The EPR™ Reactor: Evolution to Gen III+ based on proven technology

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Building on the Achievements of the N4 and Konvoi Reactors

N4	High output (1475MWe)	Very High output: ~1600MWe
	Large core (205 FA)	Very large core: 241 FA
	High steam pressure (73,1 bar)	Very High steam pressure: 77,2 bar
	Fuel building	Fuel building
	Computerized MCR	Computerized MCR
	Concrete cylindrical containment Military aircraft resistance	Best-in-class APC
KONVOI	4 independent Safety trains	4x100% independent Safety trains
	No spray system	DBA: No spray system
	Top mounted instrumentation	Top mounted instrumentation

The EPR™ design combines and improves on the best features of the French and German technologies

Main Steps of the EPR Development

1989 Cooperation agreement between Framatome and Siemens

1991 EDF and German utilities decide to join their development work

1993 GPR/RSK Proposal for a Common Safety Approach for Future Pressurized Water Reactors

1998 End of Basic Design

Until 2003 Continuation of Engineering work on specific scope of work

2005 Construction License for Olkiluoto 3, Finland

2007 Construction License for Flamanville 3, France; EPR design submitted to Generic Design Assessment in the UK

2008 US NRC accepts EPR design application for review

Joint Recommendations of French and German Safety Authorities (1993)

Three main objectives:

- **Evolutionary rather than revolutionary design;**
- **Significant reduction of core meltdown probability and improvement of the reactor containment capability (also for severe accidents);**
- **Improvement of operating conditions:**

  - radiation protection,

  - waste management,

  - maintenance,

  - reduction of human error risk

Those objectives stem from the stakeholders involved in the design process: utilities (EDF & German utilities, Safety Authorities: GRS (Germany) & IPSN (France)

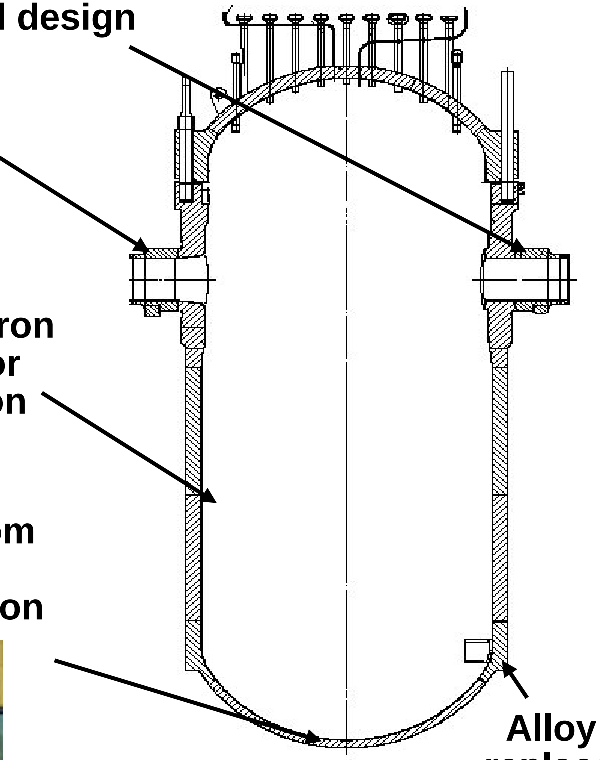
EPR REACTOR PRESSURE VESSEL MAIN DESIGN IMPROVEMENTS

- **ONE INTEGRAL FORGING FOR THE VESSEL FLANGES AND THE NOZZLE SHELL / SET-ON NOZZLES***
  - **Reduction of ISI time**
  - **Main nozzles axis located higher above active core allowing minimizing consequences in case of an intermediate break**
- **IN-CORE PENETRATIONS LOCATED ON RPV CLOSURE HEAD***
  - **No penetrations in RPV lower head**
  - **Facilitate layout of IRWST and of corium spreading area**
- **PREVENTION OF BRITTLE FRACTURE RISK IN CORE SHELL AREA:**
  - **Lower fluence**
  - **Classical low alloy steel, but with lower residual content leading to improved properties**
- **INCONEL 600 REPLACED BY INCONEL 690 FOR PENETRATIONS**

