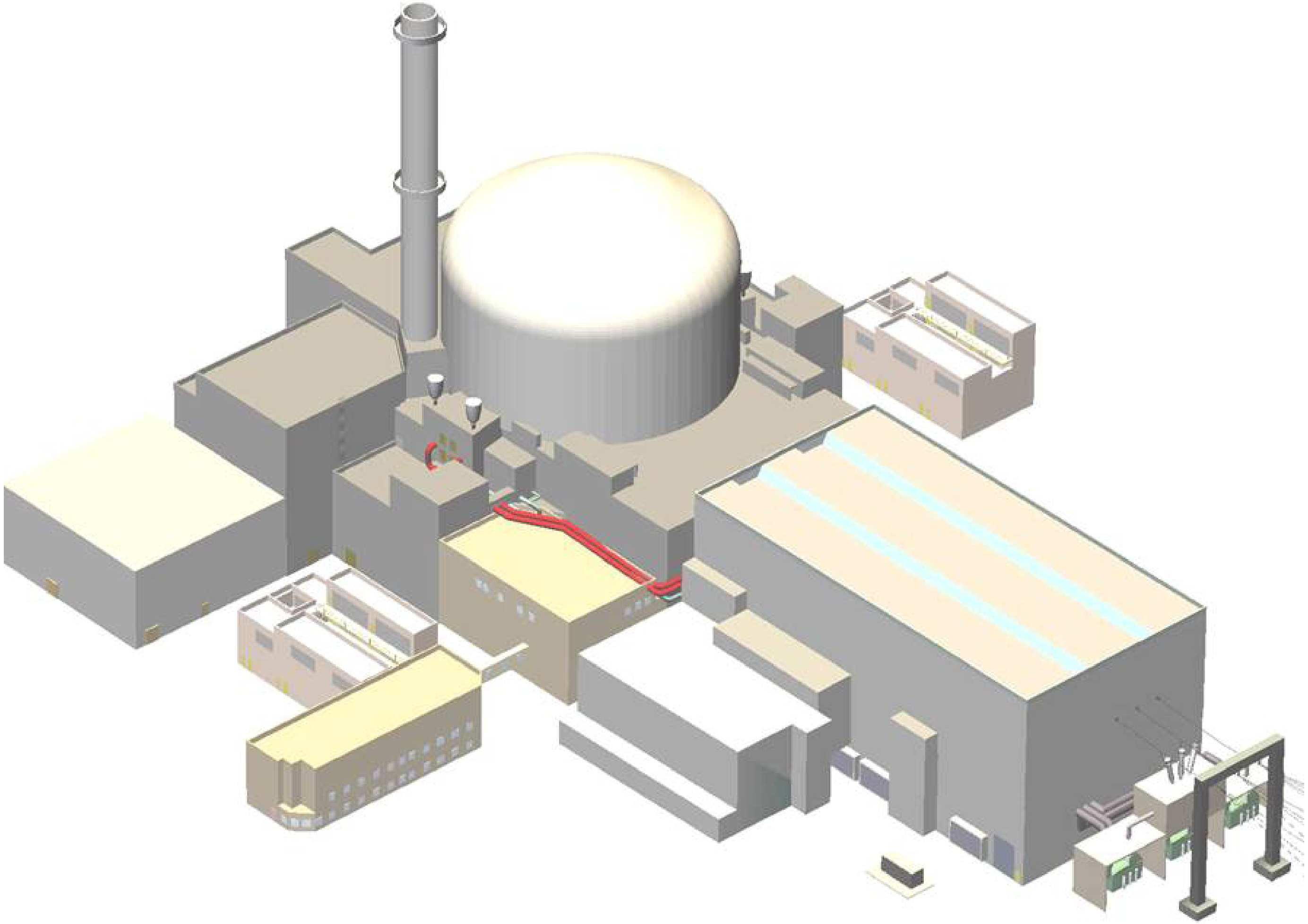
2.0 Reactor Vessel and Internals

HRTD
Human Resources
Training & Development



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Objectives

1. Describe the basic differences between the US-EPR vessel penetrations and those of a standard 4-loop PWR vessel head.
2. State the purposes of the heavy reflector.
3. Explain the differences in construction between US-EPR fuel assemblies and those of standard 4-loop PWR fuel assemblies.
4. State how US-EPR control rod drive mechanisms are cooled.
5. State the purpose of the aeroball measurement system.
6. State the purpose of the self-powered neutron detector system.

- **Upper head penetrations:**
    - **89 for CRDMs**
    - **16 for In-core Instrumentation:**
        - **12 for in-core SPNDs, aeroball probes, core-outlet thermocouples**
        - **4 for RV water level instrumentation**
    - **1 Upper plenum thermocouple**
    - **1 RV vent pipe**
- **No lower head penetrations**
- **Upper part of RV w/ nozzles is single forging.**

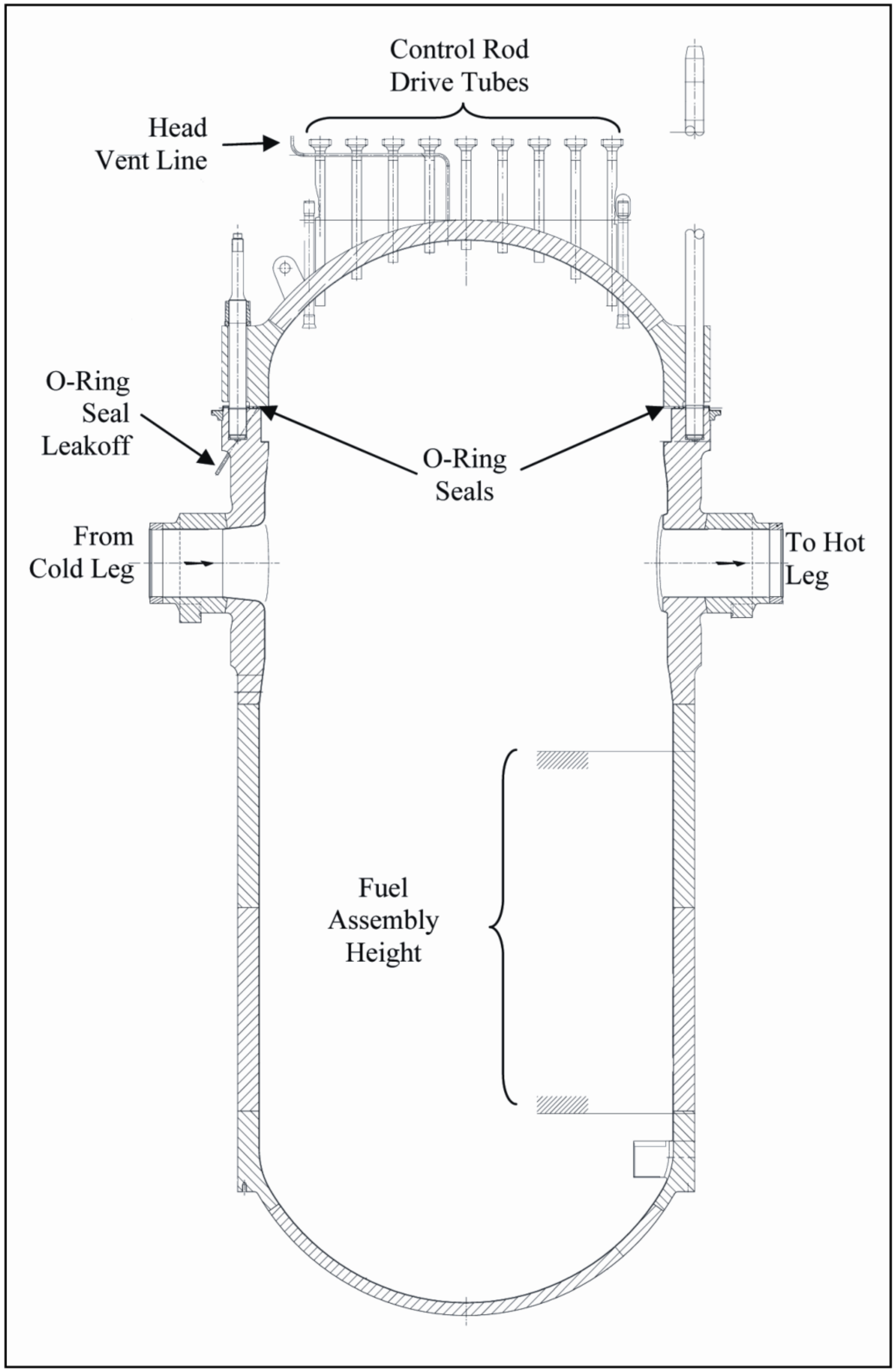
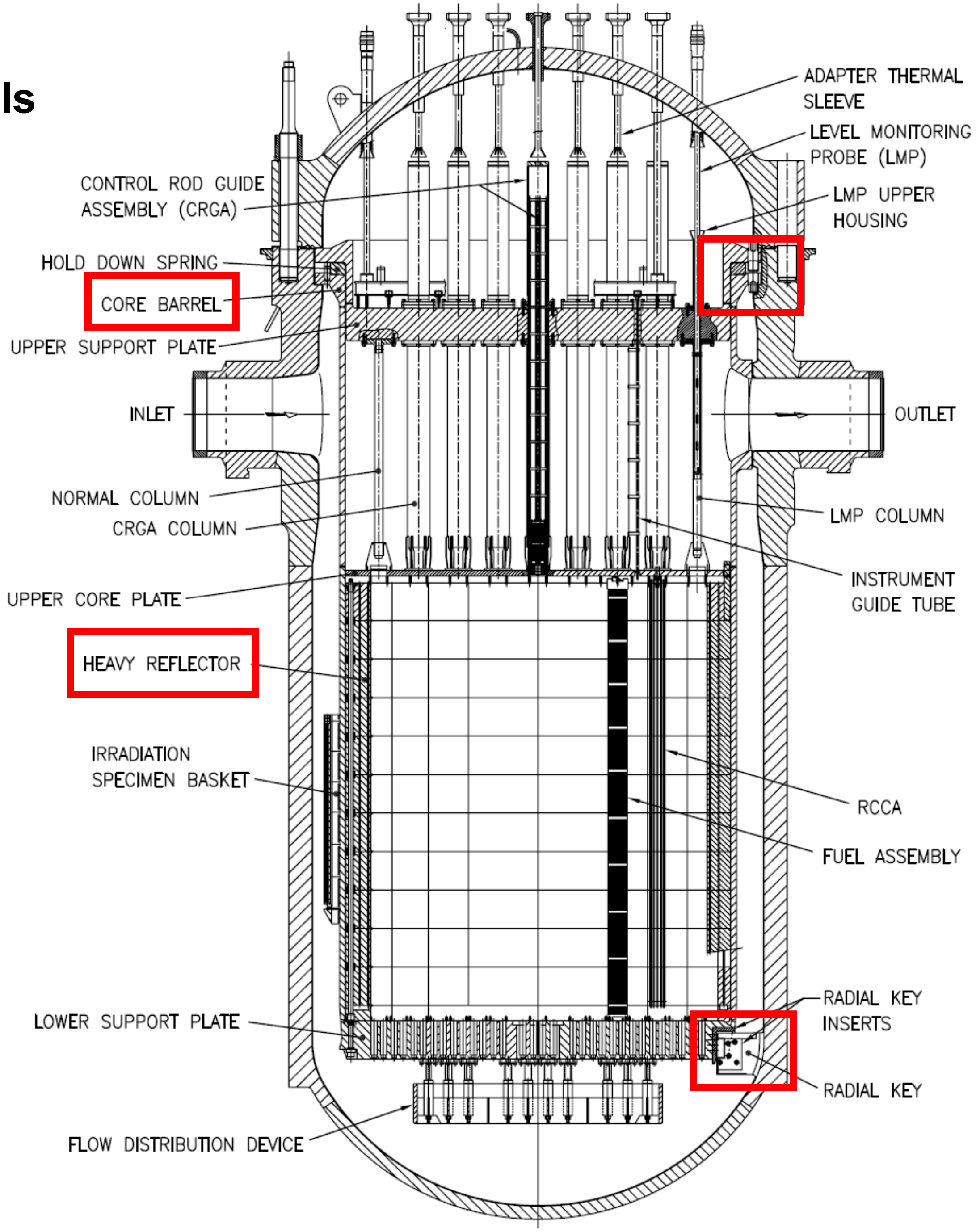


