Reactor Core Design principles
AGR and HTR

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AGRs (two reactors at each site, with the exception of the prototype WAGR)

Station	MW(t) per reactor	Channels	T1 °C	T2 °C	Criticality	Graphite	Designer/Builder
Windscale Advance Gas-cooled Reactor WAGR	100	253	250-325	500-575	1962	PGA	UKAEA
Hinkley Point B	1493	308	292	645	1967	AGL	The Nuclear Power Group
Hunterston B	1496	308	318	649	1977	AGL	The Nuclear Power Group
Dungeness B	1485	465	320	675	1984	AGL	Atomic Power Construction Ltd
Heysham 1	1500	324	287	651	1984	BAEL	Babcock, English Electric Nuclear
Hartlepool	1500	324	286	675	1985	BAEL	Babcock, English Electric Nuclear
Heysham 2	1650	332	292	635	1988	UCAR	National Nuclear Company
Torness	1650	332	298	635	1989	UCAR	National Nuclear Company

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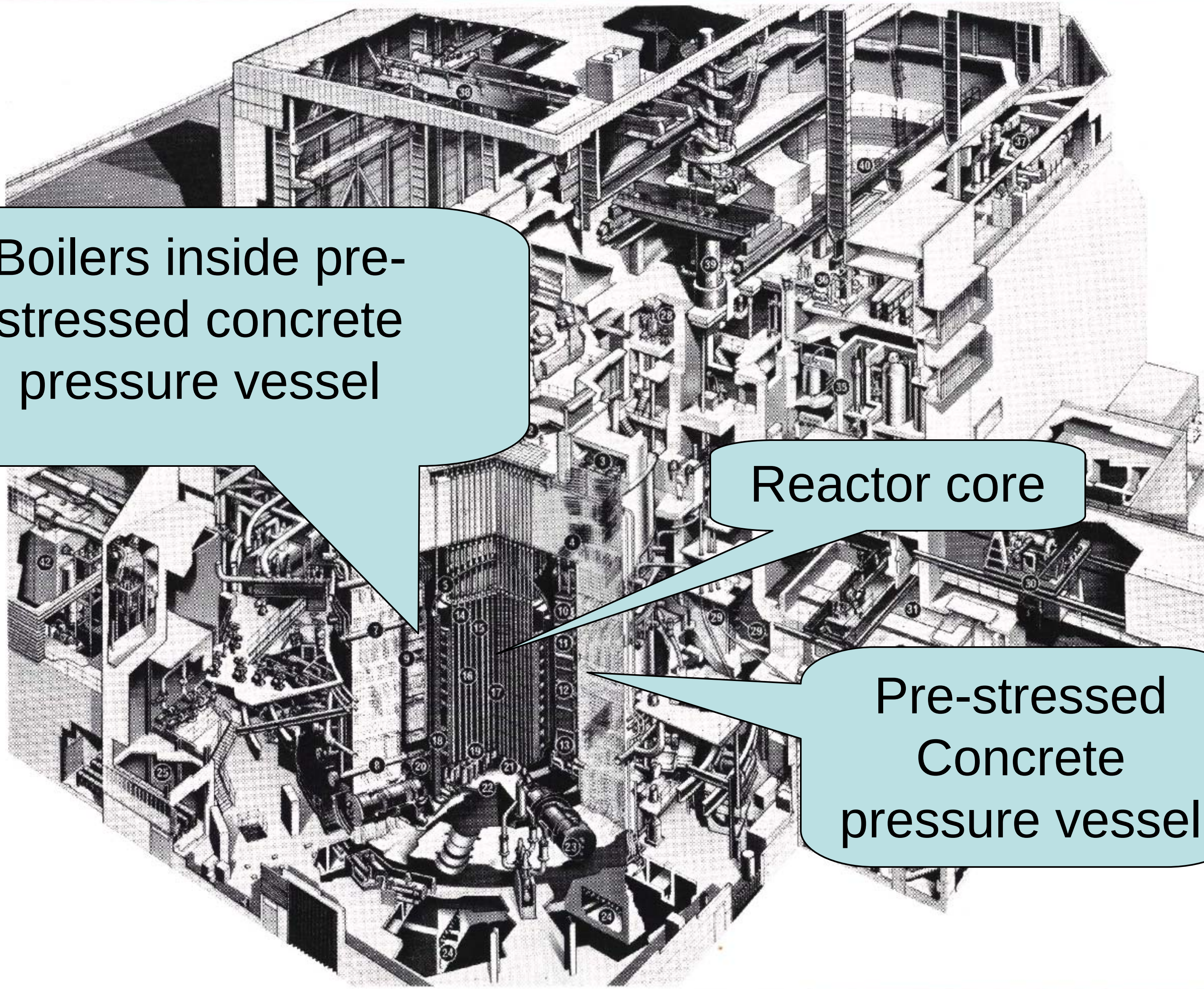
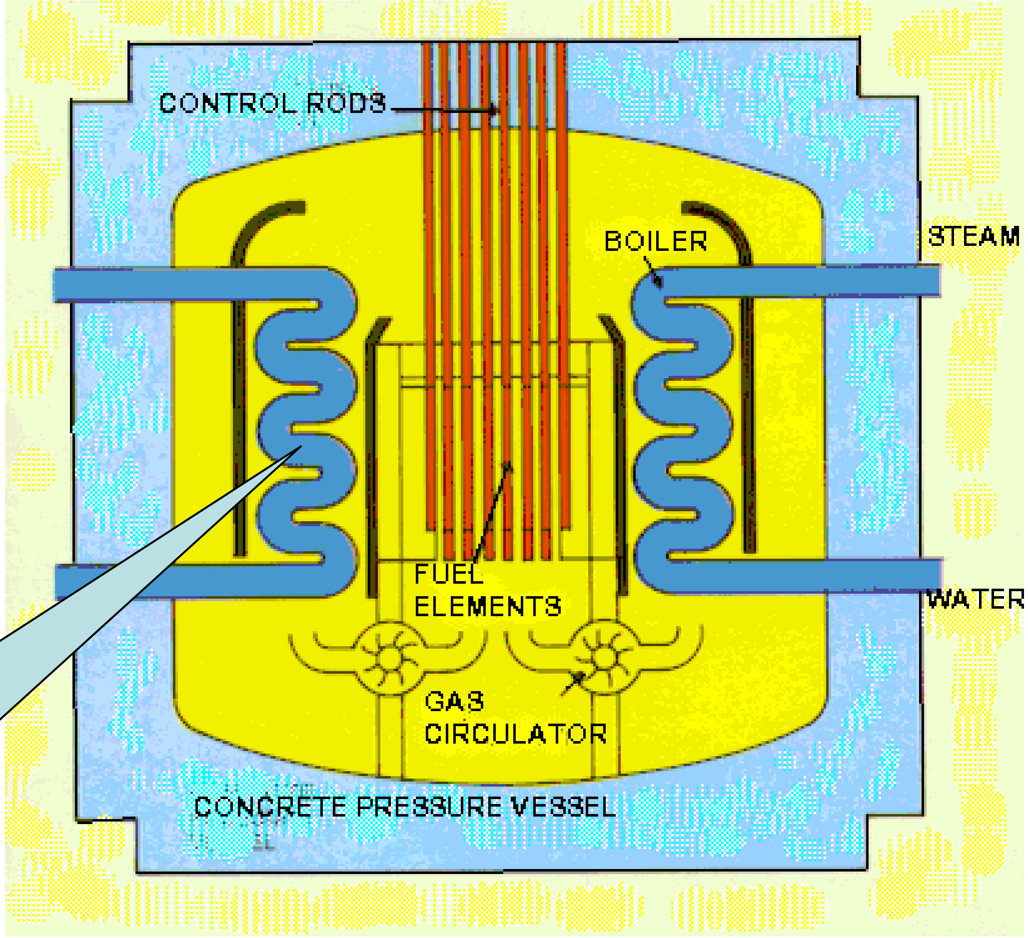
AGR Reactors

- All graphite moderated
- CO_2 cooled
- Electricity generated by an indirect steam cycle
- Higher outlet gas temperature – improved thermal efficiency (~42%) compared to ~30% for the Magnox
- Pre-stressed concrete pressure vessels
- Boilers inside pressure vessel
- Power density ~2.7MWs/m^3 compared to ~0.7MWs/m^3 for the Magnox
- Uranium dioxide fuel in stainless-steel 'pins' – 36 pins per element;
- Approx 308 large channels instead of huge number of small ones (over 6000 in a Wylfa reactor) in Magnox design;
- 'Re-entrant flow' system keeps graphite core temperature below 450C avoiding any thermal oxidation in CO_2;
- Radiolytic oxidation continues, and needs inhibitor added to coolant (methane, together with its decomposition produces hydrogen and water, are all inhibitors along with product carbon monoxide; note 'methane holes' in the graphite)

Hinkley Point B

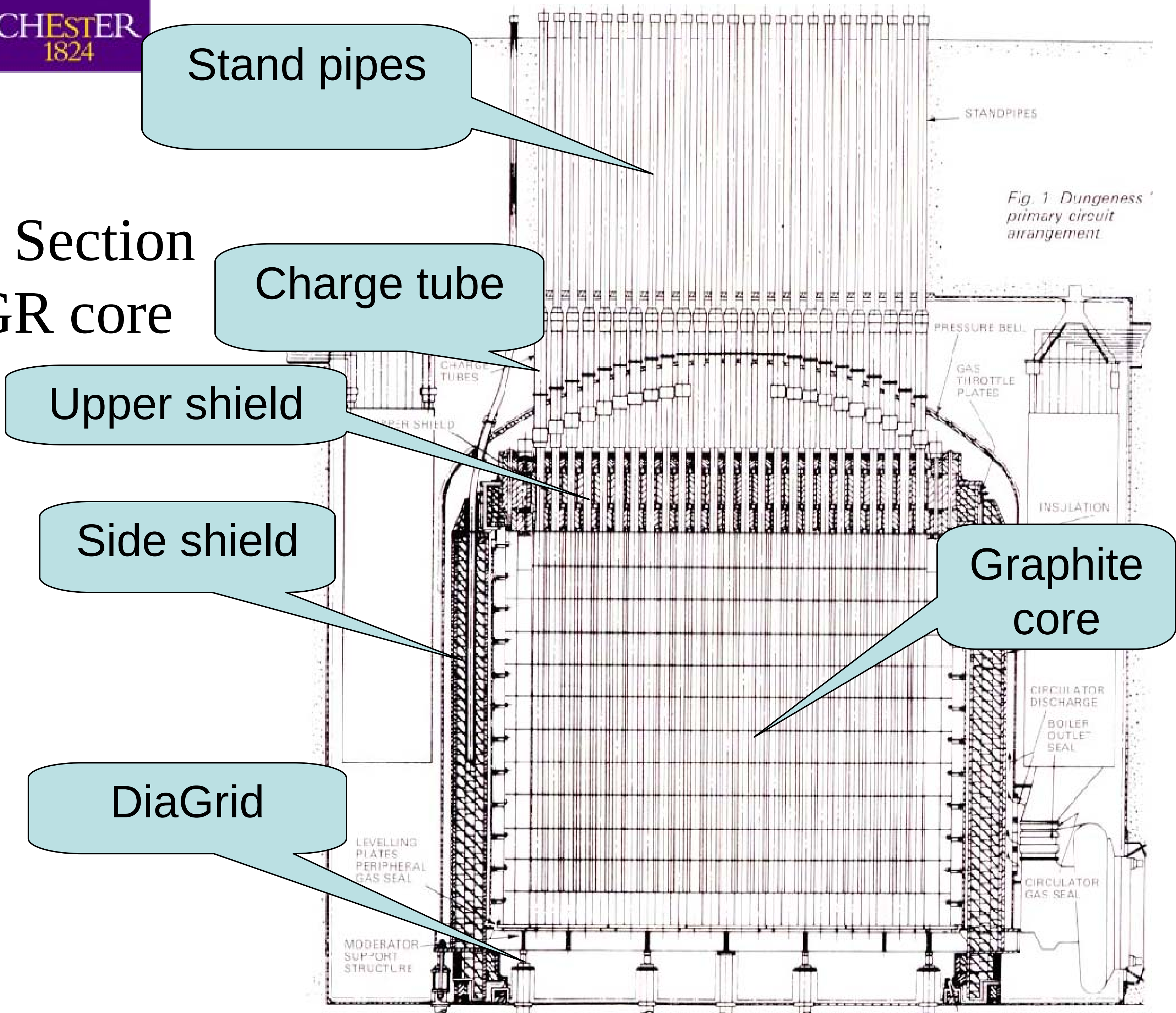


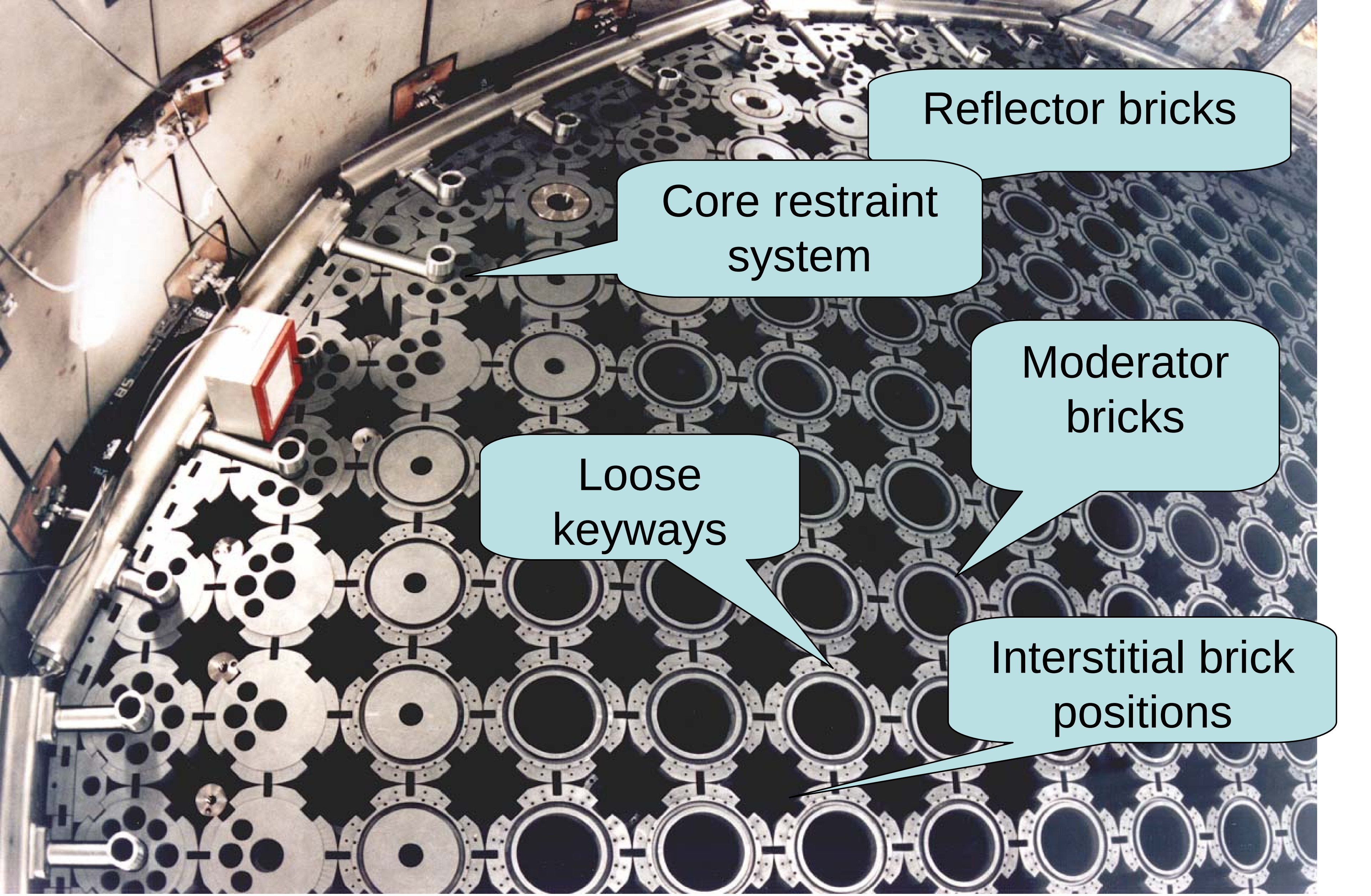
Schematic View of Advanced Gas Cooled Reactor