*** Konvoi technology**

General improvements on RPV structure

- **Systematic use of Alloy 690 replacing the Alloy 600**
- **Reduction of the neutron fluence on the core shell region**
- **One piece RPV upper part instead of two welded pieces for N4**
- **Irradiation surveillance program**



One piece forged design

Improved bimetallic weld

Lower neutron fluence for core region shell

No bottom head penetration

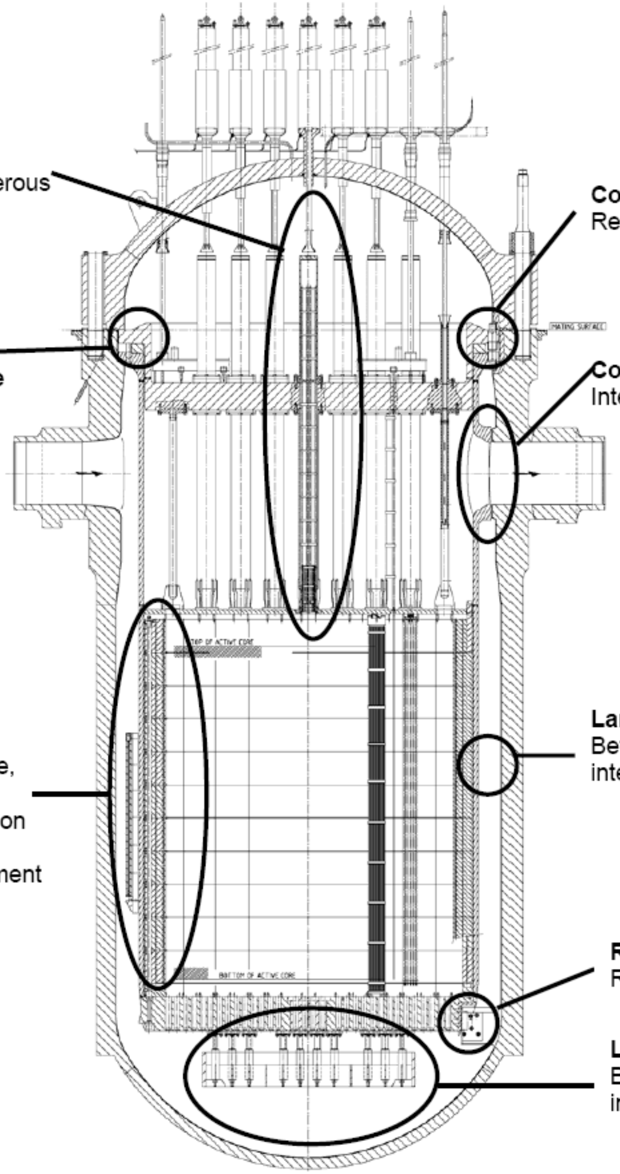
Alloy 600 replaced by alloy 690

EPR REACTOR PRESSURE VESSEL INTERNALS MAIN DESIGN FEATURES

- **USE OF A GENERAL ARRANGEMENT SIMILAR TO N4:**
  - **Inverted hat design for the RCCA guide support**
  - **Similar flow distribution in upper plenum and closure head dome**
  - **Forged core support plate**
  - **Fuel assemblies resting directly on the core support plate**
  - **Same principles regarding centering and maintaining inside the RPV**
  - **Same materials with more stringent requirement on Co residual content**
- **INCORPORATION OF 3 MAIN MODIFICATIONS**
  - **Adaptation to an in-core instrumentation introduced through the RPV closure head (KONVOI design)**
  - **Installation of a dedicated annular structure under the core support plate to ensure a proper flow distribution at core inlet**
- **INCORPORATION OF AN INNOVATIVE COMPONENT: THE HEAVY REFLECTOR**