**Figure 2-1
Reactor Pressure Vessel**

Figure 2-3
Reactor Vessel and Internals



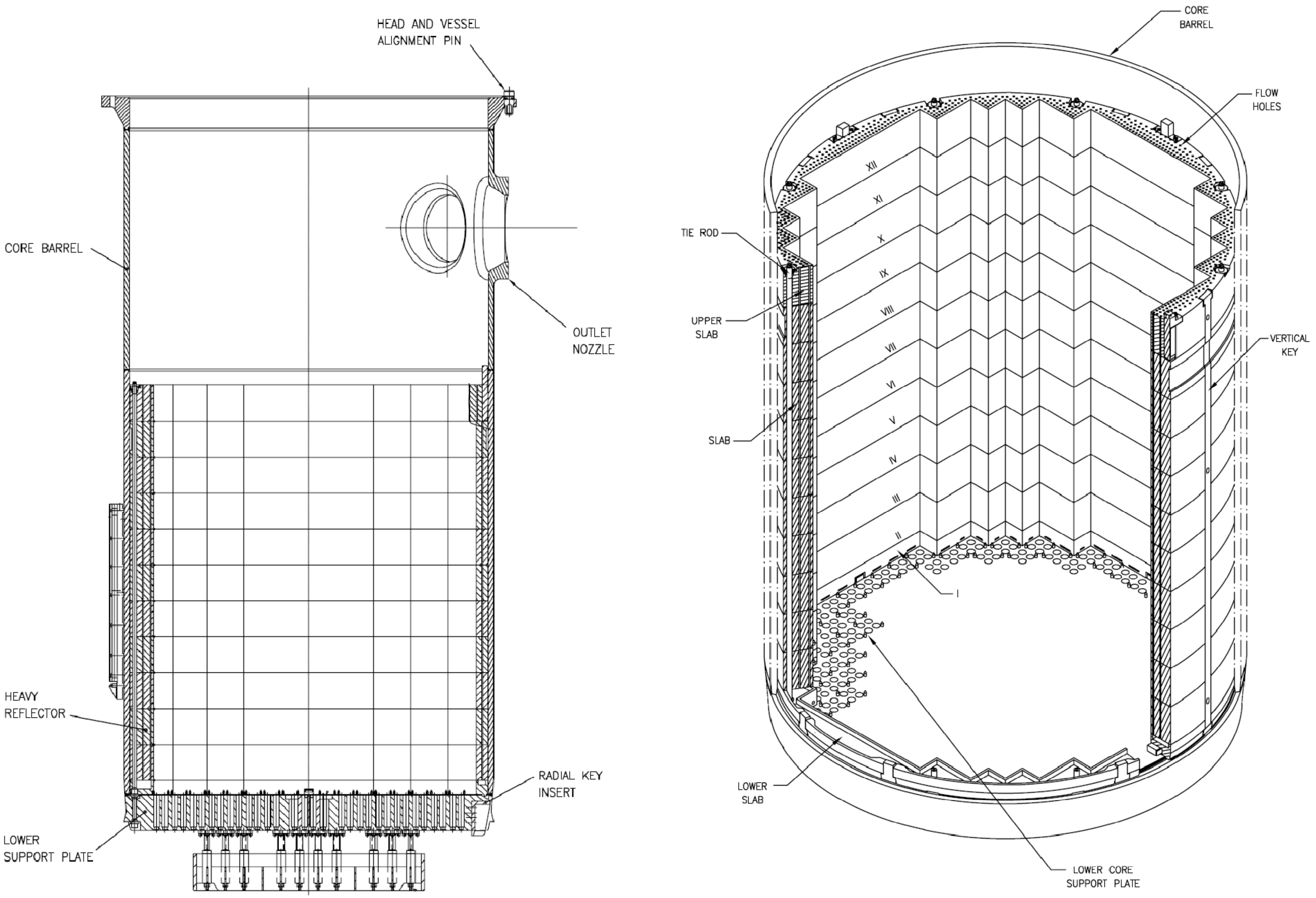


Figure 2-4 Lower Internals

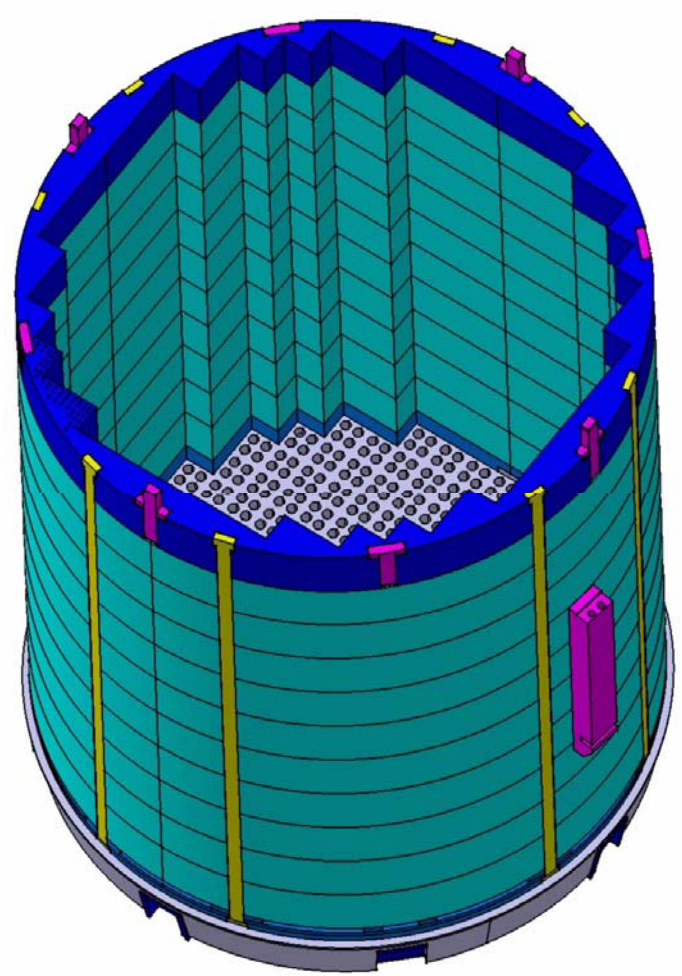


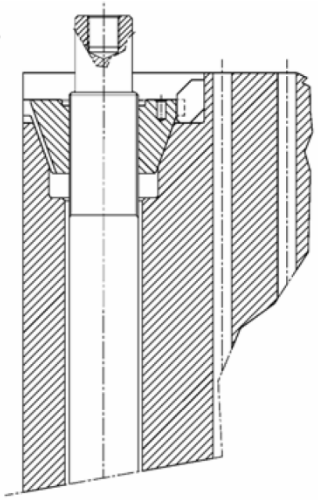
Figure 2-5   Heavy Reflector

EPR Heavy reflector

Core baffle assembly replaced by heavy reflector

- **Reduces fuel-cycle cost**
- **Improves long-term mechanical behavior of lower internals:**
  - **No bolts or welds in the most irradiated areas**
  - **Temperature distribution in heavy reflector controlled via flow holes**
  - **No "baffle jetting"**
- **Protects RV against radiation embittlement**

- Provide the vertical restraint for the individual slabs
- Restrained at the top and bottom of the heavy reflector
- No threaded connections within the active core region



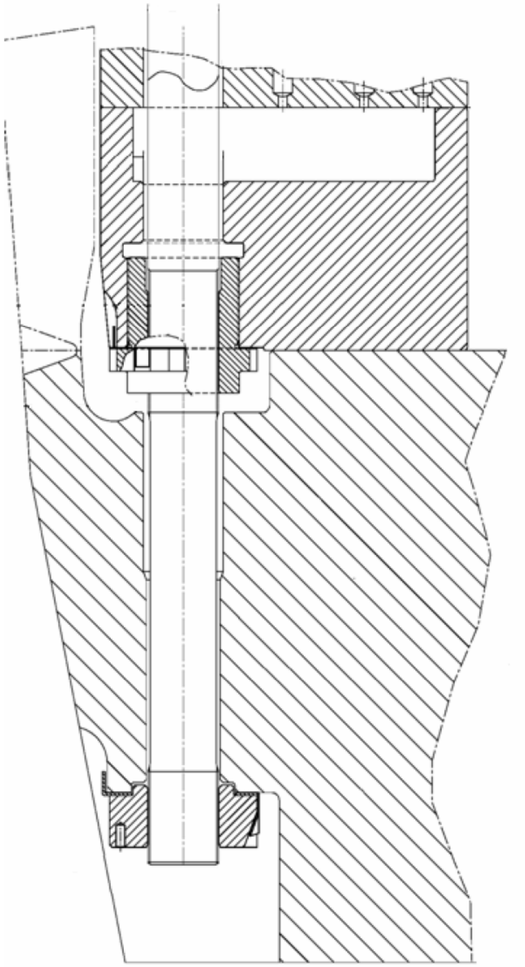
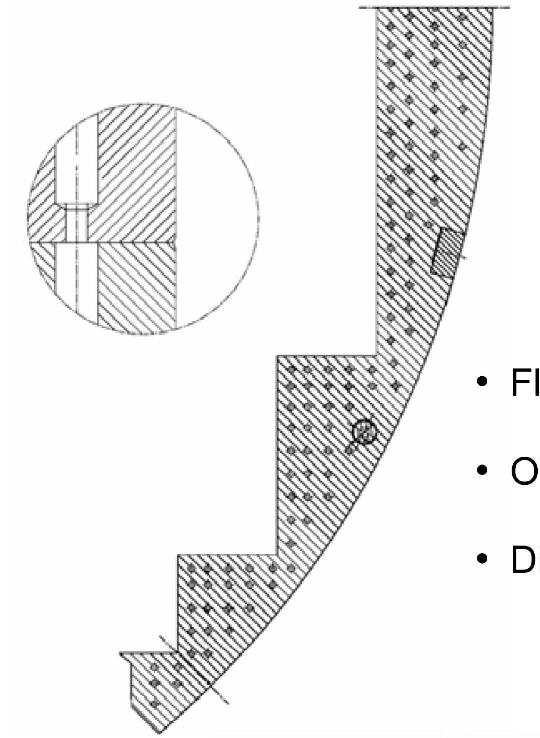
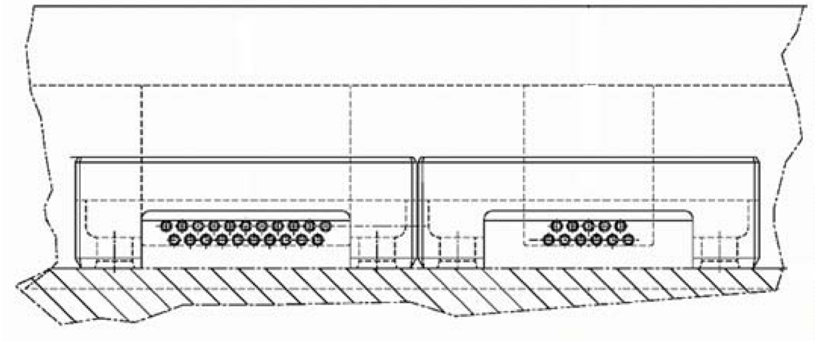


Figure 2-6
Heavy Reflector Tie Rods

Figure 2-7 Heavy Reflector Cooling



- Flow holes to remove heat from gamma heating
- Openings in the first slab allow flow to enter the heavy reflector
- Distribution chamber provides even flow



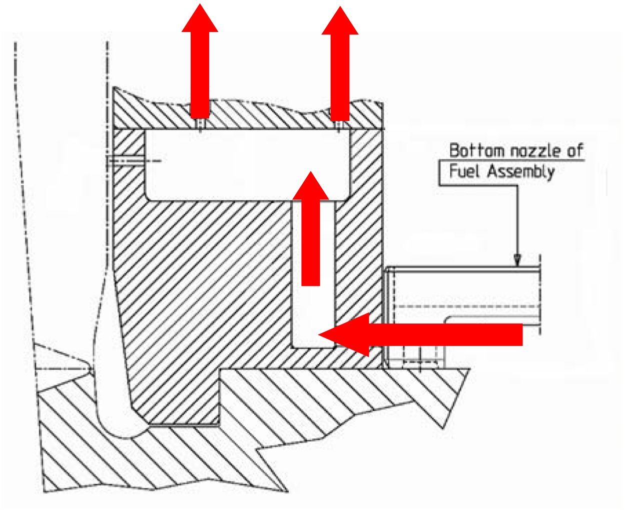
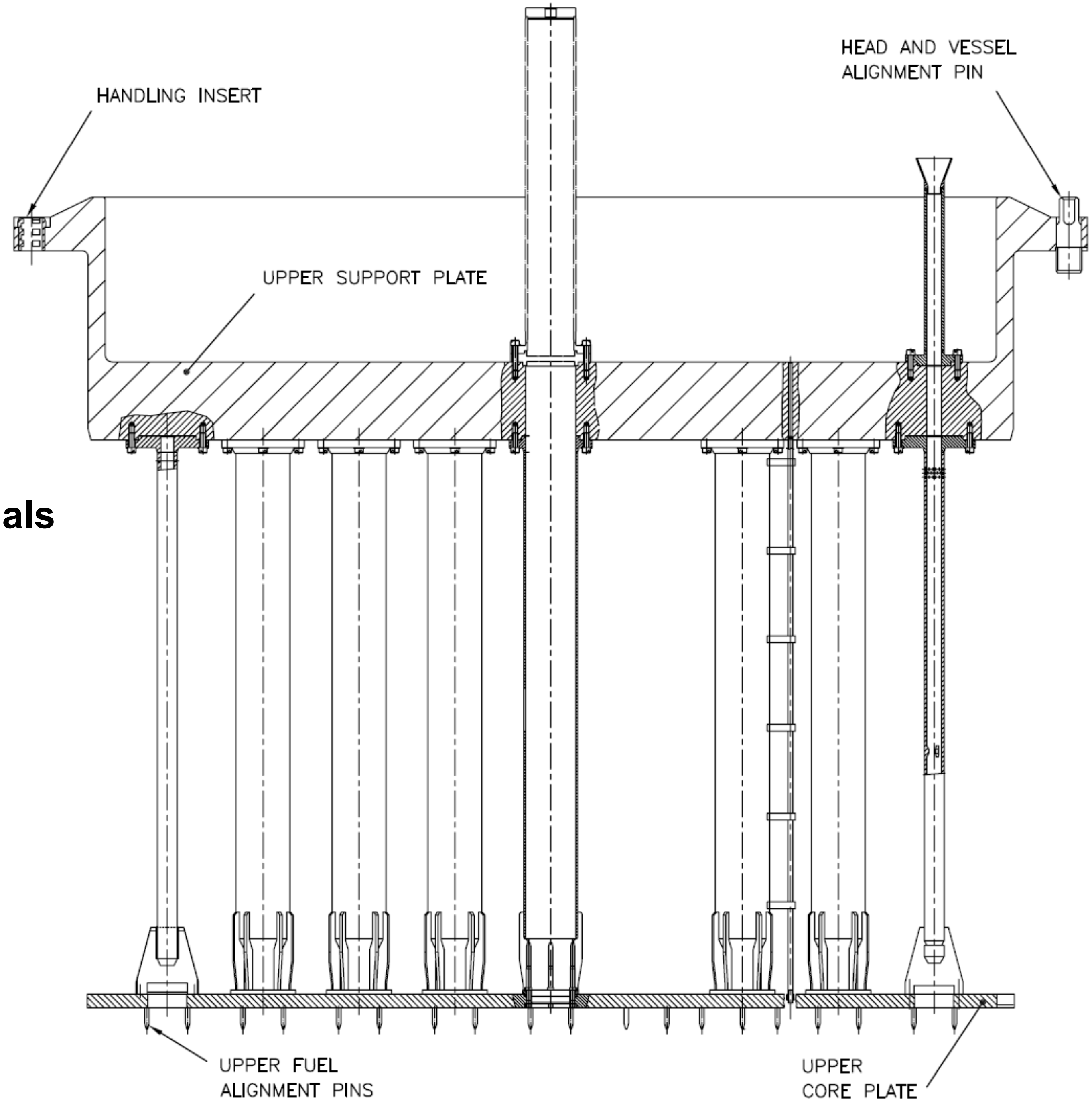


