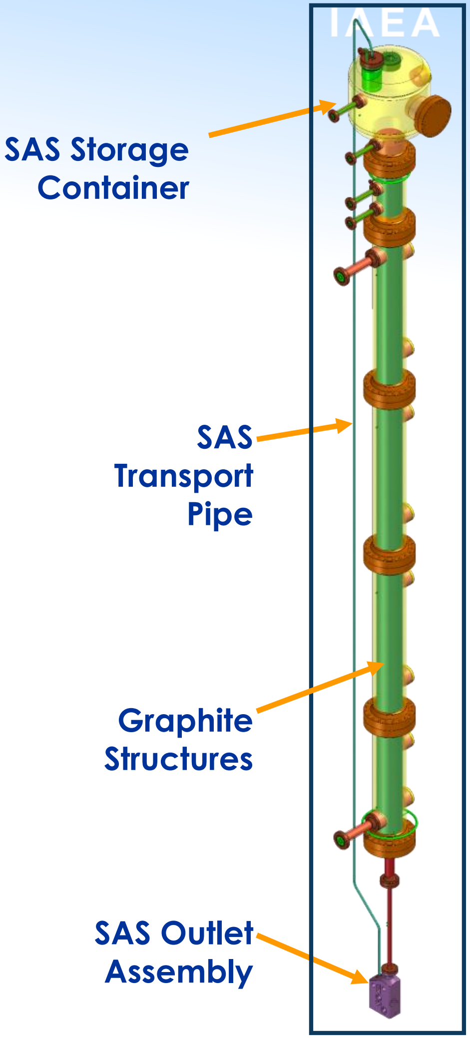
Functionality successfully tested

Reserve Shutdown System

Full scale discharge vessel tests in HTF

Valve actuator rod to be tested in HTF

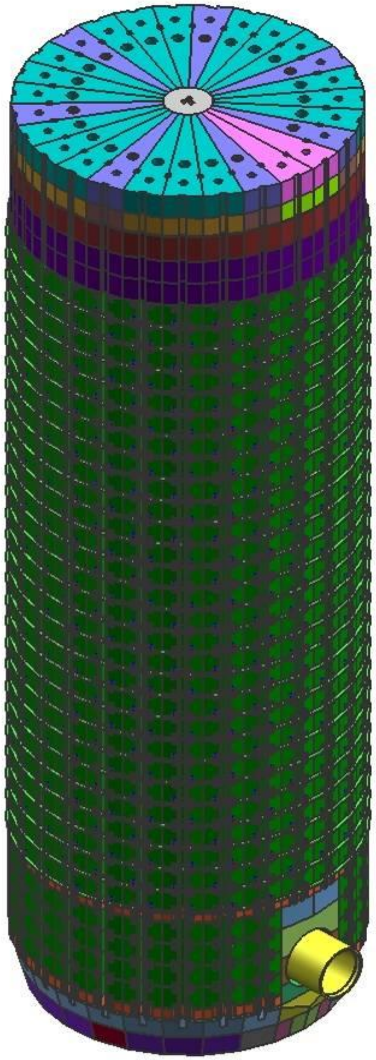




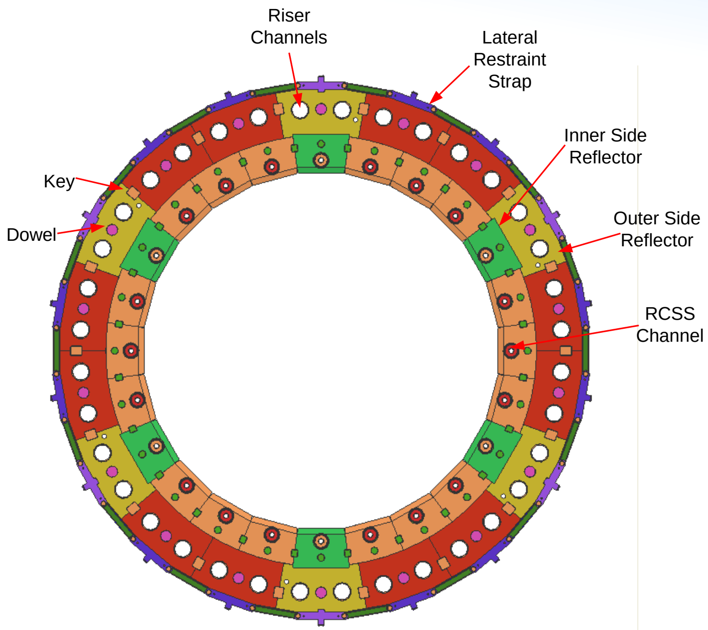
Functionality successfully tested

Core Structures Description

Core Structures Dimensions (for a typical 250 MWth core)	
Overall Height	19 m
Outside Diameter	5 m
Inside Diameter (Core Diameter)	3 m
Mean Core Height	10.5 m
Top Reflector Height	2 m
Side Reflector Thickness	1 - 1.1 m
Side Reflector Height	14 m
Bottom Reflector Height	4 m
Angle of Core Bottom (Top Layer)	30°

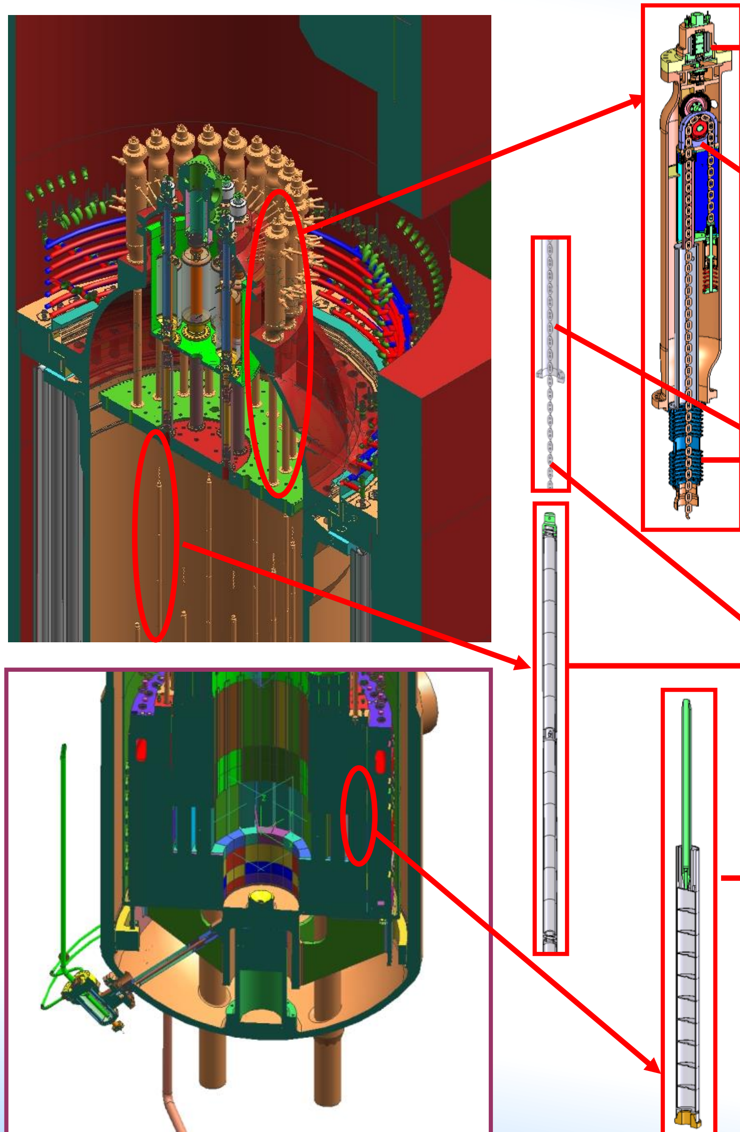


Side Reflector



- Side reflector is constructed from separate graphite blocks to form a ring
- Graphite sleeves and keys are used to reduce gas leakage between the blocks
- Graphite dowels are used to position the blocks in free moving columns

Control Rod Description



RCS Drive Motor

The main function is to keep the RCS rods in position, move the rods up and down and allow insertion during power failure.

Control Rod Drive Mechanism (CRDM)

Transfer rotational movement of the RCS motor into linear movement of the control rods.

RCS Guide Tube

Connects the CRDM housing and the Core Structures and serves as guide for the rod between the CRDM and the Core.

Control Rod & Chain

The function of the Control Rod is to absorb neutrons inside the core whereas the chain connects the CRDM and the Control Rod.

Secondary Shock Absorber

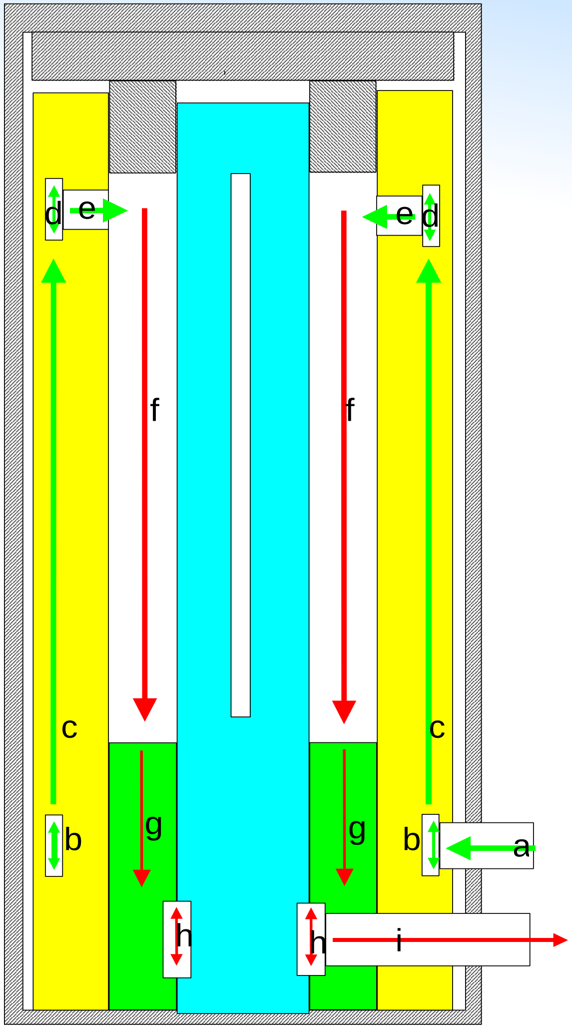
The function of the Secondary Shock Absorber is to prevent damage on the Rod and the Graphite Core Sleeve in the inadvertent event of a rod drop.

Coolant Flow Paths

- The coolant gas needs to be guided from the HTS to the top of the pebble bed and extracted again from the bottom
- The pressure gradients created by this flow path causes gas leakages between the reflector blocks
- The flow paths are designed to prevent high temperature gas from the core coming in contact with metallic vessel

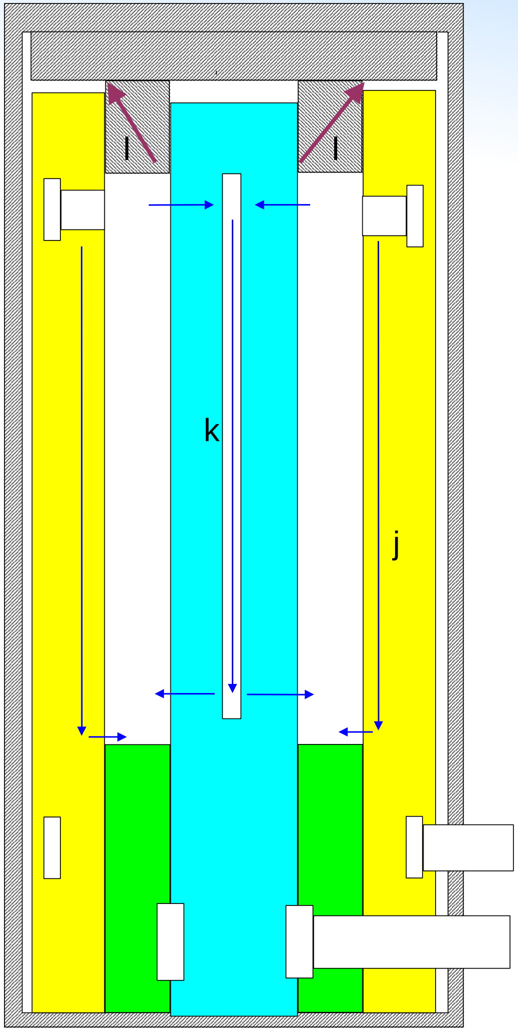
Primary Flow Paths

Key	Description
A	Core Inlet Pipes – Return the gas from the HTS.
B	Inlet Plenum – Inside graphite, redistributes the gas to the riser channels.
C	Riser Channels – Provide a flow path for the gas to the top of the core.
D	Secondary Core Inlet Plenum – Inside the top of the side reflector. Accumulates the flow from the riser channels before introduction to the core.
E	Inlet flow slots – Introduce the gas to the core.
F	Core Flow – The gas flows downwards through the core and absorbs heat.
G	Core Outlet Flow Slots – Remove the gas from the core.
H	Outlet Plenum – Accumulates the gas from the outlet slots before returning to the HTS.
I	Core Outlet Pipe – Returns the gas to the HTS.



Secondary Flow Paths

Key	Description
J	**Control rod cooling flow – This is to provide cooling to the control rod.**
K	**Centre Reflector Cooling Flow – This is to remove heat from the centre reflector.**
L	**Annulus pressurisation flow – Pressurises the annulus between the core barrel and the side reflector.**

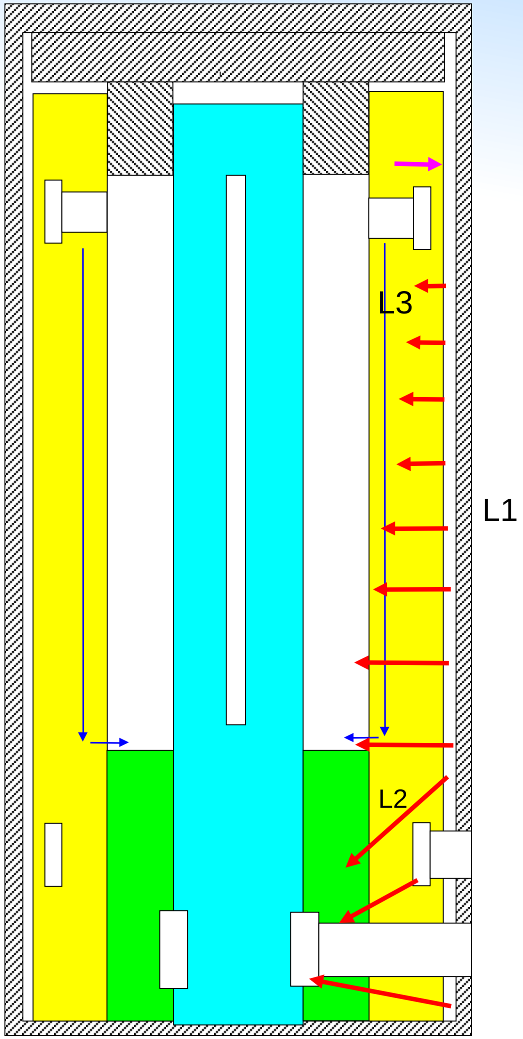


These are engineered flows

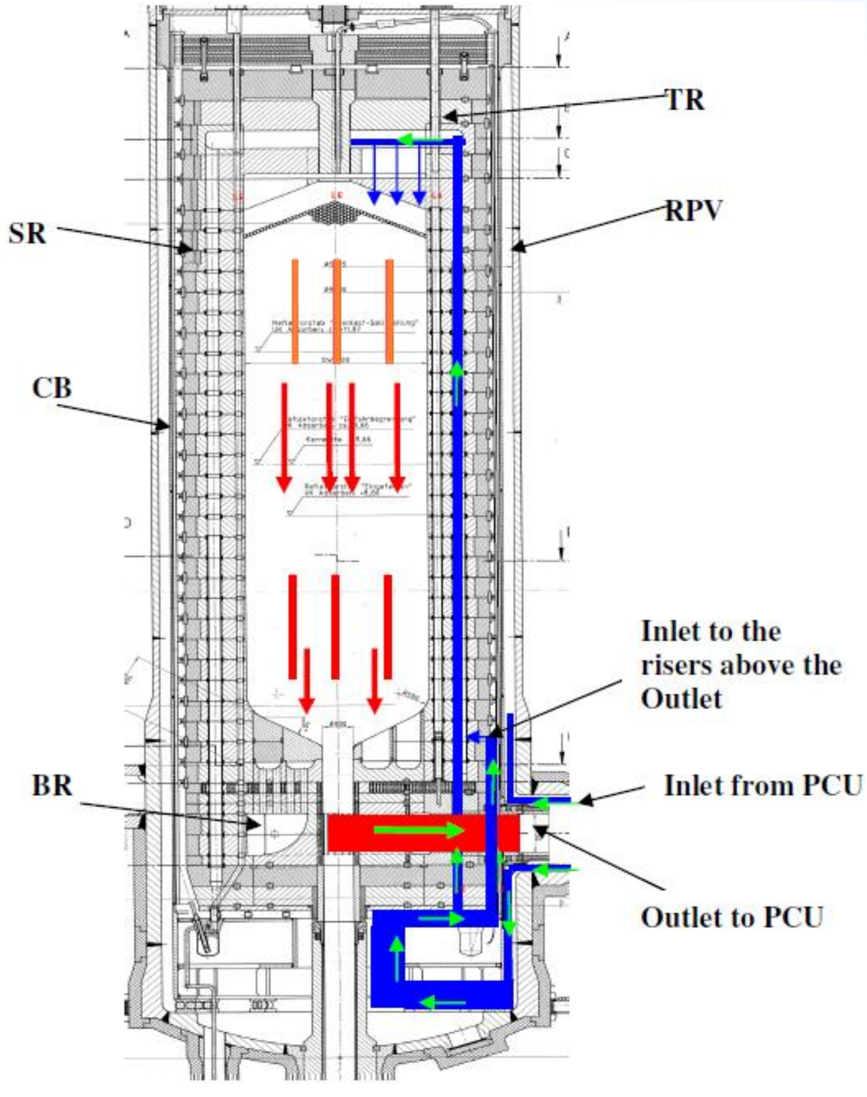
Leakage Paths

Key	Description
L1	**Across Side Reflector Leakage**
L2	**Inlet to Outlet Leakage**
L3	**Along Side Reflector Leakage**