General improvements on RPV internals

- **Increased margin with respect to RPV embrittlement achieved through neutron fluence reduction :**
  - **New heavy reflector design reducing neutron leakage at the core periphery**
  - **RPV diameter enlarged**
- **Prevention of low induced vibrations**
- **Better inspectability and easier replacement thanks to new design**



CRGAs proven design validated through numerous tests

Reinforced upper internals flange

Heavy Reflector
Reduced neutron leakage,
Extended service life
RPV Wall fluence reduction
Efficient cooling system
Improved internals alignment

Core barrel outlet nozzles
Reduced stellite coatings

Core barrel outlet nozzles
Integral with the forging

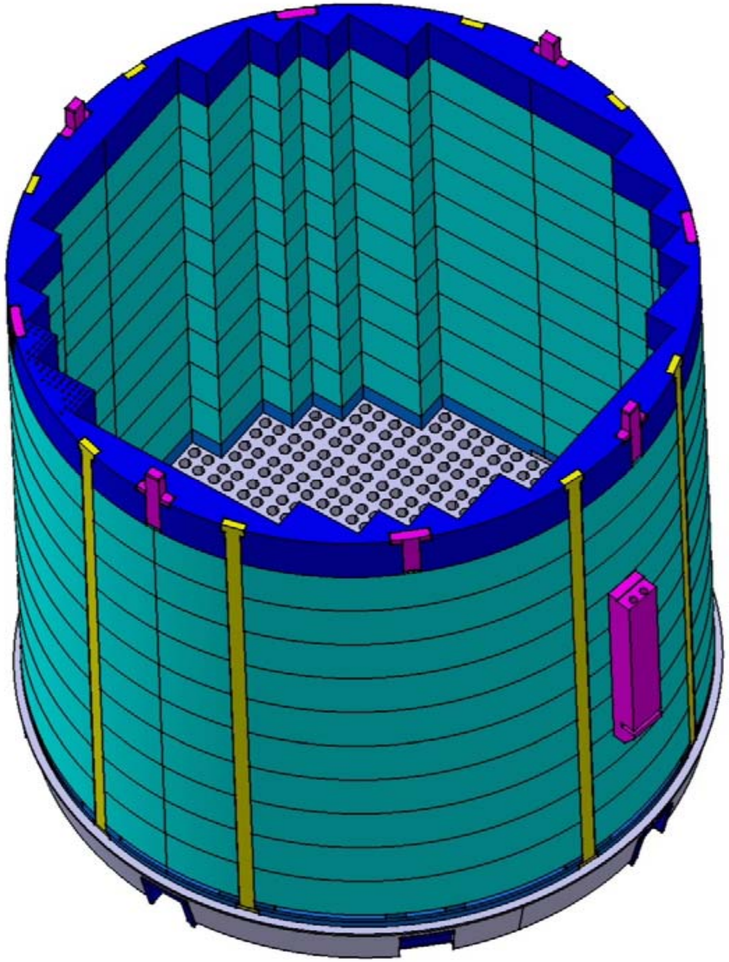
Large downcomer
Better access for lower internals visual inspections

