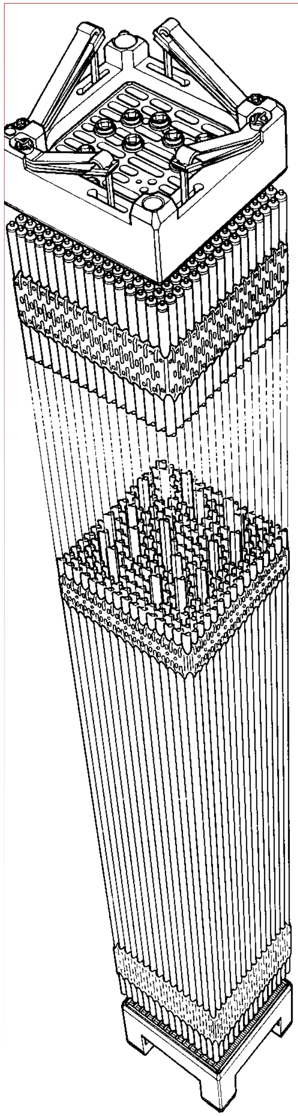


U.S. EPR Fuel/Core Design

Marty Parece
Chief Engineer
Manager, Technical Integration
AREVA NP, Inc

Core Design

Core Size

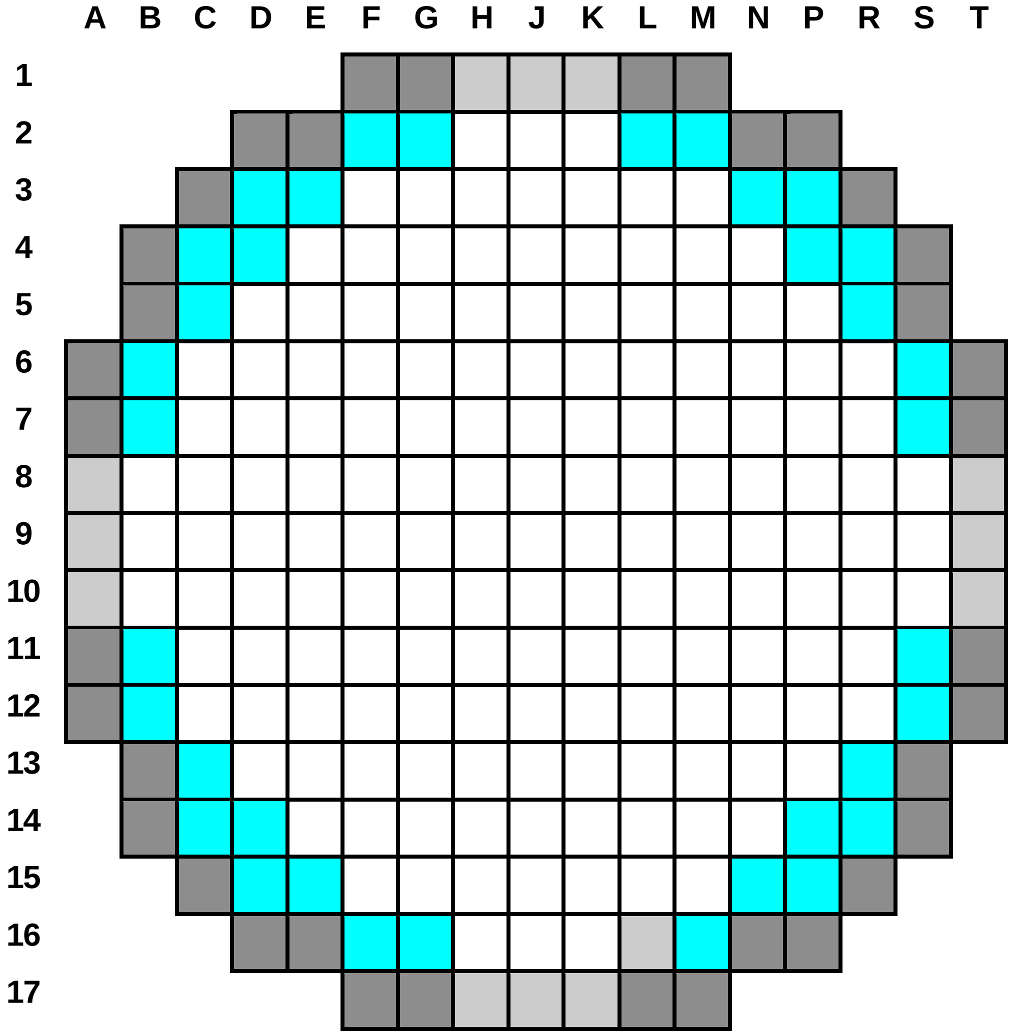
- 241 fuel assemblies
- active fuel length 4.2 m (≈ 13' 9")
- Allows long fuel cycles (up to 2 years) with a good fuel cycle economy
- Low Linear Heat Rate
  - ≈ 5.1 kW/ft (for 4590 MWth)
  - High Radial Peaking Factor $F\Delta h \leq 1.63$ $Fq < \approx 2.7$
  - Full low leakage loading pattern capability
- Design margin preserves future flexibility