Boilers inside pre-stressed concrete pressure vessels

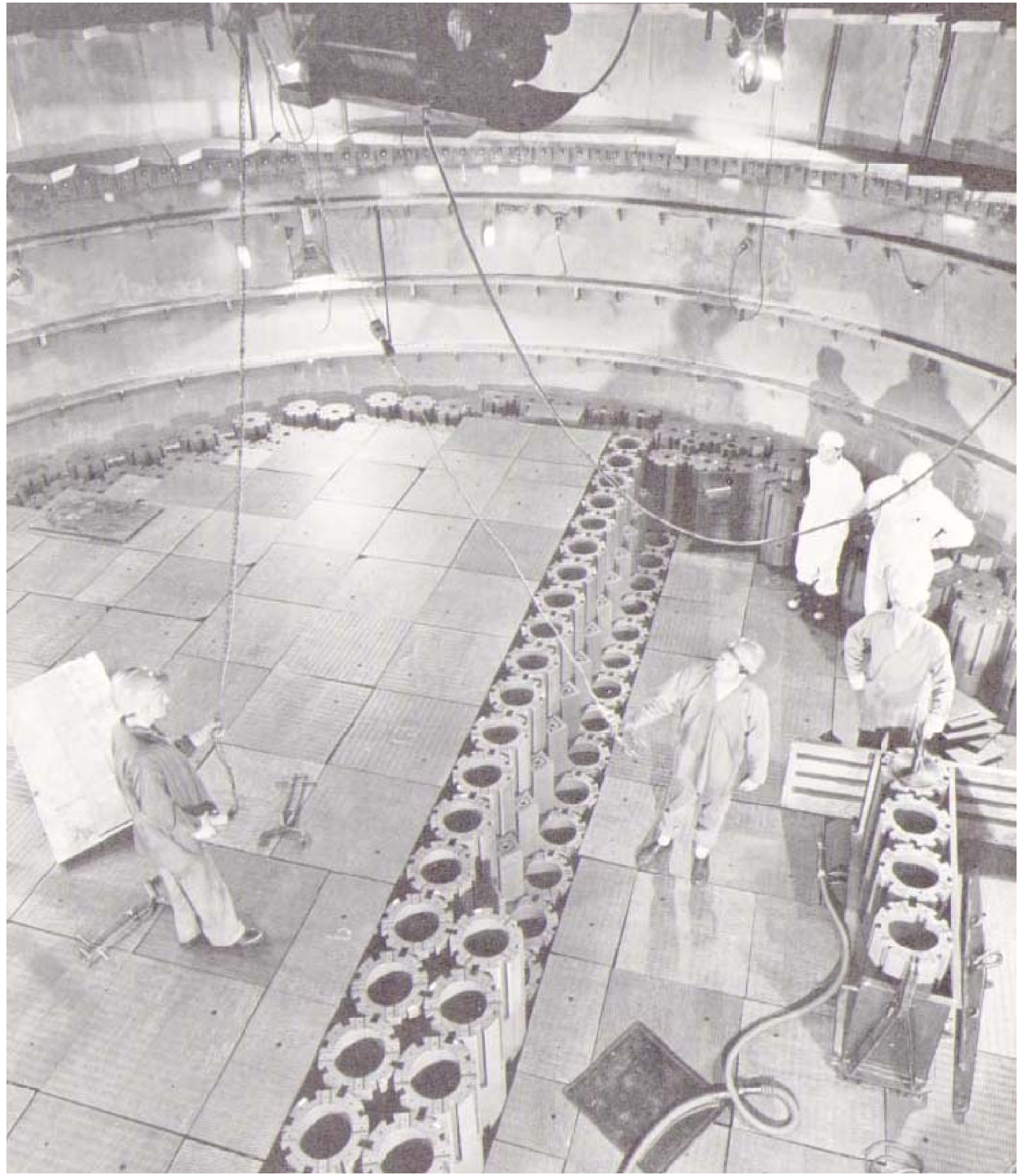
Cross Section of AGR core





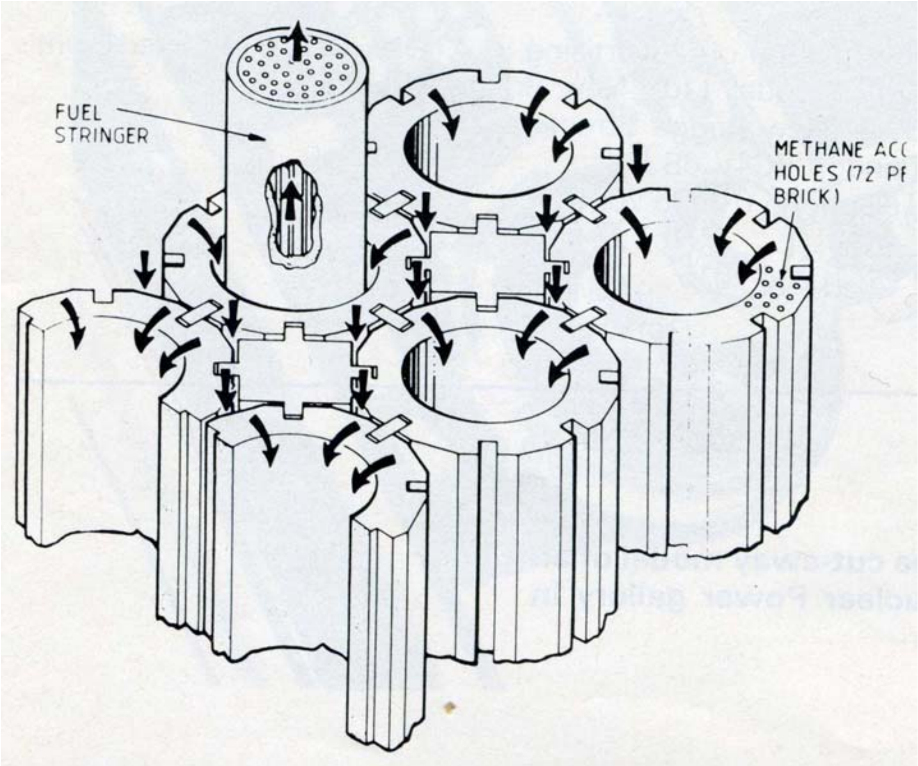
Construction of Torness Core

AGR Core Assembly

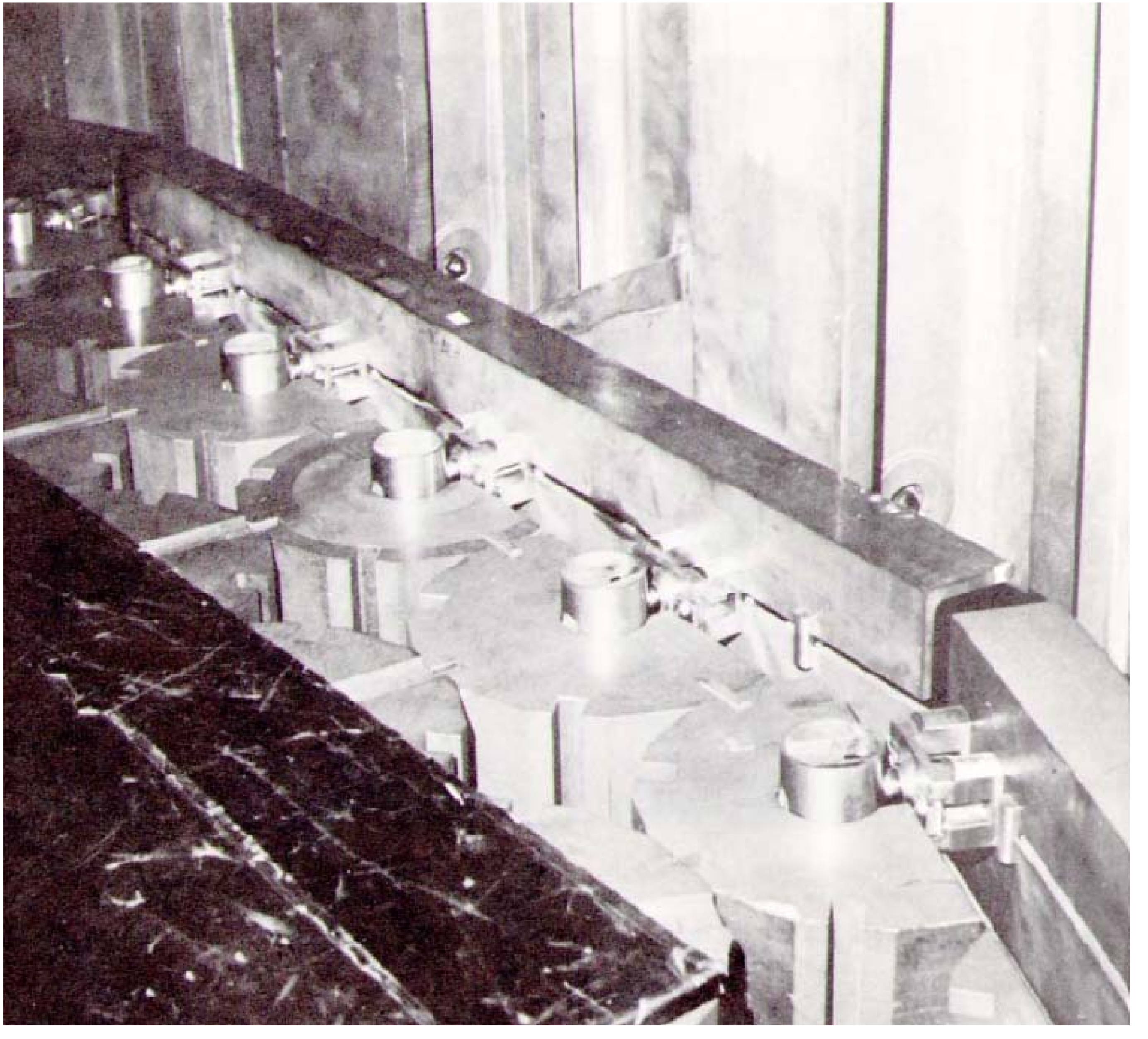


AGR Brick Assembly Showing Flow Directions

- The main coolant flow is upwards along the fuel sleeves around the fuel pin bungles
- Reverse interstitial flow:
  - between fuel stringer and brick
  - down arrow head passages
- Cross brick pressure drop in most cases (by design or accident)
- Methane holes provided to try and give access to the graphite coolant throughout the brick



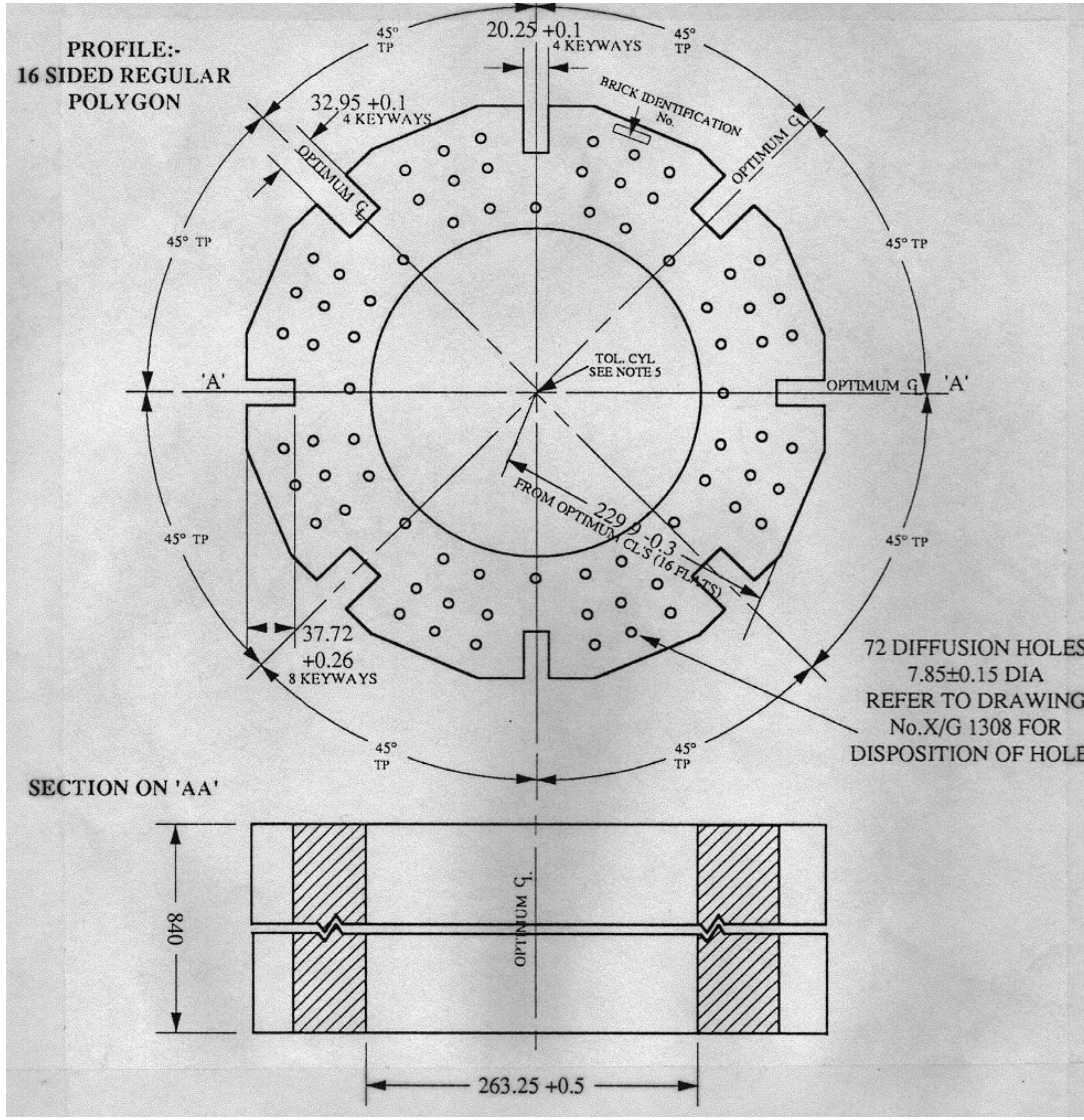
AGR Core Side Restraint



AGR Brick Design

- Four different basic designs
- All include methane holes
- All have sharp keyway corners
- Some are keyed 1/3 the length
- Others keyed the whole length but with location keys over the mid 1/3 and filler keys over 2/3s the length
- Some cores include complex rocking features