These are unintentional flows

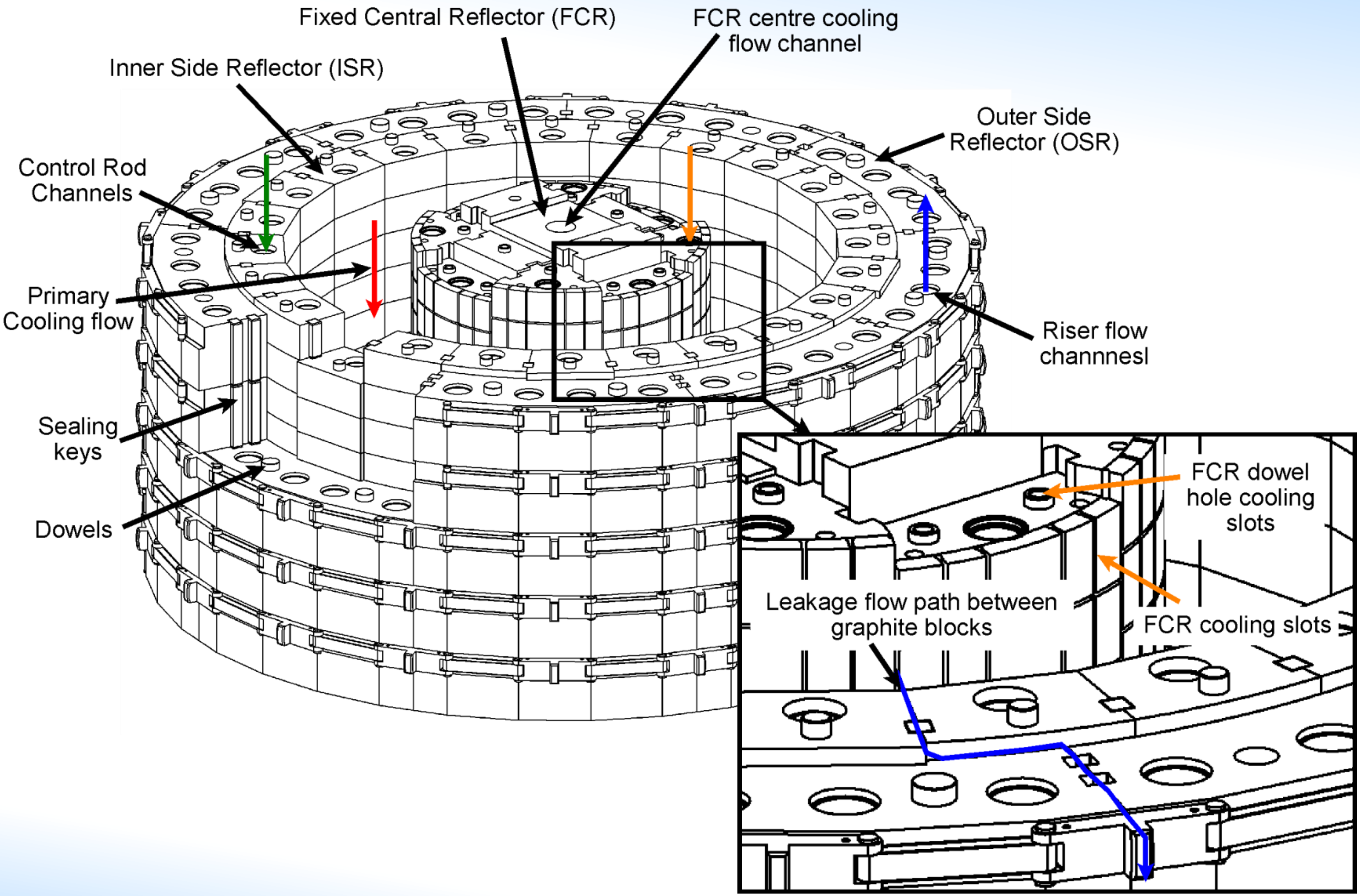


Coolant Flow Design

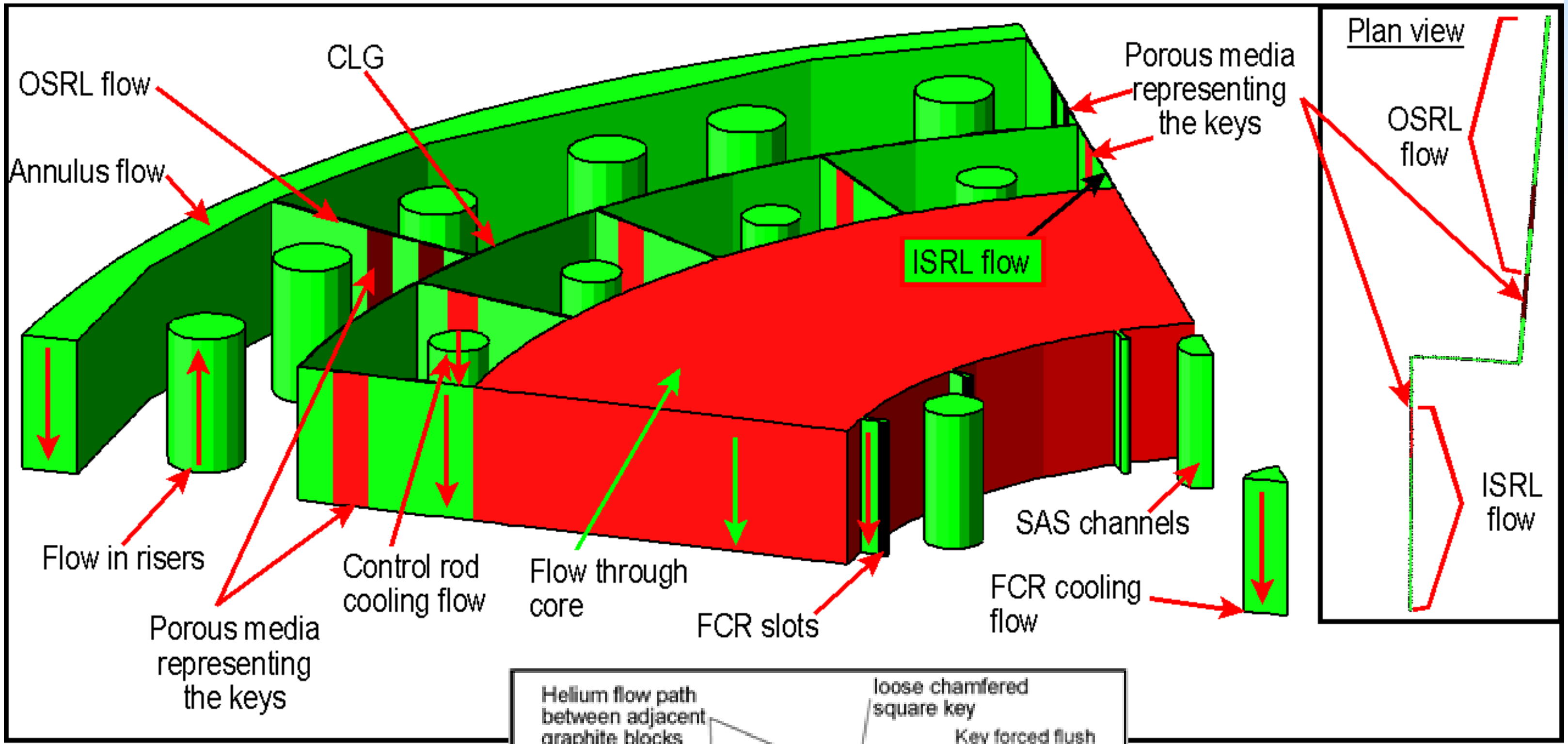


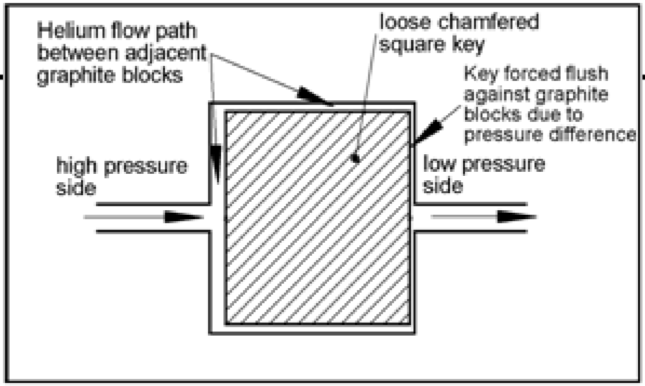
- The coolant flow path design needs to consider the following aspects:
  - cool the metallic structures where necessary
  - reduce bypass flows
  - provide a uniform temperature distribution
  - mix the bypass flows to lower the thermal stratification in the outlet gas

Leakage flow in Side reflector



Keys and Flow Paths in Side Reflector

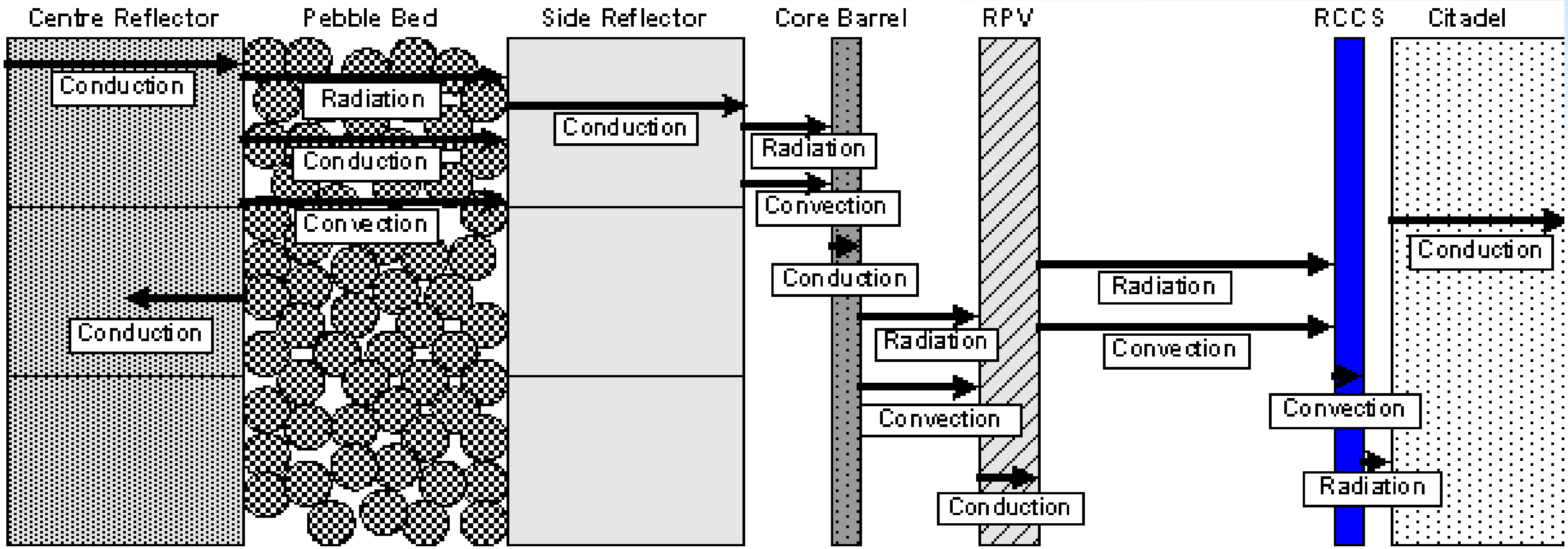




Passive Heat Transfer Path

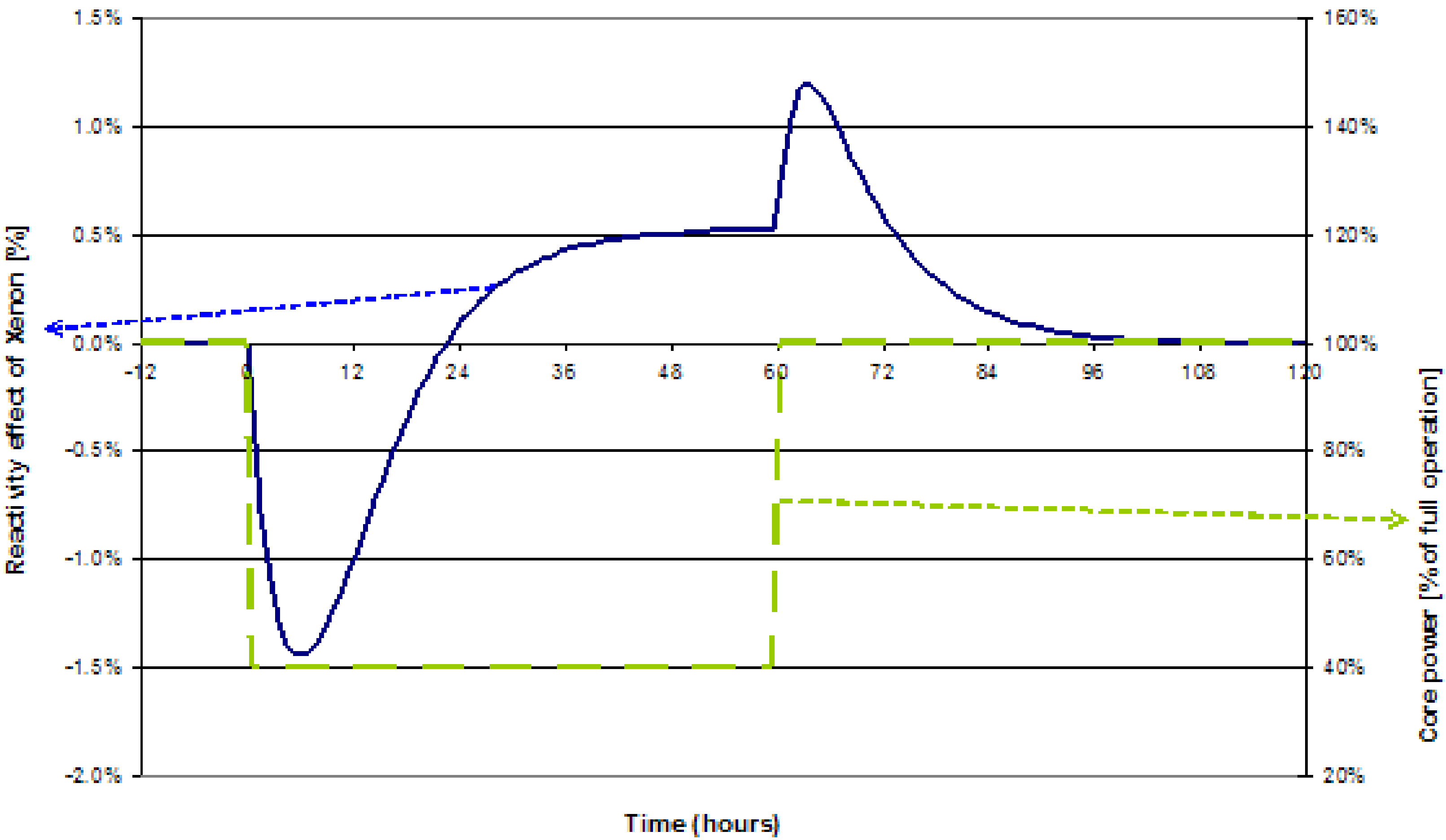
- Provided for conduction cooldown cases (when forced convection by circulator is not available, both pressurized and depressurized)
- Relies on heat transfer mechanisms such as thermal radiation, conduction and convection that cannot be switched on or off and are always there
- Combination of thermal capacitance and heat transfer resistance determines maximum component temperatures expected for given residual heat loading