From The 900 Mwe 3-loop Plant To EPR

From the 3-loop to the
4-loop 1300 MWe
+36 assemblies

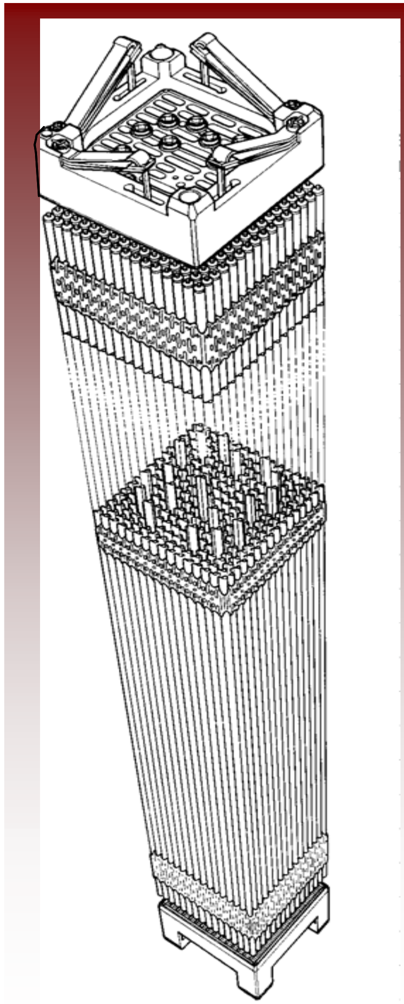
From N4 to EPR
+36 assemblies

Type of plant	Nb of fuel assy	
3-loop	157	⬜
4-loop 1300 MWe	193	🟦
4-loop N4	205	▨
EPR	241	■

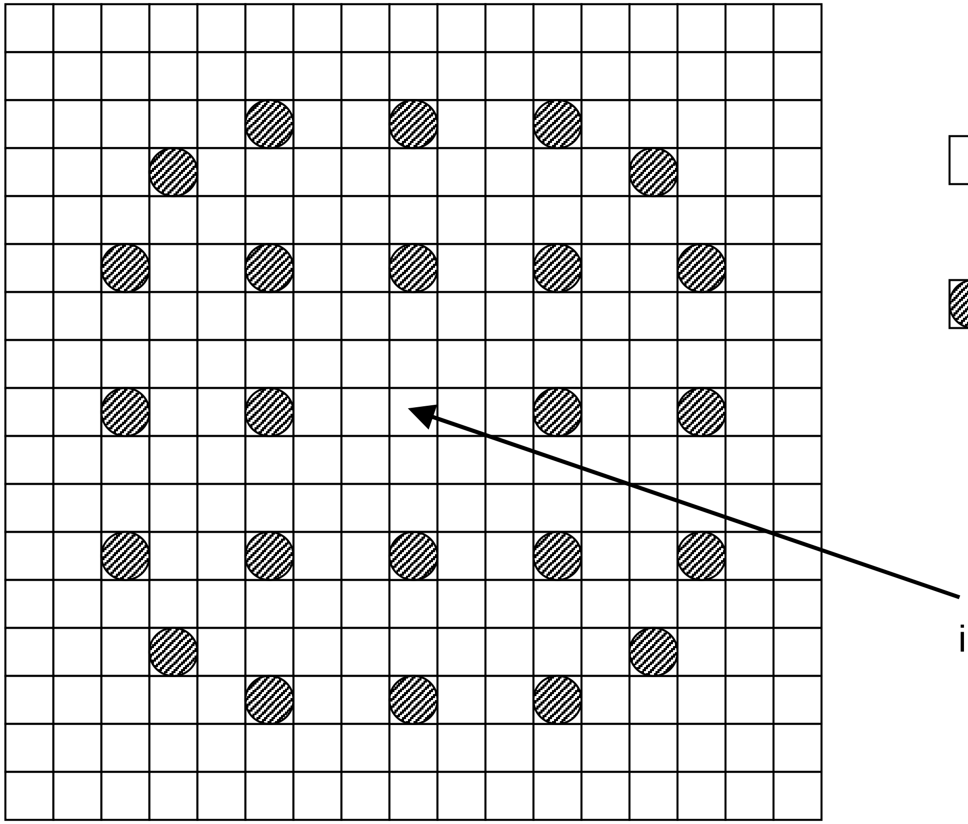


Fuel Assembly

- 17x17
- Typical Pitch-to-Diameter Ratio
- 265 Fuel Rods Per Assembly
- M5 Cladding
- Heated Length (13.78') Similar to N4 (14')
- M5 HTP Mixing Vane Grids (8)
- Anti-Debris Lower End Fitting
- Significant Design Margins
- Variable Gd_2O_3 content up to 8%
- U_{235} enrichment up to 5%
- MOX Compatible