Figure 2-8
Upper Internals



Core Characteristics

- Increased uranium utilization
    - ~7% reduction in uranium consumption

- Designed for use of MOX fuel
- Designed for 12 to 24 month fuel cycle
- Up to 5% enrichment

Designed for increased flexibility & performance

EPR Core Design Parameters

Parameter	Current 4-Loop (Uprated)	EPR
Core Thermal Power, MWth	3587	4590
Number of Fuel Assemblies	193	241
Fuel Lattice	17 x 17	17 x 17
Active Fuel Length, ft	12	13.78
Rods Per Assembly	264	265
Average Linear Heat Rate, kw/ft	5.84	5.22
Peak Linear Heat Rate, kw/ft	14.6	13.6
Number of Control Rods	53	89

Fuel Design

- 17 X 17
- 265 Fuel Rods, 24 Guide Tubes
- M5^{TM} Cladding
- HMP Upper & Lower Grids
- 8 HTP Mixing Vane Grids
- Anti-Debris Lower Nozzle
- Quick-Disconnect Top Nozzle
- Gd_2O_3 Burnable Poison Rods (Some FAs, 4-28 rods/FA)
- MOX Compatible

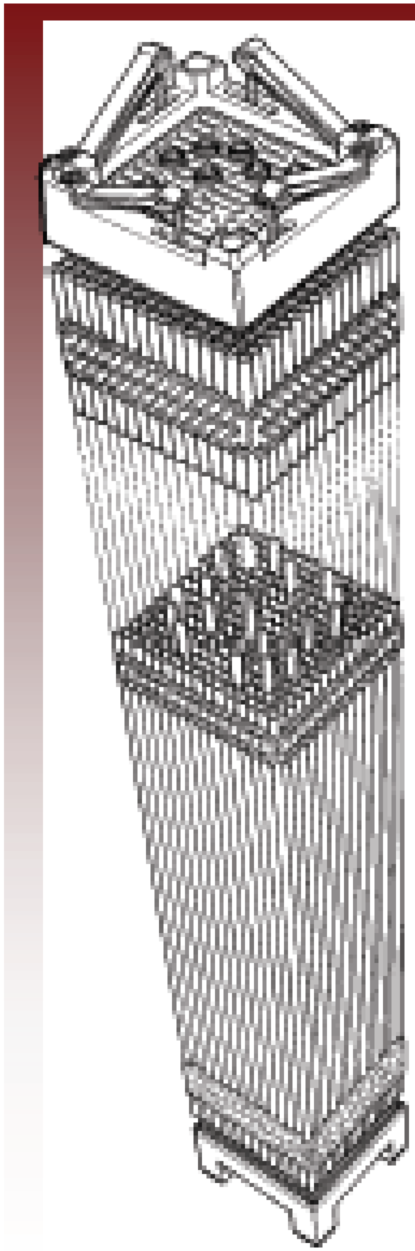
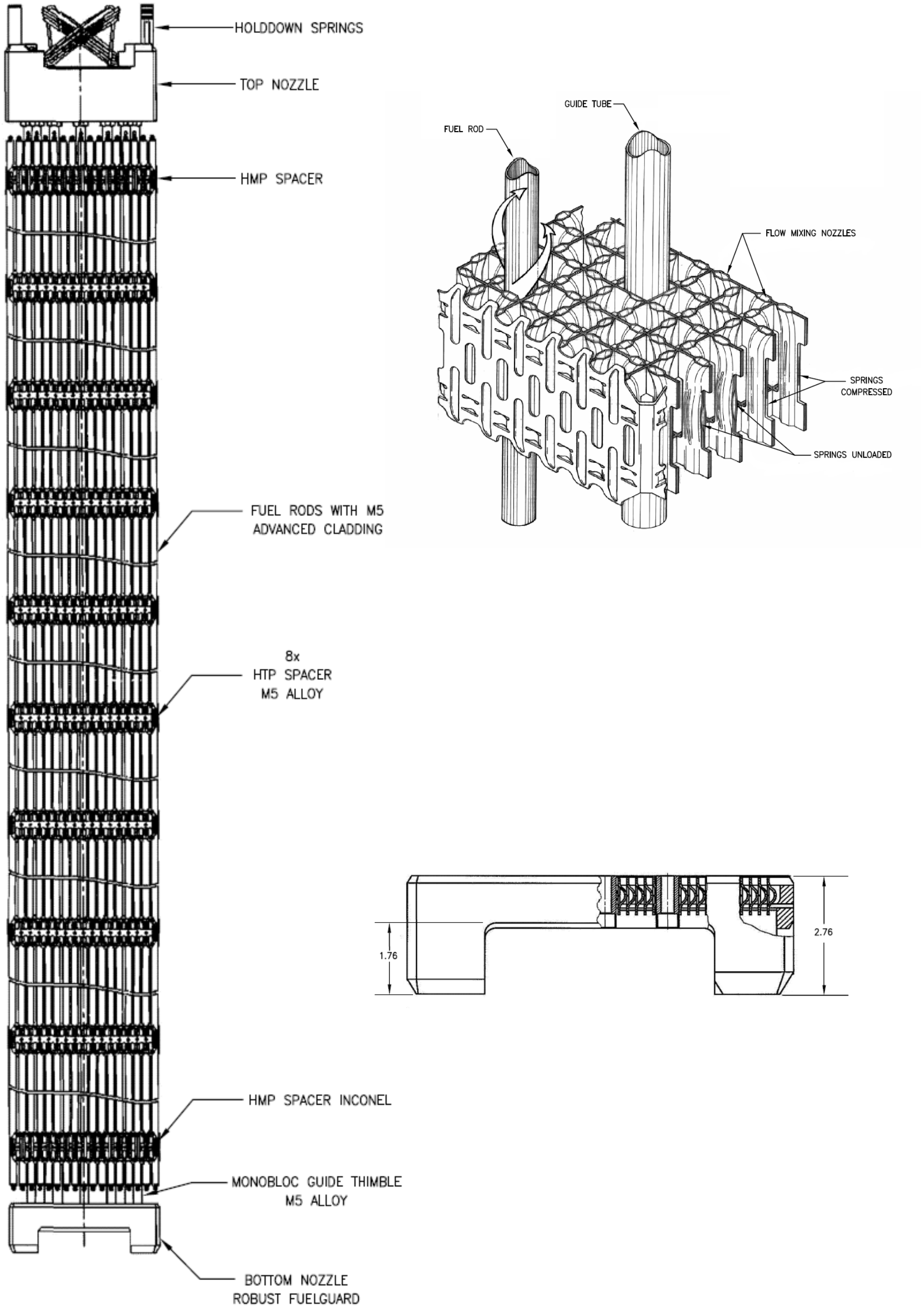
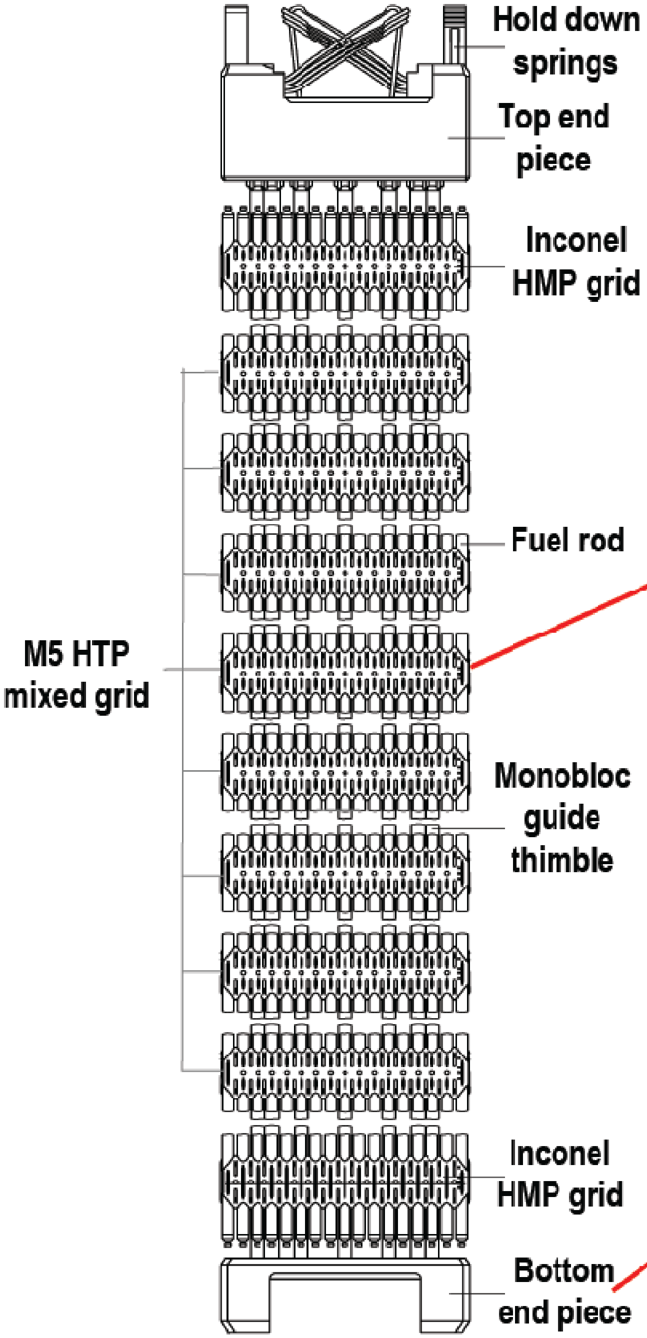
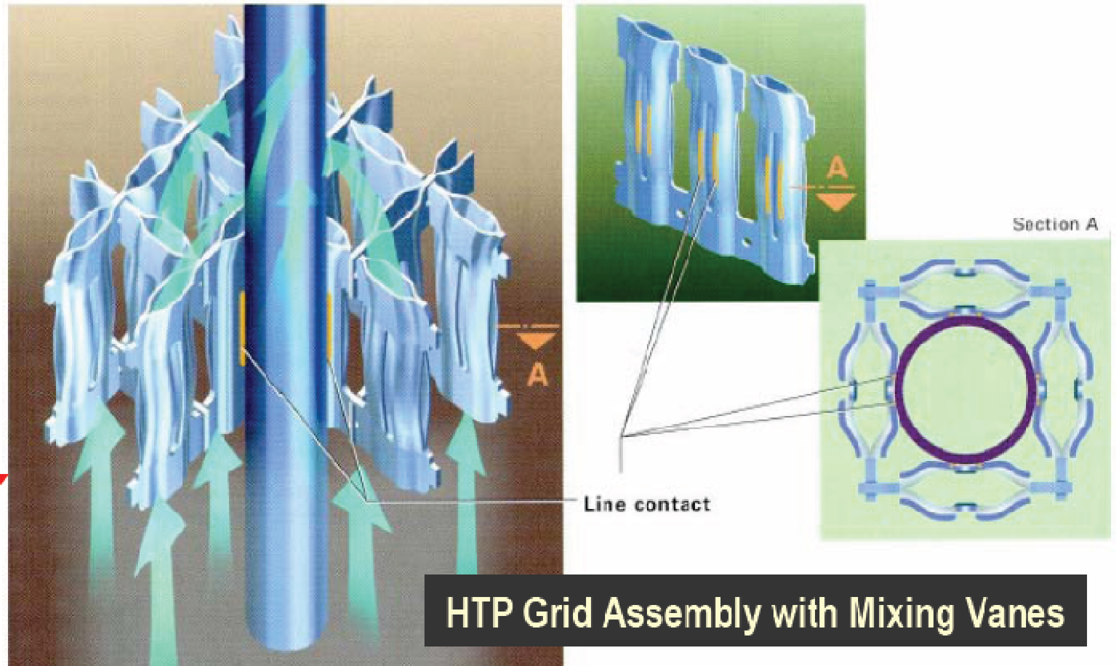