Passive Heat Transfer Path Description



- This was discussed in the safety characteristics presentation

Load Following Requirements



Flexibility is essential for future SMR deployment

Excess Reactivity

- The excess reactivity is the additional reactivity available in the core during operating conditions by the loading of a fuel mixture that is more reactive (less burned) than what is required to keep the reactor critical at the full power operational conditions (temperatures and equilibrium fission products)

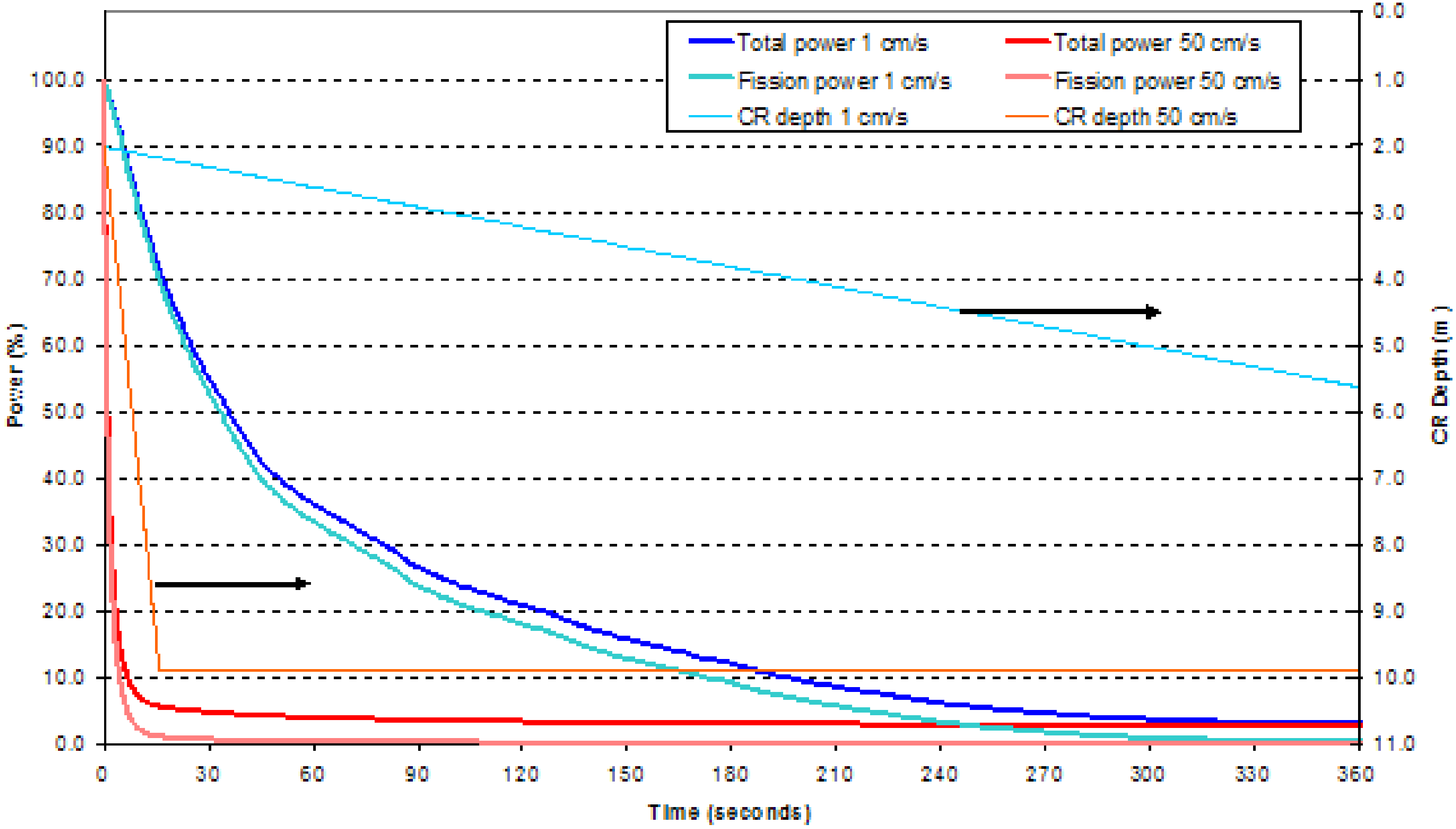
- The excess reactivity is balanced by the insertion of the control rods to keep the reactor critical

- The excess reactivity can be changed by changing the position of the control rods and the loading of fresh fuel into the core

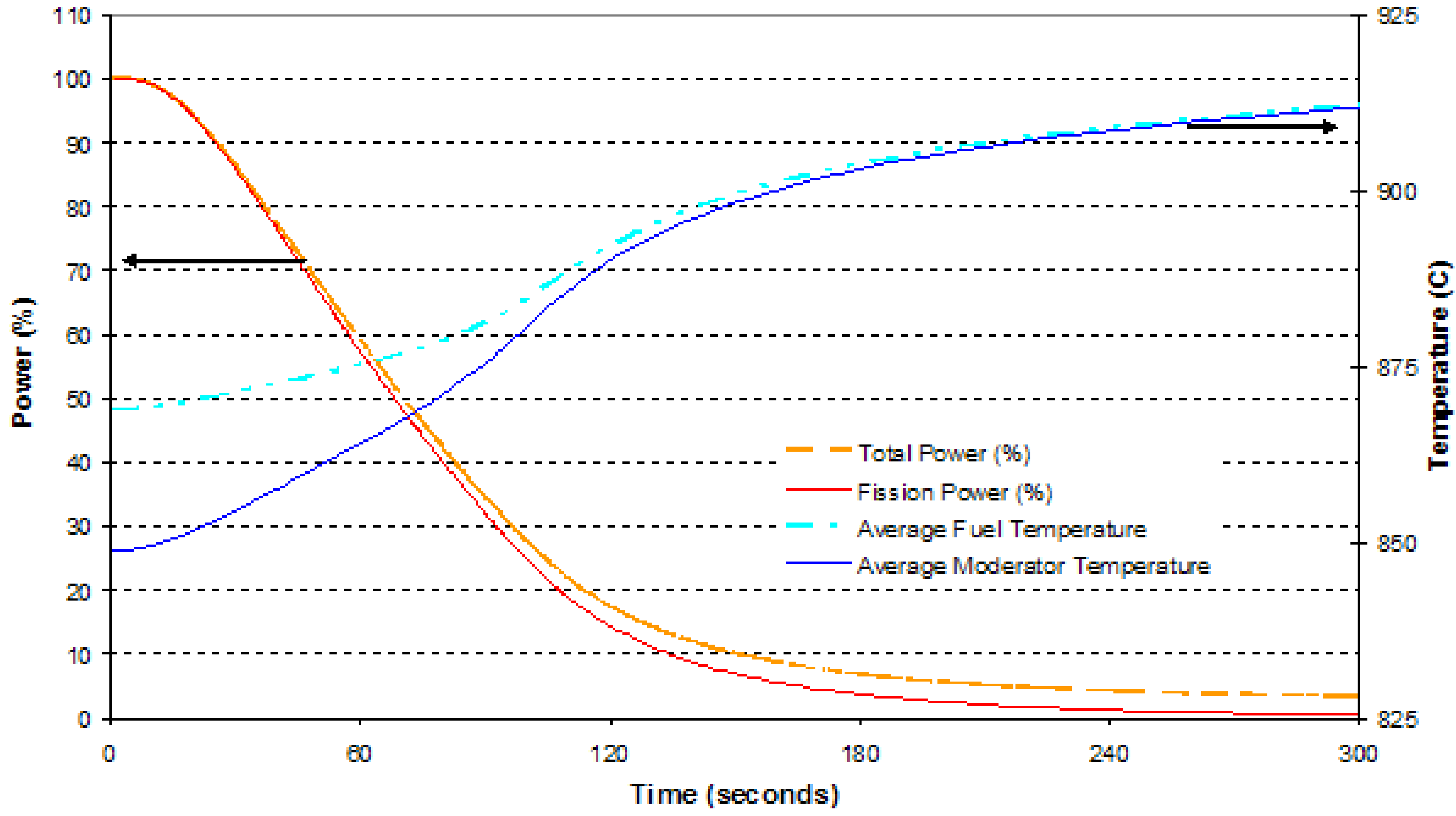
Neutron Control and Instrumentation Requirements

- Provide two independent and diverse systems of reactivity control for reactor shutdown
- Each system shall be capable of maintaining hot subcriticality
- One system shall be capable of maintaining cold shutdown
- Provide neutron flux (low, intermediate and high range) and axial profile measurements

Reactor Shutdown with Control Rods



Shutdown by Interruption of Coolant Flow

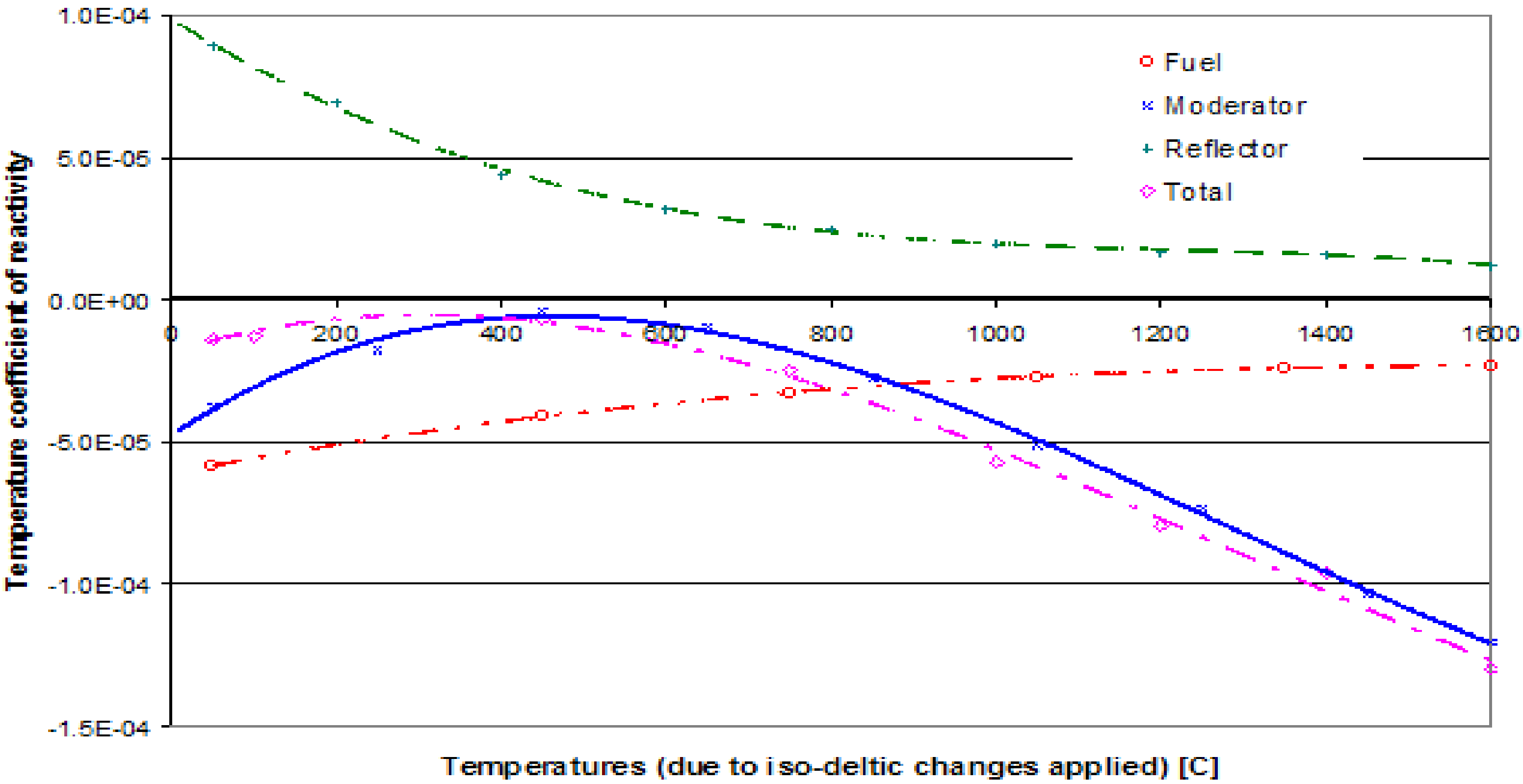


Temperature Coefficients

Temperature Coefficients	Unit	At Operating Conditions	At Room Temperature (20 °C)
Fuel (Doppler coefficient of mainly ^{238}U)	Δρ/°C	- 3.2 x10^{-5}	- 6.7 x10^{-5}
Moderator	Δρ/°C	- 3.1 x10^{-5}	- 4.2 x10^{-5}
Reflector regions (all together)	Δρ/°C	+ 2.6 x10^{-5}	+ 8.6 x10^{-5}
Central graphite reflector	Δρ/°C	+ 1.4 x10^{-5}	+ 4.9 x10^{-5}
Side reflector	Δρ/°C	+ 1.2 x10^{-5}	+ 3.8 x10^{-5}
TOTAL	*Δρ/°C*	*- 3.8 x10^{-5}*	*- 2.3 x10^{-5}*

- The Doppler temperature coefficient acts promptly and stabilizes the nuclear chain reaction.
- The moderator coefficient acts promptly when temperature change of the moderator is the primary event, and causes a response in the neutron flux and fission rate. However, its action is delayed when neutron flux changes become the primary event.
- The reflector temperature changes are not so strongly coupled to power changes in the fuel. The side reflector temperature is dominated by the coolant temperature in the riser channel and combined with the large heat capacity will cause a considerable delay of effect of the reflector temperature coefficient.

PBMR-GT Temperature Coefficients



- Reactivity always decreases as the core temperature increases

Xenon Oscillations

- Xenon oscillations refer to the degree to which the spatial flux distribution varies for a specific reactor design due to spatial xenon dynamics

- The main question is whether the change in xenon concentration with time exhibits a damped or un-damped oscillatory behaviour

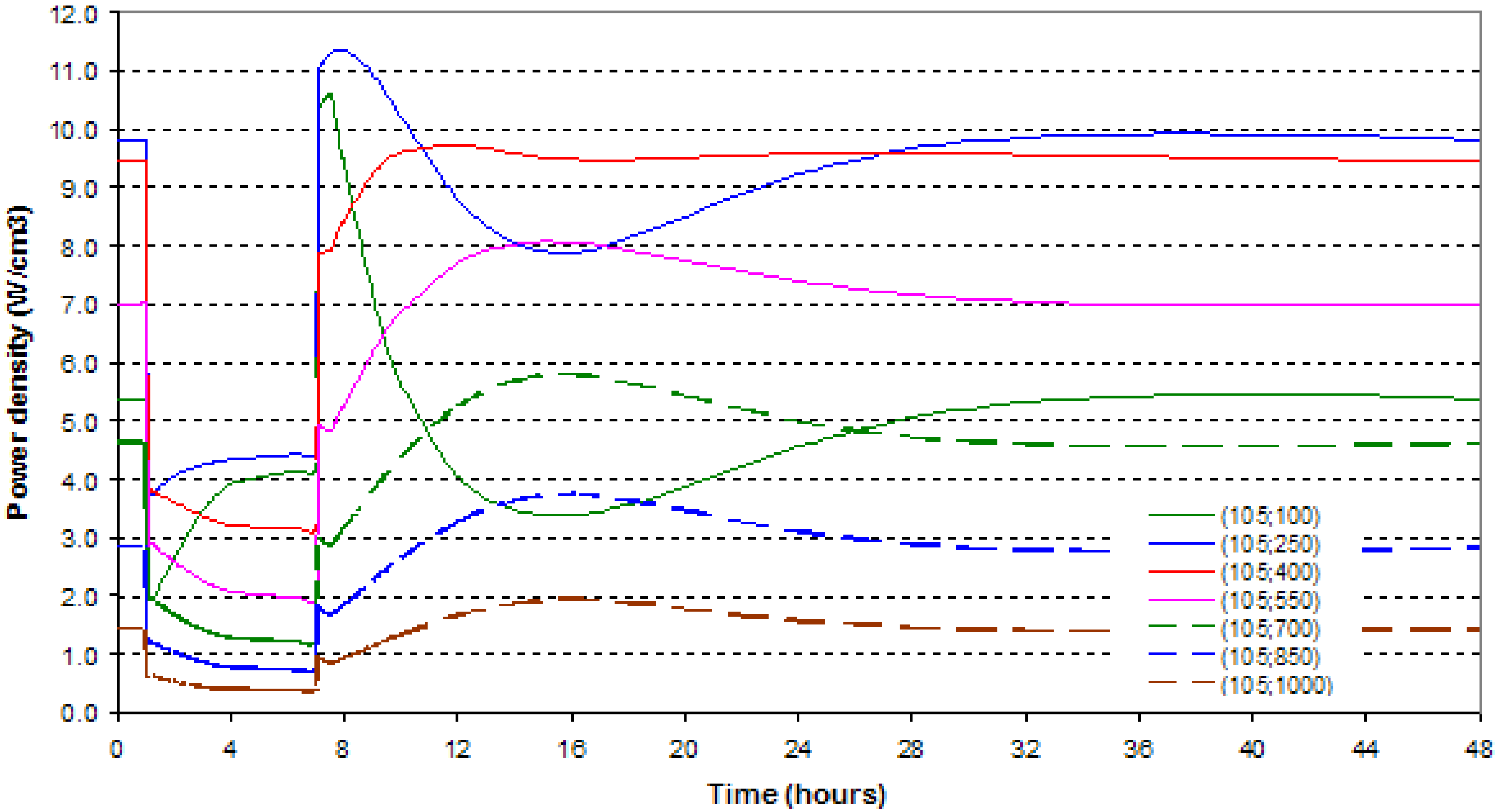
- For a given reactor design to experience undamped xenon oscillations, the reactor must be large enough and the neutron flux sufficiently high to make the rate of consumption of 135Xe by neutron capture large in comparison with the rate of 135Xe decay