17x17 ASSEMBLY

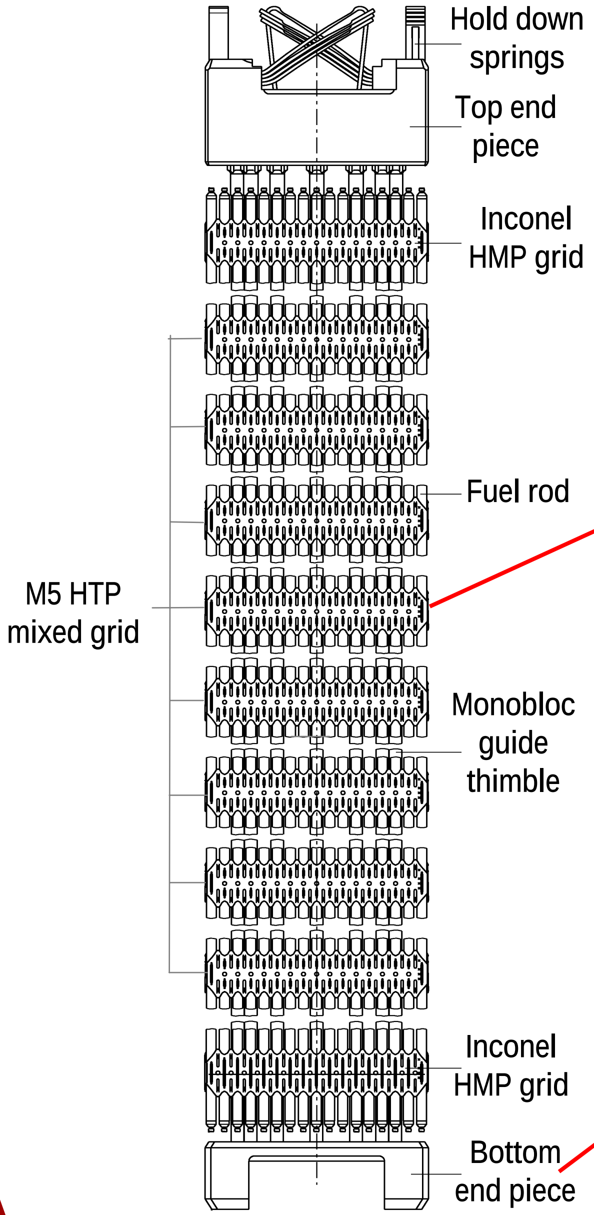


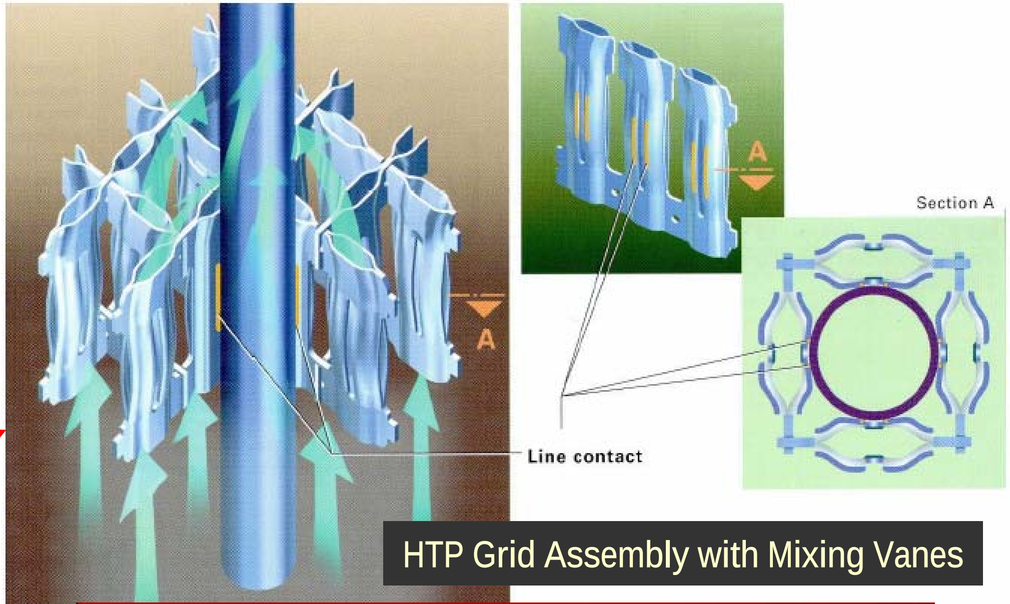
☐ Fuel Rod

▨ Guide Tube
for RCCA absorber rod or
instrumentation thimble

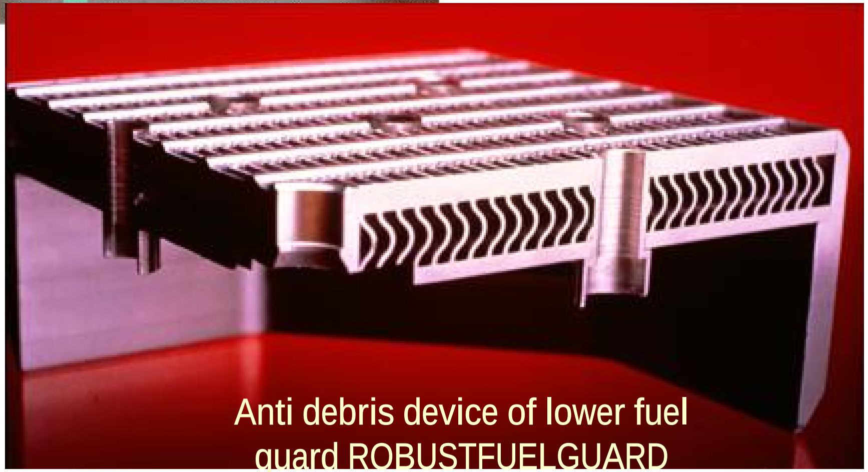
No central
instrumentation
guide tube

HTP Fuel Assembly



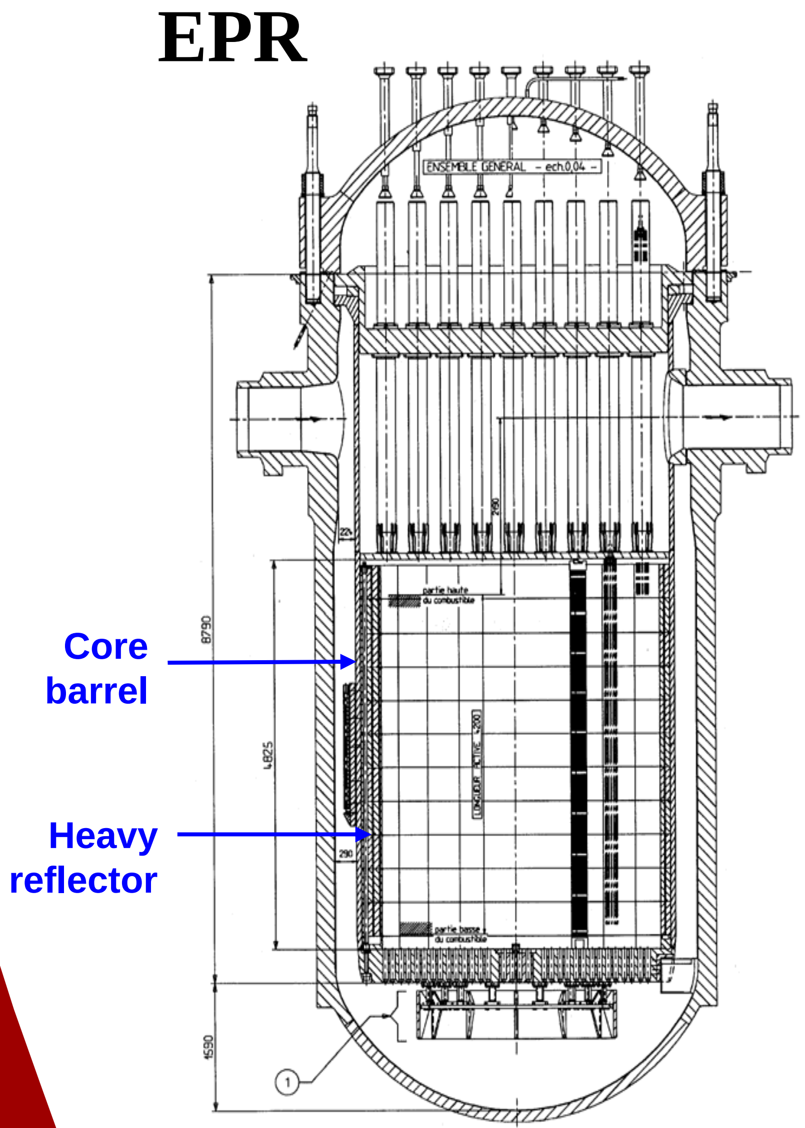


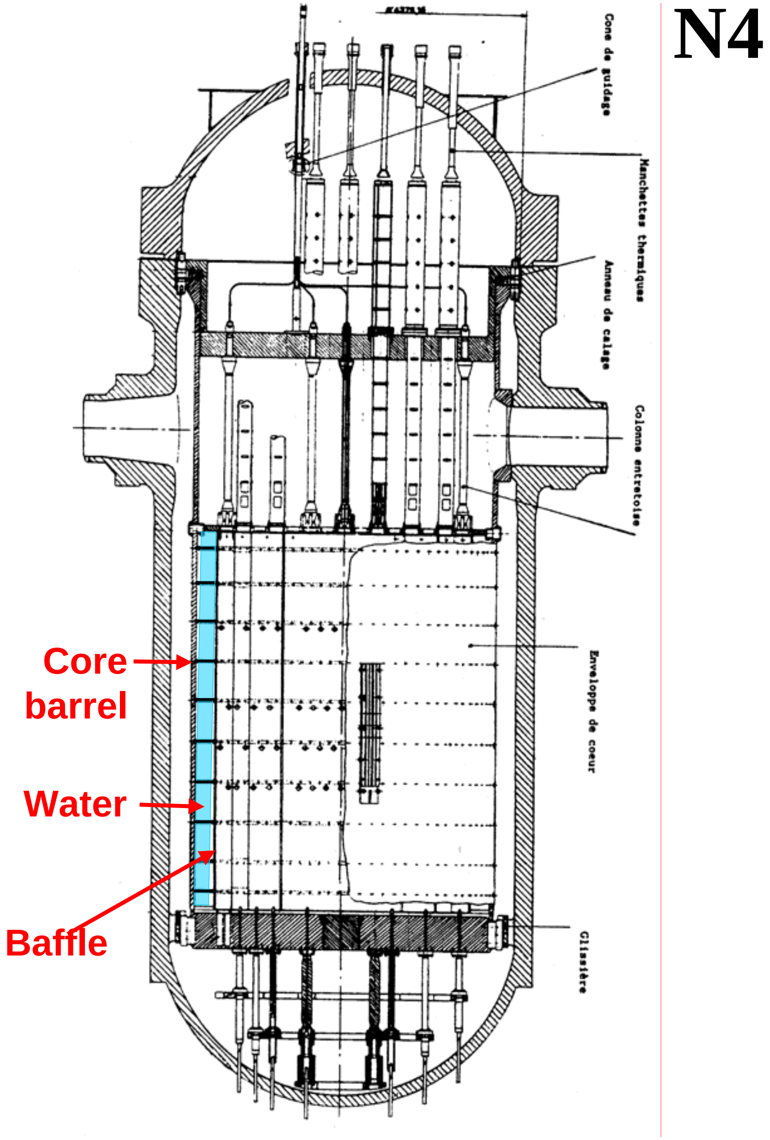
HTP Grid Assembly with Mixing Vanes



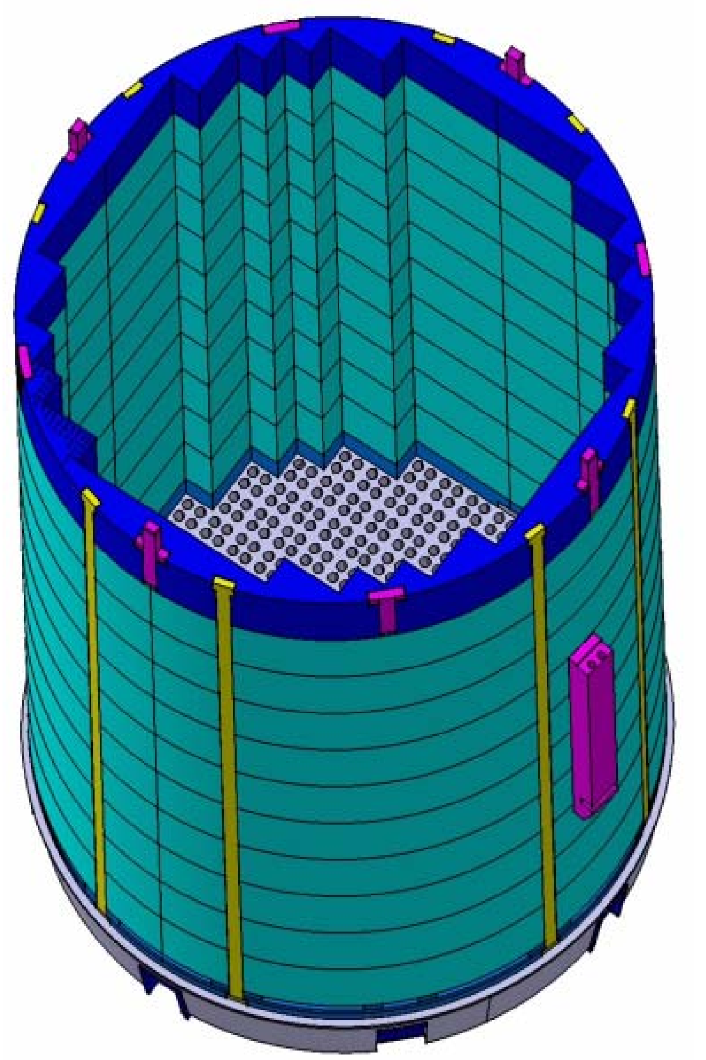
Anti debris device of lower fuel guard ROBUSTFUELGUARD

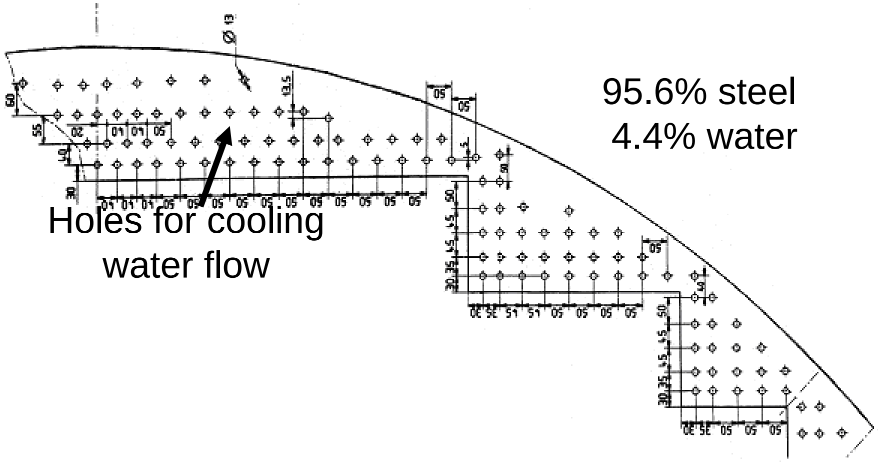
The Heavy Reflector in the Reactor Pressure Vessel