Figure 2-9
Fuel Assembly, HTP Grid, Bottom Nozzle

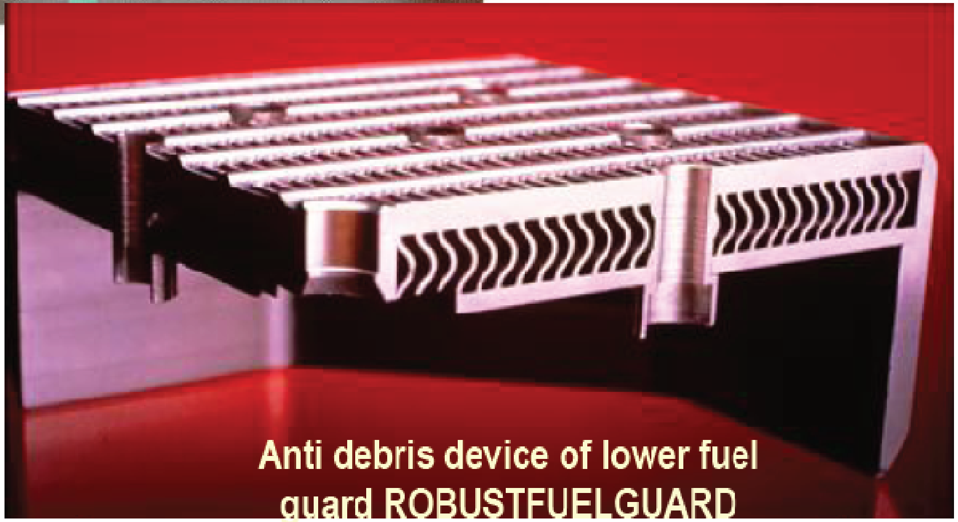


HTP Fuel Assembly



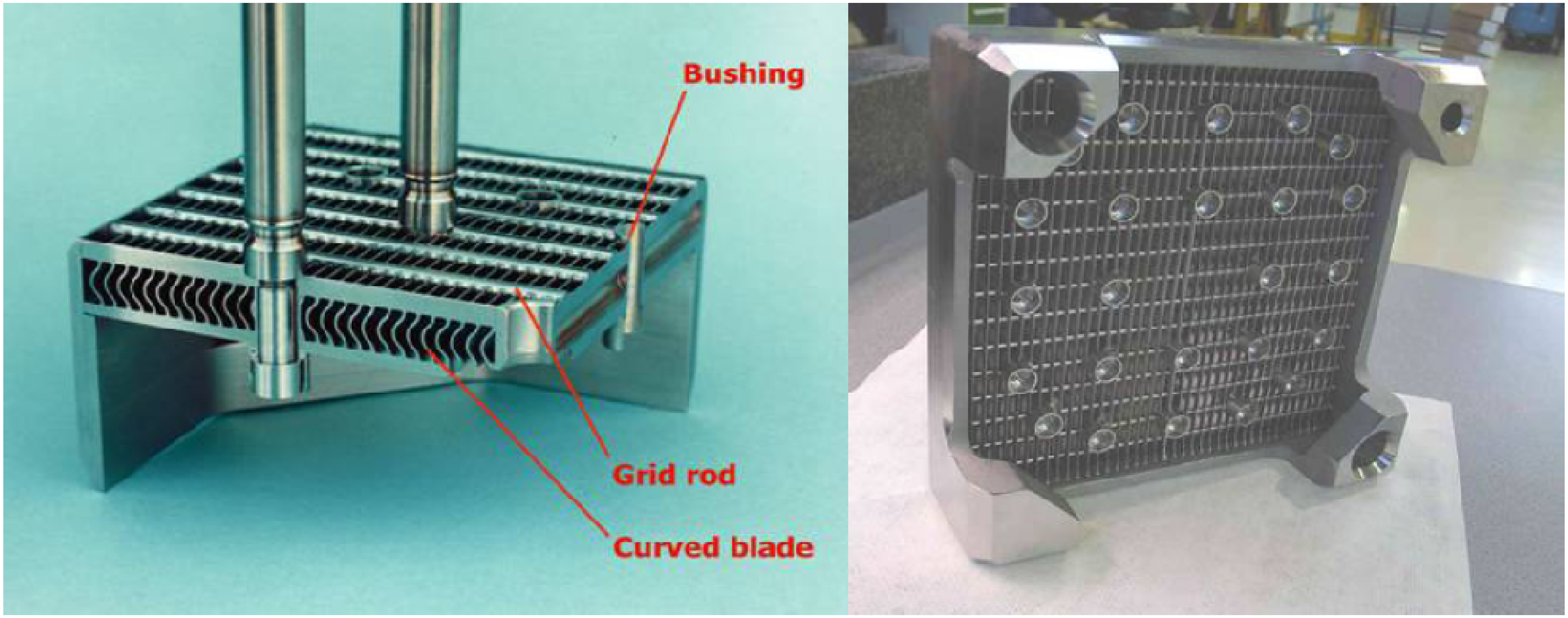


HTP Grid Assembly with Mixing Vanes



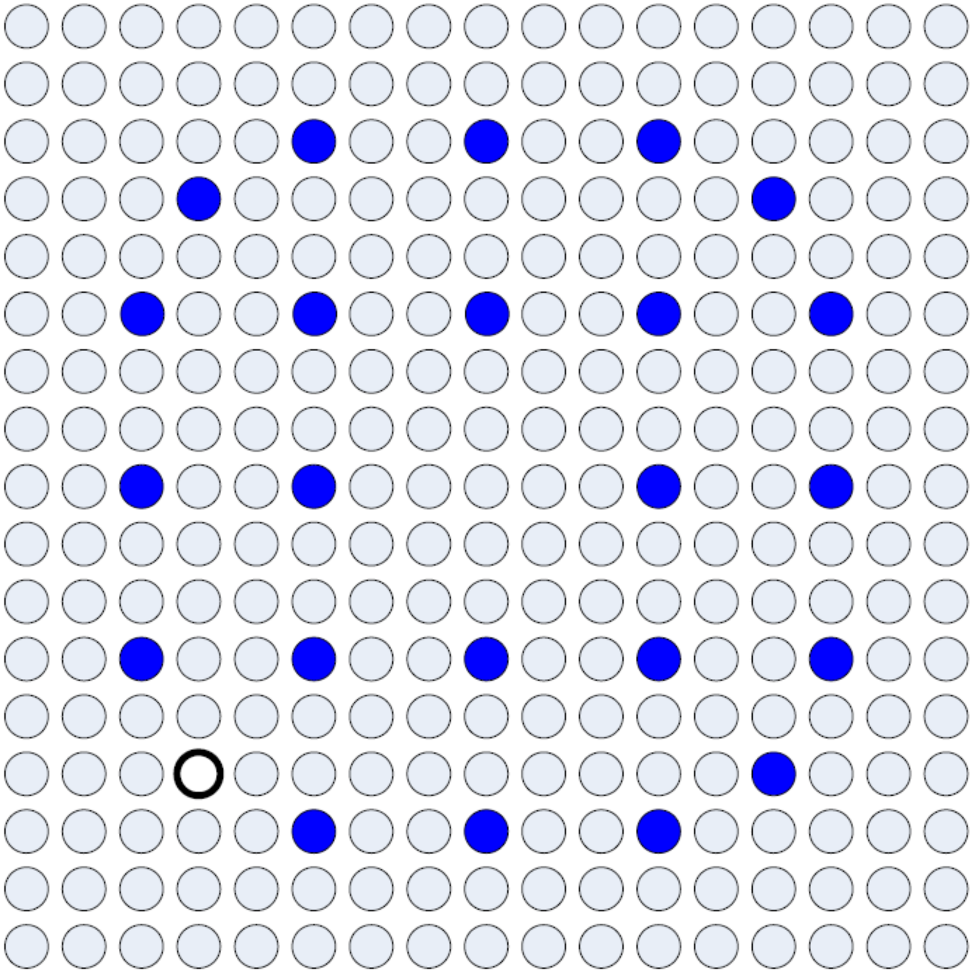
Anti debris device of lower fuel guard ROBUSTFUELGUARD

Bottom Nozzle



Robust FUELGUARD™ Bottom Nozzle

Figure 2-10 Fuel Assembly Cross Section



Rod Type	# of Rods	Rod Description
○	265	Fuel Rod
●	23	Guide Tube
◯	1	Guide Tube – This tube represents the four symmetric locations in the assembly that may contain incore instrumentation. There is a maximum of two instrumentation guide tubes per assembly.

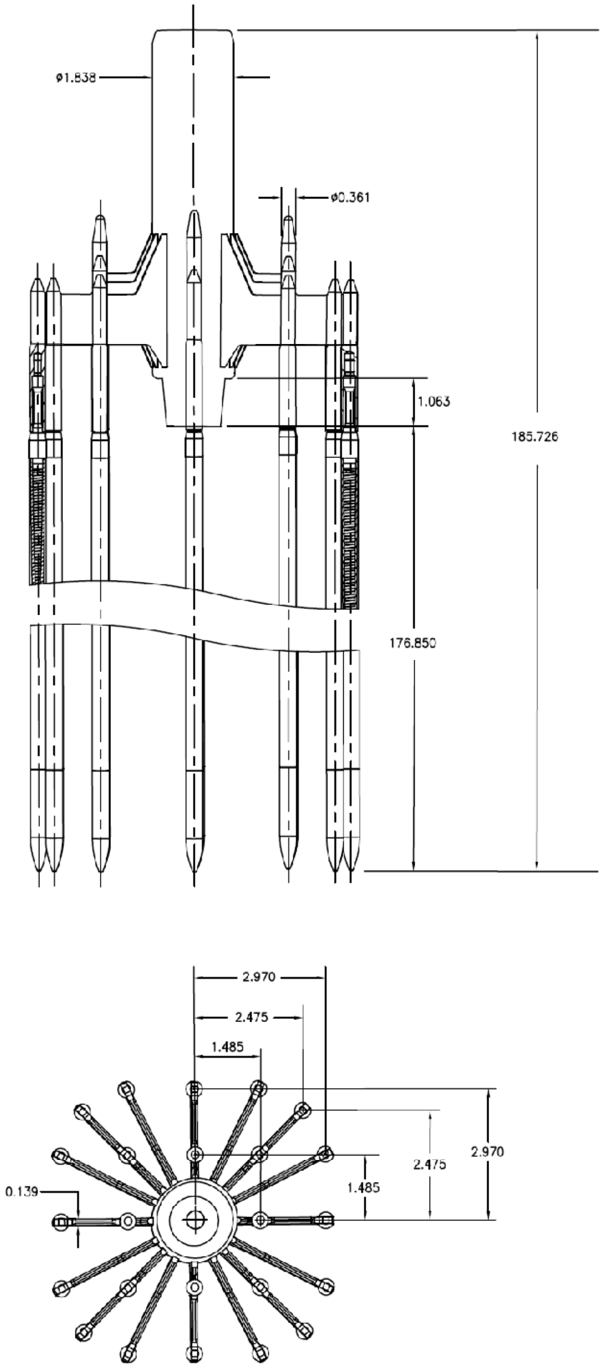
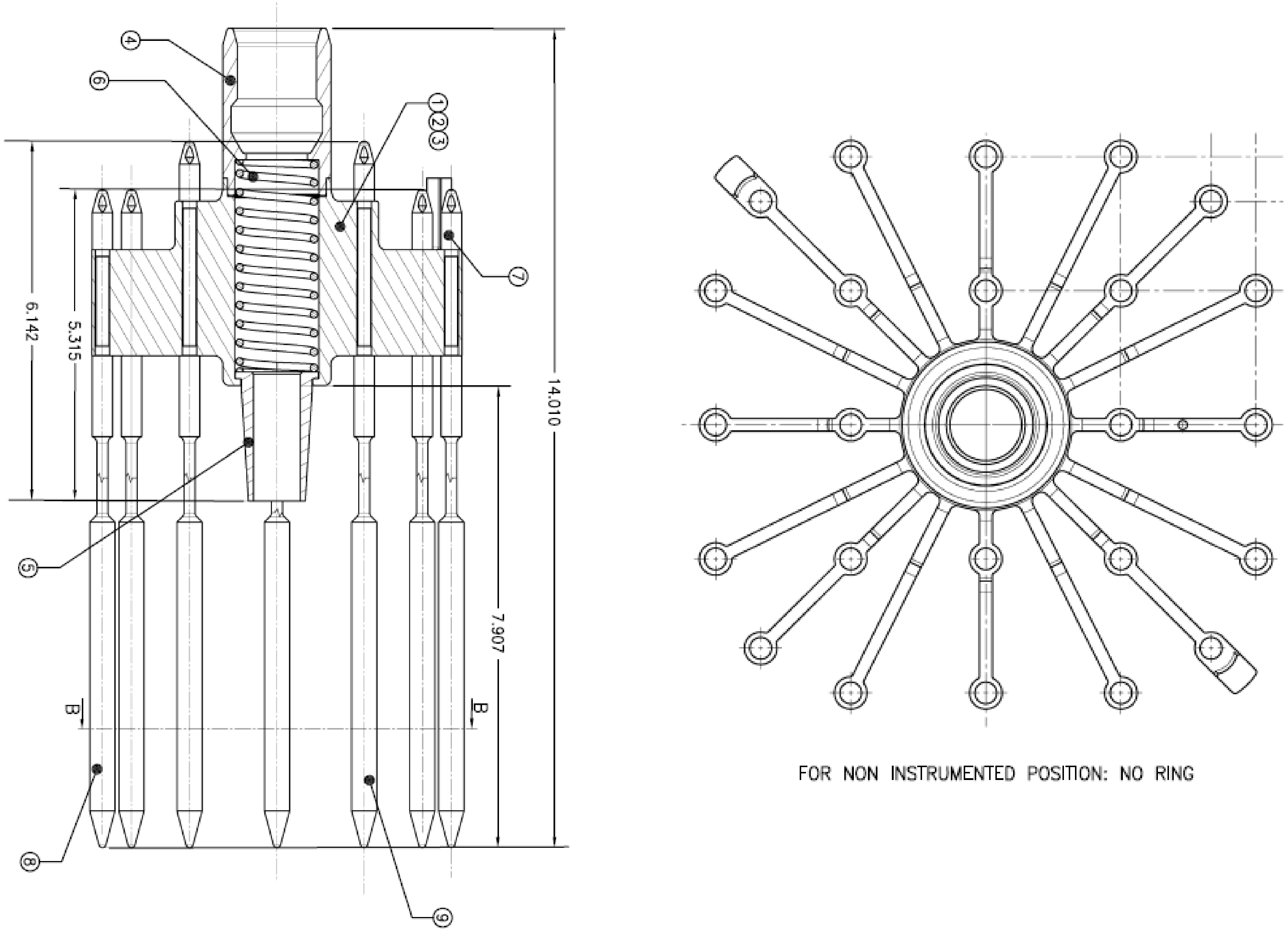
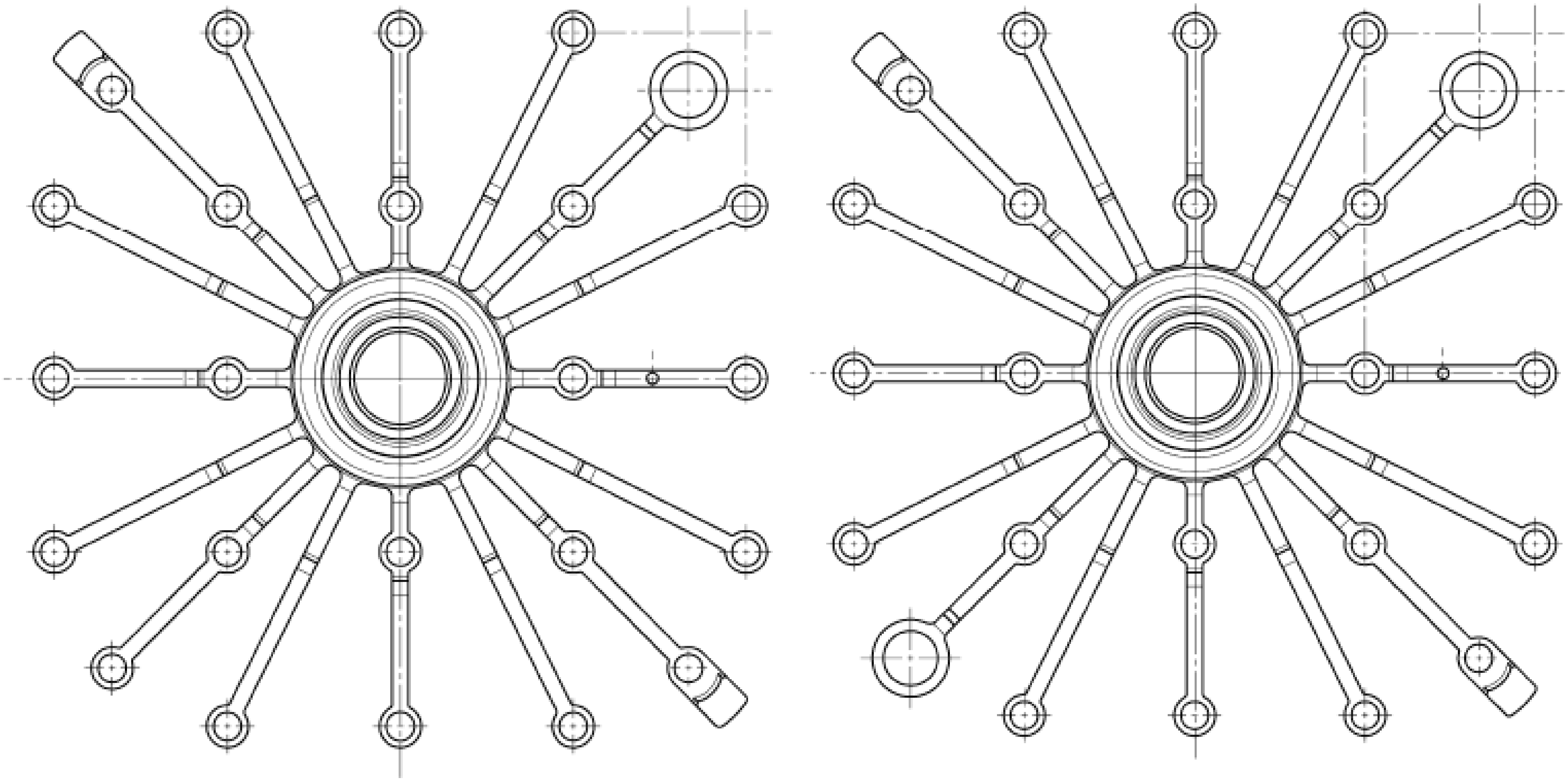