- In a neutronically large reactor, the axial, radial or azimuthal dimensions must be several times greater than the thermal neutron diffusion length, for xenon oscillations to occur in that dimension

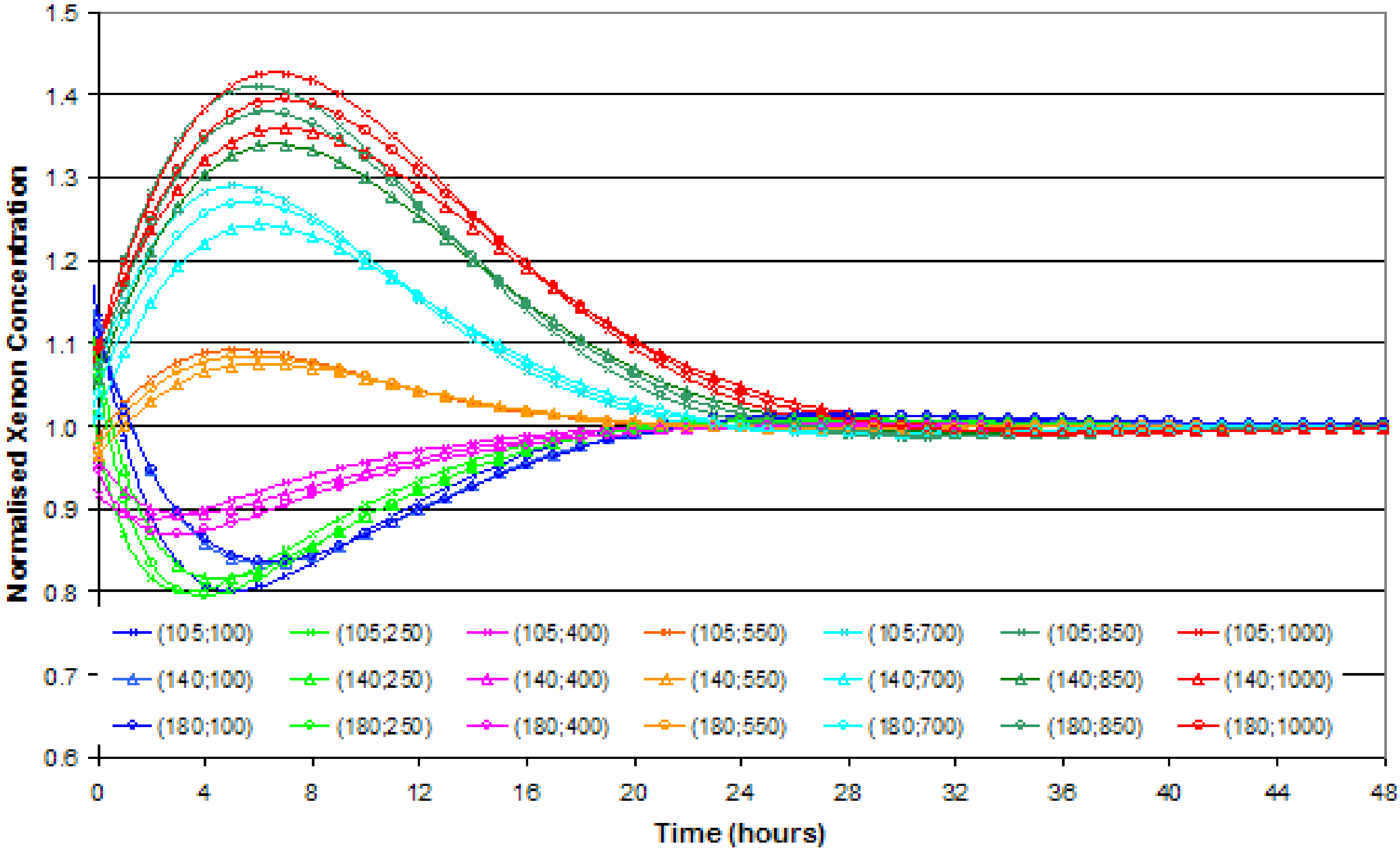
Xenon Stability Guidance

- Previous studies on HTGR-specific xenon stability reported the following conclusions:
  - Un-damped axial xenon oscillations only occurred for HTR cores when the core height was increased to larger than 8 m, with a simultaneous power density increase to more than 20 MW/m^3
  - No un-damped radial xenon oscillations were observed for cylindrical cores of up to 6.4 m in radius

Results from 100%-40%-100% Power Variation



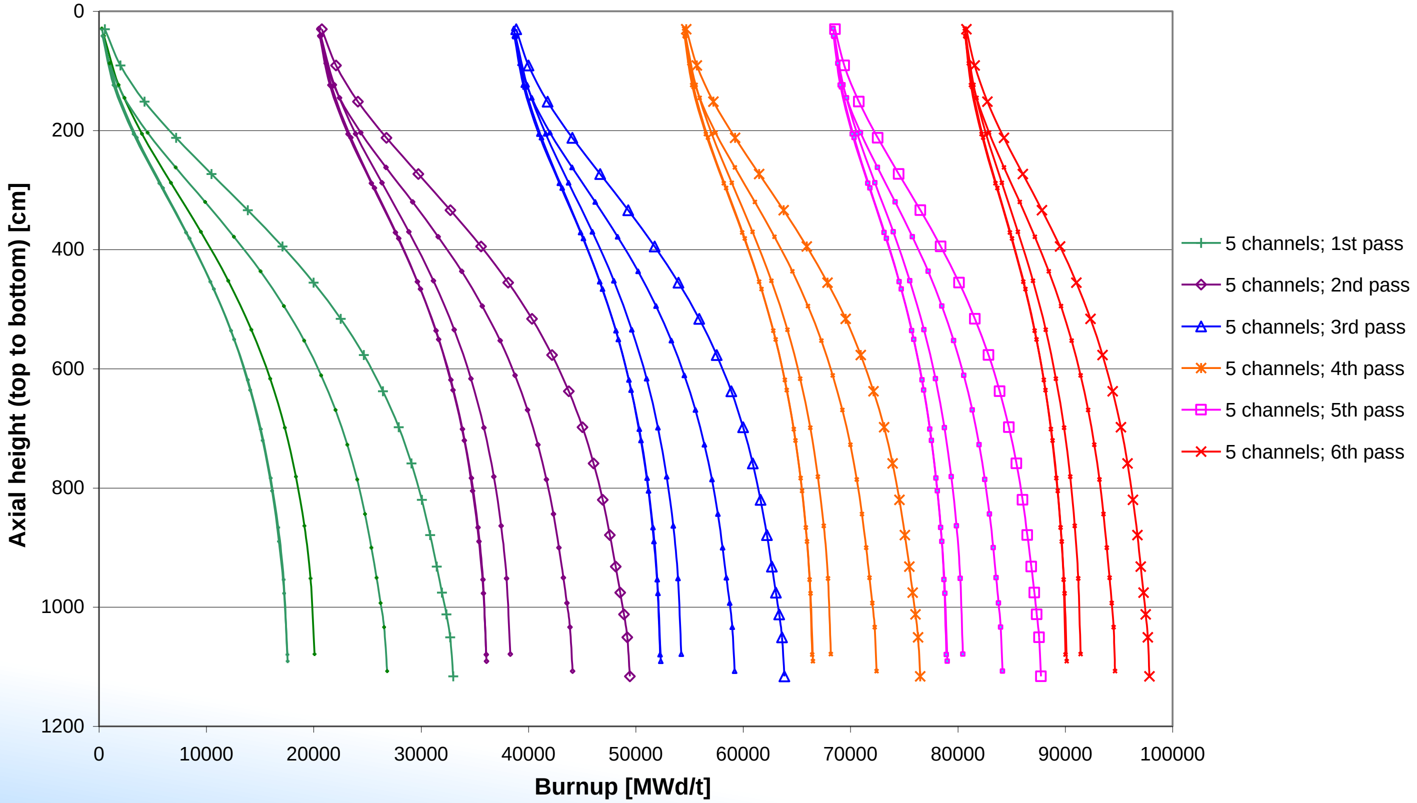
Hypothetical Power Shape Disturbance Damped Out

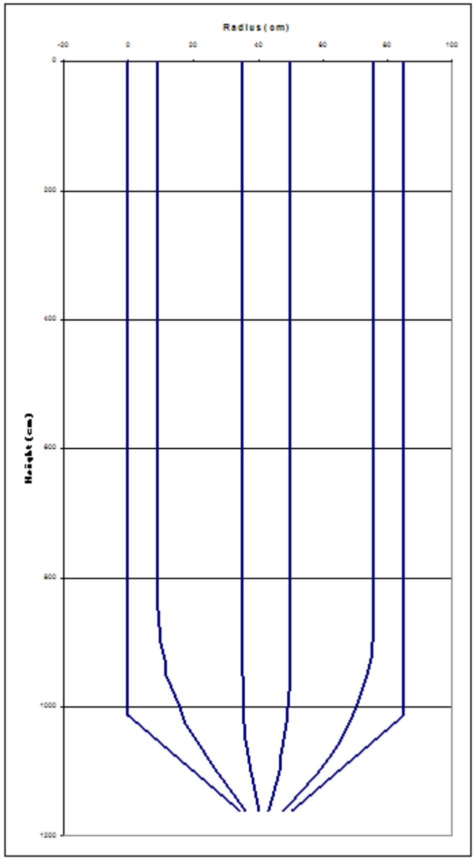


Burn-up

- The reactor employs an on-line refueling scheme, and therefore never has to be taken out of service for refueling.
- Fuel spheres that have not yet reached target burn-up, or more specifically the BUMS setpoint, can be reloaded and recycled continuously during normal reactor operation.
- Fuel spheres with higher burn-up as the BUMS setpoint are discharged from the refueling line, and replaced with a fresh fuel sphere. In practice some fuel may pass through the reactor less than the average number of passes while others may pass more times before reaching the BUMS setpoint burnup value.
- The BUMS discriminates between spent and used fuel spheres by analysing the gamma energy spectrum to determine the inventory of specific nuclides (burn-up measurements).

Burnup of Fuel for Various Radial Positions (Channels)





Power Shaping

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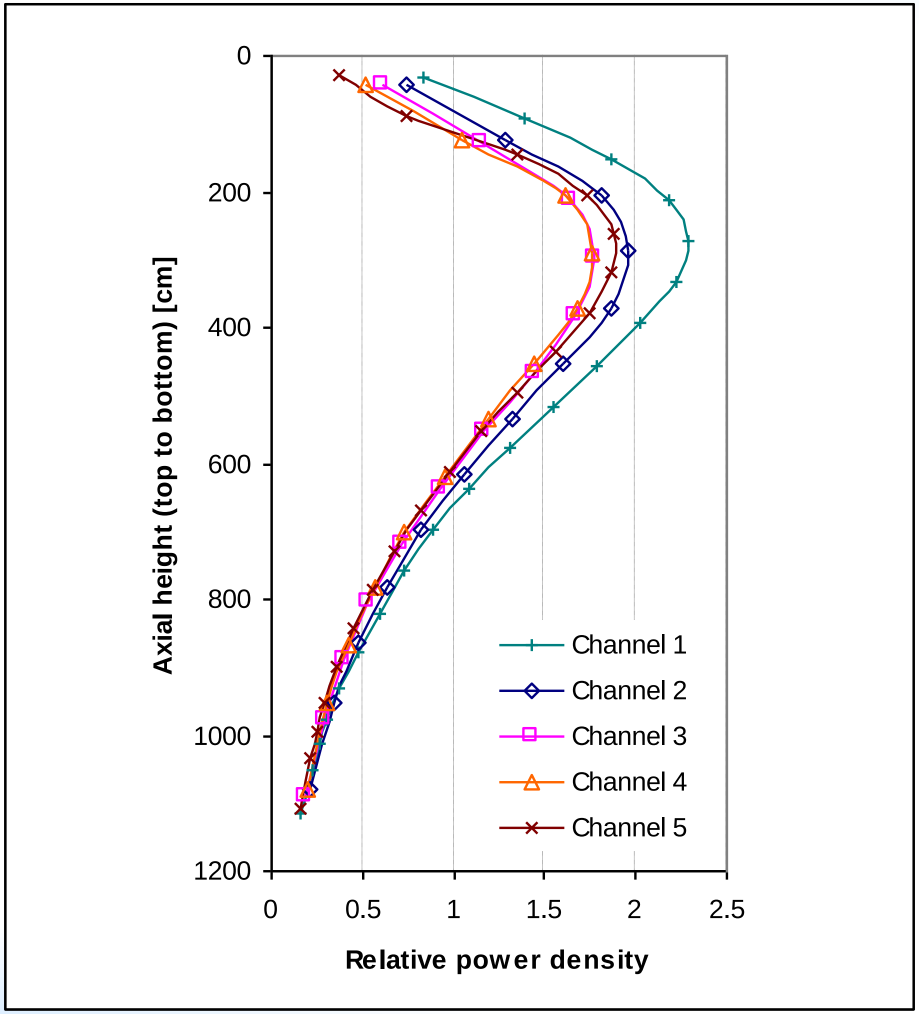
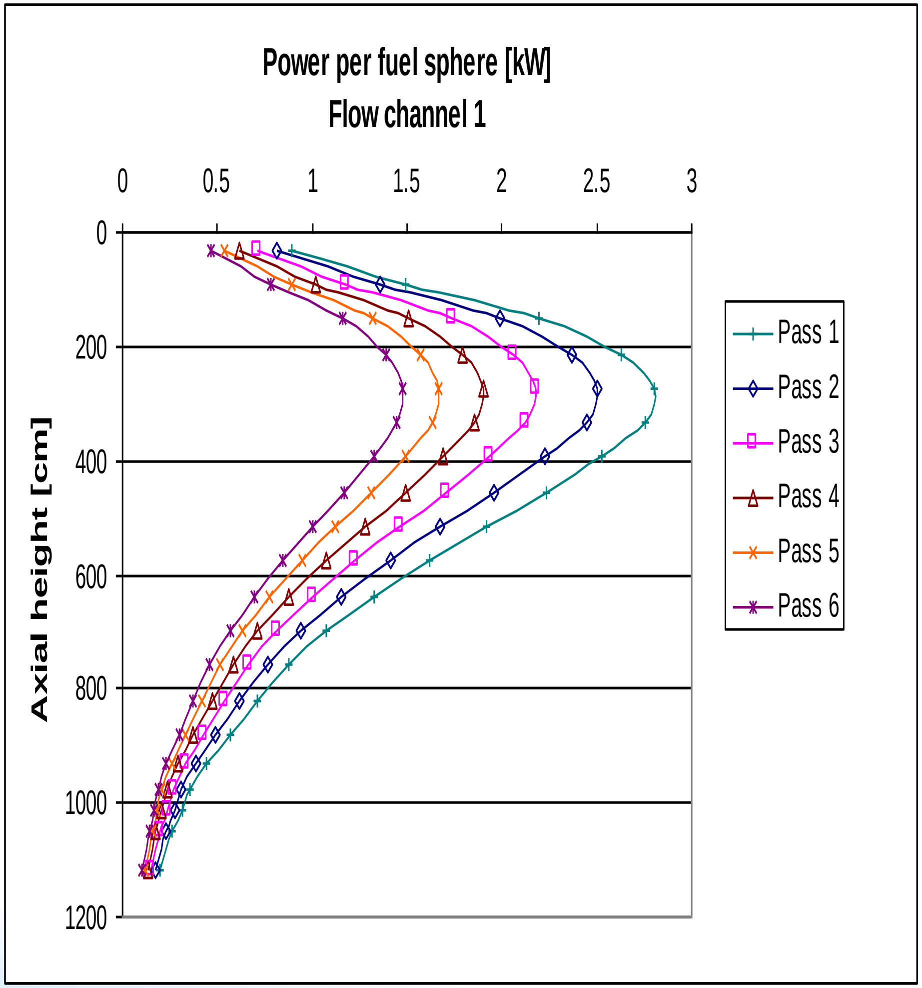
- Pebble beds do not use fuel loading or burnable poison to affect power shaping
- Fuel can be circulated faster through the core to flatten the axial power profile
- Once equilibrium conditions are established control rods do not need to be moved to compensate for burnup