Hinkley Point B
Hunterston B
Fuel Brick



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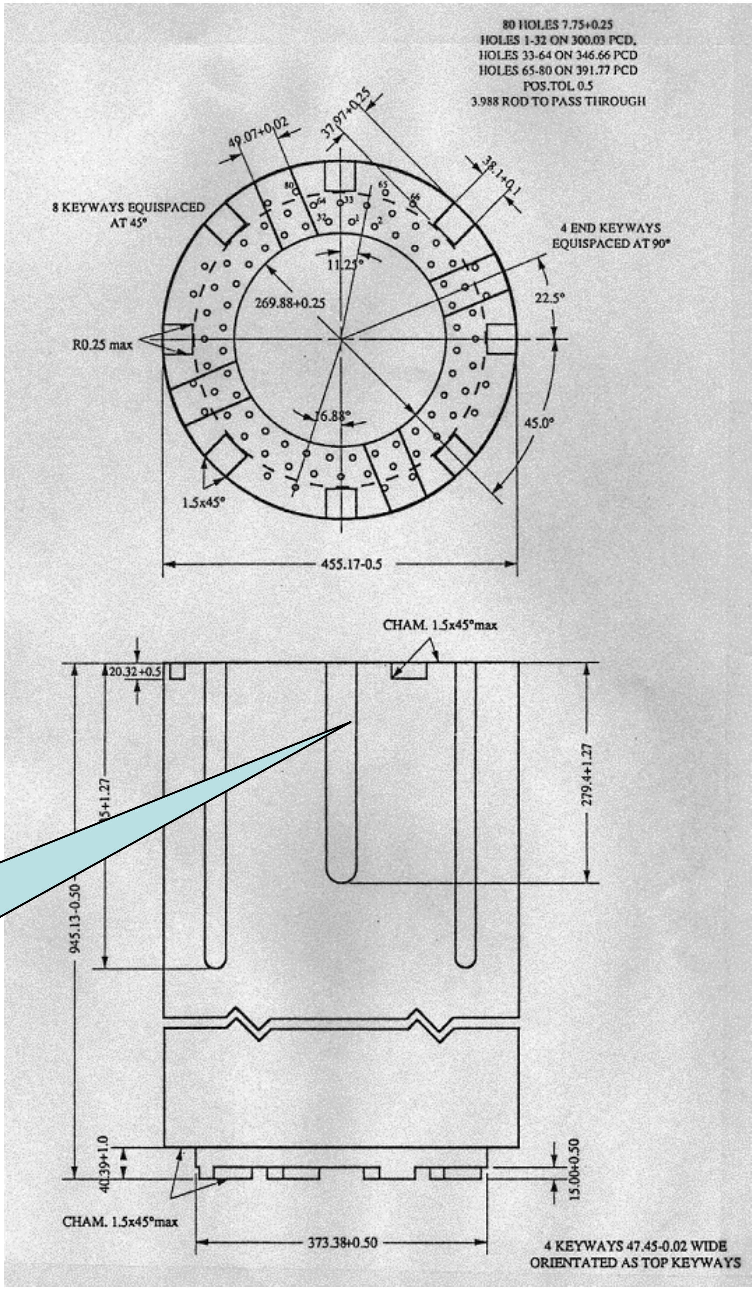
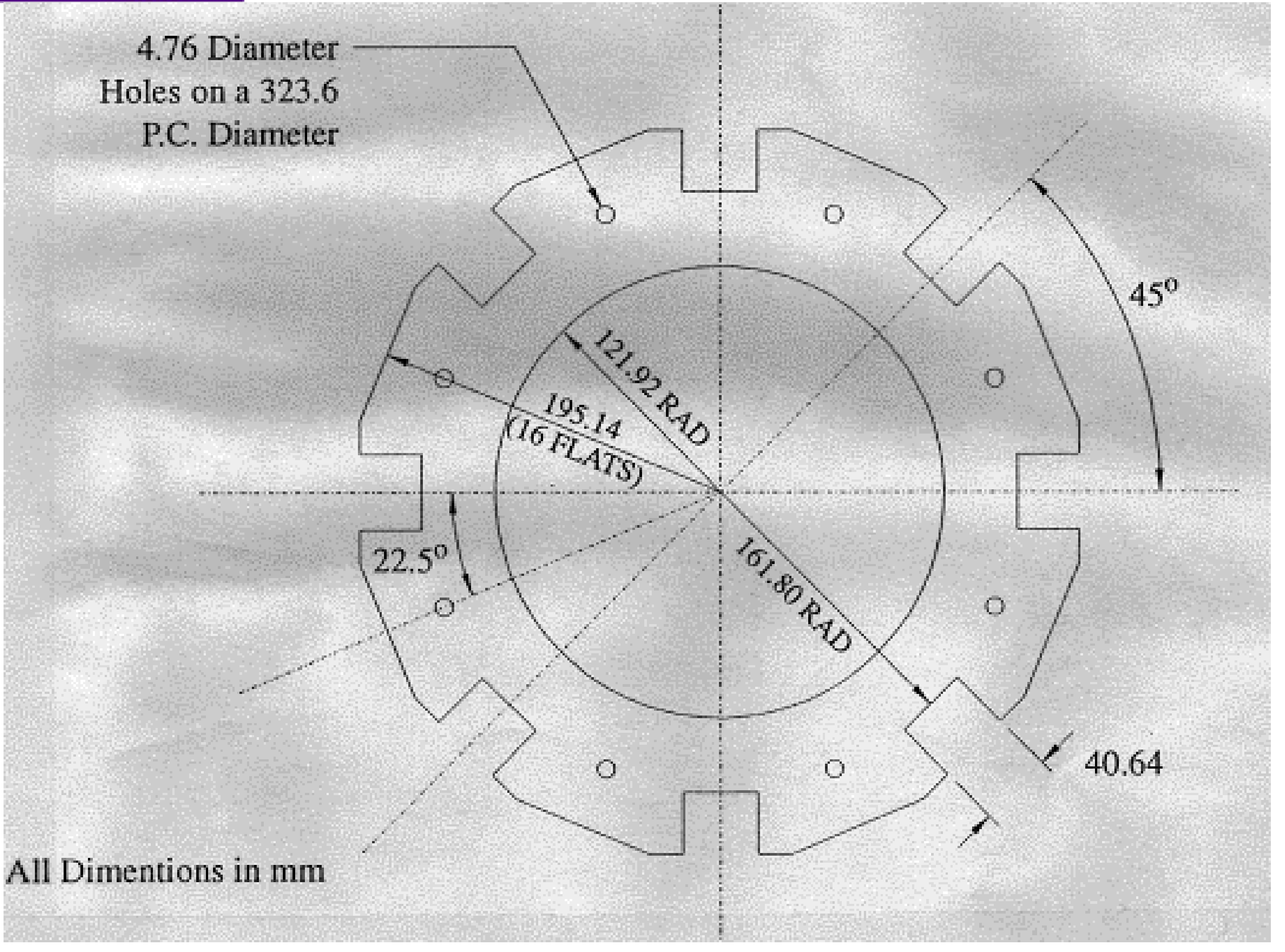
Hartlepool

Heysham 1

Fuel Brick

Keys only extend 1/3 the length of the brick





Dungeness B Fuel Brick

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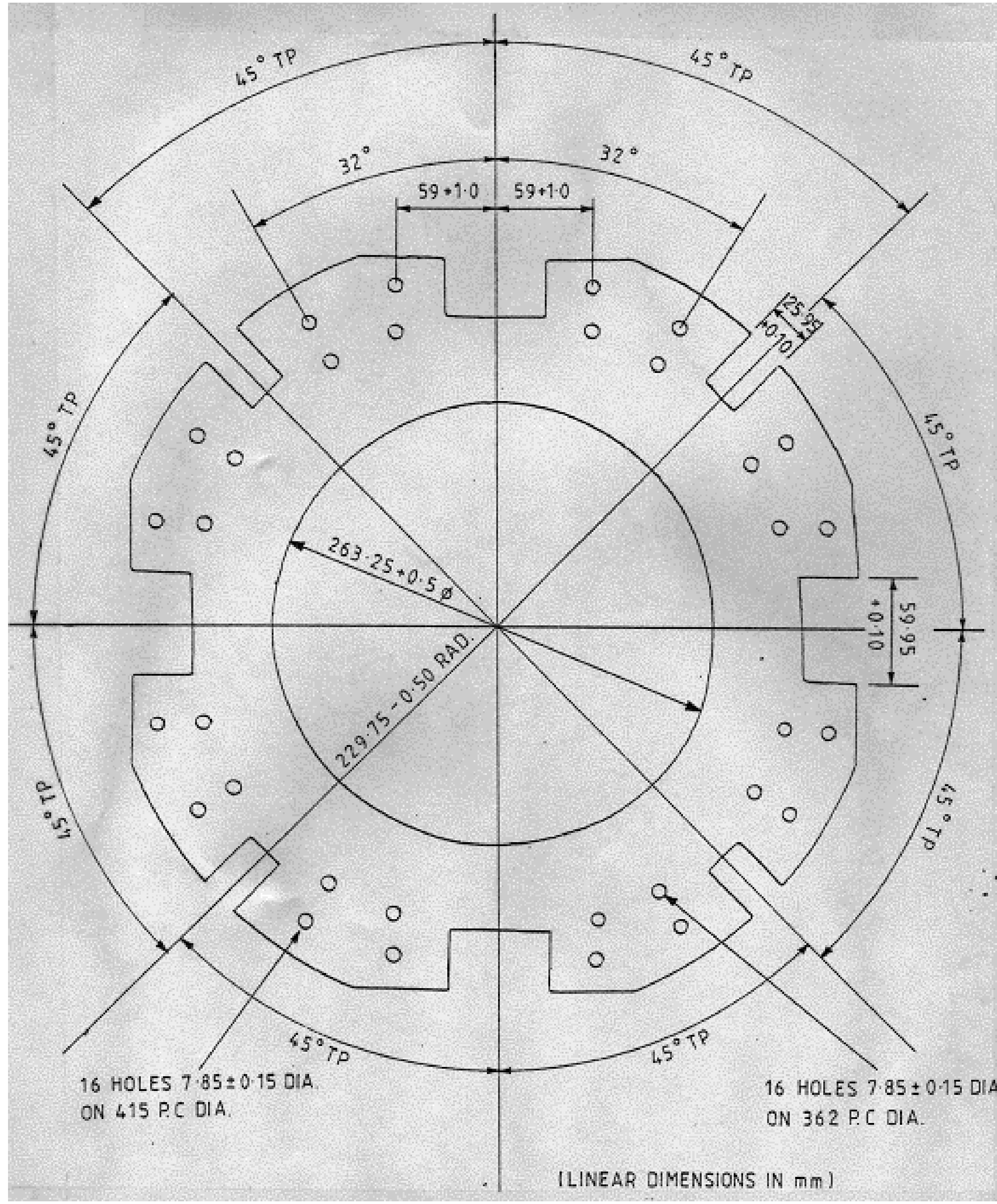
Heysham 2

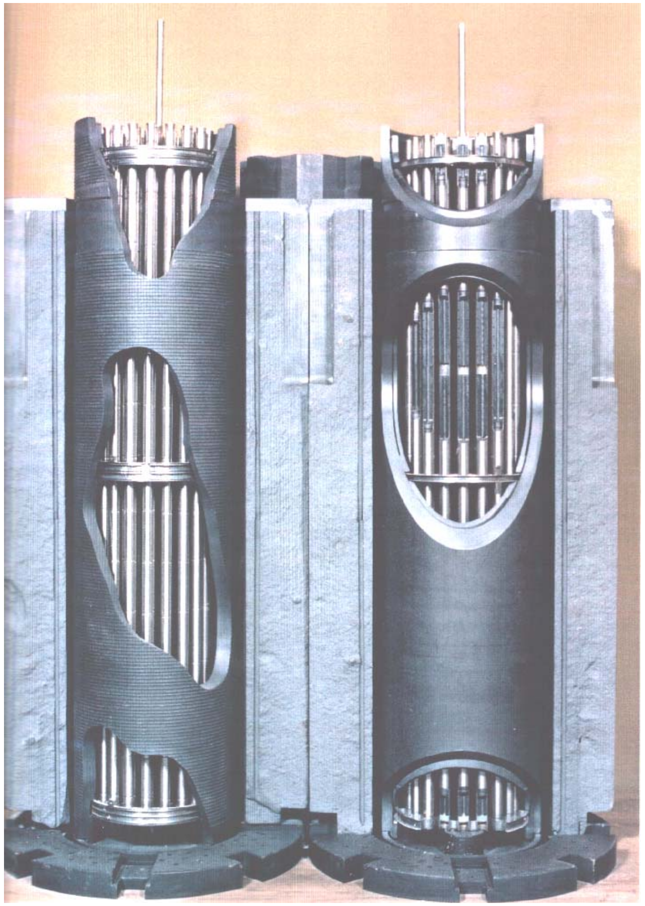
Torness

Fuel Brick



Cut away section of Hartlepool / Heysham 1 Fuel and moderator Bricks

- Eight fuel sleeves in a “stringer” suspended from tie rod (7 at Dungeness B (DNB))
- 36 pins (30 at DNB) held in 3 grids/braces
- Right double sleeve Mark 1 fuel sleeve design
- Left single sleeve Mark 2 fuel sleeve design



Safety Shut-Down Features

MAGNOX

- Control rods containing B, Cd
- Additional ‘hold-down’ rods
- Secondary system of ‘boron balls’ (actually high-B steel) – recoverable
- Boron ball system in Calder Hall / Chapelcross
- Ultimate system – blowing in ‘boron dust’ – actually boron oxide (Never used).