The Heavy Reflector





95.6% steel
4.4% water

Holes for cooling water flow

- **Good mechanical behavior**
  - *No bolts in high fluence region.*
  - *No welds.*
  - *Reduced LOCA forces*
  - *No "baffle jetting"*
  - *Removable*
- **Reduces neutron leakage**
  - *Fuel cycle cost saving : 1%*
  - *Smaller pressure vessel diameter for a given limiting vessel flux level*

Flexible Cycle Length And Fuel Management Strategy

- Special attention was paid to flexibility with respect to possible reload enrichments, fuel types, core designs and discharge burnup
  - Fuel cycle length of 18 months taken as design basis. Also considered:
    - 24 months fuel cycle length
    - In/Out and Out/In loading pattern
  - Maximum enrichment of 5%
  - Average discharge burnup consistent with licensed limits (62 GWD/Mt), but consider future stretch
  - Stretch out or coast-down operations at end of cycle
- Maneuverability capability ensured for the different type of fuel loading
- Capability for Plutonium recycling (MOX assemblies)

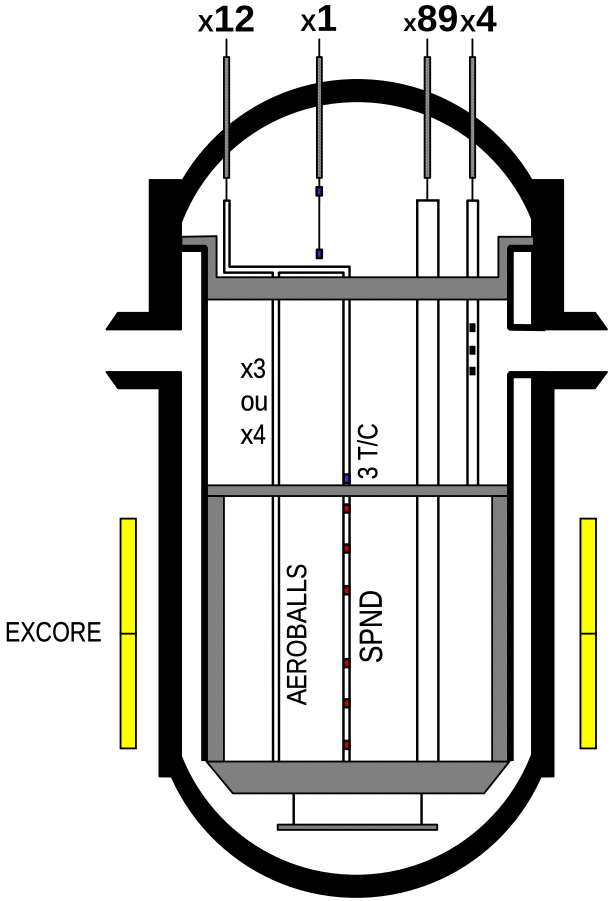
80 FA Feed For 18 Month Equilibrium Cycle At 4.9 w/o