Figure 2-11
Rod Cluster Control Assembly



FOR NON INSTRUMENTED POSITION: NO RING

Figure 2-12 Thimble Plug Assembly (for noninstrumented fuel assembly)



WITH ONE INSTRUMENTATION GUIDING RING

WITH 2 INSTRUMENTATION GUIDING RINGS

Figure 2-12 Thimble Plug Assemblies (for instrumented fuel assemblies)

Figure 2-13
Control Rod Drive Mechanism

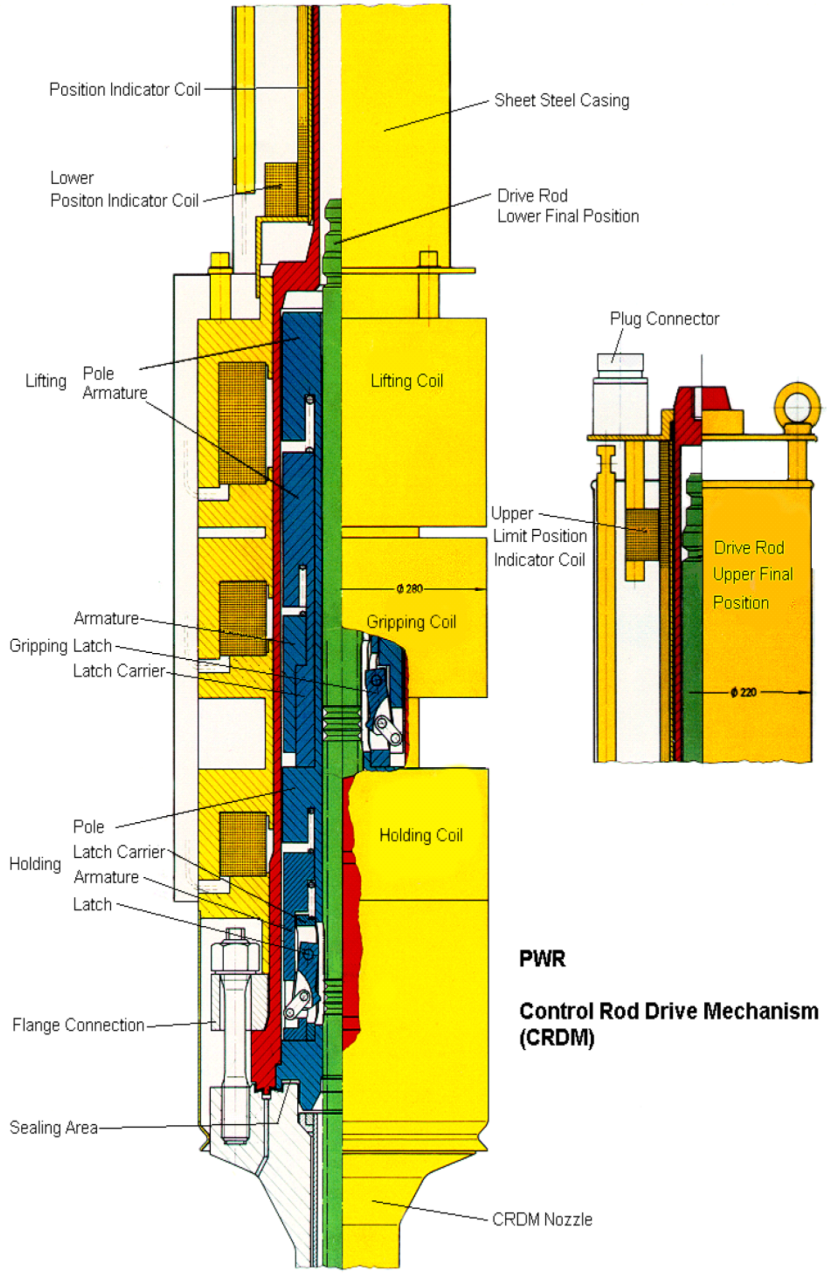
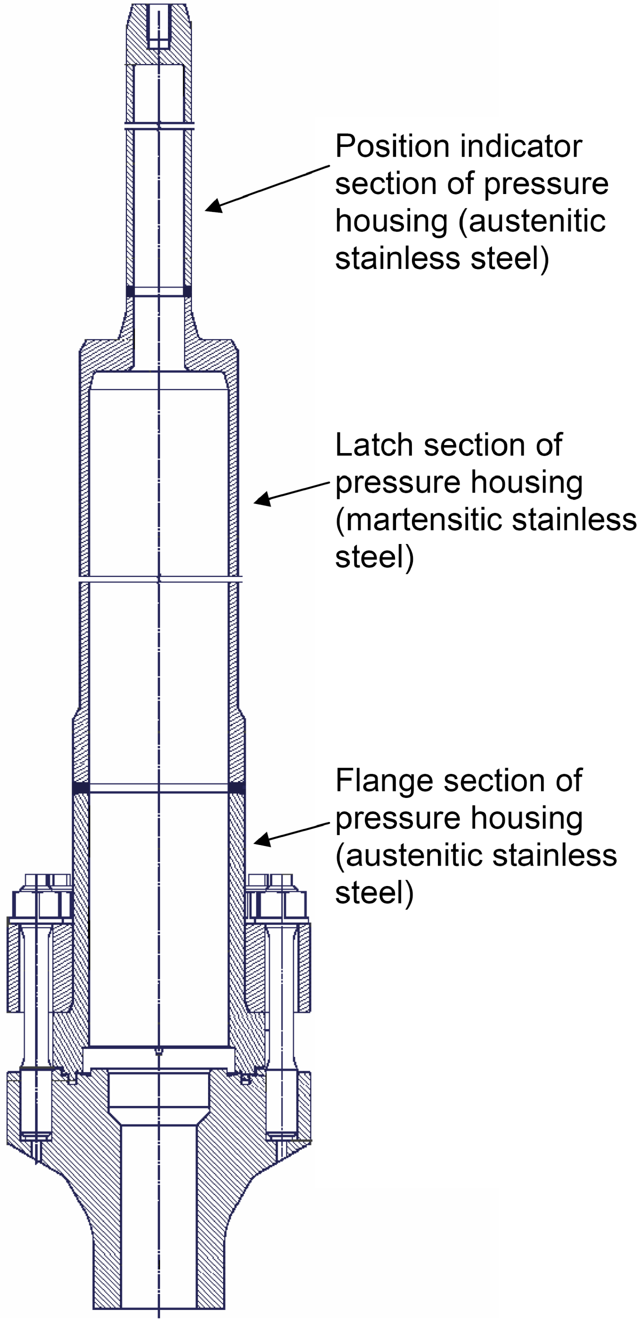


Figure 2-14 Pressure Housing



Position indicator section of pressure housing (austenitic stainless steel)

Latch section of pressure housing (martensitic stainless steel)

Flange section of pressure housing (austenitic stainless steel)

Figure 2-15 Latch Unit

Table 3.9.4-1—Control Rod Withdrawal Sequence

Step	Operating Coil Energizing Sequence	Latch Unit Response
1	Gripping coil is energized	The rest position; the drive rod is on gripping latches.
2	Lifting coil is energized	The lifting armature lifts up the drive rod one groove pitch (0.4 in) by means of the gripping latches.
3	Holding coil is energized	The holding latches are engaged in a groove and the load is removed from the gripping latches by raising the holding armature.
4	Gripping coil is de-energized	The gripping armature drops down and withdraws the gripping latches from the groove.
5	Lifting coil is de-energized	The lifting armature drops down, thus reverting to its starting position.
6	Gripping coil is energized	The gripping latches engage into the next groove.
7	Holding coil is de-energized	The holding armature drops down, the load is transferred to the gripping latches, and the holding latches are withdrawn from the groove.
8	Repeat	The sequence described above (steps 2 through 7) is termed one cycle. The RCCA assembly moves approximately 0.4 in for each cycle. The RCCAs can be withdrawn at a variable rate. The maximum speed is 29.5 in per minute.

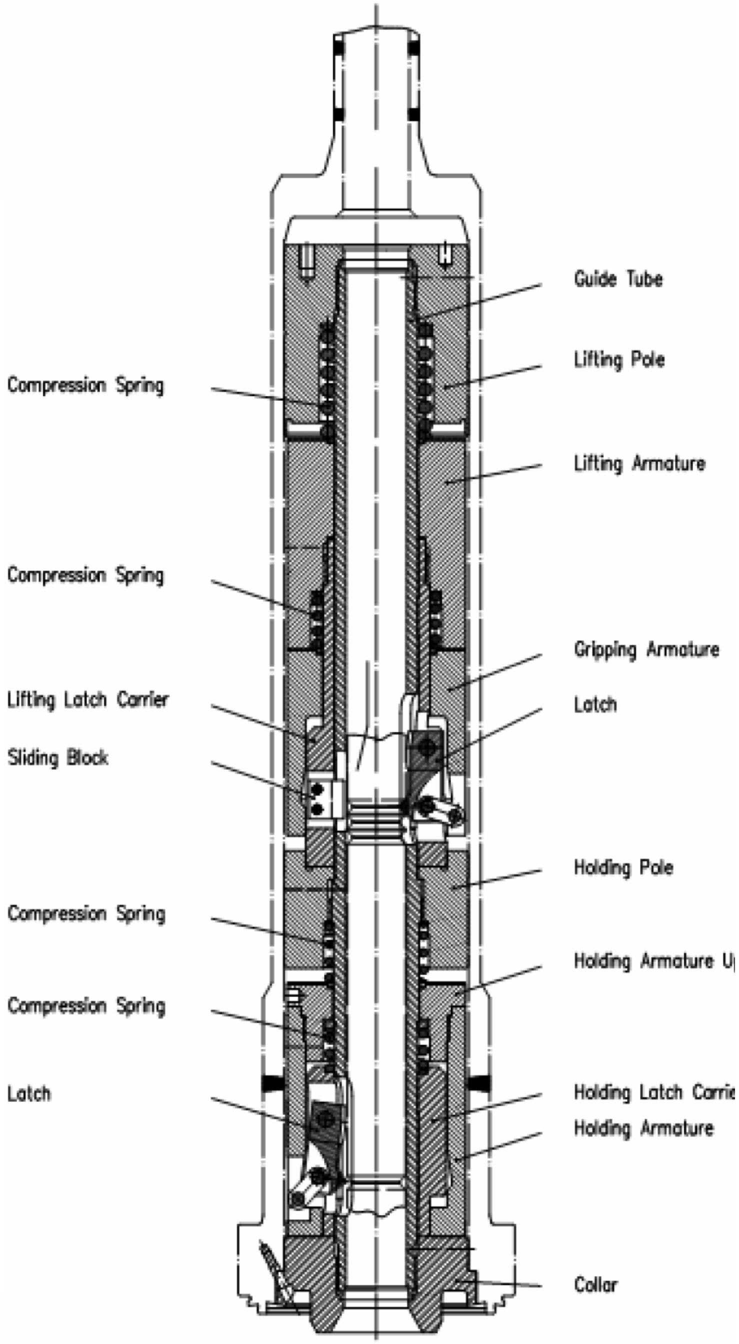
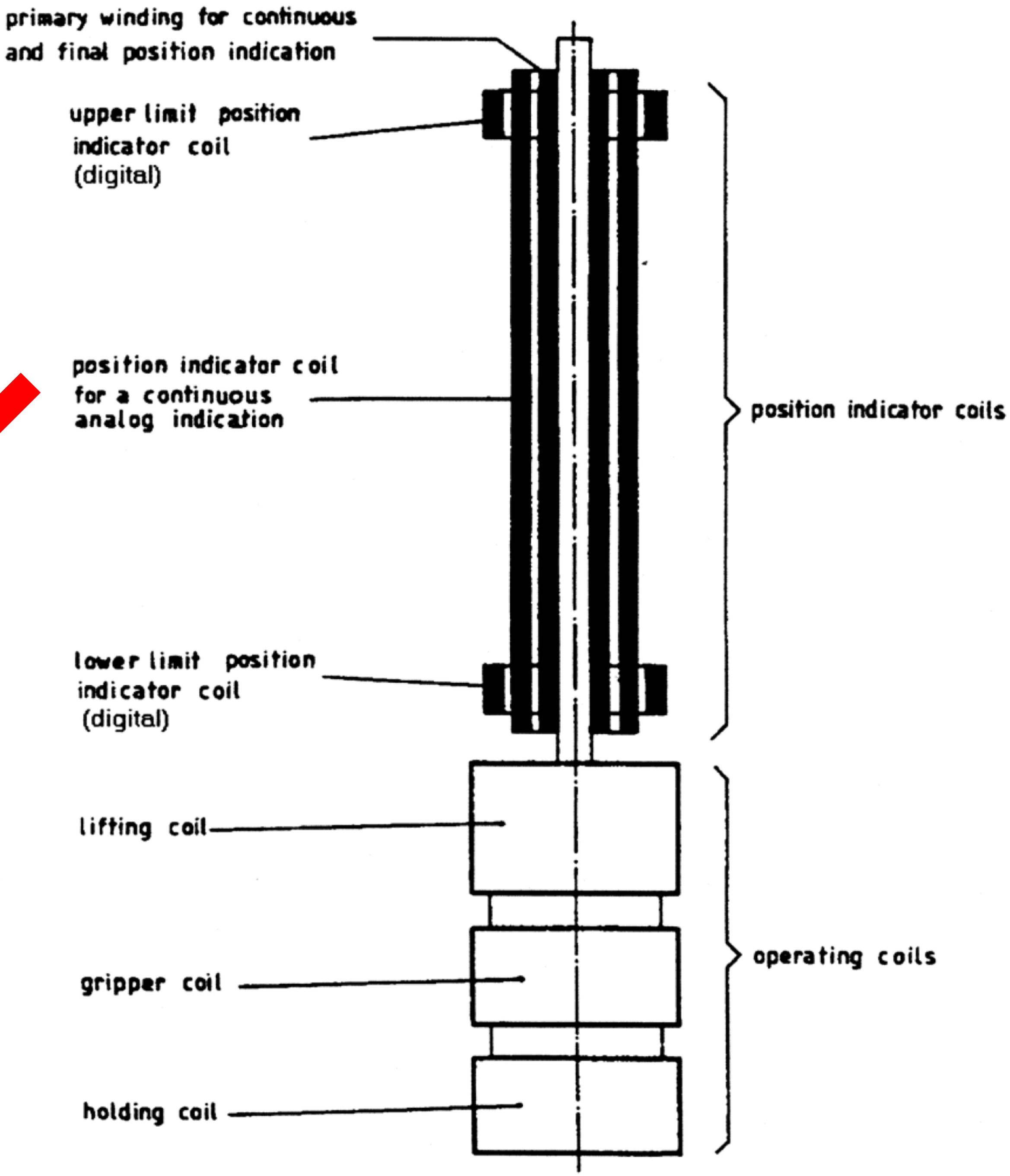


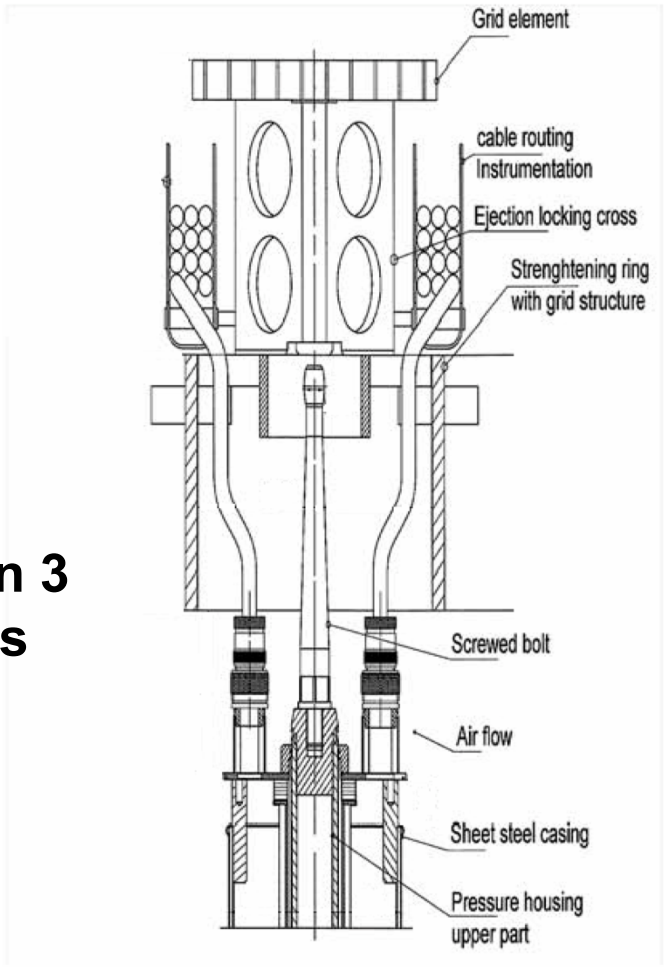
Figure 2-16
Operating Coil Assembly

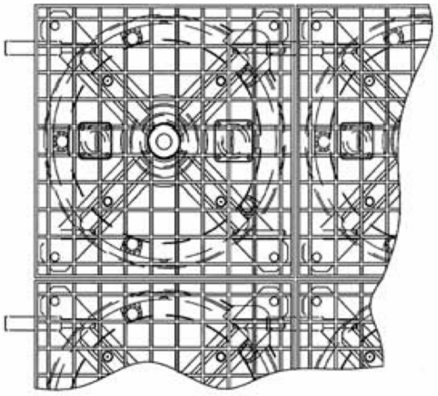


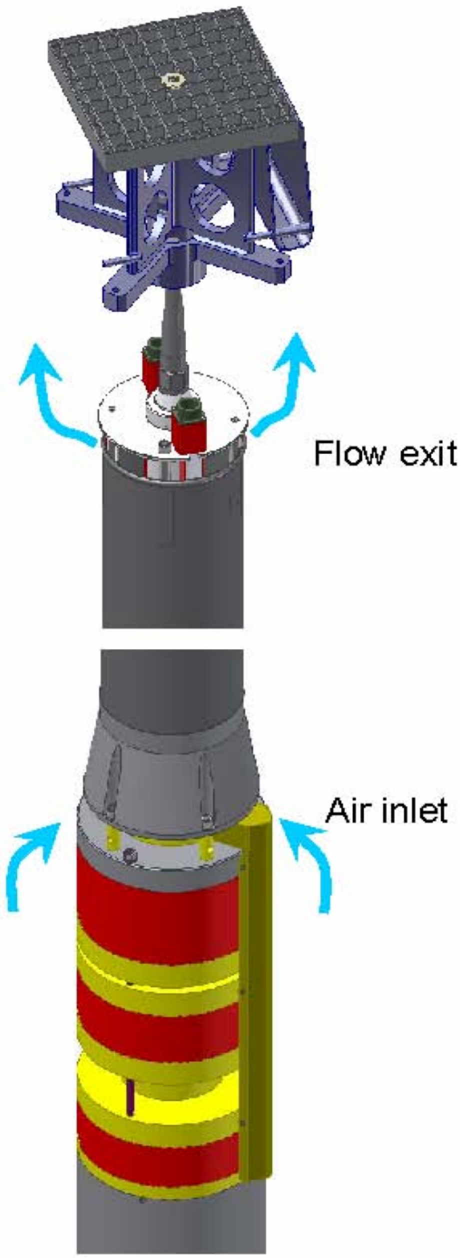
Provides input to RPS: Rod drop info for Low DNBR trip

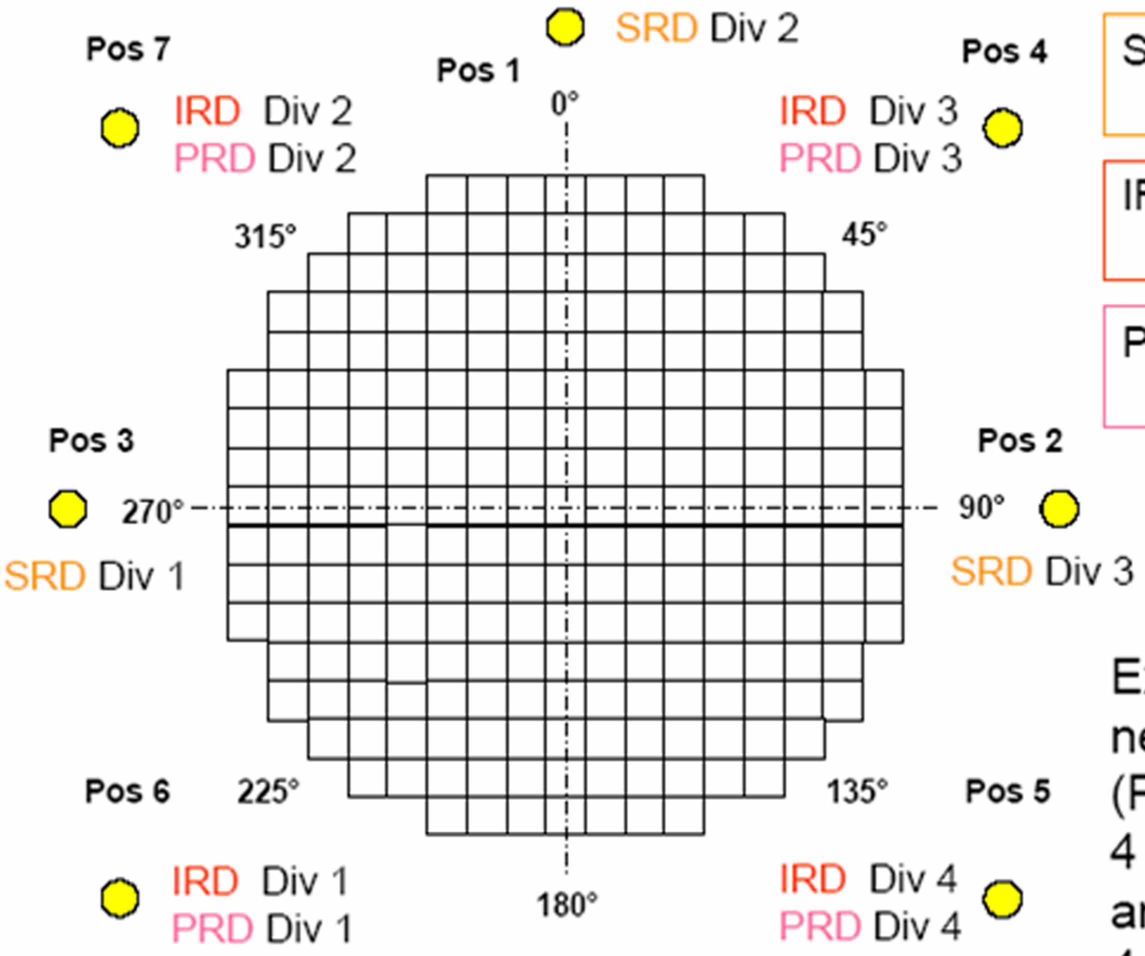
Figure 2-17
Natural Convection Air Flow Path