AGR

- Articulated Control rods containing B, Cd
- Additional ‘hold-down’ rods
- Secondary system of nitrogen injection
- Additional systems such as ‘boron balls’ are being considered as retrofit to satisfy the Nuclear Installations Inspectorate’s concerns about core integrity and core restraint integrity

HTR Core Design

High Temperature Reactor

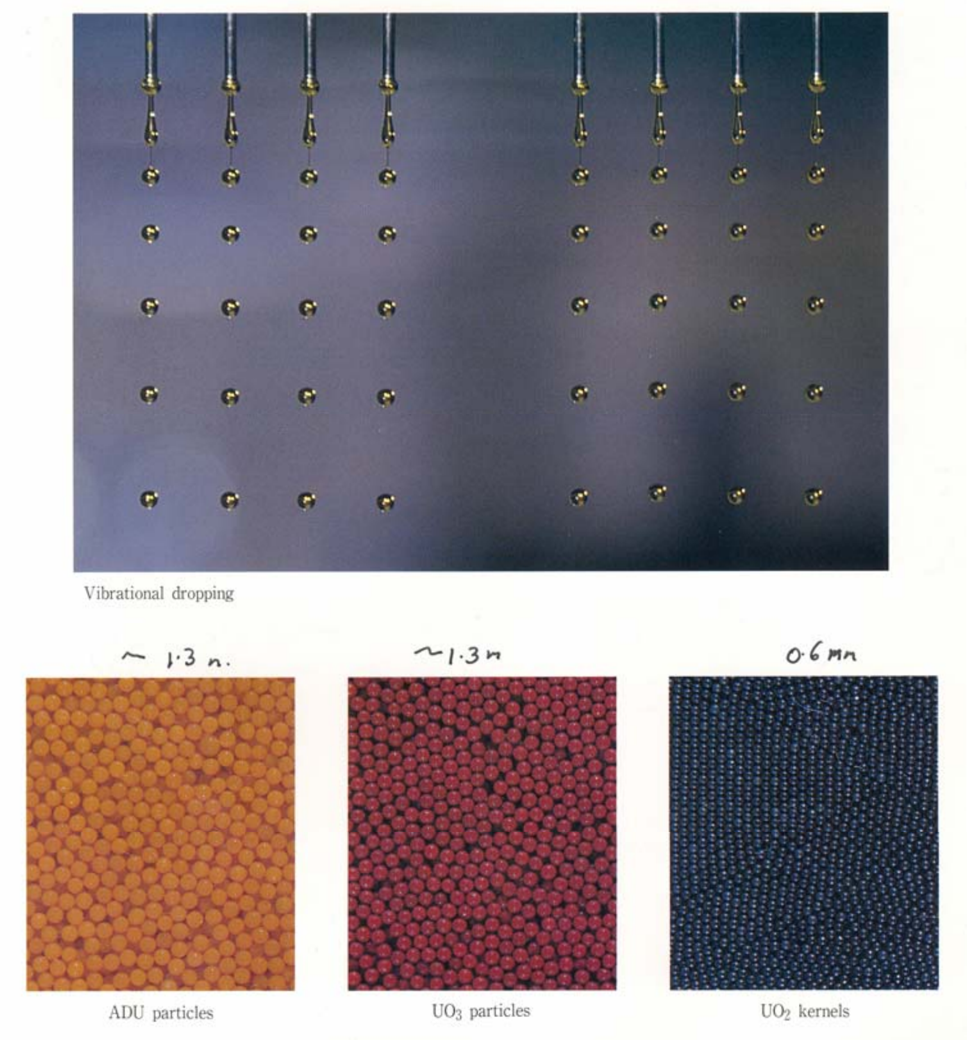
- High gas output temperature, above 700^{o}C
- Ceramic Fuel
    - Pyro-carbon and Silicon Carbide Coating
- Graphite Reflector
- Helium Gas Cooling
- Direct Gas Turbine or Indirect steam generation
- Prism or Pebble Bed configuration

High Temperature Reactors

Reactor	Purpose	Country	Criticality	Shut-down	Type	MW(t)
Dragon	Research	OECD	1962	1976	Prism	20
Peach Bottom	Research	US	1966	1974	Prism	115
Fort St. Vrain	Power	US	1977	1992	Prism	842
AVR	Research	Germany	1967	1988	Pebble	49
THTR	Power	Germany	1983	1989	Pebble	750
HTTR	Research	Japan	2003	Operating	Prism	30
HTR-10	Research	China	2003	Operating	Pebble	10
HTR-PM	Prototype	China	Under Design		Pebble	two 250 units
PBMR	Power	South Africa	Under Design		Pebble	240
GT-MHR	Power	International	Design Concept		Prism	600
ACAICA	Power	NRG	Design Concept		Pebble	40
NGNP	Research	US	Under Design		Pebble or Prism	600

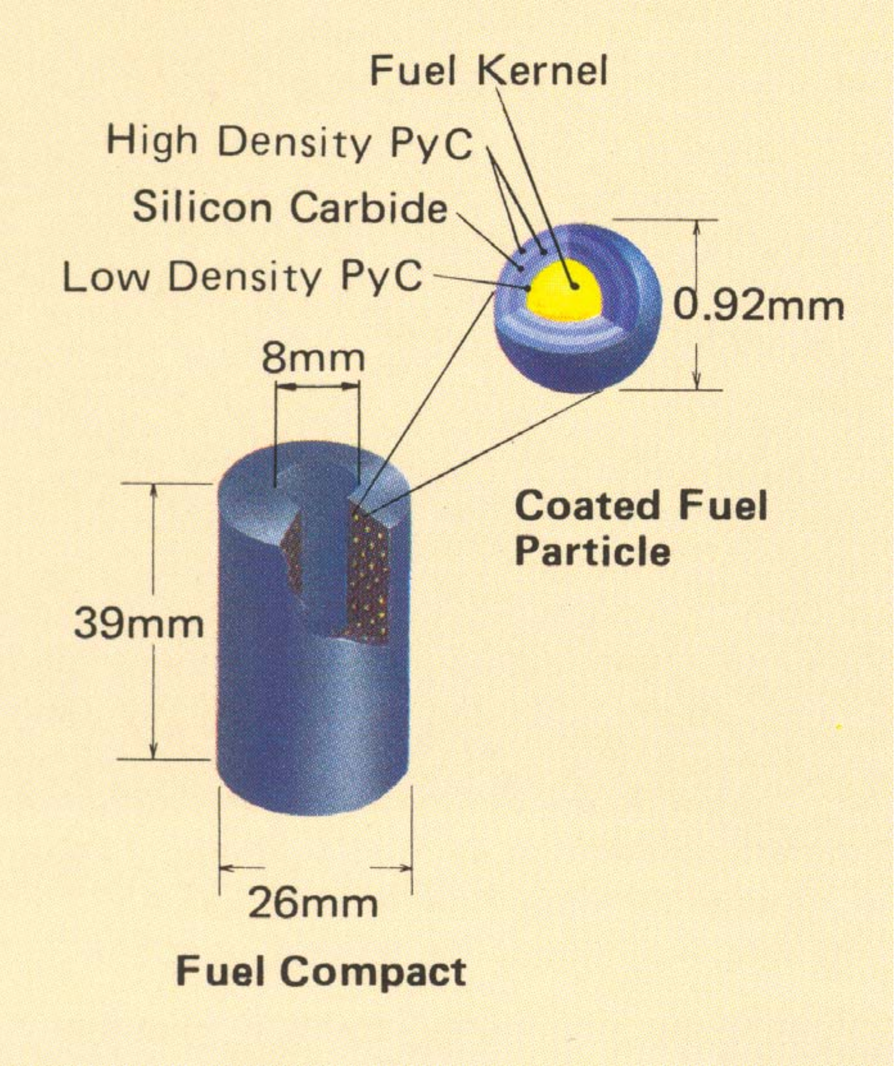
Production of Coated Fuel Particles

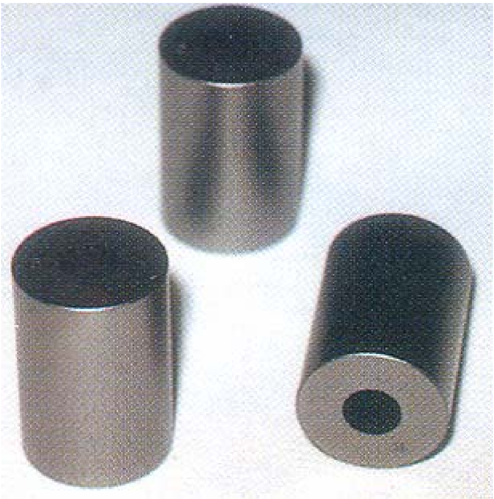
- Uranyl Nitrate droplets
- ADU Particles
- Calcined to Produce
- UO_3 Particles
- Sintering and coating to produce UO_2 Kernels



HTR Prism Fuel Compact

Compacts manufactured from crushed natural and artificial graphite in formaldehyde resin (baked)





Prism Fuel Compact

Pebble Fuel

60 mm diameter

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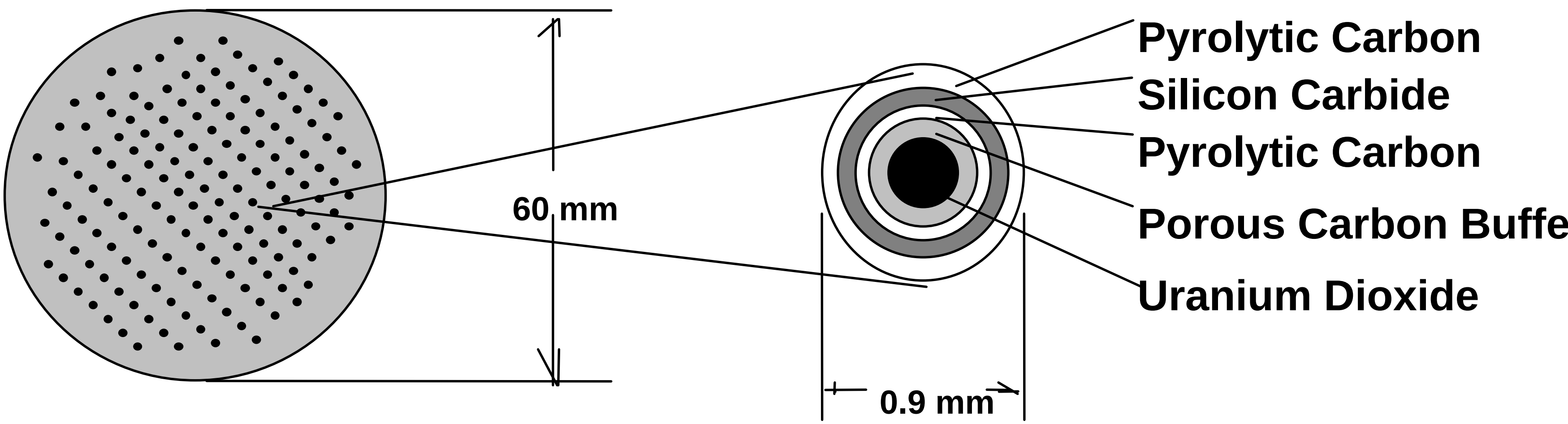
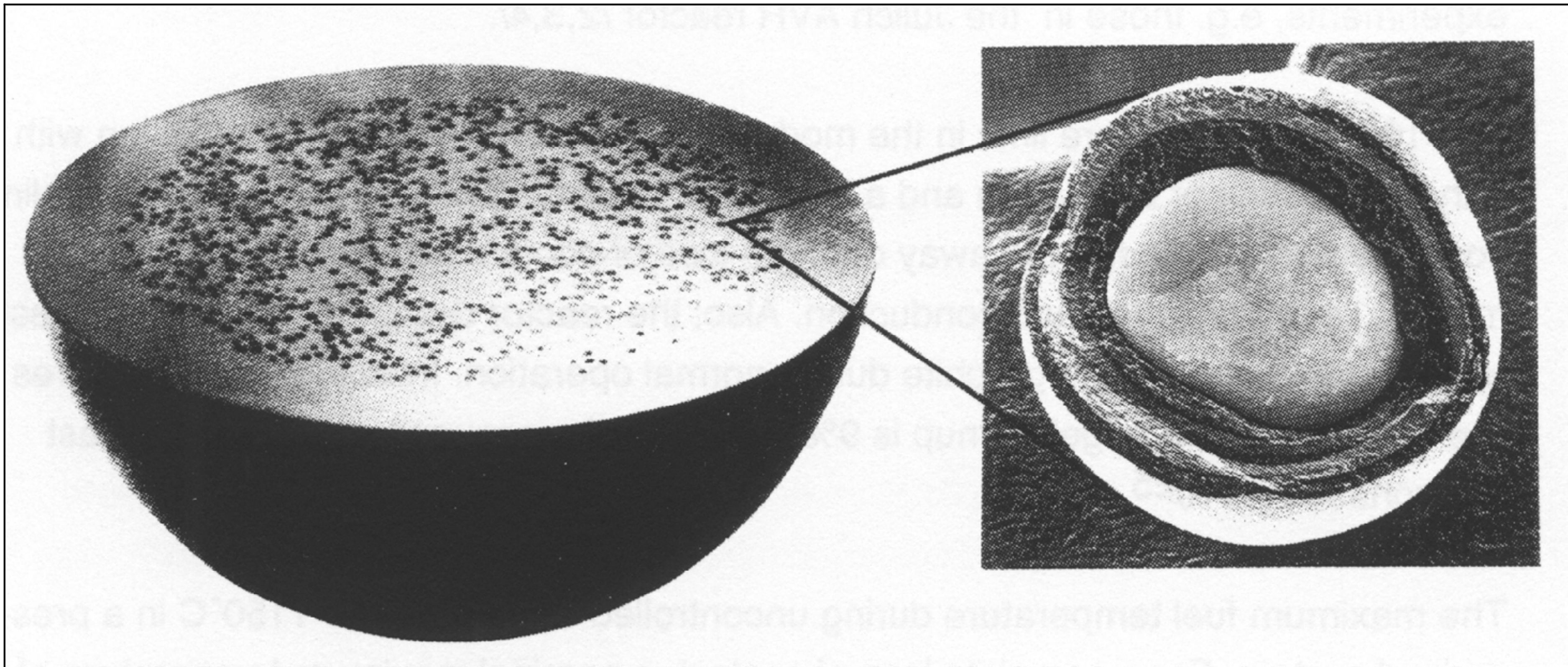
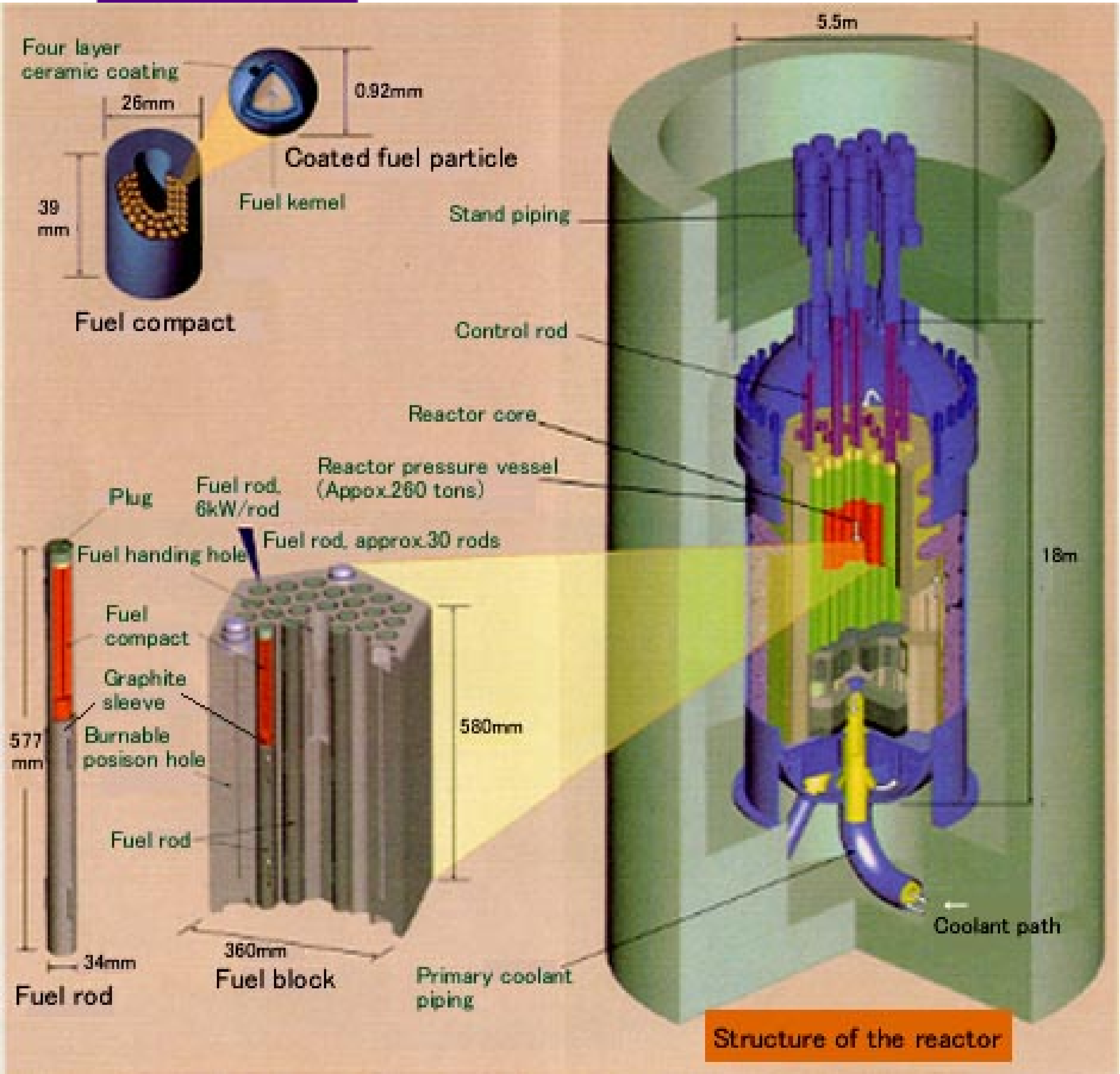
Fuel Design