Radial keys
Reduced stellite coatings

Lower plenum
Better access for lower internals visual inspections

RPV LOWER INTERNALS HEAVY REFLECTOR

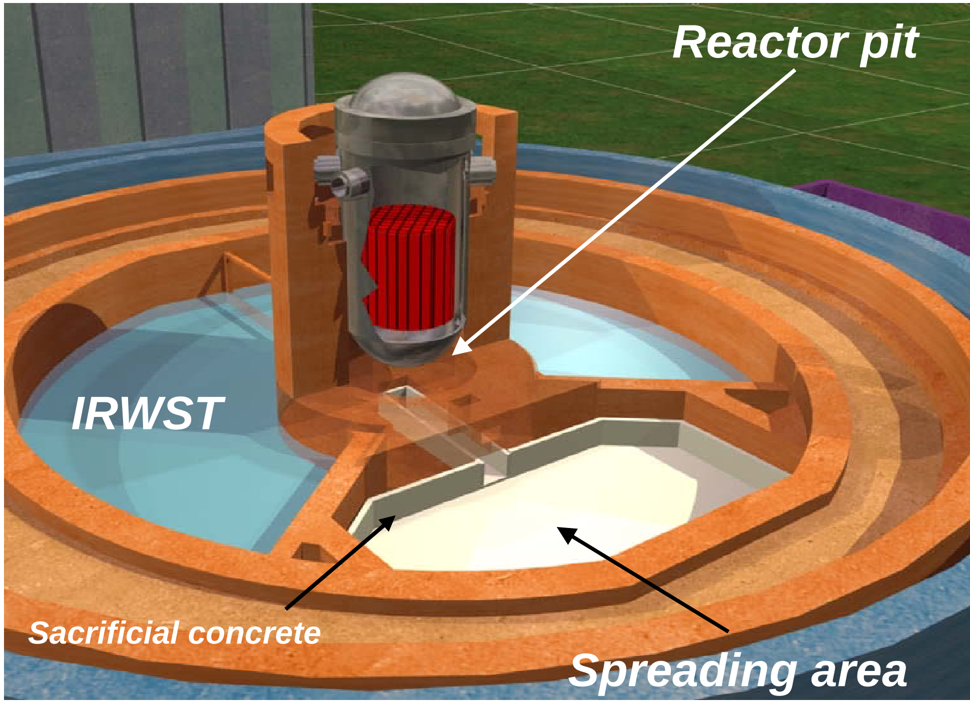
- **REPLACEMENT OF CONVENTIONAL CORE BAFFLE ASSEMBLY BY A HEAVY REFLECTOR**
  - **fuel cycle cost reduction**
  - **Improvement of long term mechanical behavior of lower internals:**
    - **no bolt in the most irradiated areas**
    - **well managed temperature distribution in the structure**
    - **very low depressurization effects in case of LOCA**
  - **Protection of RPV core shell against radiation embrittlement**



Core Melt Retention System (CMRS)

In case of reactor vessel failure, the strategy consists in :