Fuel Management

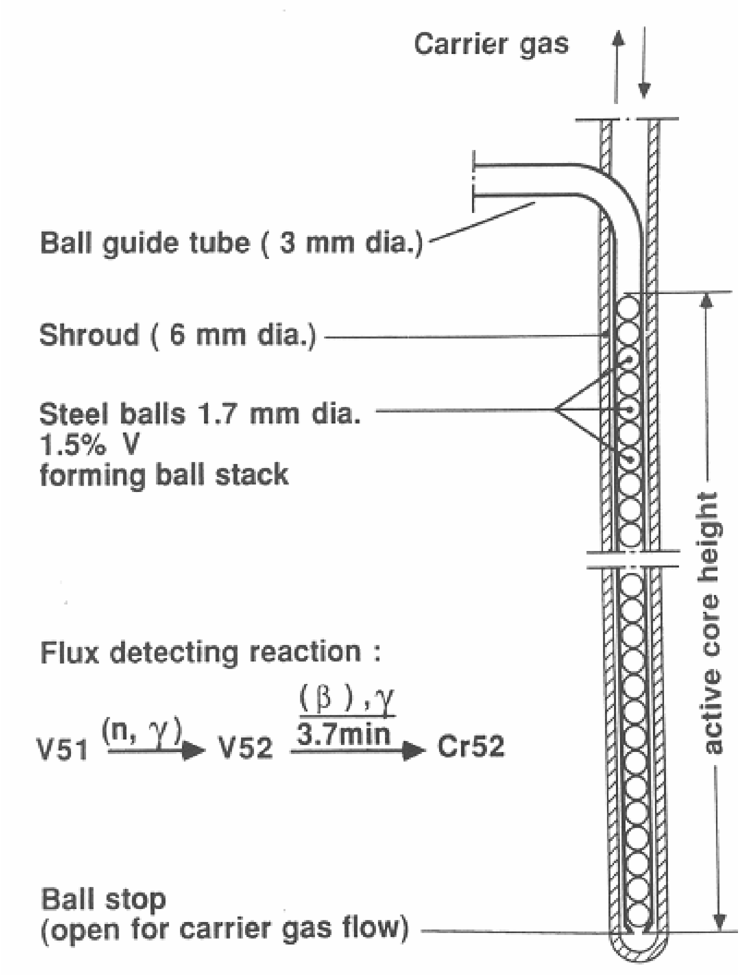
- Moderator coefficient always negative
  - bounding conditions : zero power ; all rods out
  - the amount of Gd poison is set in order to limit boron concentration
- Hot channel enthalpy rise factor restricted to avoid fuel corrosion
  - 1.63 during Basic Design studies
- Core subcritical after partial cooldown (520 F)
- Enriched B_{10} for the core reactivity control
- Accommodate MOX

Nuclear Instrumentation

- In-core instrumentation based on German design and experience
  - Aeroballs
    - Reference instrumentation for power distribution measurement
  - Self Powered Neutron Detectors
    - Fixed incore instrumentation for online core monitoring (surveillance and protection)
    - Calibration based on Aeroball measurements
- Excore neutron detectors
  - Source, intermediate and power ranges
  - Protection against fast reactivity increase



Aeroball system



- Aeroball measurement system (AMS)
  - activity measurement of a ball (steel+vanadium) stack after insertion into fingers in the assembly.
- Reference Instrumentation
  - Periodical neutron flux map for checking the core conformity and calibrating the fixed incore nuclear instrumentation
- Short measuring time
  - Very short activation time => flux mapping in 15 minutes
  - No impact on plant maneuverability : no need of xenon equilibrium when performing a flux map

Fixed incore instrumentation

- Fixed incore instrumentation based on cobalt SPNDs
  - 12 fingers with 6 Self Powered Neutron Detectors each
- Signals used for control, surveillance and protection of the core
  - on line calculation
    - Axial offset *
    - Hot spot factor (Fq) and High Linear Power Density (HLPD)
    - Minimum DNBR
  - Periodic calibration every 15 days

* *Core Axial Offset :* $AO = \frac{P_T - P_B}{P_T + P_B}$

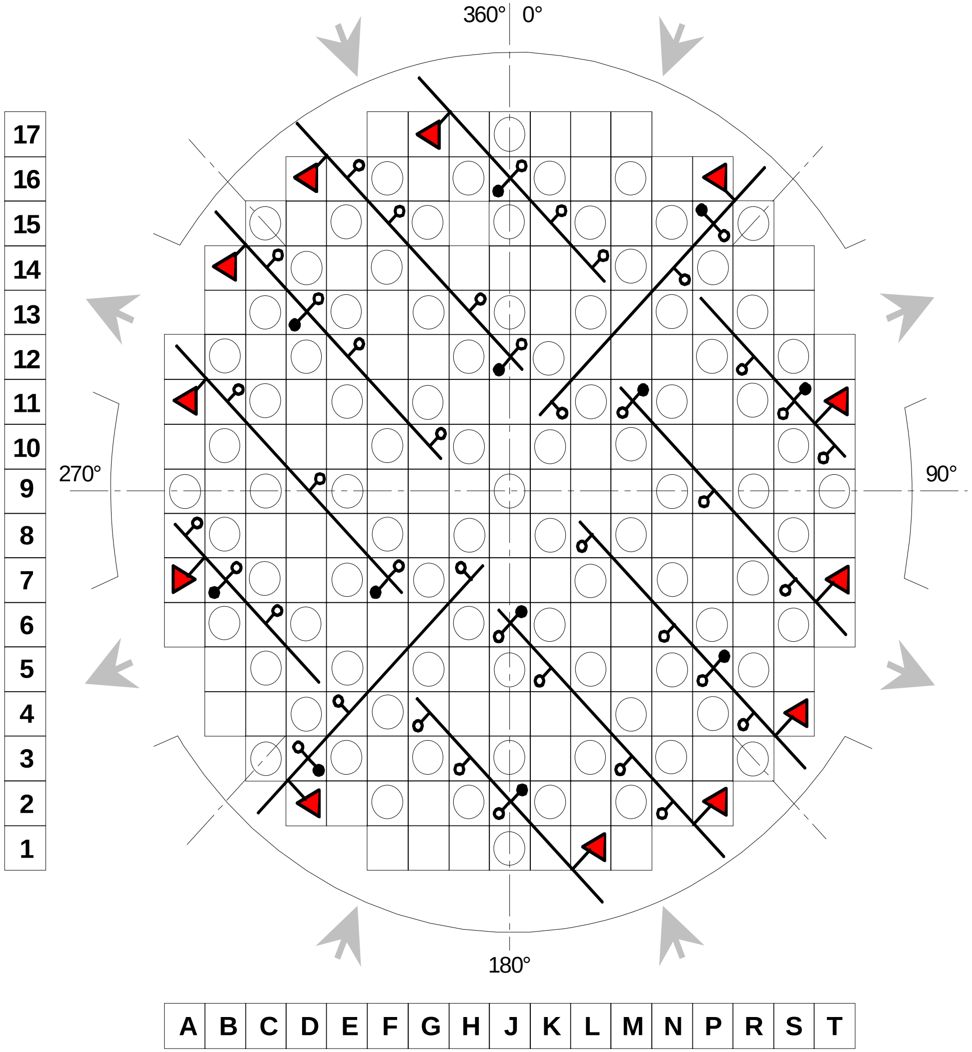
P_T *and* P_B *: Power generated in the top and bottom halves of the core*