Pebble Fuel

HTR Pebble Cross-section **Cut-away Coated Particle**

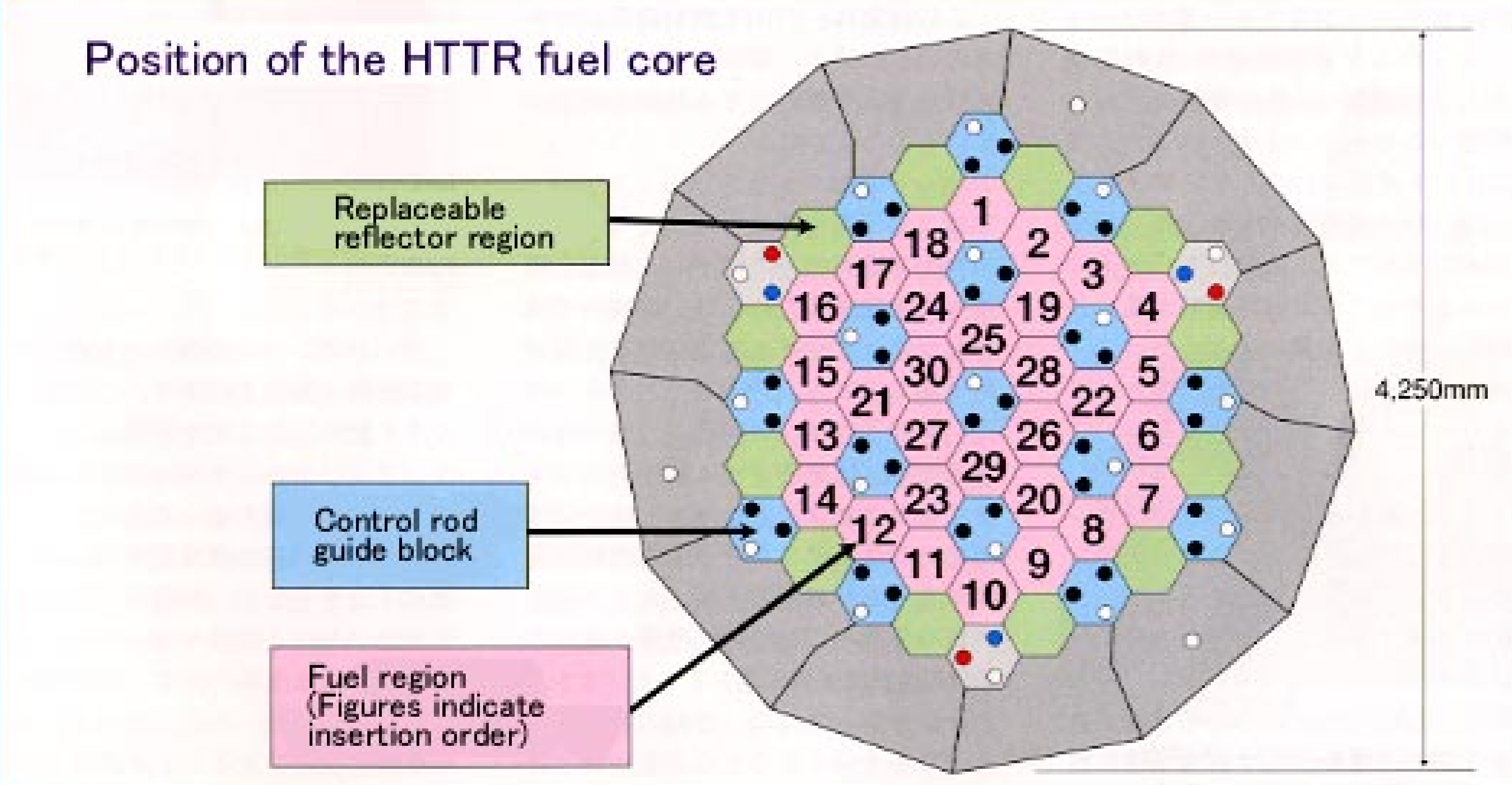




HTTR

Prism Design

HTTR Core Cross Section Prism Design



HTTR JAERI - OARAI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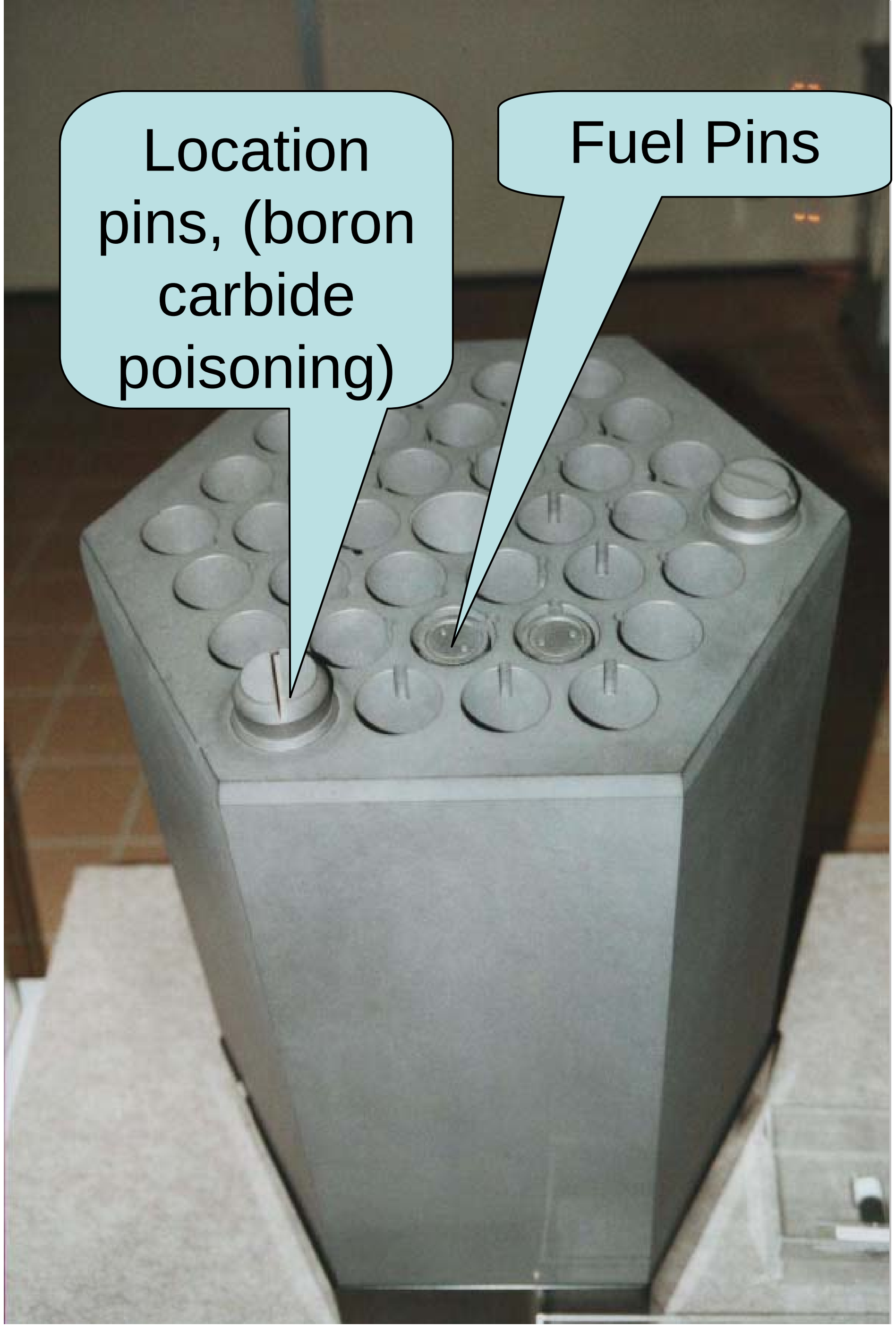
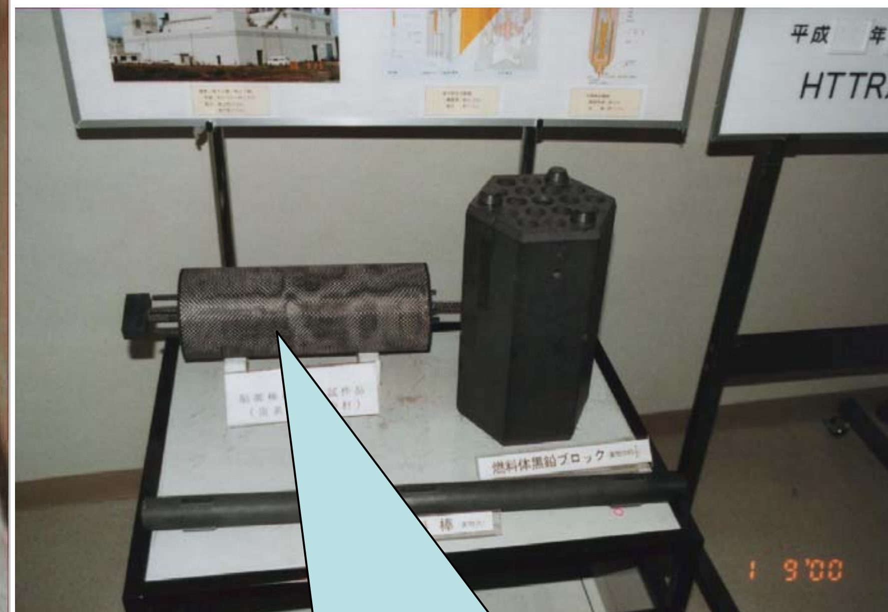
Fuel Blocks