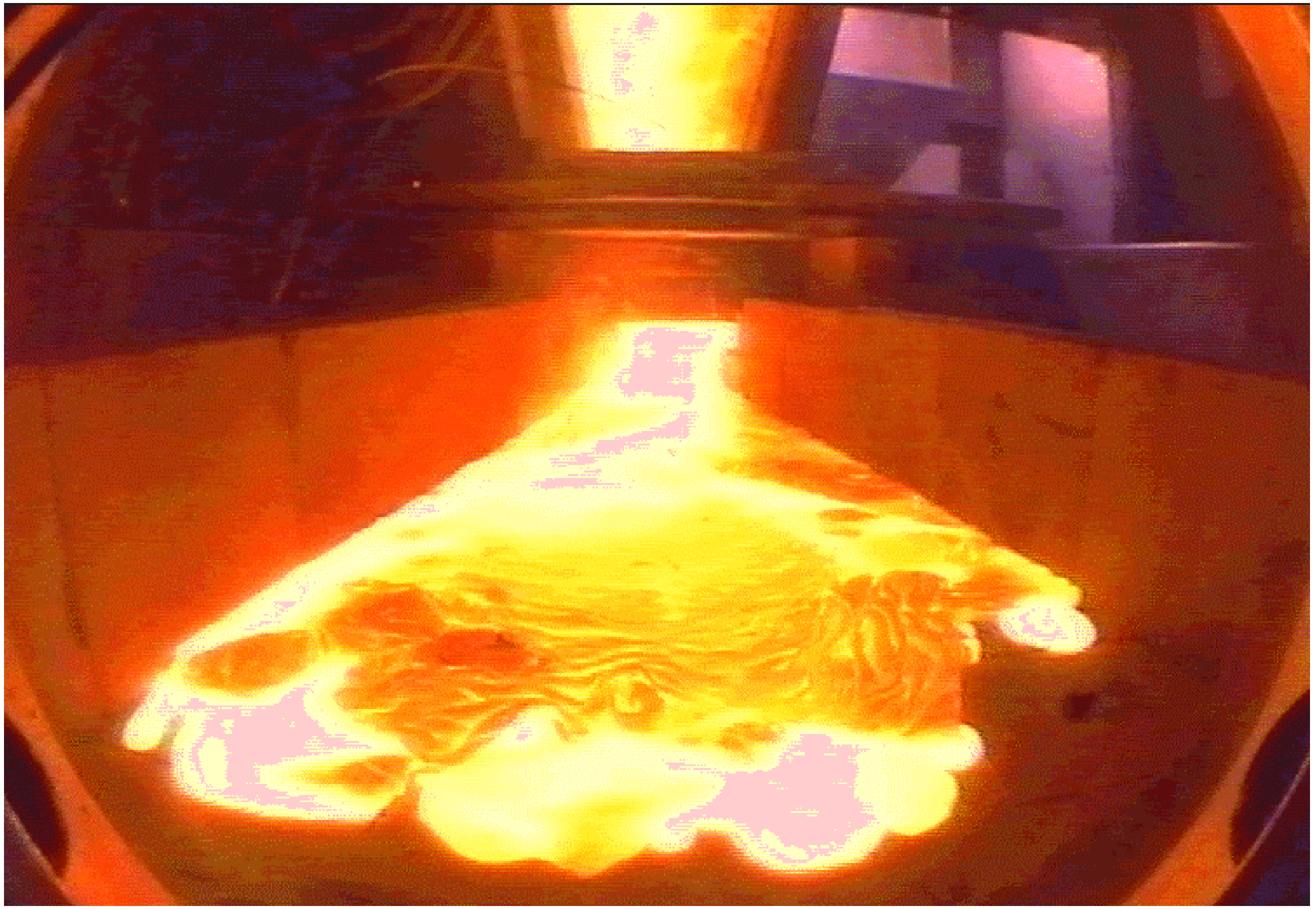
- Preventing corium-basemat interaction so as to avoid significant releases and durable contamination of sub-soil and underground waters.
- Accumulating corium and temporarily retain it in the reactor pit after RPV failure
- Ensuring delayed melting of a metal gate located at the bottom of the reactor pit
- Spreading the corium on a large surface outside of the reactor pit
- Flooding and cooling the spreading area with the help of IRWST water



All stages (retention, spreading, flooding, cooling) are fully passive

Corium spreading test at the French CEA VULCANO (real UO_2 with some Zr O_2)