In-core Instrumentation Pattern

Detectors are located only in unrodded fuel assemblies

No significant impact on the flux map accuracy

- □ 241 FUEL ASSEMBLIES
- ⚲ 40 AEROBALL PROBES
- ▲ 12 RPV INSTRUMENTATION NOZZLES WITH INSTRUMENTATION LANCES
- ○ 89 CONTROL ASSEMBLIES
- ● 12 FINGERS WITH POWER DENSITY DETECTORS (SPNDs) AND THERMOCOUPLES
- ╱ 12 LANCE YOKES



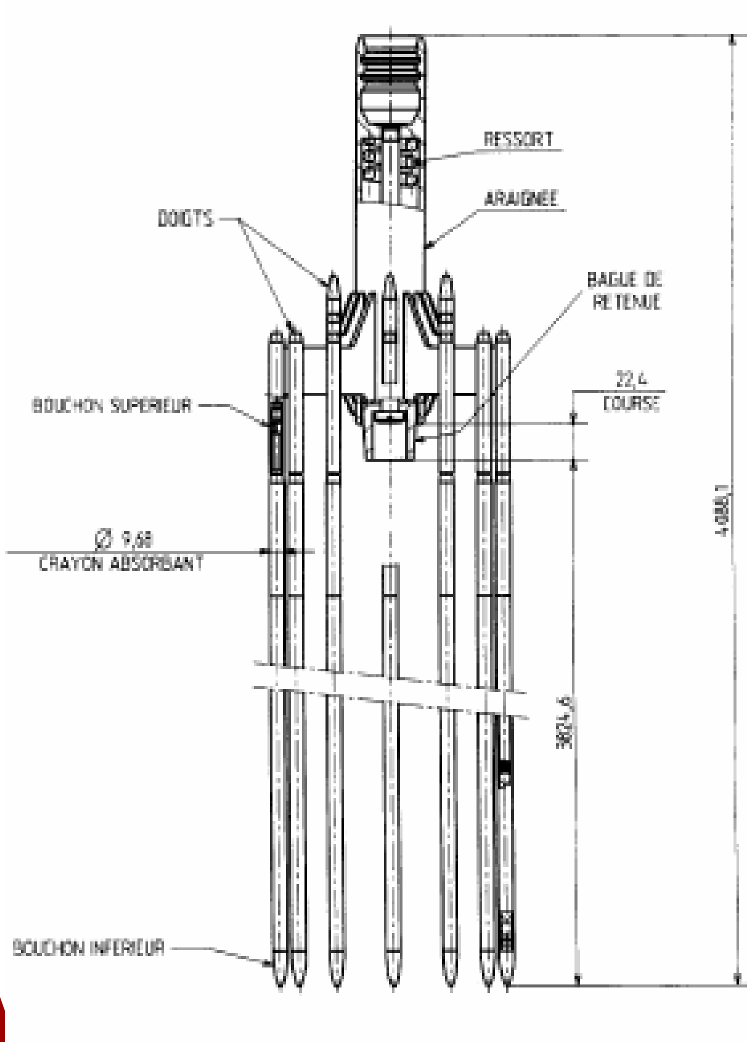
Core Thermal Hydraulic Monitoring

- **Minimum DNBR is calculated by an algorithm accounting for :**
  - **Inlet temperature,**
  - **Pressure,**
  - **Flow rate (RC Pumps speed)**
  - **Power level**
  - **Radial distribution (FΔh)**
  - **Hot channel axial power distribution**
    - **The axial hot channel power distribution is reconstructed from the six signals of the SPND thimble.**
  - **Tracking Error**
    - **Account for the accuracy of the relationship between the SPND signals and the parameter (Fq, FΔh) in the monitoring zone**
- **Core protection against low DNBR**
  - **Surveillance/Limitation**
    - **1) Stop control rod withdrawal and load increase**
    - **2) Power reduction: rod insertion (partial trip)**
  - **Protection**
    - **Reactor trip**