Location pins, (boron carbide poisoning)
Fuel Pins


Fuel Pin

Control rod holes



Prototype carbon composite control rod segment

Fuel Handling Head

Seismic Assessment Rig

Horizontal assembly

Vertical assembly

Scale components, metal insert to give density of fuel

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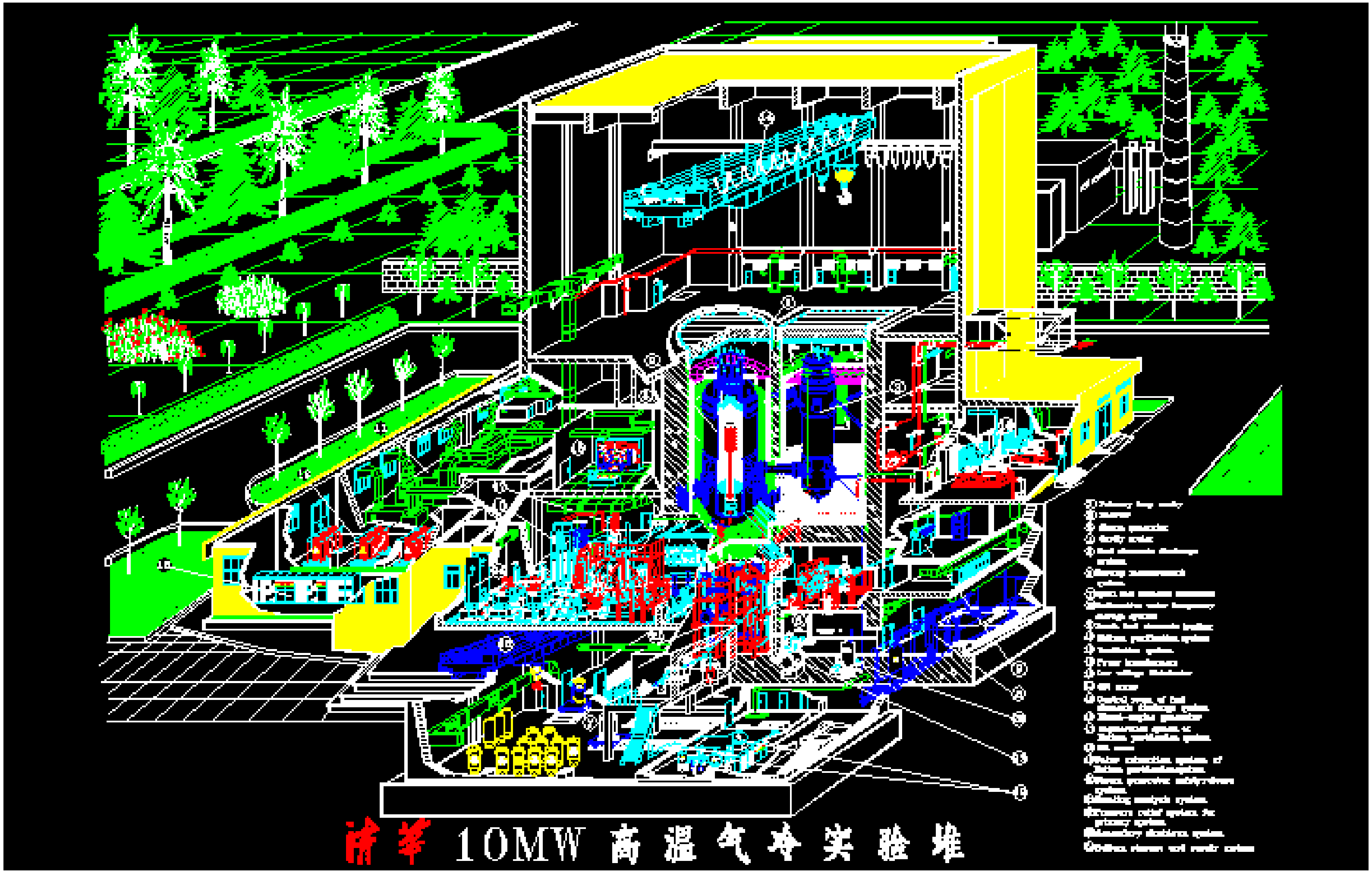
Waste Heat

HTR-10



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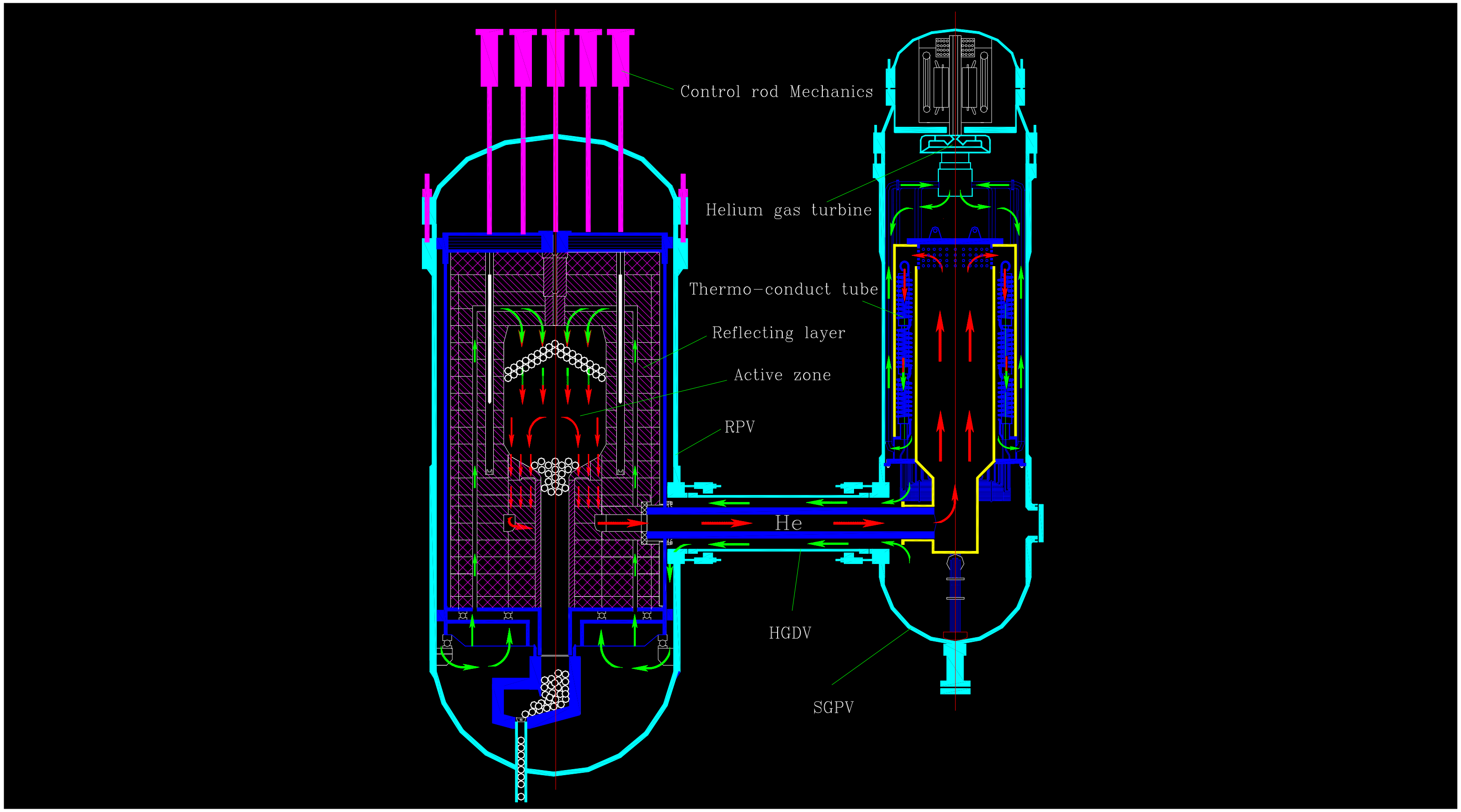
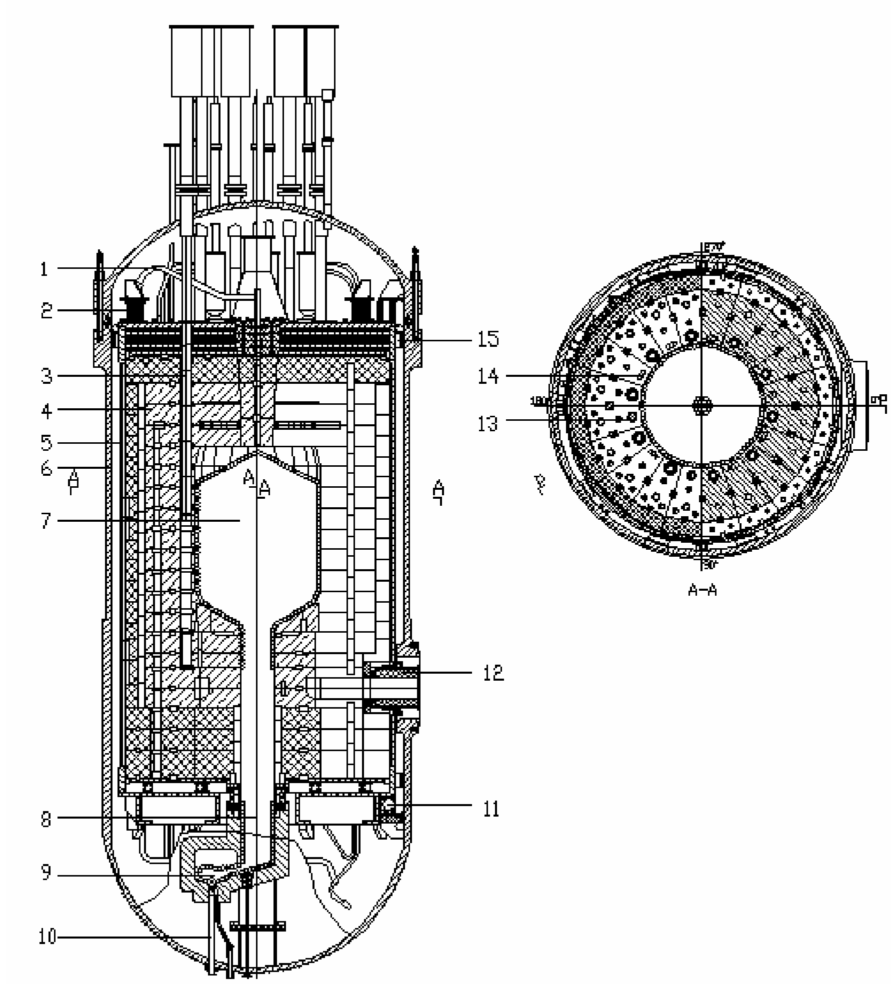
Vertical Cross Section Through Reactor



Cross Section Through Reactor Core



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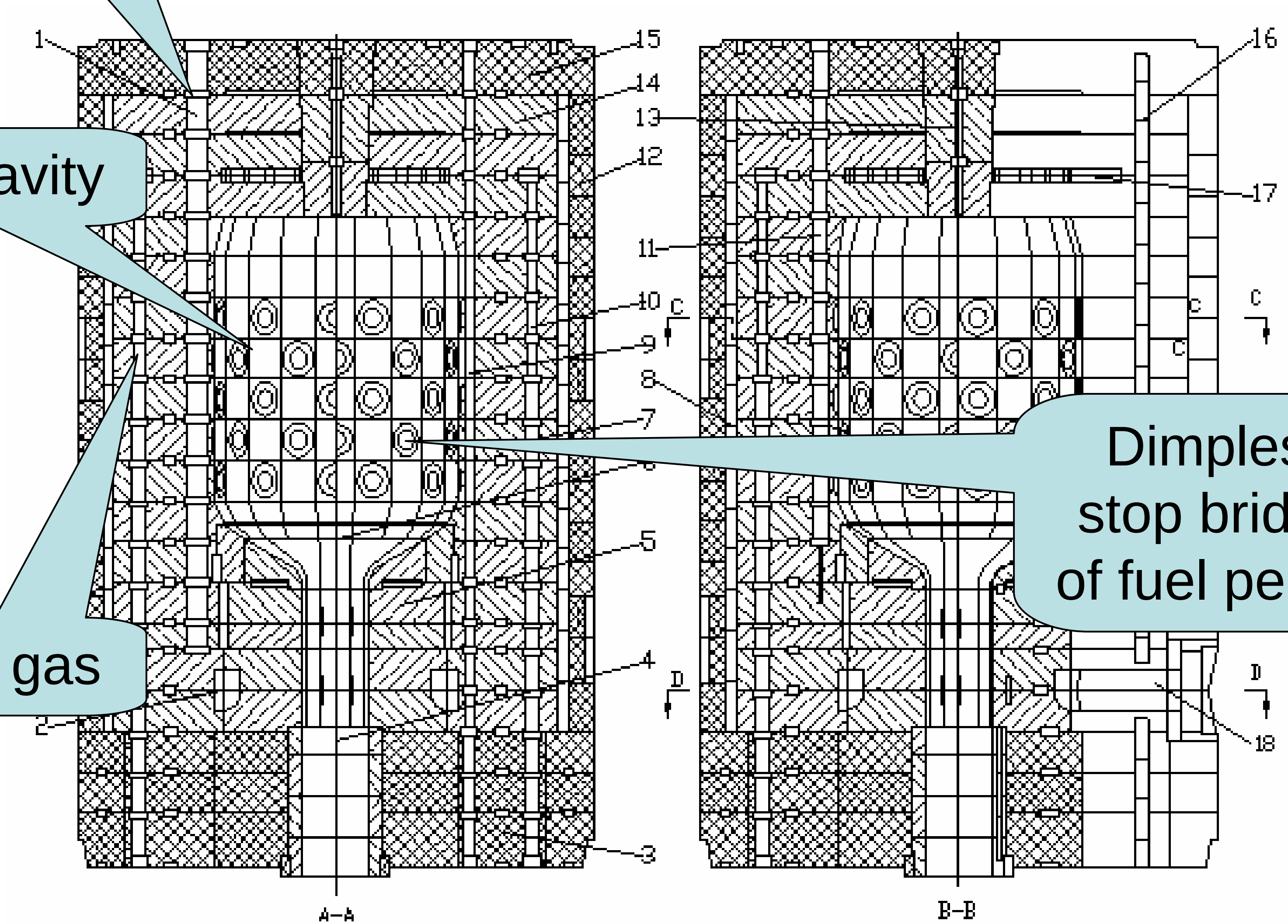
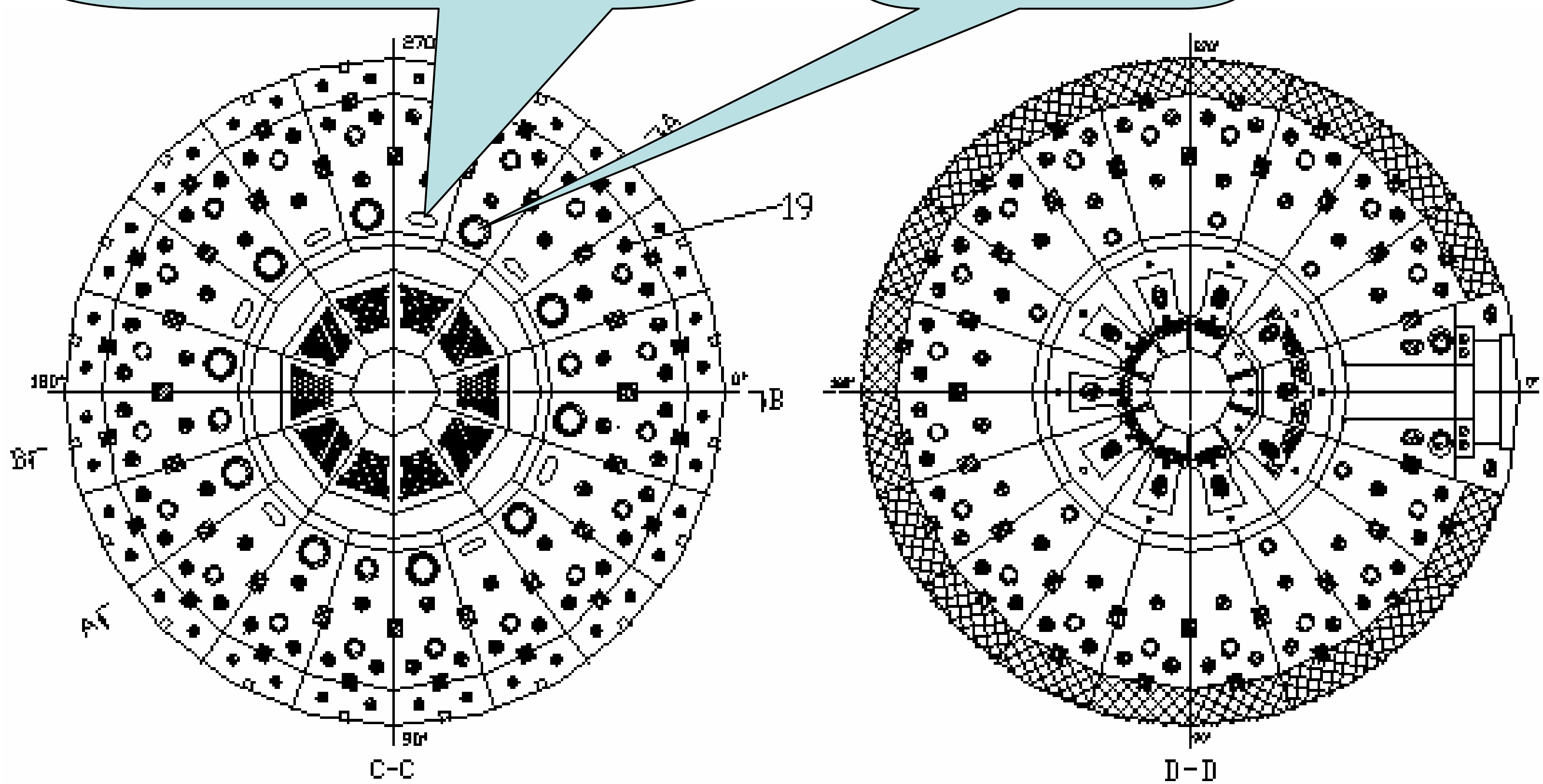