Axial Power Distribution



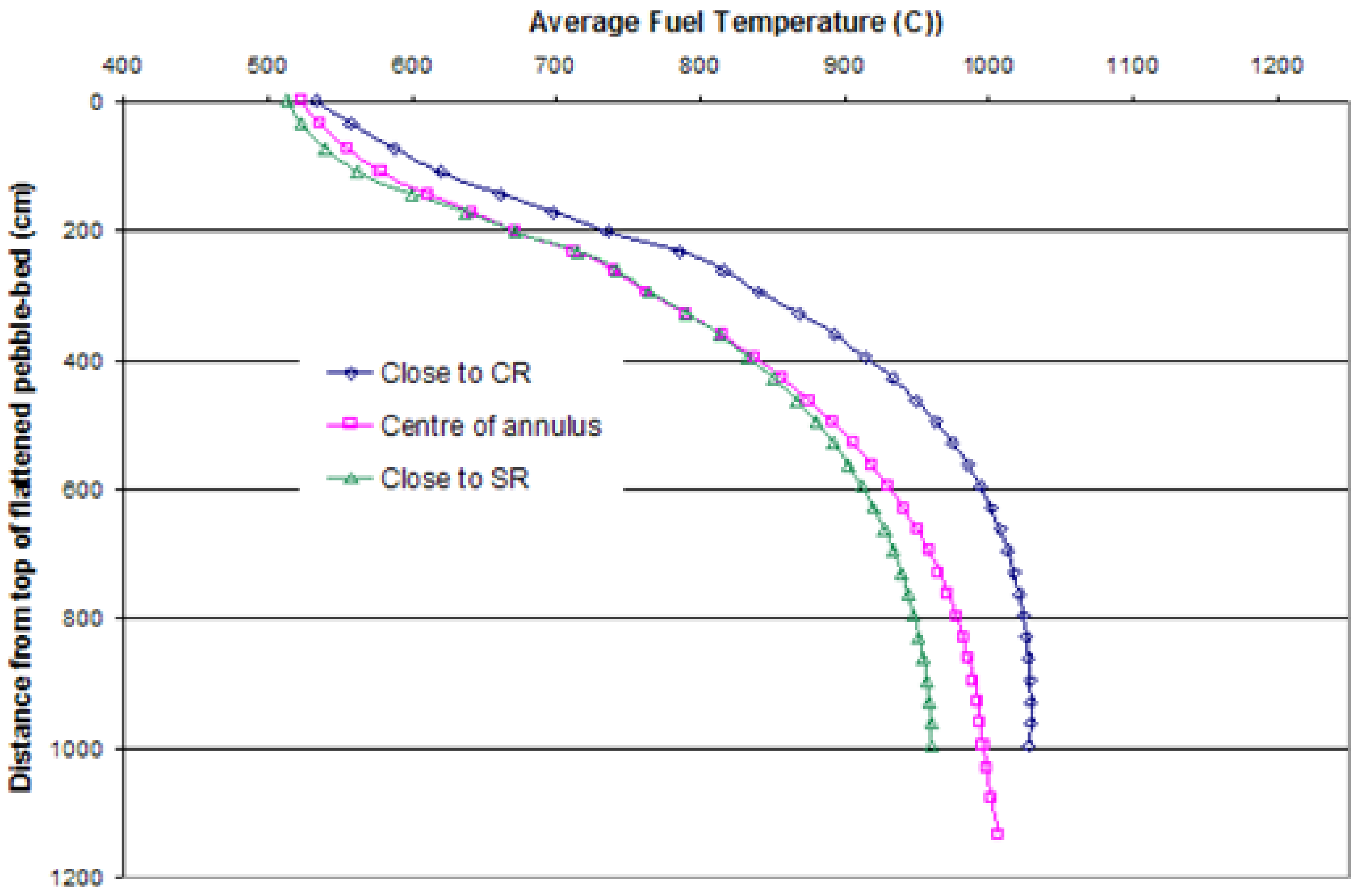
- The power profile is biased towards the top of the core due to the lower fuel temperatures and fresh fuel
- The top of the power profile is depressed due to the partially inserted control rods
- Since no burnable poisons are used with on-line refueling, this power profile is representative of the greater part of plant operation

Power Distribution per Pass

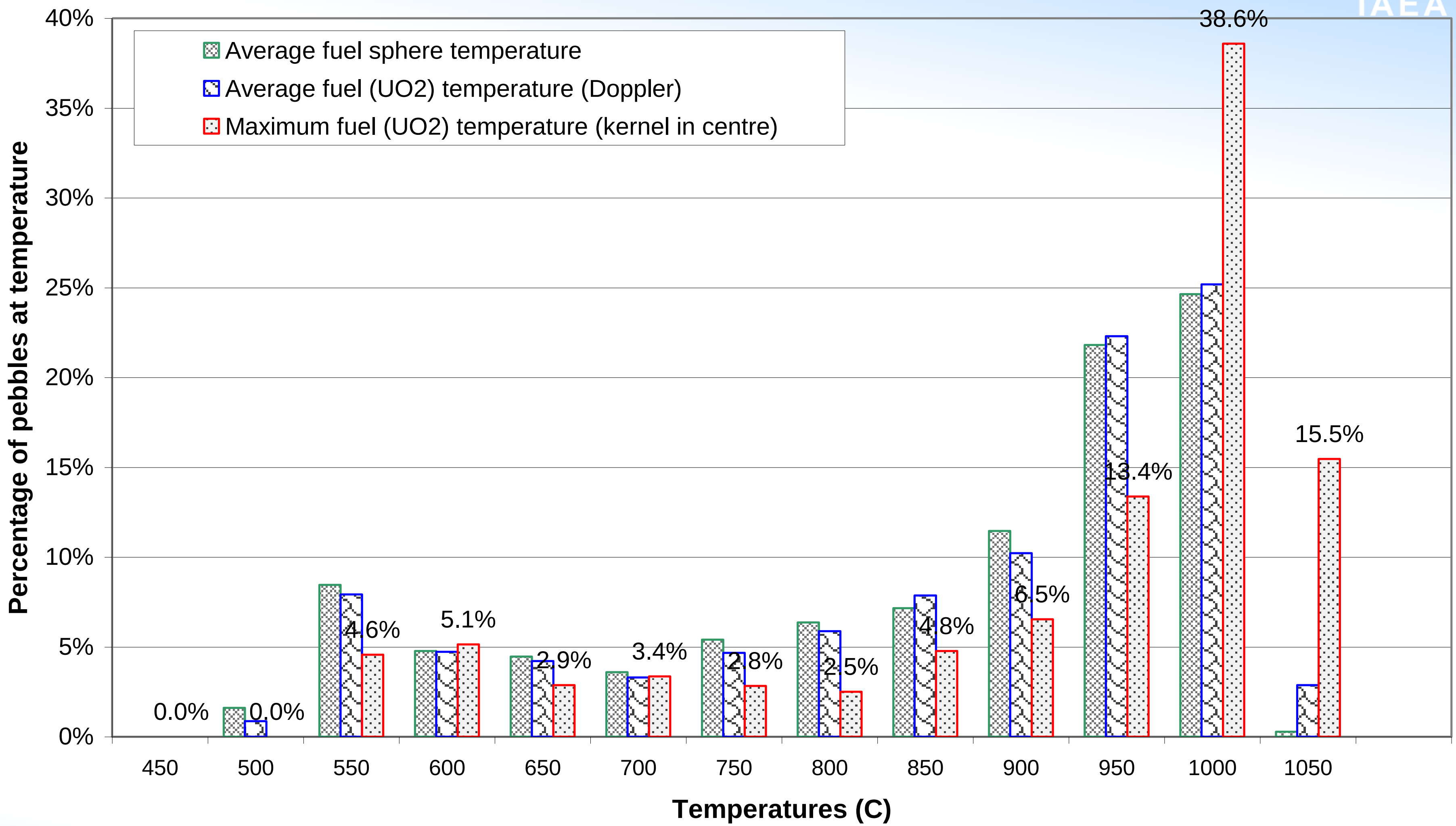


- The power produced per fuel sphere reduces with each pass through the core

Temperature Distribution for Equilibrium Core

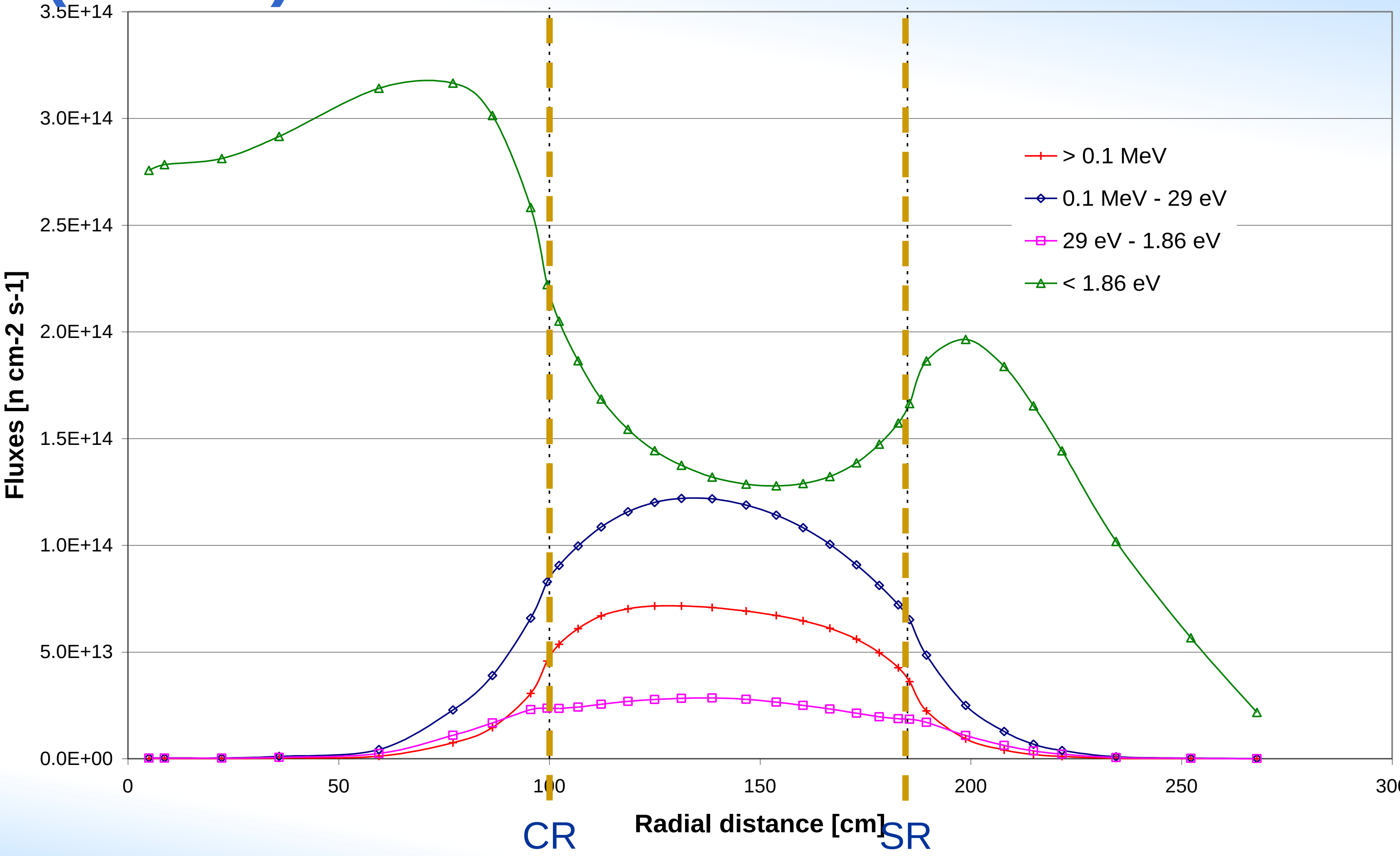


Fuel Temperature Distribution

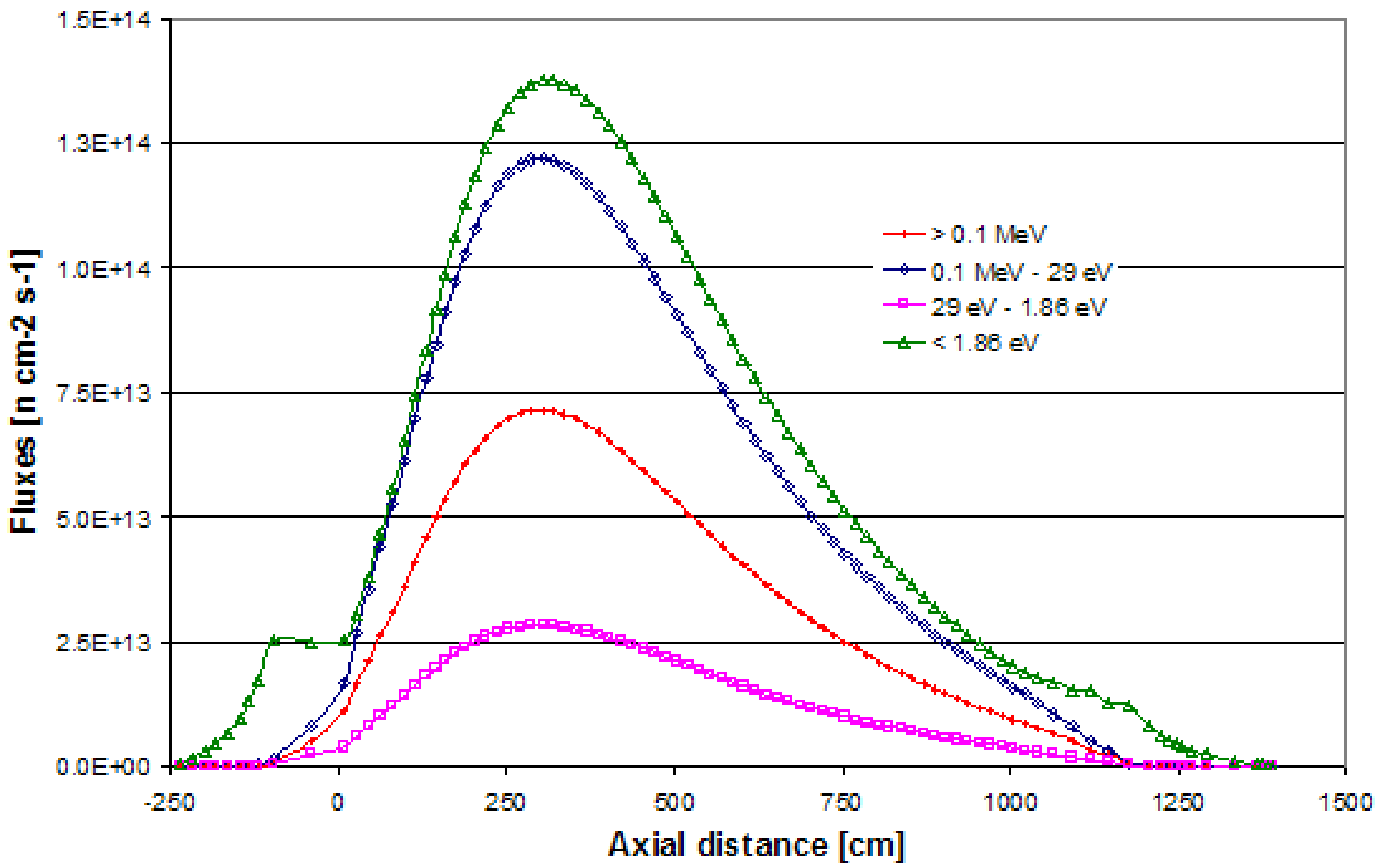


- This represents the average fuel temperature distribution of a 400MWt annular core operating at 900°C during normal full power operation

Neutron Flux Distribution (Radial)



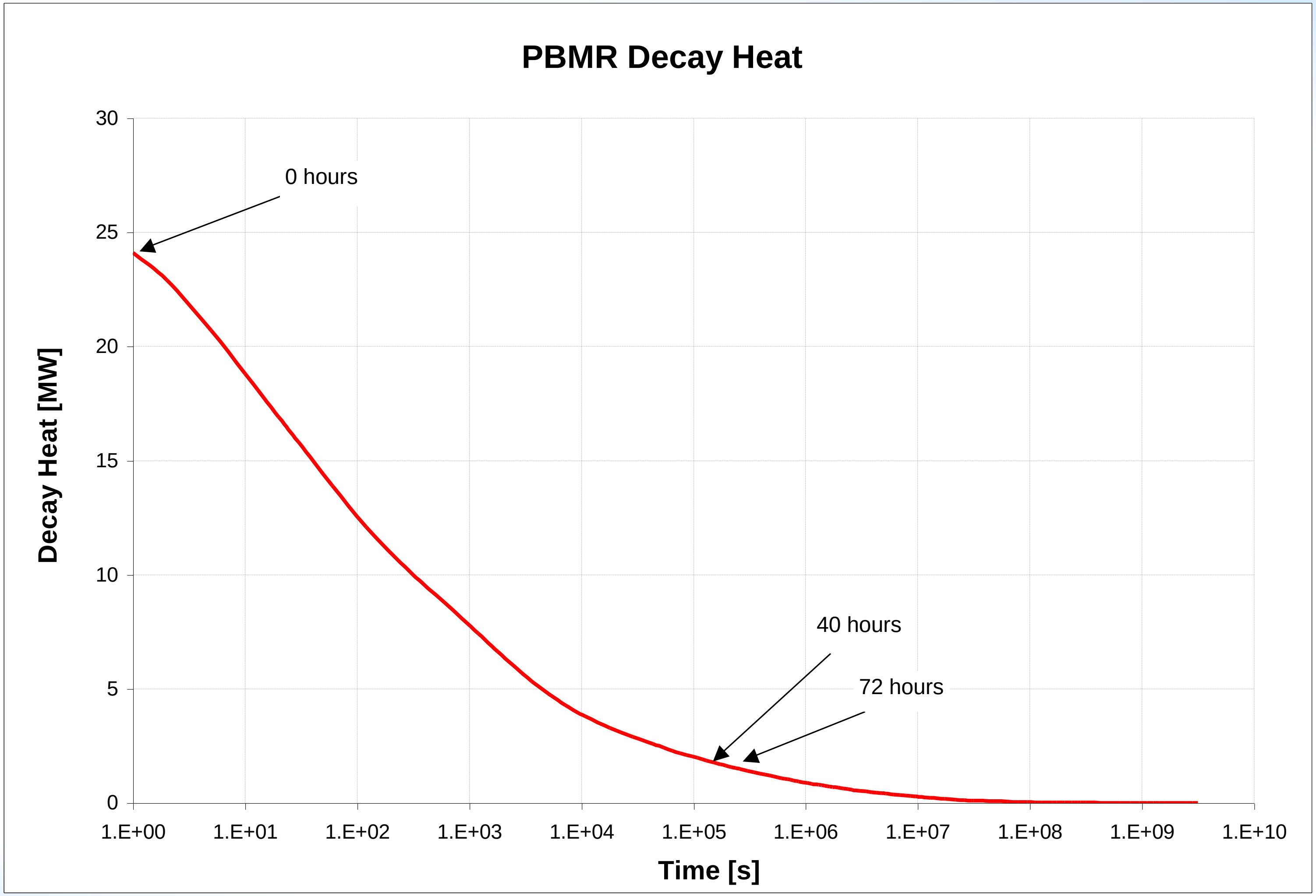
Neutron Flux Distribution (Axial)



Decay Heat

- German standard DIN 25485 is used to evaluate decay heat
- The standard provide the methodology to calculate the heat power generated by the decay of the fission products (valid for all kinds of thermal reactors) and rules concerning the additional sources of decay heat (activation) are valid for non-recycled fuel of pebble-bed high temperature reactors, exclusively

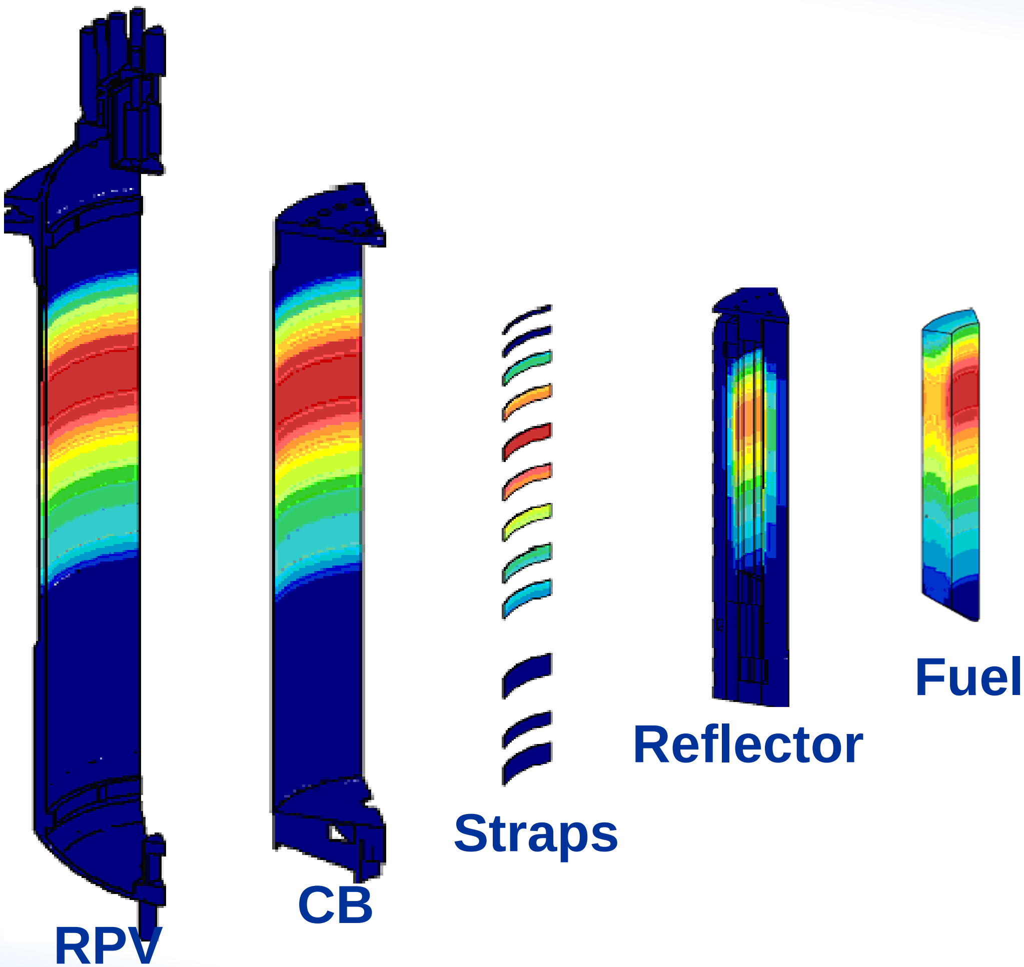
Decay Heat Curve (400MWth)



Basic Core Thermal Fluid Attributes

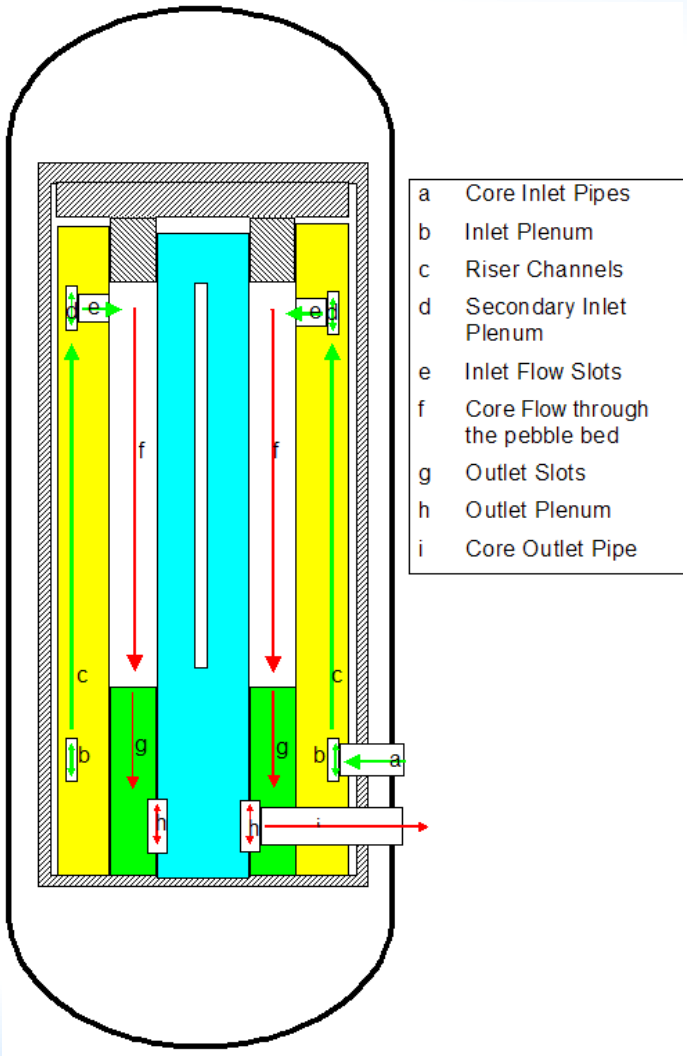
- Large ΔT across inlet to outlet
  - Requires a smaller coolant mass flow rate resulting in lower pumping requirements
- High coolant outlet temperatures
  - Allows for higher thermal efficiency in power conversion cycles and process heat applications
- Small ΔT between fuel and coolant
- Large temperature margins in the fuel
- Slow thermal transients
  - Large thermal capacitance in the fuel and graphite combined with a low power density results in slow transients
- Pebble bed is one flow channel
  - Strong coupling in the pebble bed resulting in more uniform flow distribution

Heat Generation Input



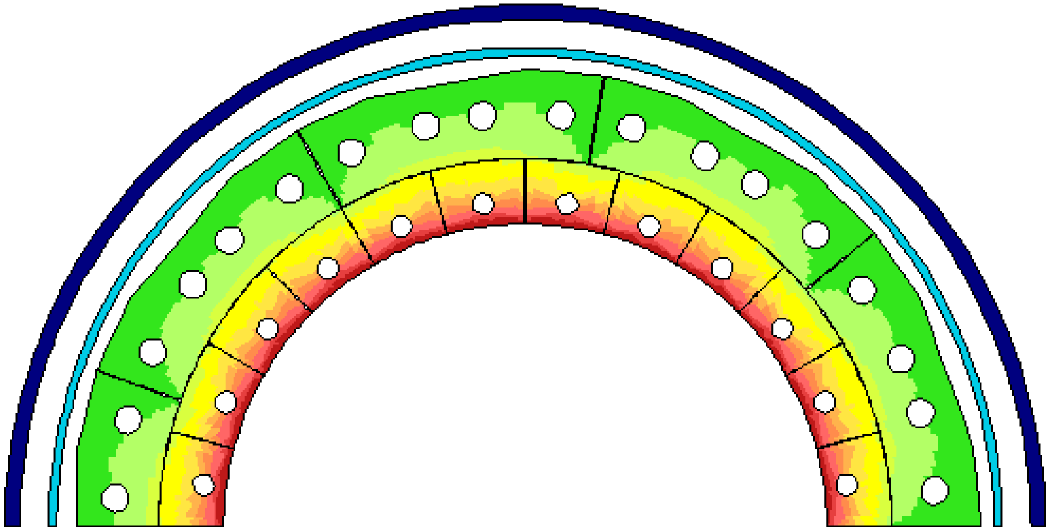
- Modeling of both local (in the fuel) and non-local heat generation
- Heat sources:
  - Fuel
  - Reflectors
  - Control rods
  - Lateral restraints
  - Core barrel
  - Reactor vessel

Primary Flow Path



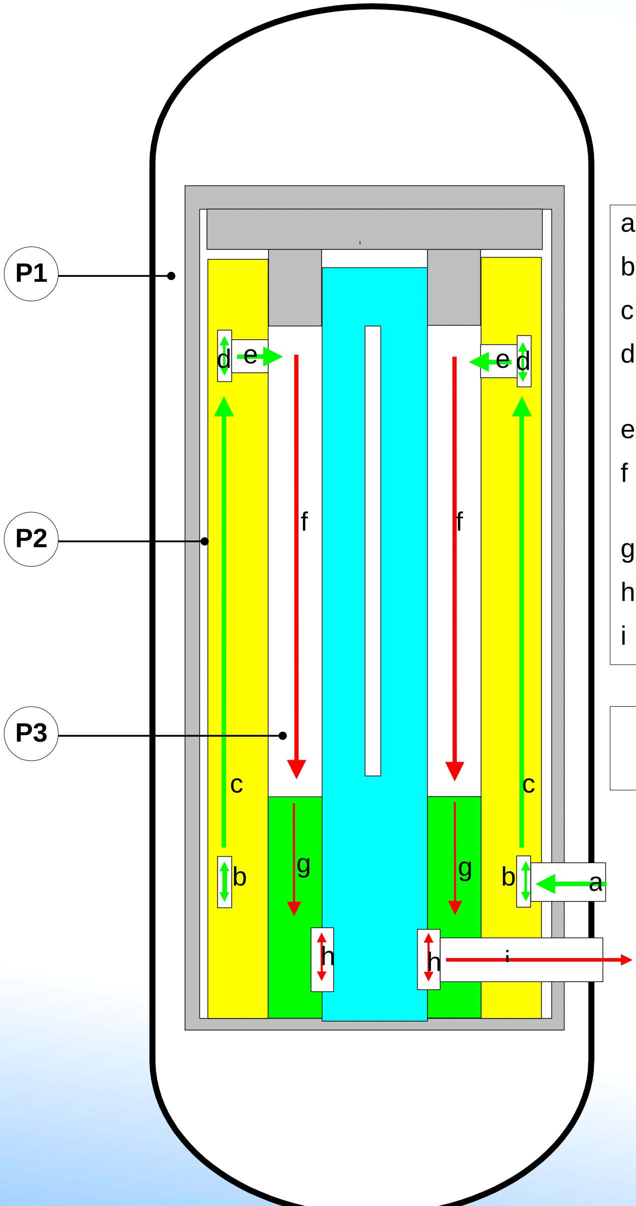
- Inlet flow can be separate hot gas ducts in designs with high reactor inlet temperatures (e.g. direct Brayton cycles)
- Inlet flow can be in annulus around outlet duct in designs with lower reactor inlet temperatures (e.g. indirect Rankine cycles)

Non-uniform Flow in Riser Channels



- Temperature profiles shows very little effect due to uneven flow in the gas riser channels due to high conductivity of graphite and good heat transfer properties of helium

Pressure Zoning

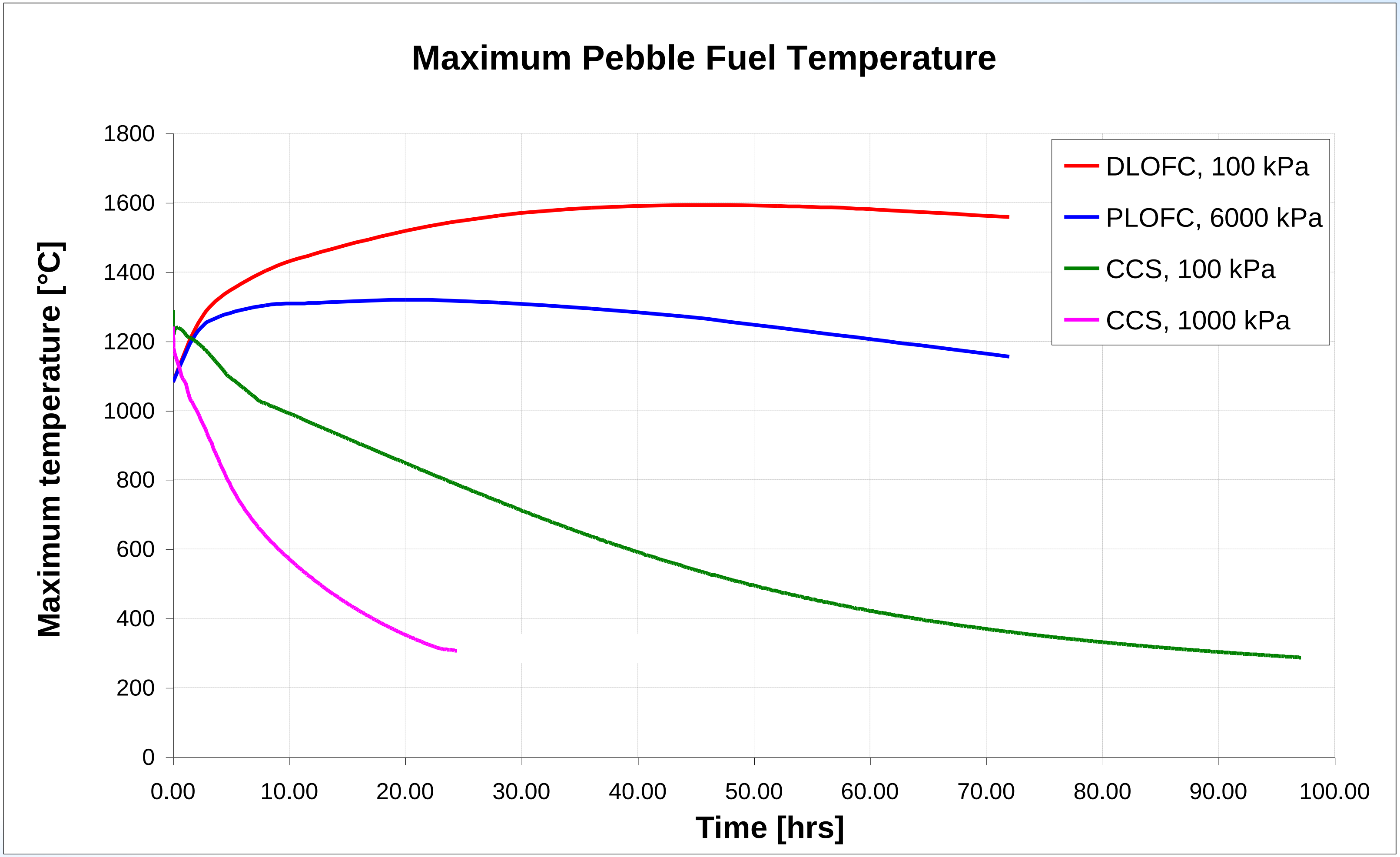


a	Core Inlet Pipes
b	Inlet Plenum
c	Riser Channels
d	Secondary Inlet Plenum
e	Inlet Flow Slots
f	Core Flow through the pebble bed
g	Outlet Slots
h	Outlet Plenum
i	Core Outlet Pipe

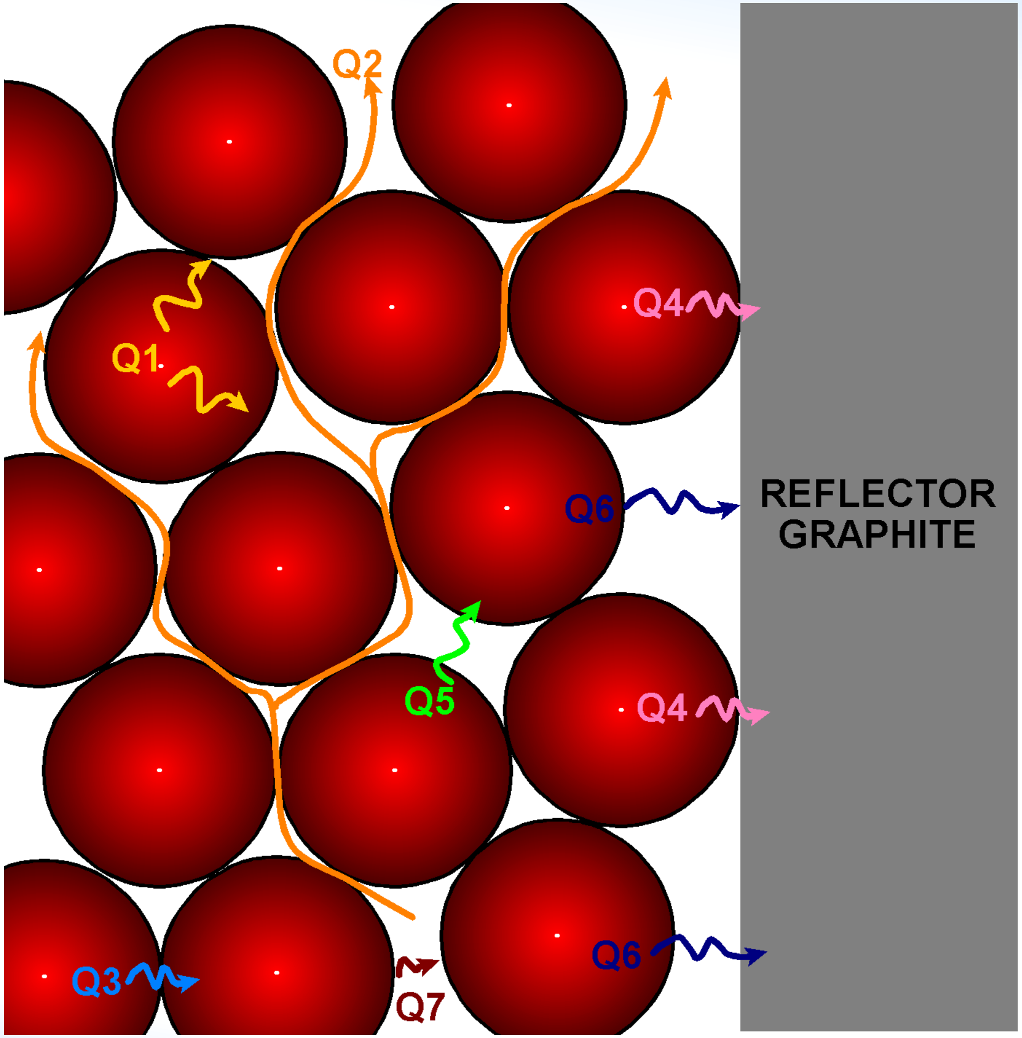
P1 > P2 > P3

- Principle is to always surround hot gas with cooler gas at a higher pressure
- This prevents any hot gas from leaking out in case of a failure
- This protects the metallic reactor vessel

Effect of Different Residual Heat Removal Mechanisms on Peak Fuel Temperature



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

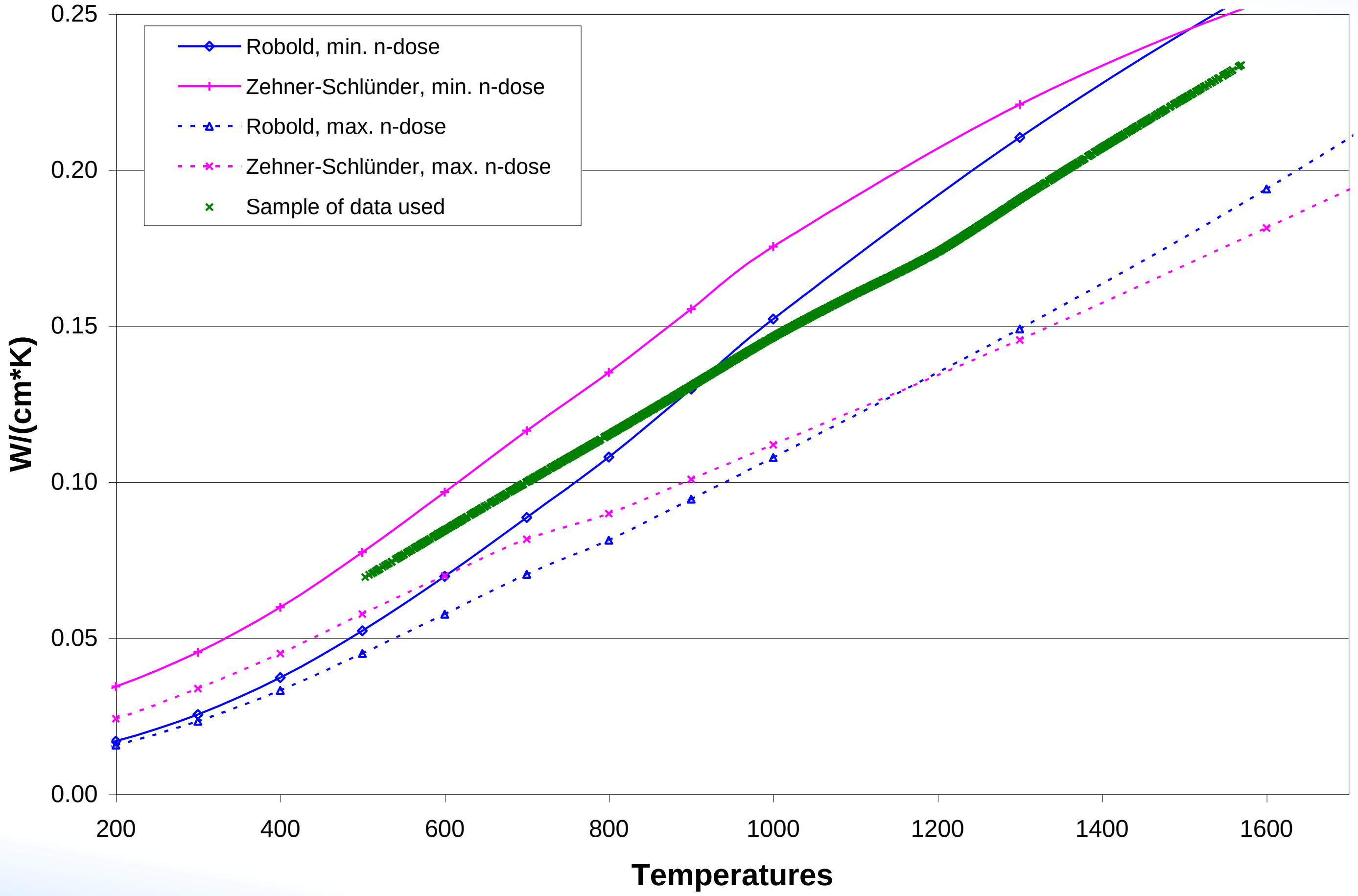
Q5: Thermal radiation between the pebble surfaces

Q6: Thermal radiation between the pebble surfaces and the reflector

Q7: Conduction in the gas

Effective Thermal Conductivity Correlations

Effective conductivity is used for point contact conduction, and radiation heat transfer between the pebbles.



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Fuel handling in pebble bed reactors

Principal Functions of Pebble Bed Fuel Handling

- Charge Fresh Fuel
- Circulate Used Fuel
  - Use gravity as the primary means of transporting spheres
  - Use pneumatic means for sphere transport when they need to be elevated
  - Separate spheres not meeting requirements
    - Undersized spheres
    - Broken/damage spheres
  - Determine burnup
  - Distribute spheres to inner and outer core depending on burnup and reactor requirements (AVR & THTR)
- Discharge Spent Fuel

AVR Circulation System

- Circulate about 500 Spheres per EFPD
  - Reducer - takes a batch of a few pebbles
  - Singulizer - ensures that only one pebble moves down the line at a time
  - Burn Up (using Cs-137 gamma spectrometry) and Activity Measurement (gross gamma measurement)
  - Broken Sphere Separator
  - Scrap Container
  - Dosing Wheel - selects the line to be used
  - Elevator
  - Core Feed Lines (1 center, 4 outer)
  - Miscellaneous Isolation Valves and Sphere Counters

AVR Discharging System

- Discharge about 60 Spheres per EFPD
  - Single Line Discharge Air-Lock
  - Spent Fuel Can

AVR FHS Performance

- Circulated 2,400,000 Pebbles
- Charged/Discharged: ~ 300,000 Pebbles
- Overall Impact on Plant Unavailability <3% (higher initial period, later lower)

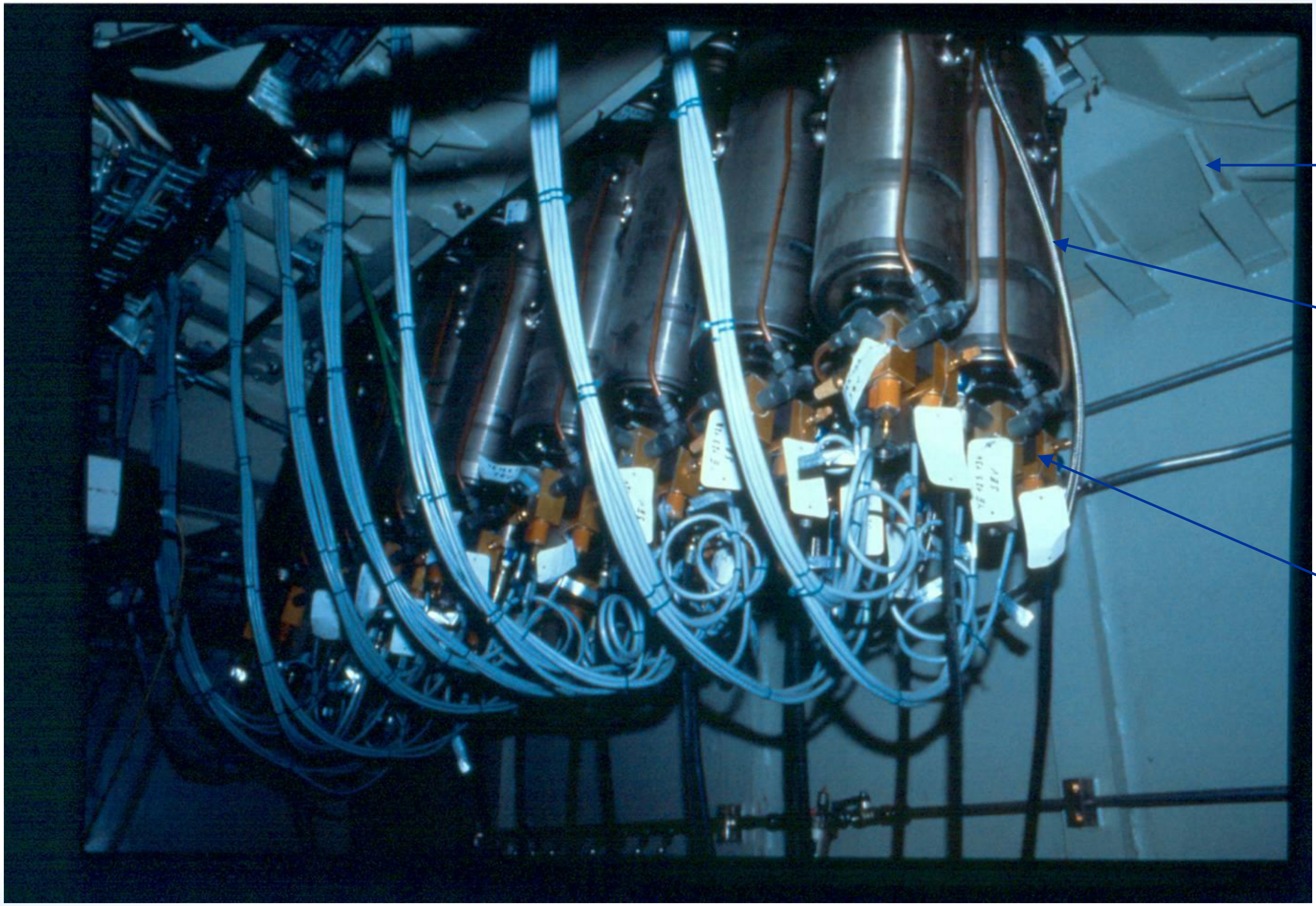
- Note: Low AVR Broken Sphere Rate: ~10^{-4} (and even better the latter part of life: ~$2*10^{-5}$) had significant positive impact on the reliability

Lessons Learned from AVR for THTR FHS Design

- Simplify sphere removal from core:
  - 2 (redundant) Core Unloading Devices (CUD) that take over the function of the reducer, singularizer, and the broken sphere separator
- Improve actuation method for various moving components
  - Electro-pneumatic actuators for valves and indexers, diverters and collectors, mounted in functional blocks for easier maintenance, instead of the dosing wheel and elevator
- Improve Burn Up Measurement speed
  - Use of Small Critical Assembly for Burn Up Measurement instead of Cs-137 (7 seconds vs 30 seconds)
- Maintenance on AVR components can be done readily after some decontamination (dust is not a major issue)

THTR Fresh Fuel Loading Station

THTR Distribution Block



Building Floor

Actuator Inserts

Electro-Pneumatic Drives

THTR Discharging System

- Discharge about 700 spheres per EFPD
  - 3 Discharging Air-Locks
  - 3 Spent Fuel Drum Loading Station, including automatic welding of Lids
    - Each Drum holds about 2000 spheres
  - Spent Fuel Storage Area
    - 100 Day Storage Area
    - Extended Storage Area (300 additional days)
    - High Level Waste Storage Area

THTR FHS Performance

- Circulated: ~1,400,000 pebbles
- Charged/discharged: ~235,000 pebbles
- Overall impact on plant unavailability ~15% (higher initial, lower later)
- THTR completed the core unloading in 10 month, without major interruptions, demonstrating that the modifications to the FHS performed as designed

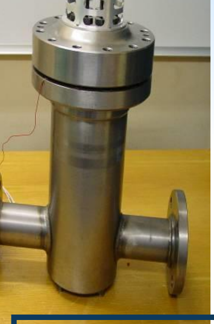
- Note: high broken sphere rate: initially~1.5% to latest ~0.6% caused jamming in the FHS near the discharge of the CUD, Also required frequent exchange of the damaged sphere container

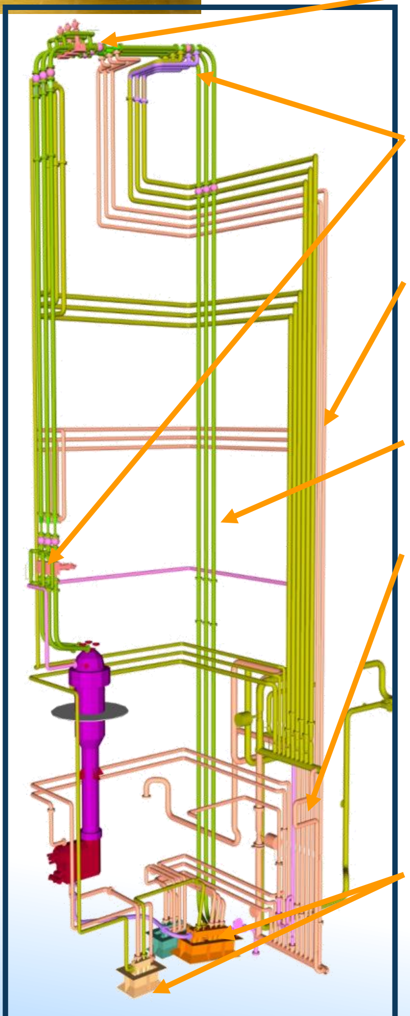
Lesson Learned from THTR for PBMR FHS Design

- Early troubles can be resolved – but more testing prior to plant installation reduces the downtime
- Dust is there, but has not been a maintenance/health-physics issue at either AVR or THTR
- Do not use in-core rods which causes high failure rate of spheres resulting in frequent exchange of broken sphere can and jamming in the sphere circulation system
- Pebble-bed FHSS allows online maintenance of most of the system (10 to 20 day reactivity reserve)

HTF Fuel Handling System (FHS)

- >19 000 successful sphere passes completed
- The functioning of the sphere counter was tested
- Leak tests were done on shaft penetrations, to determine the helium leak flow rate





Sphere Indexers

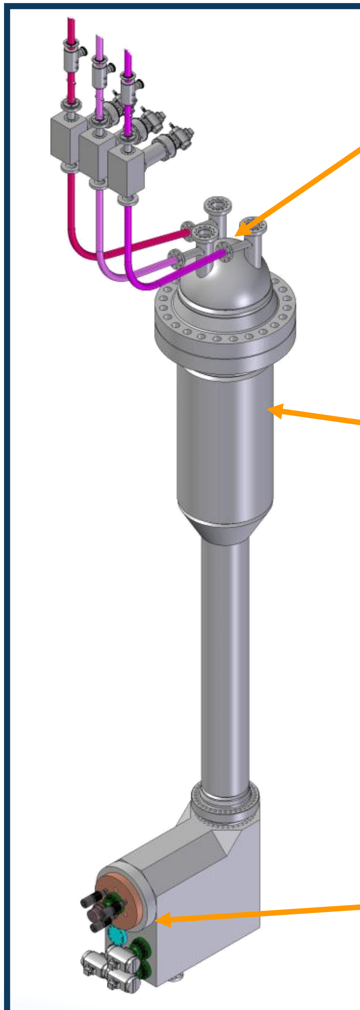
Gas Brakes

Helium Return

Sphere Lines

Helium Supply

Valve Blocks

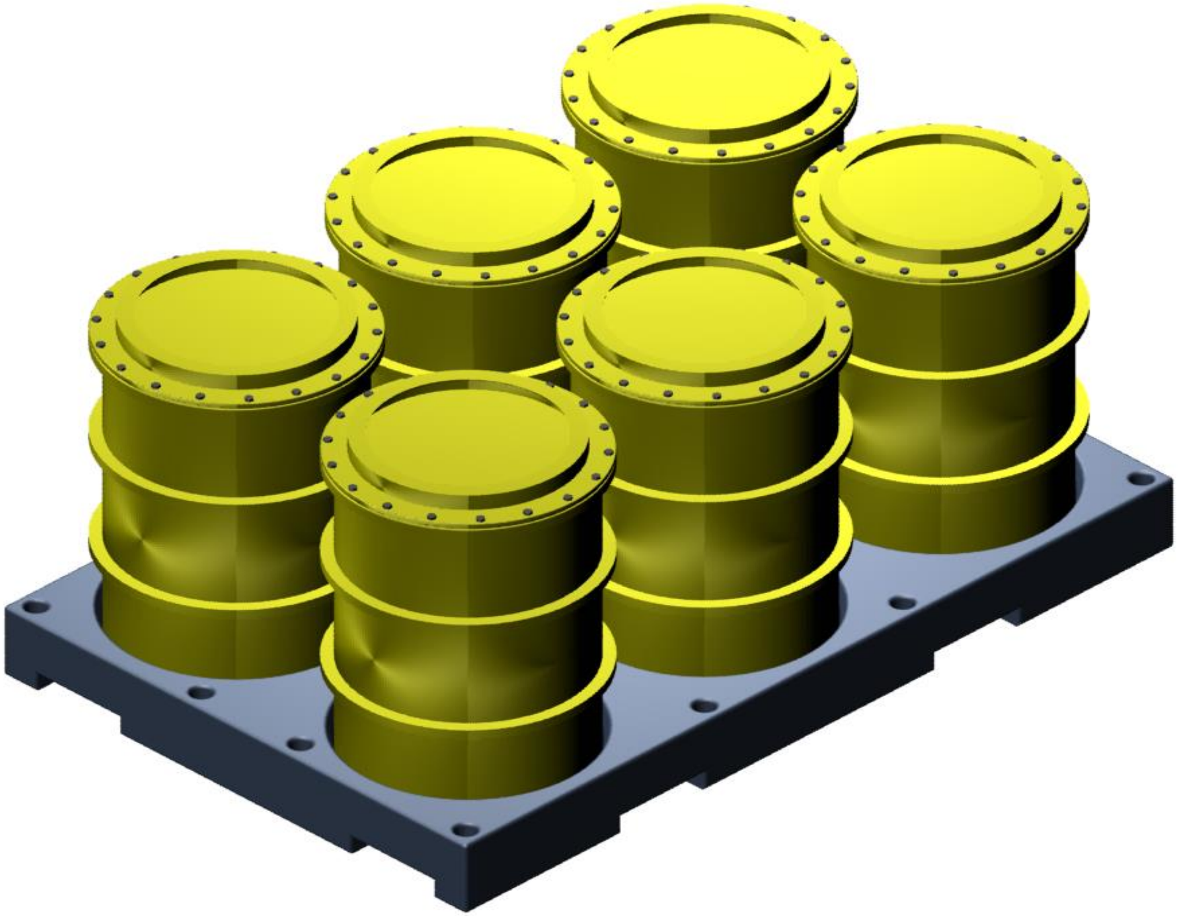


Core Loading Device

Test Vessel

Core Unloading Device

Fresh Fuel Drums on a Pallet



Broken Sphere Removal

- Improvements:
  - Increase slope of feeder box to CUD
  - Broken sphere containers can be changed on-line

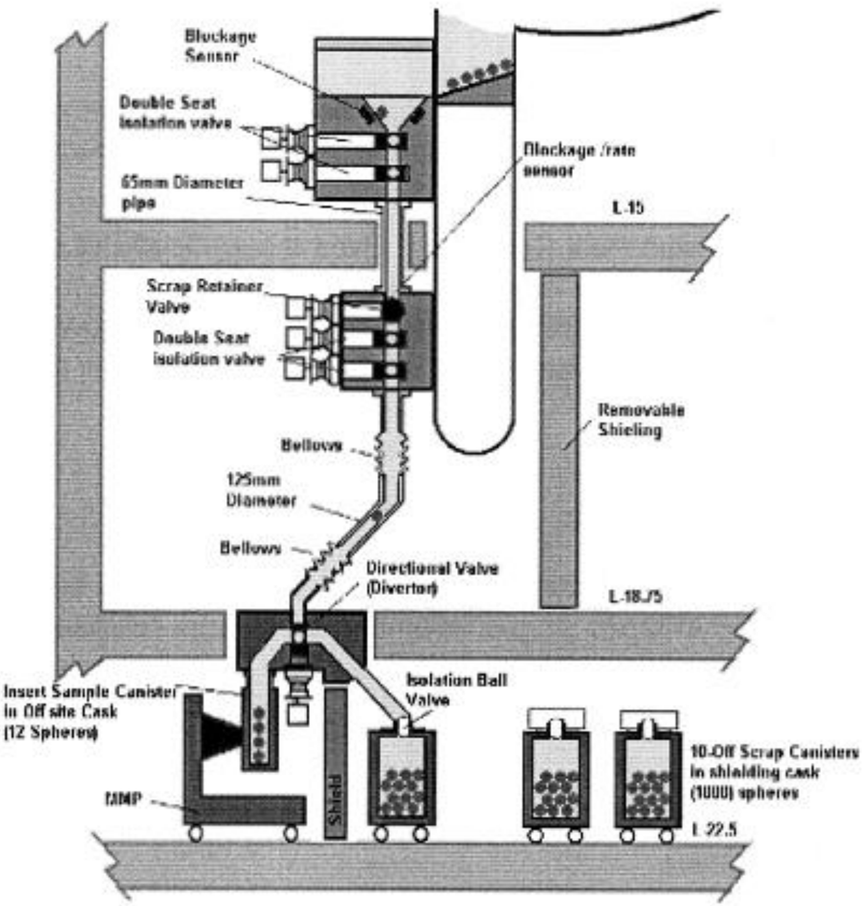
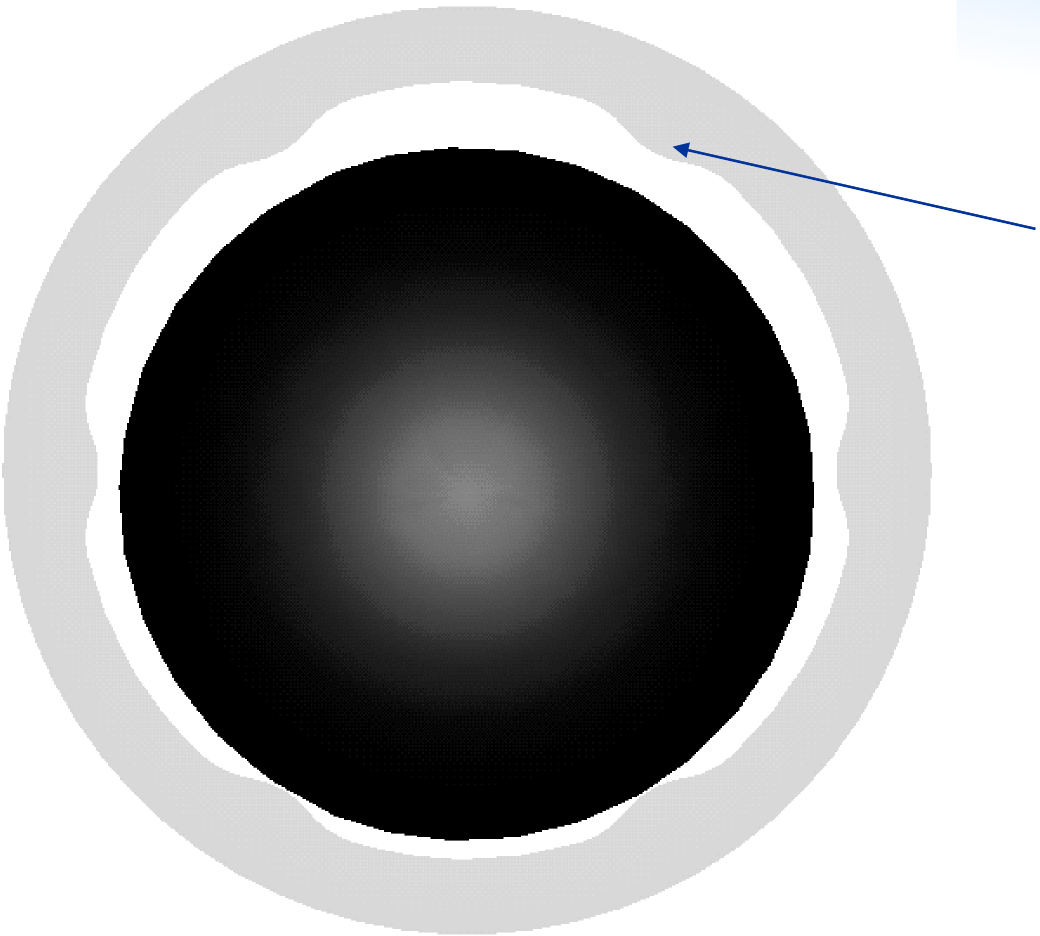
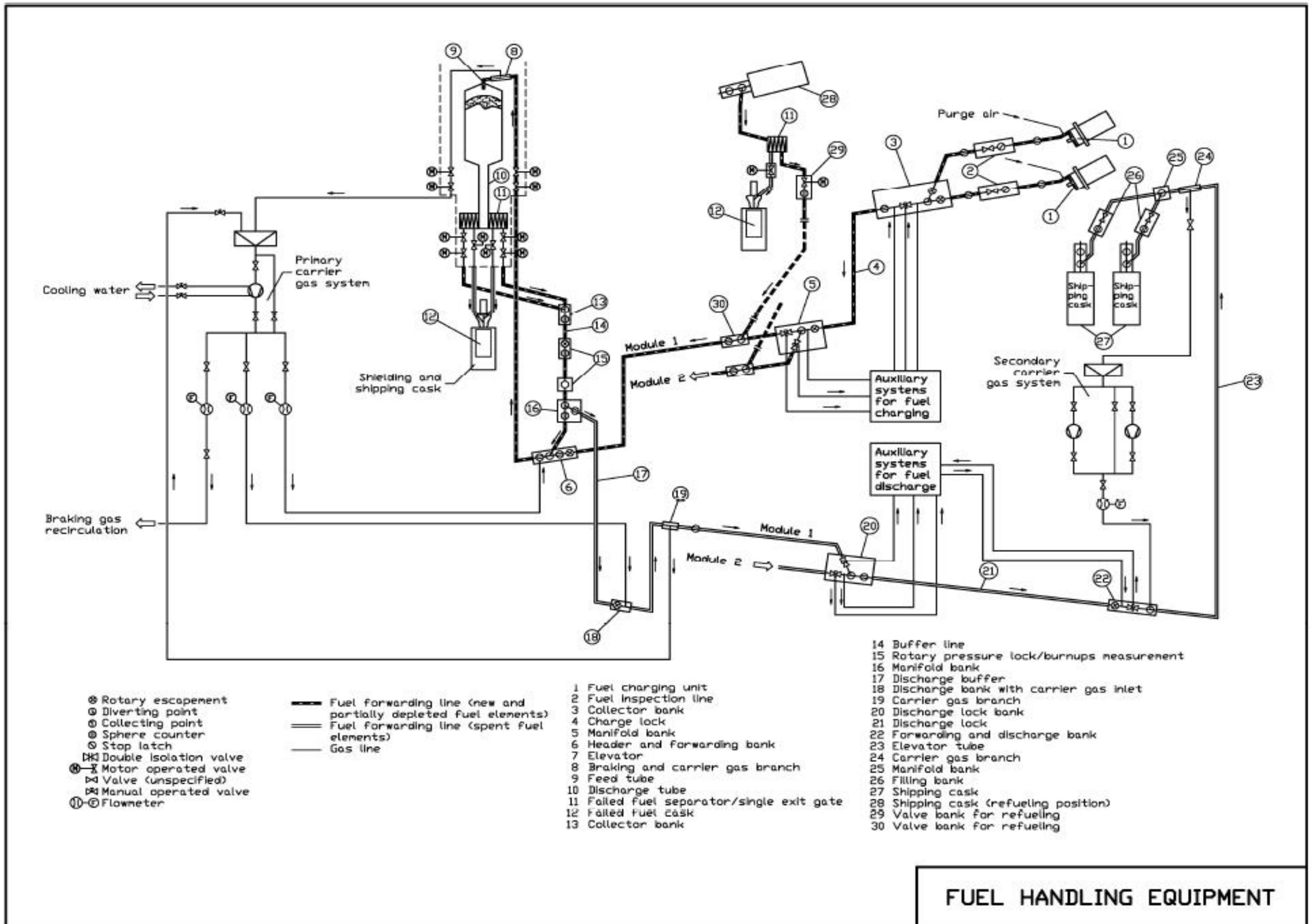


FIGURE 45: BROKEN SPHERE REMOVAL

Fuel Sphere in Pipe



Fuel Handling Equipment for Pebble Bed Reactors



Presentation Objectives

By the end of this session, participants should be able to:

- Define pebble type modular HTGRs
- Consider operation modes
- Identify design aspects that need special care
- Identify the main design considerations
- Know the main systems

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Thank You

Questions?

Frederik Reitsma
Nuclear Power Technology Development Section
Department of Nuclear Energy