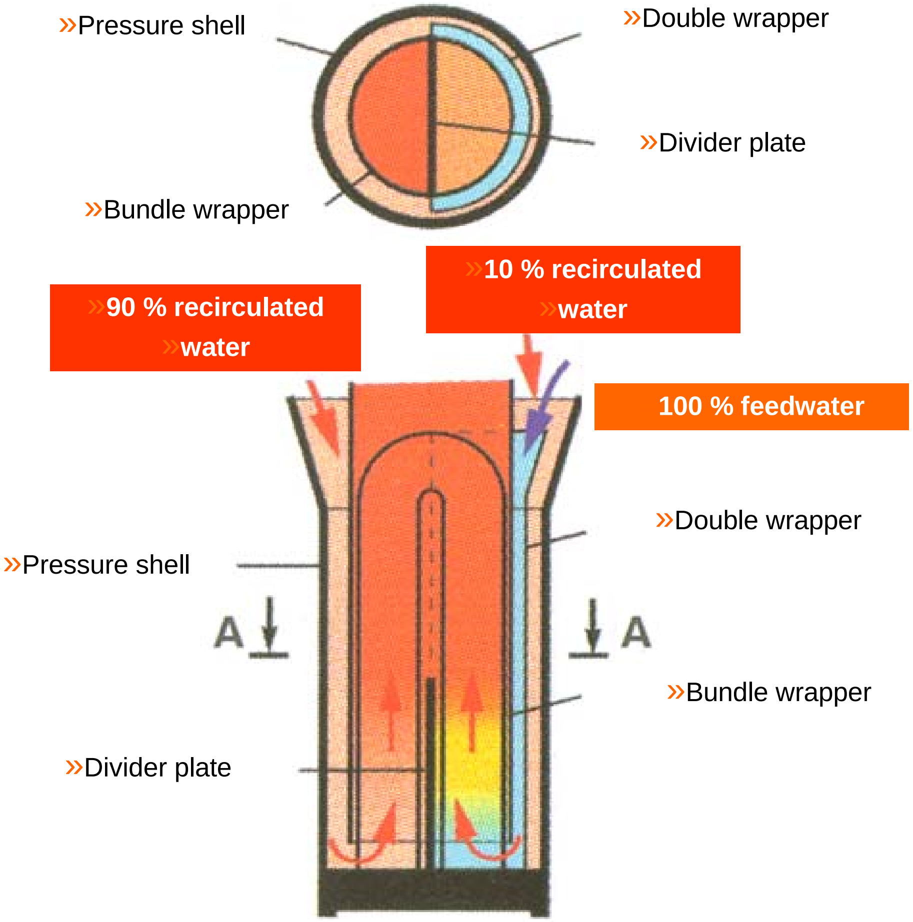
Melt spreading phenomena have been extensively investigated



EPR STEAM GENERATOR AXIAL ECONOMIZER PRINCIPLE

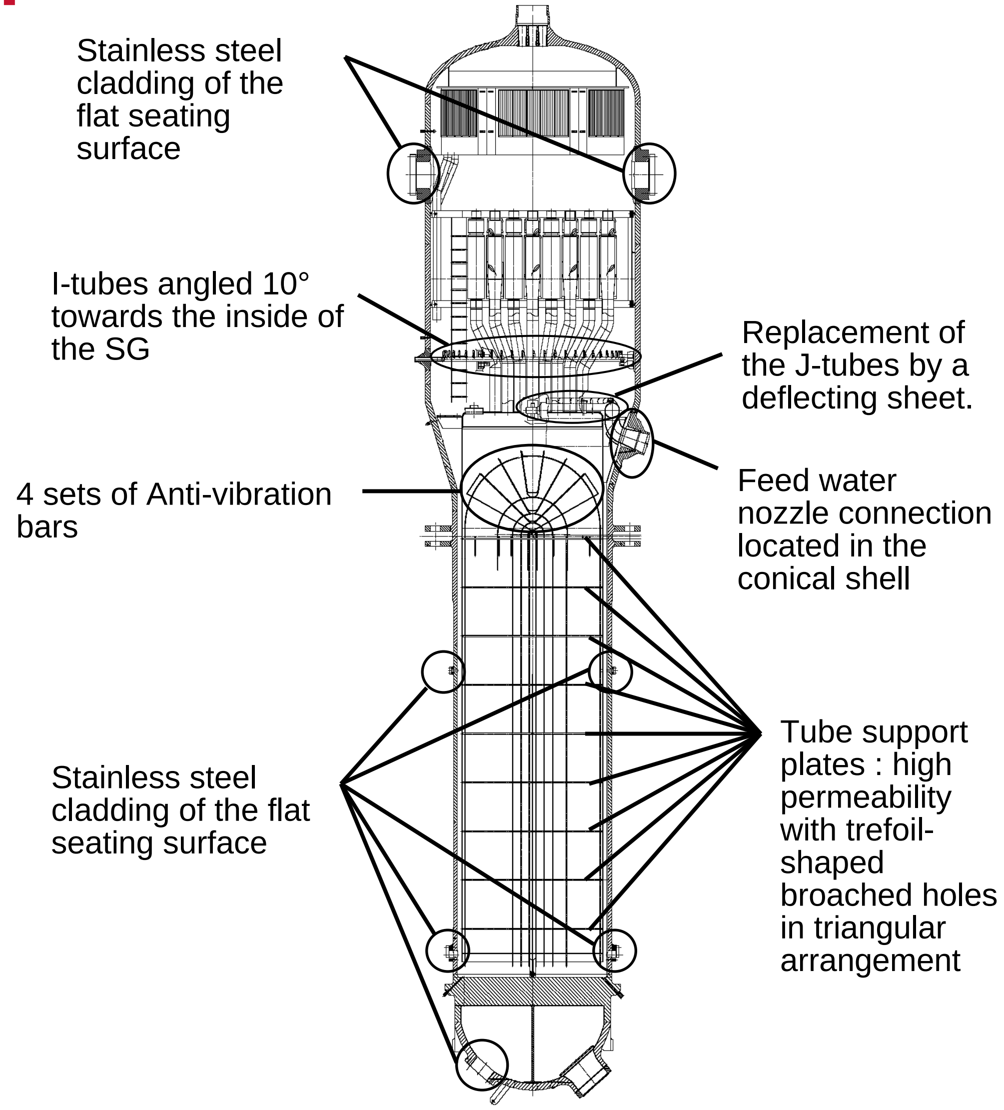
The axial economizer design principles consist in adding a plate to separate cold from hot leg on secondary side and directing all the main feed water to the cold leg thanks to a double wrapper. It leads to higher steam pressure and hence, to higher thermal efficiency

This improved design has been thoroughly confirmed by ~40 reactor.years of N4 reactor experience.



General improvements on SG

- **Reduction of thermal stratification in main feedwater nozzle (inclined nozzle, elevated feed water ring, leak tight connection, start-up system)**
- **Reduction of thermal fatigue and thermal shocks when actuating emergency feedwater (start-up system, I-tubes on EFW distribution ring)**
- **4 sets of AVBs instead of 3 (all the bends above row 2 are supported)**
- **High permeability trefoil tube support plates to prevent clogging**
- **Moister separators in stainless steel (prevention of erosion/corrosion)**
- **Tube sheet cladding in alloy 52**
- **Alloy 690 partition plate in channel head**

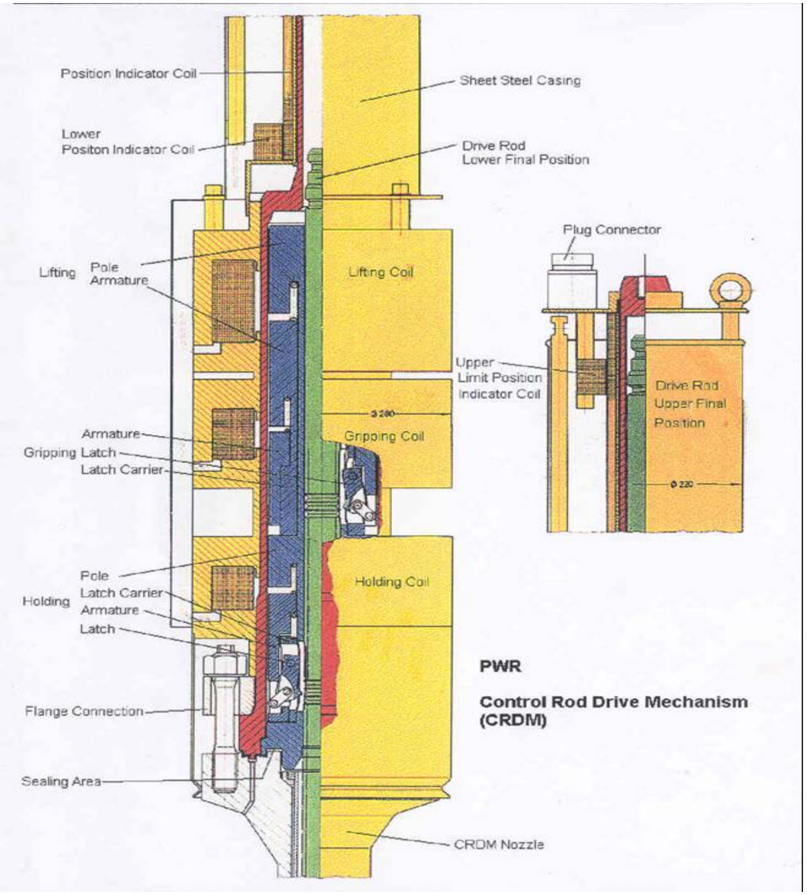


EPR REACTOR COOLANT PUMP MAIN DESIGN FEATURES

- **EPR RCP DESIGN IS BASED ON THE N4 RCP**
  - **Hydrostatic pump bearing (good vibratory behavior)**
  - **Design of the shaft / impeller assembly (Hirth type)**
- **WITH ADDITIONAL IMPROVEMENTS:**
  - **Increased performances obtained by**
    - Slight increase of casing inner diameter (2100 mm instead of 2060 mm)
    - Impeller extrapolated from the N4 one (similitude ratio 1.07)
    - 13 vanes diffuser, instead of 11 for N4
    - 500 mm motor length increase
    - Slight increase of the motor shaft diameter
  - **Addition of a standstill system**
    - designed to remain leaktight in case of simultaneous loss of CVCS (seal injection) and CCWS (thermal barrier)

CONTROL ROD DRIVE MECHANISM MAIN DESIGN FEATURES

- **THE CRDM IS A MAGNETIC JACK BASED ON KONVOI TECHNOLOGY**
  - **No forced air cooling thanks to:**
    - **Coil electrical insulation designed for high operating temperature**
    - **Martensitic stainless steel for the latch housing in front of magnetic coils**
    - **Sheet steel casing with high efficiency of natural convection all along the CRDM**
  - **Double gasketed flange to fasten the latch housing on the RPV closure head adaptor**
- **MAIN CHARACTERISTICS**
  - **step increment: 10 mm**
  - **max. stepping speed: 75 s/mn**
  - **max. rod velocity: 750 mm/mn**
  - **max. load capacity: 300 daN**



PWR

Control Rod Drive Mechanism (CRDM)

Beyond Safety: what benefits for the users?

- **Improved operational performance:**
  - **The EPR reactor is not only designed for enhanced safety, but also for improved operational performance:**
  - **Four-train architecture and accessibility of RB during power operation: 92%+ availability over lifetime**
  - **High steam pressure, larger core and heavy neutron reflector:**
    - 15%+ UNat savings[1]
- **Improved sustainability:**
  - **EPR™ reactor, lower fuel consumption:**
    - 23%+ used fuel reduction[1]
    - 10%+ final waste reduction[1]
  - **La Hague reprocessing plant & MELOX:**
    - La Hague plant: 40y of operational experience
    - MELOX: the reference MOX fuel fabrication facility allow to reduce the volume and toxicity of final waste even further

1- all savings/reductions computed in quantities per MWh produced

Concluding remarks

- **EPR is an evolutionary reactor incorporating most recent technologies from N4 and KONVOI plants.**
- **This approach offers a safe path to improved safety and performance**
- **The proven technologies included in the EPR design will be leveraged further in AREVA's new design, undertaken in cooperation with MHI: the ATMEA1™ reactor**