Control rod hole
Core cavity
Return gas
Dimples to stop bridging of fuel pebbles
1
2
3
4
5
7
8
9
10
11
12
13
14
15
16
17
18
C
D
A–A
B–B

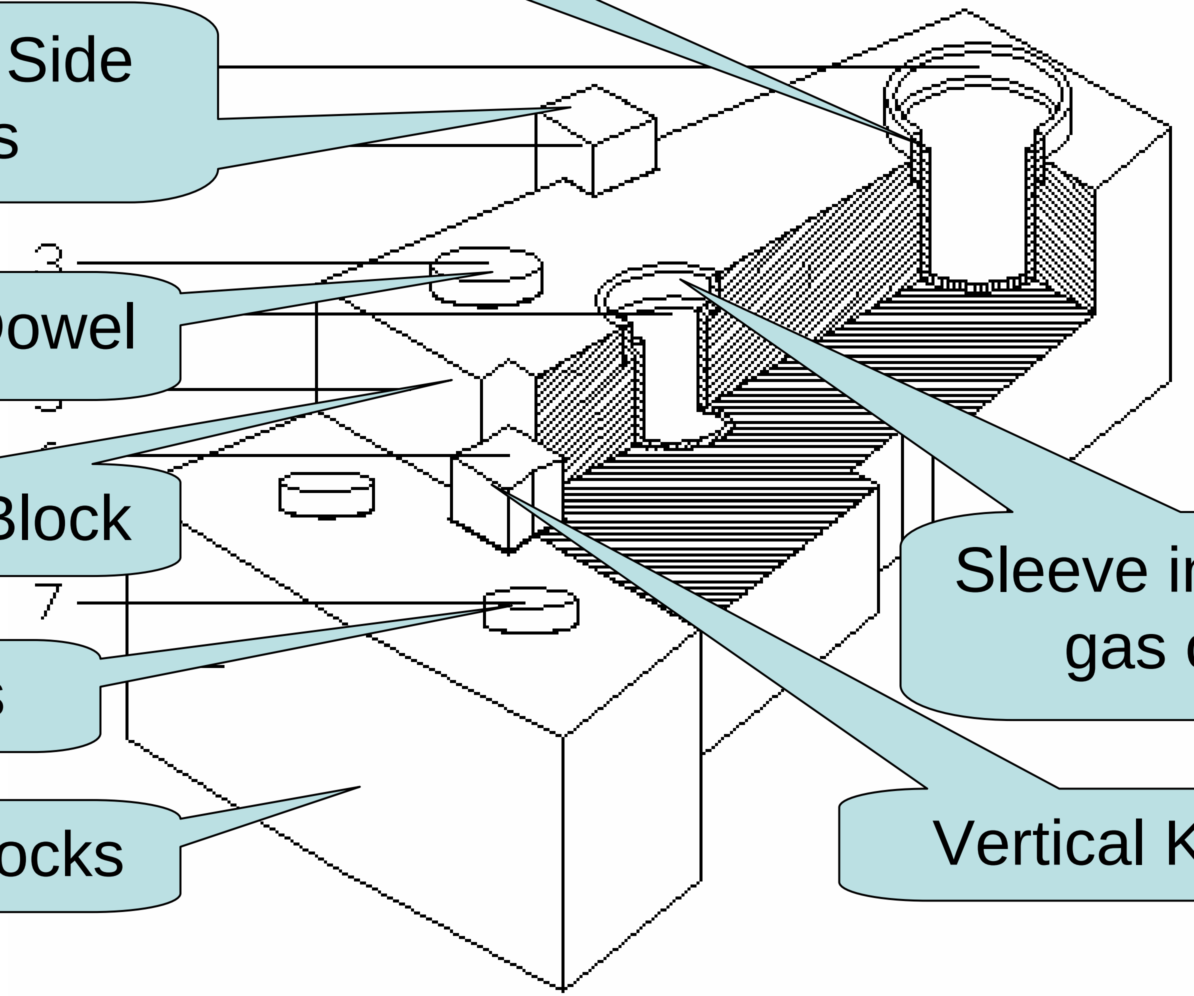
Horizontal Cross Section

Boron ball shut down holes

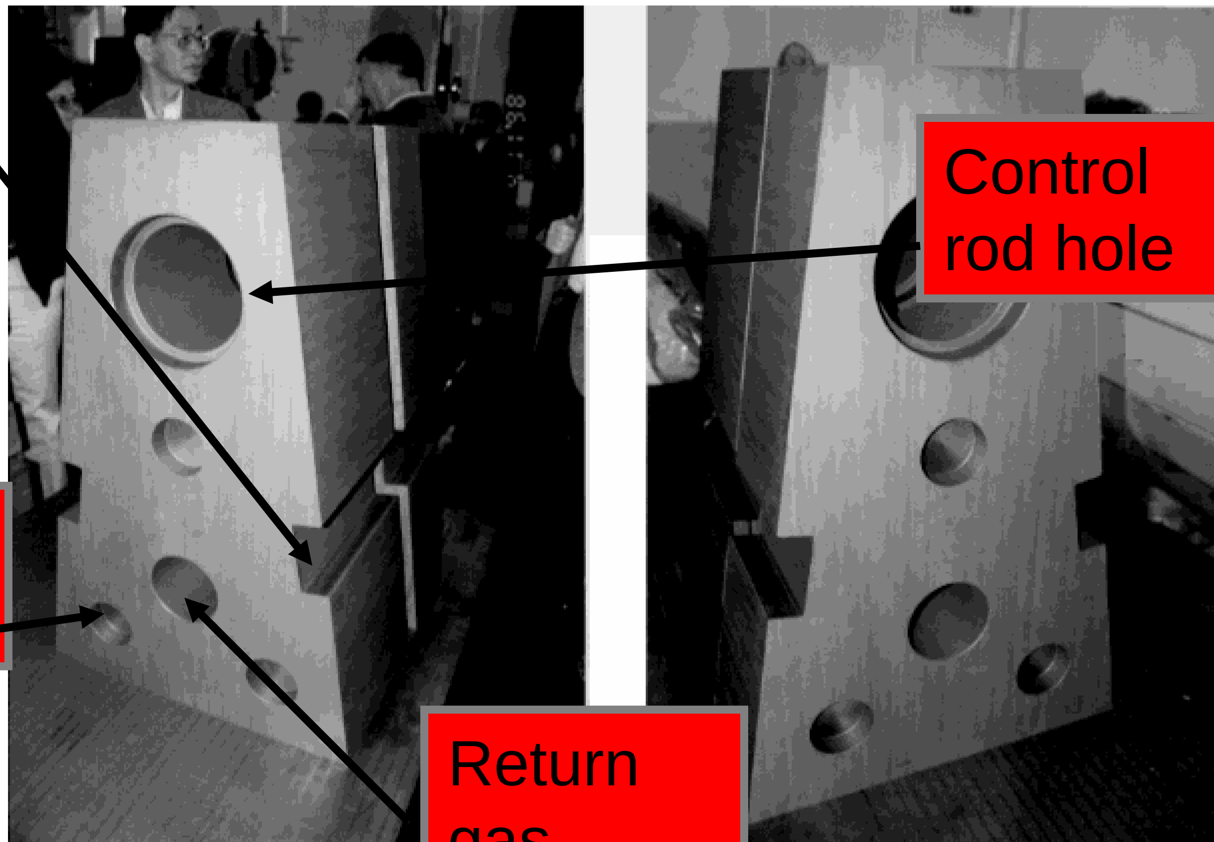
Control rod hole



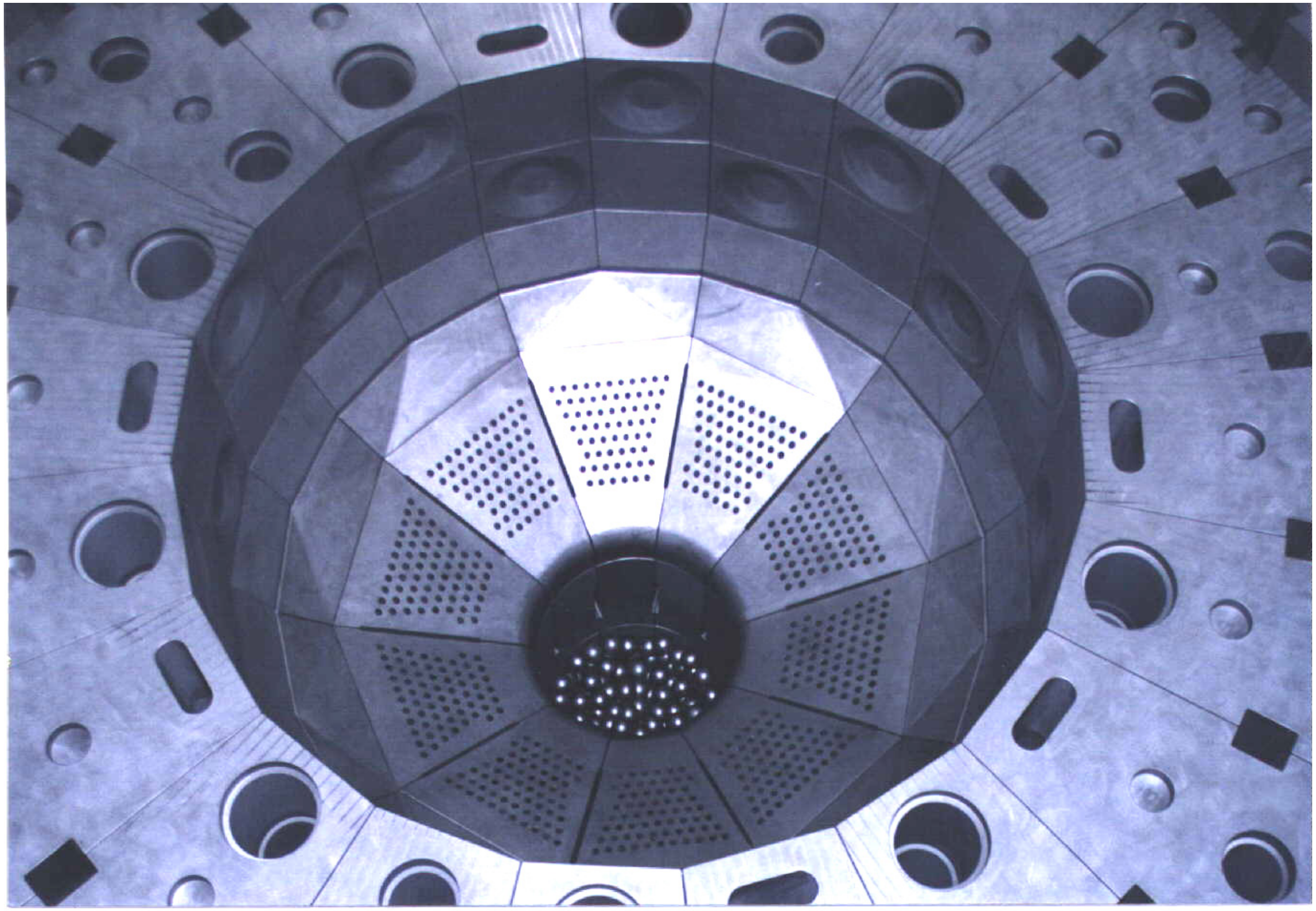
Construction



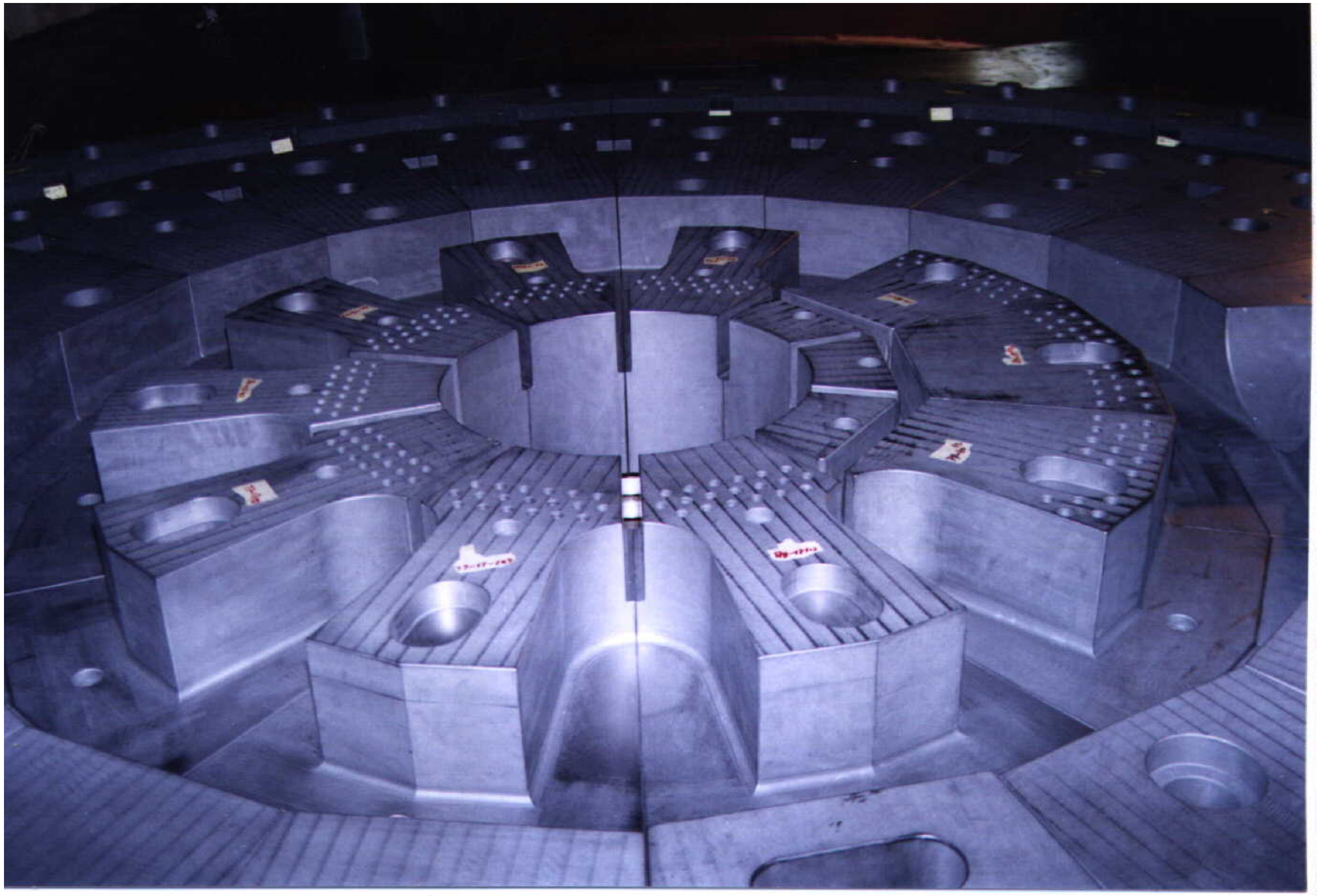
Typical HTR Graphite Reflector Blocks HTR-10