Similar to design used in 3 KONVOI (German) plants









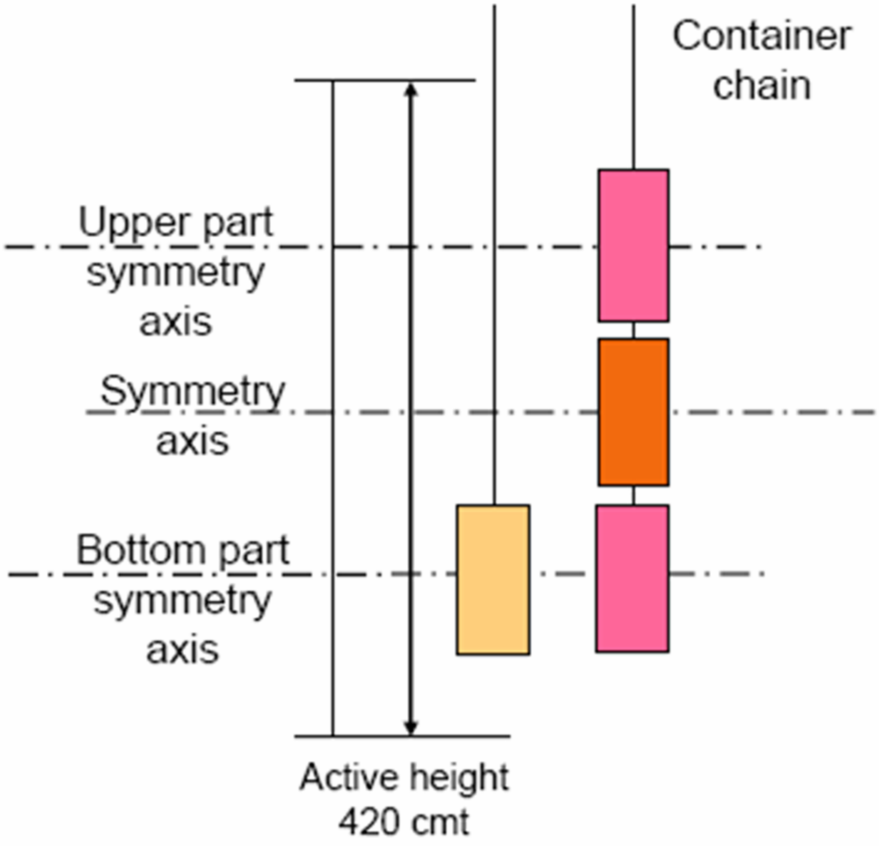
SRD: Source Range Detector 3 x 1

IRD: Intermediate Range Detector 4 x 1

PRD: Power Range Detector 4 x 2

Ex-core detectors of neighbouring angles (Pos) are grouped in 4 divisions (Div), which are related to the 4 core quadrants.

Figure 2-18 Excore Instrumentation Radial Locations



Ex-core detectors are placed in container chains and are inserted from the top of the reactor pit through Aluminium-tubes by the help of cable lines.

🟨 Source range detector

🟧 Intermediate range detector

🟥 Power range detector

Figure 2-19 Axial Locations of the Excore Detectors

Figure 2-20
Incore Instrumentation

SPNDs:

- **12 SPND strings**
- **6 detectors/string**
- **Co-59 emits electron when irradiated**
- **Calibrated ~ every 15 EFD w/ Aeroball system**
- **SPNDs supply inputs to Low DNBR, High Linear Power Density trips**

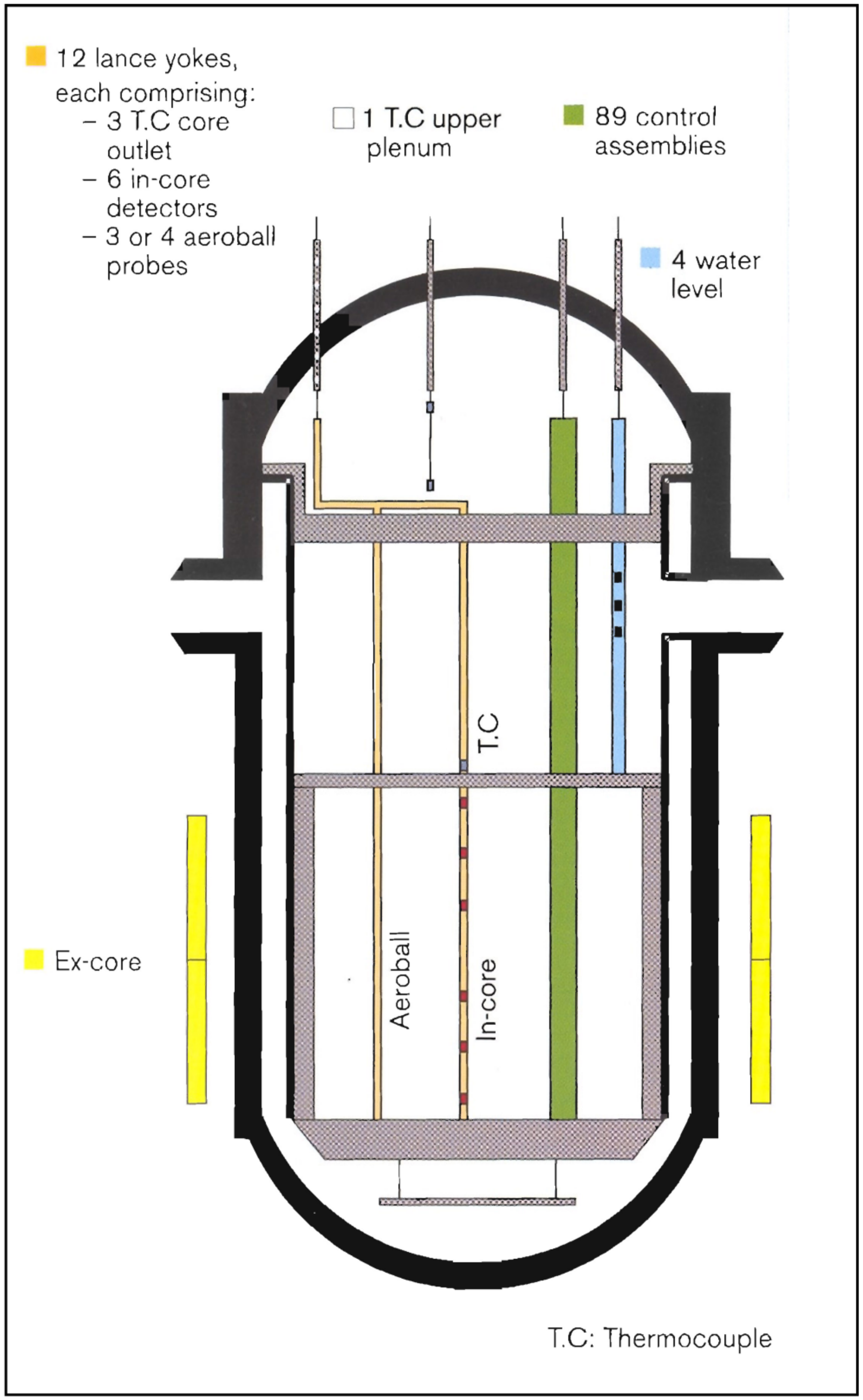
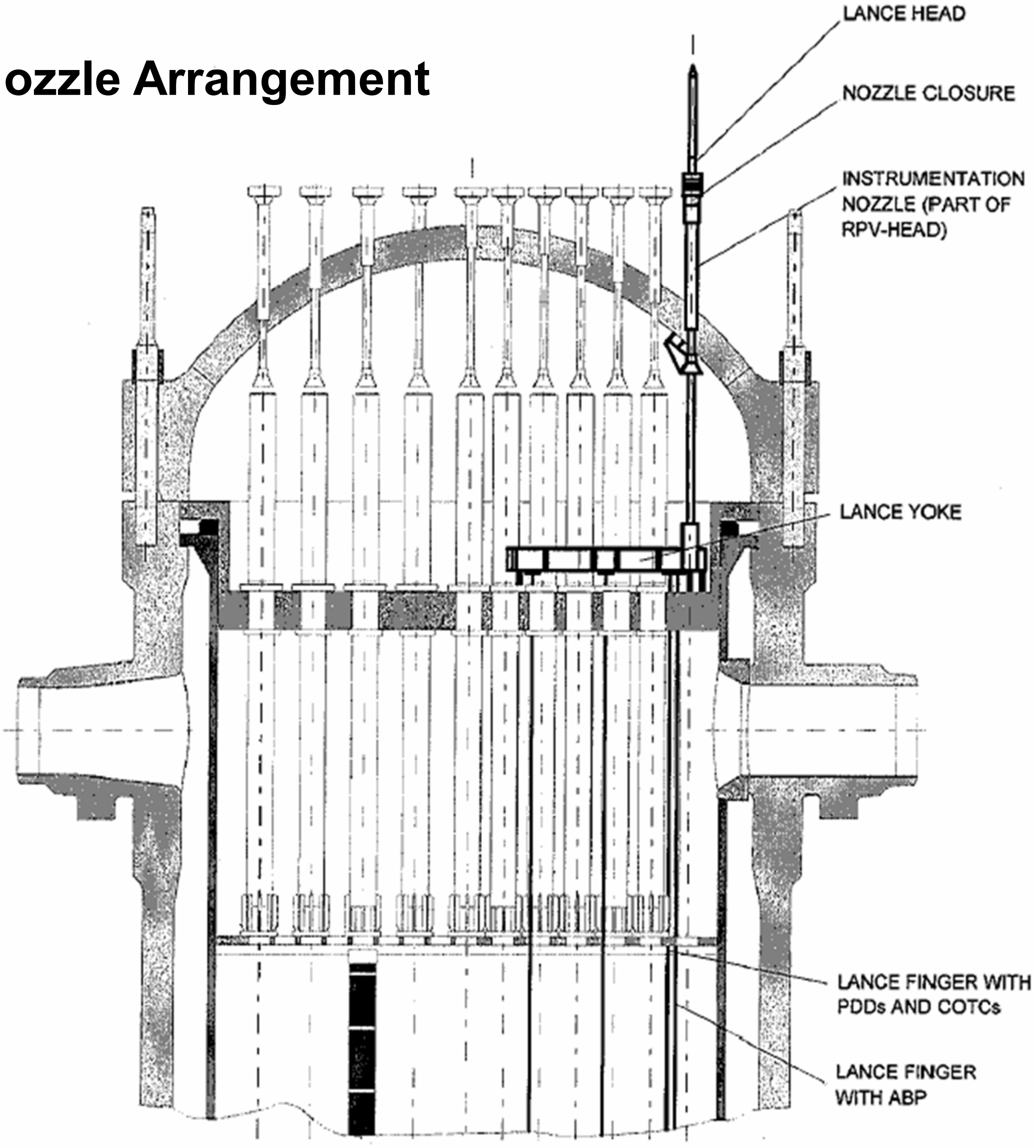


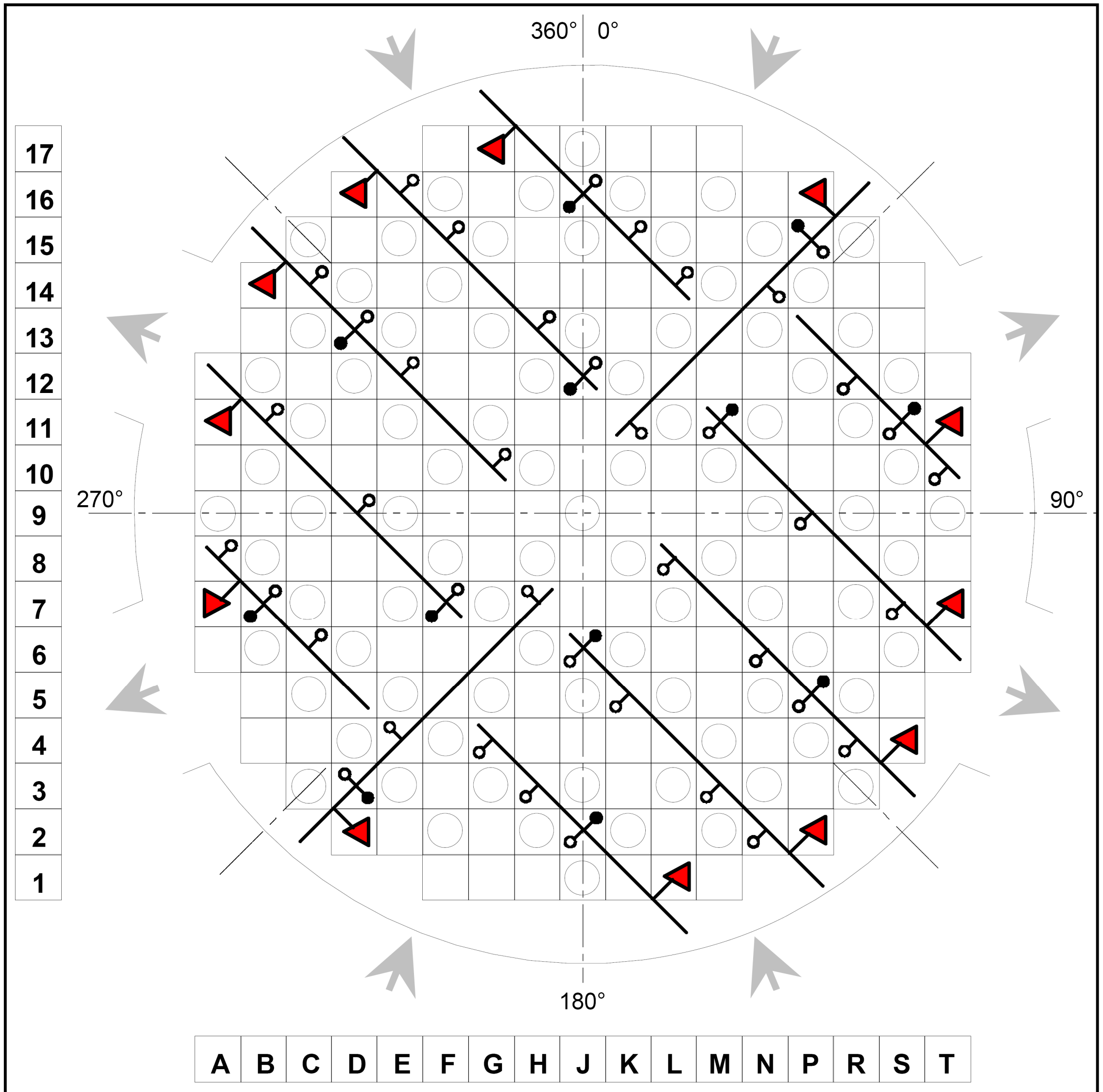
Figure 2-21
Instrumentation Lance and Nozzle Arrangement



LANCE, INSTRUMENTATION NOZZLE AND COOLANT NOZZLE ARRANGEMENT DRAWN ROTATED
SOME CONTROL ROD GUIDE ASSEMBLIES AND NOZZLES NOT DRAWN

ABP	AEROBALL PROBE
PDD	POWER DENSITY DETECTOR
COTC	CORE OUTLET THERMOCOUPLE

Figure 2-22
Arrangement of Incore Instrumentation



☐ 241 FUEL ASSEMBLIES

○ 89 CONTROL ASSEMBLIES

40 AEROBALL PROBES

12 FINGERS WITH POWER DENSITY DETECTORS (PDDs) AND THERMOCOUPLES

▲ 12 RPV INSTRUMENTATION NOZZLES WITH INSTRUMENTATION LANCES

/ 12 LANCE YOKES

Figure 2-23 Aeroball System

- ~ 2500 balls/stack
- 0.067-in. diameter balls
- 1.5% Vanadium-51 balls

- Radiation detection:

- $V\text{-}51 \xrightarrow{(n,\gamma)} V\text{-}52 \xrightarrow{\beta,\gamma} Cr\text{-}52$

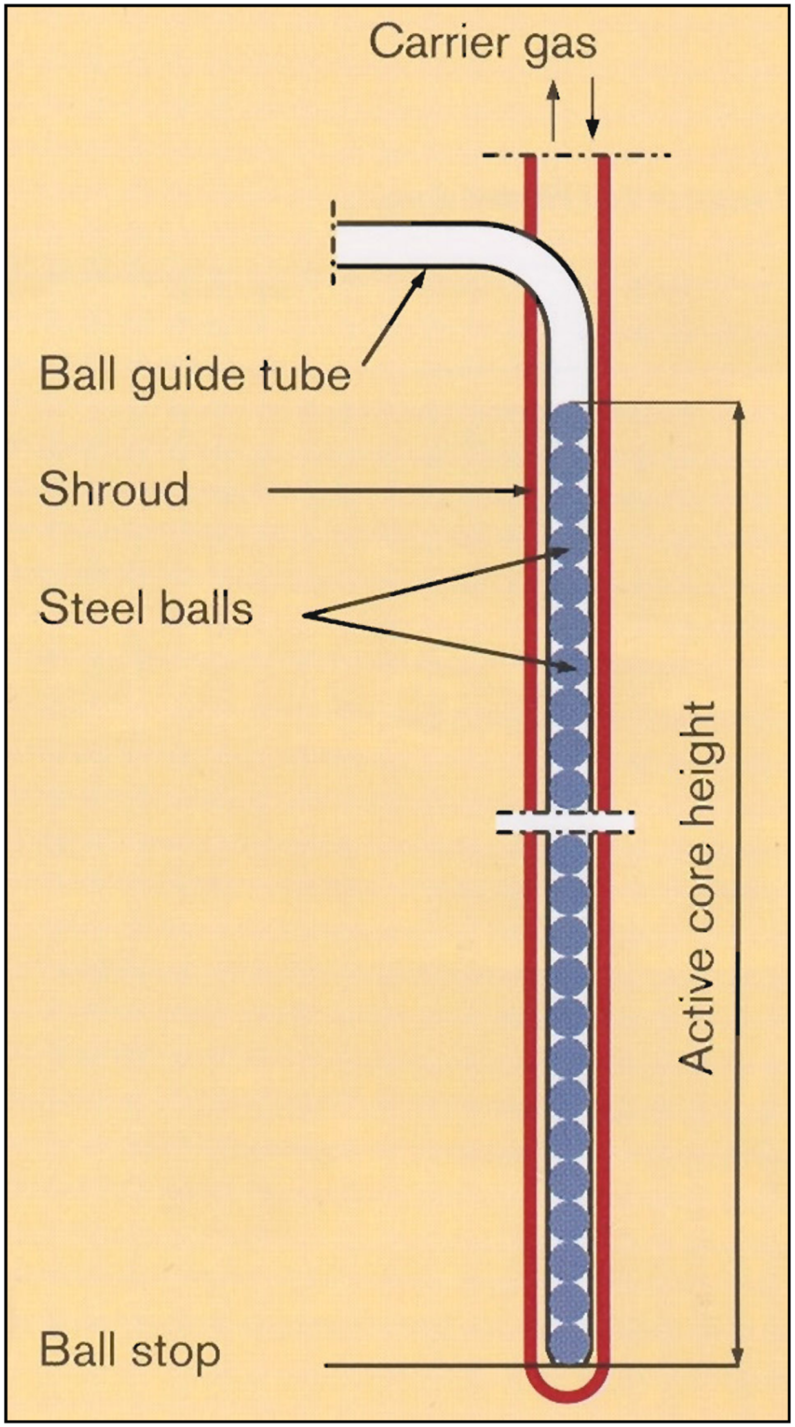


Figure 2-24

Aeroball System Schematic

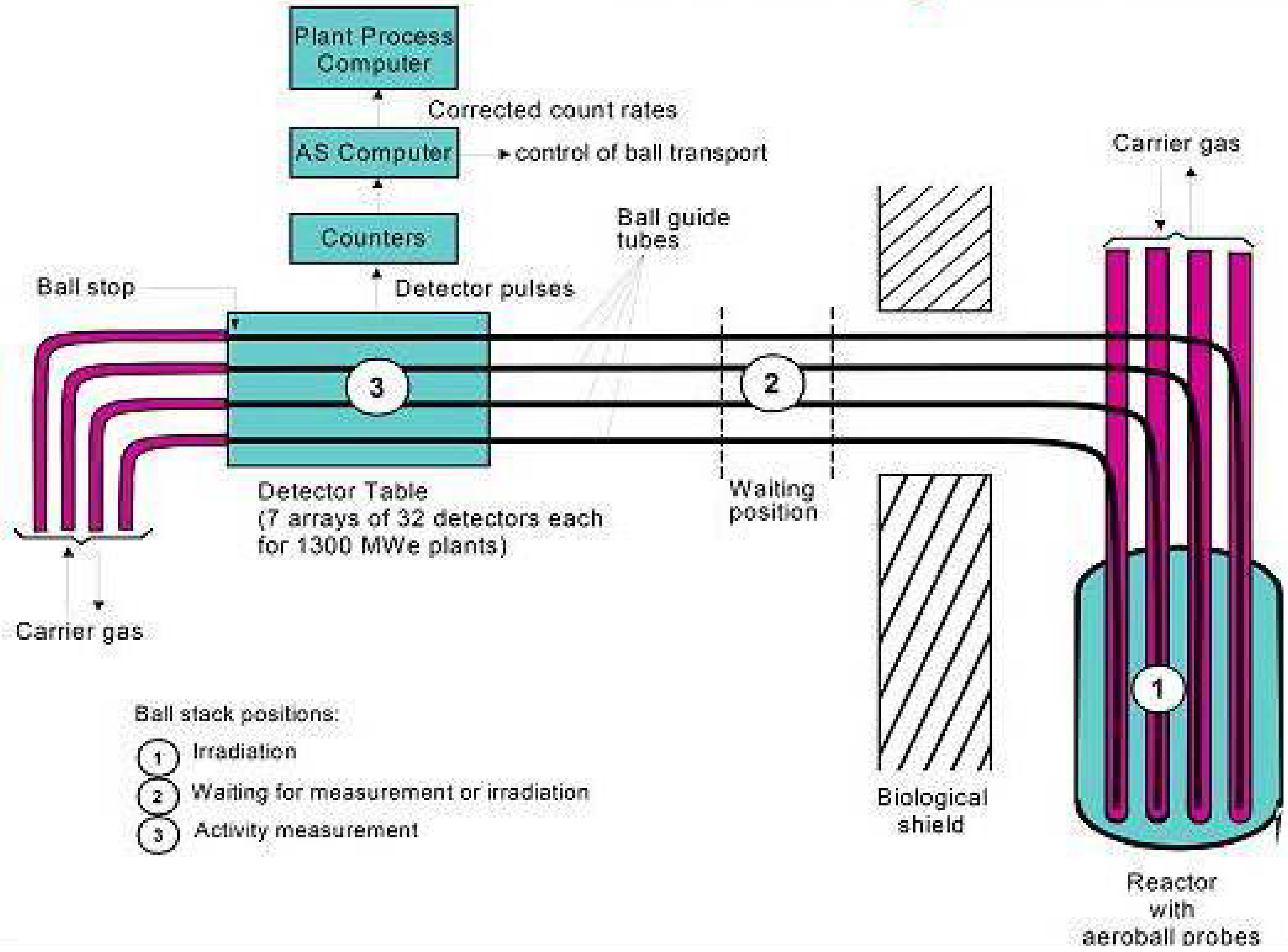


Figure 2-26 Aeroball Pneumatic Transport System

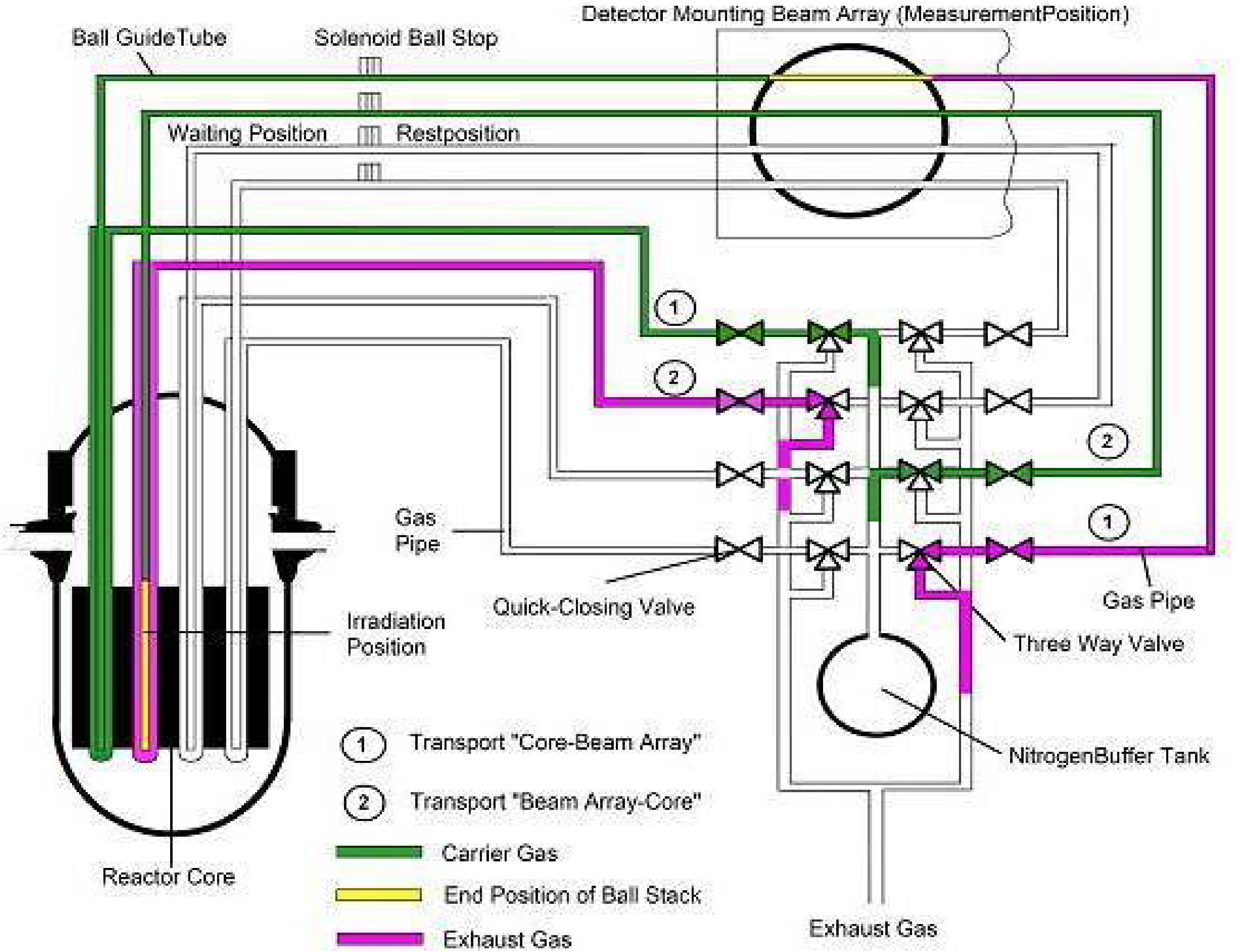


Figure 2-27 Aeroball Measurement Processing Time