Core Reactivity Control Principles

Soluble Boron - CVCS - EBS	Fuel burnup compensation Xenon compensation Ensure subcriticality at cold state	Enriched B_{10} keeps $C_B < 1400$ ppm (HFP, BOC)
Control rods 89 black rods	Control - Reactor coolant T°avg - Axial Offset Ensure subcriticality for core safe shutdown (260 °C)	Control of rod bank insertion Partial trip Reactor trip
Burnable absorbers (Gd_2O_3)	Reduce boron conc at BOC Limit radial power peaking factor	Moderator T° coef < 0 $F\Delta h < F\Delta h$ limit

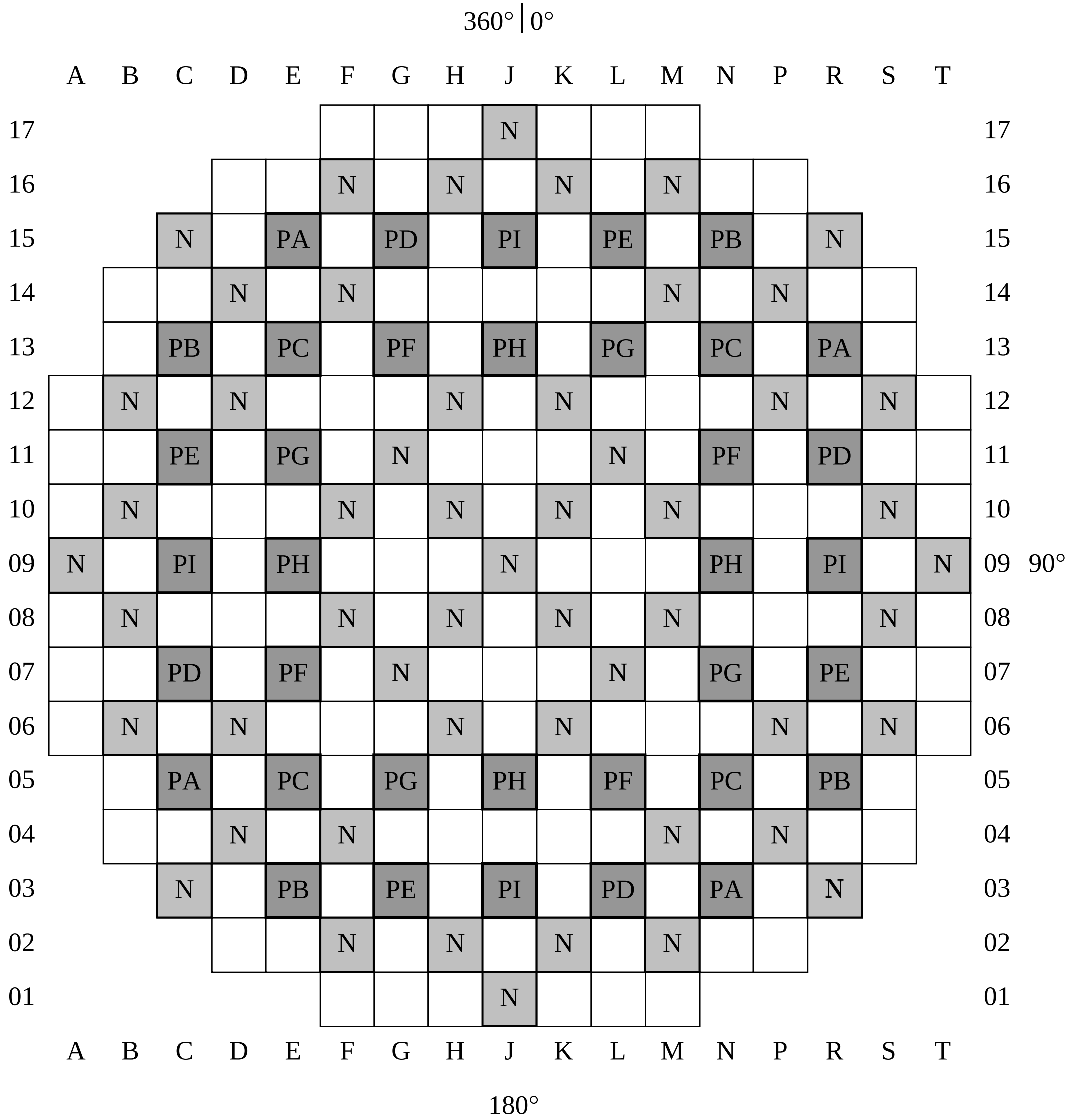
Rod Cluster Control Assembly (RCCA)



- **Only "black rods"**
  - **24 hybrid control rodlets**
  - **upper part B4C natural boron**
  - **lower part Ag/In/Cd**
  - **U.S. EPR – AIC RCCAs**
- **Control rod drive mechanism with magnetically operated jack**
  - **1 step = 10 mm**

RCCA Pattern

- **89 RCCA for maximizing the shutdown margin**
- **53 for shutdown (N)**
- **36 for control**
  - **9 banks of 4 rods symmetrically located (PA to PI)**
  - **The 4 rods move at the same time with the same signal**
- **Assignment of bank to control groups can be changed during the fuel cycle**



360° | 0°

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T	
17									N									17
16						N		N		N		N						16
15			N		PA		PD		PI		PE		PB		N			15
14				N		N						N		N				14
13			PB		PC		PF		PH		PG		PC		PA			13
12		N		N				N		N				N		N		12
11			PE		PG		N				N		PF		PD			11
10		N				N		N		N		N				N		10
09	N		PI		PH				N				PH		PI		N	09
08		N				N		N		N		N				N		08
07			PD		PF		N				N		PG		PE			07
06		N		N				N		N				N		N		06
05			PA		PC		PG		PH		PF		PC		PB			05
04				N		N						N		N				04
03			N		PB		PE		PI		PD		PA		N			03
02						N		N		N		N						02
01									N									01
	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T	

270°

90°

180°