Lower Core Structure



Lower Half of Hot Gas Chamber



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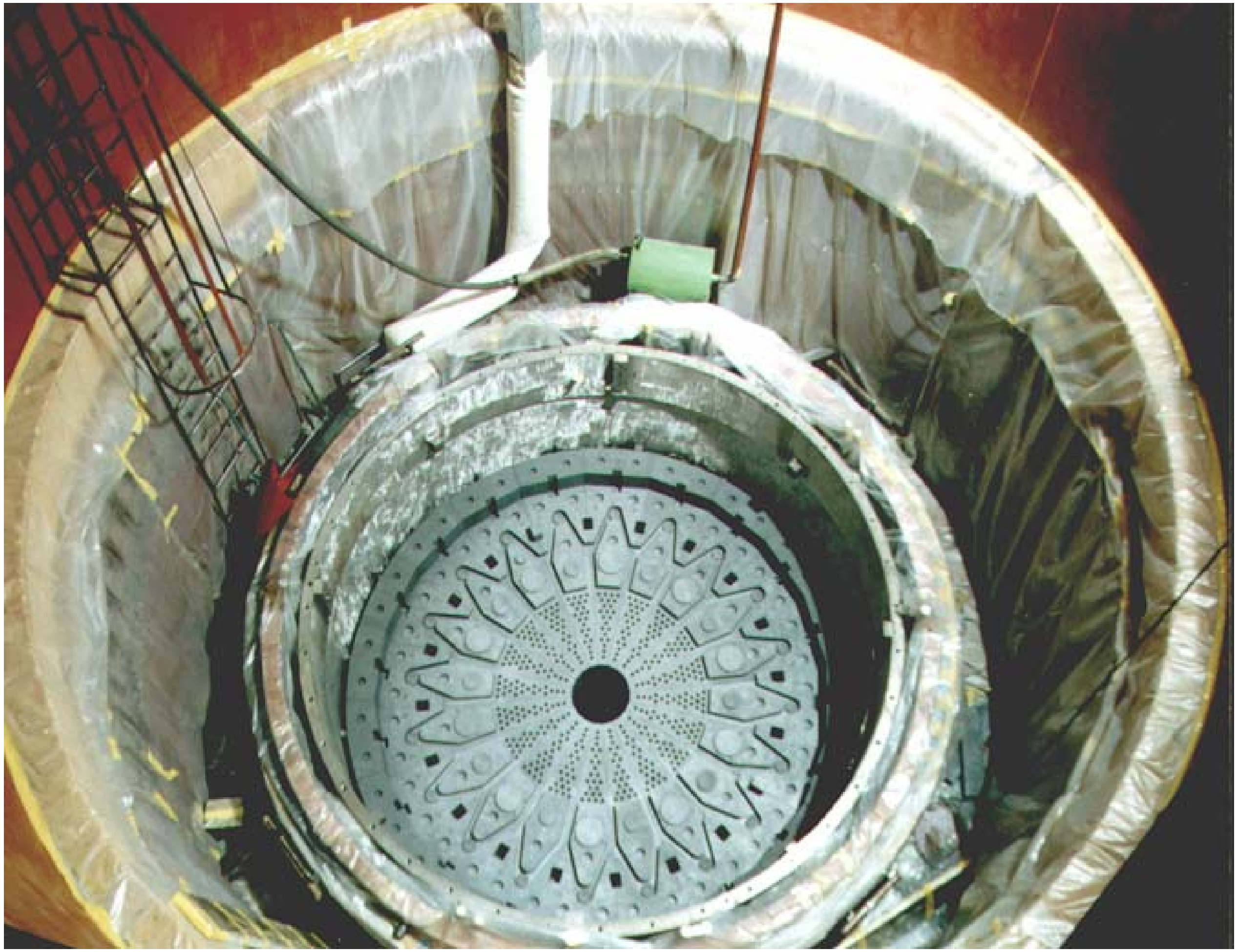
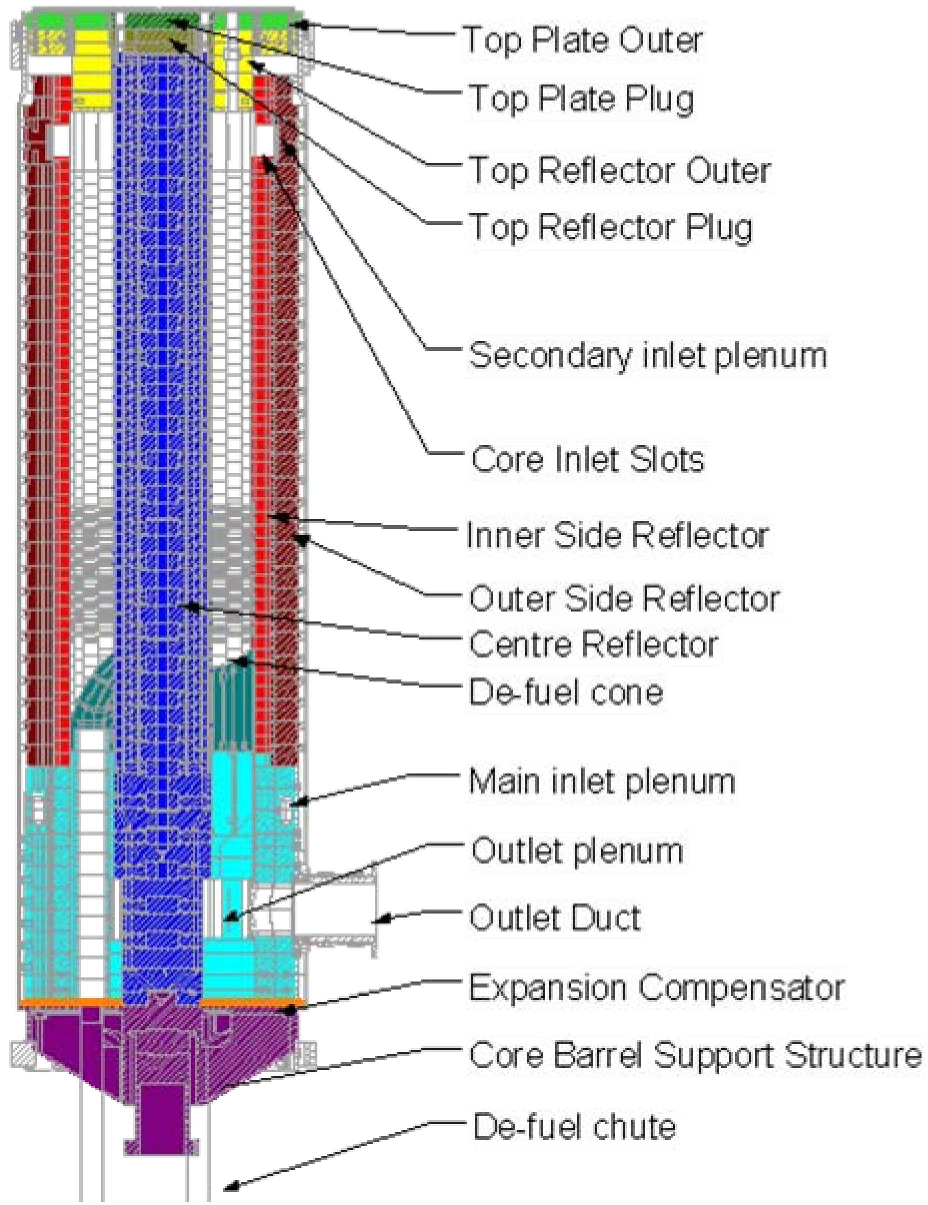
Top Reflector



PBMR Design Features (Original Concept)

- Utilises direct-cycle gas turbine
- note central graphite reflector



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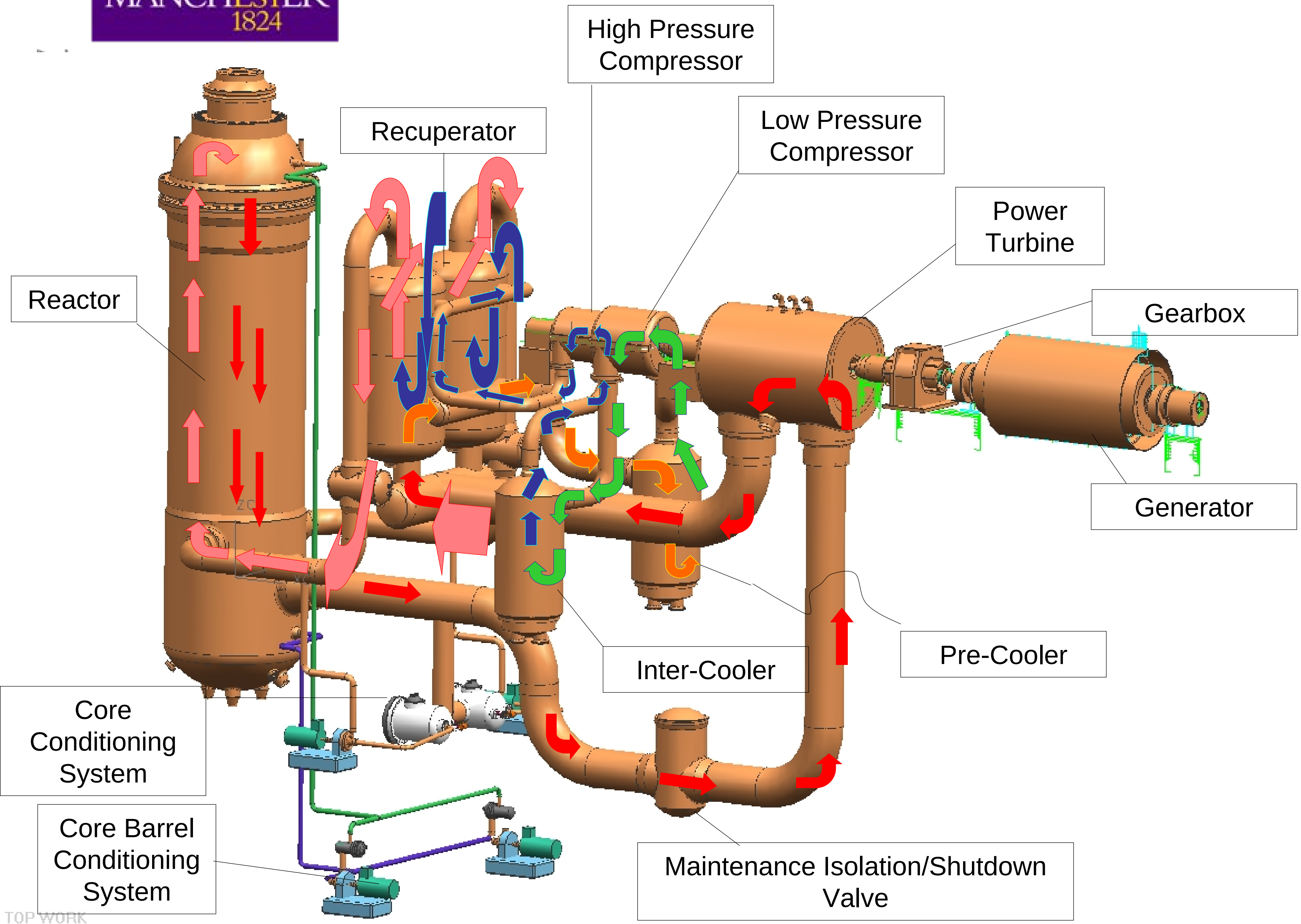

VHTR Migration Path: