EDF Operating Experience RV Internals

NRC Workshop - Rockville

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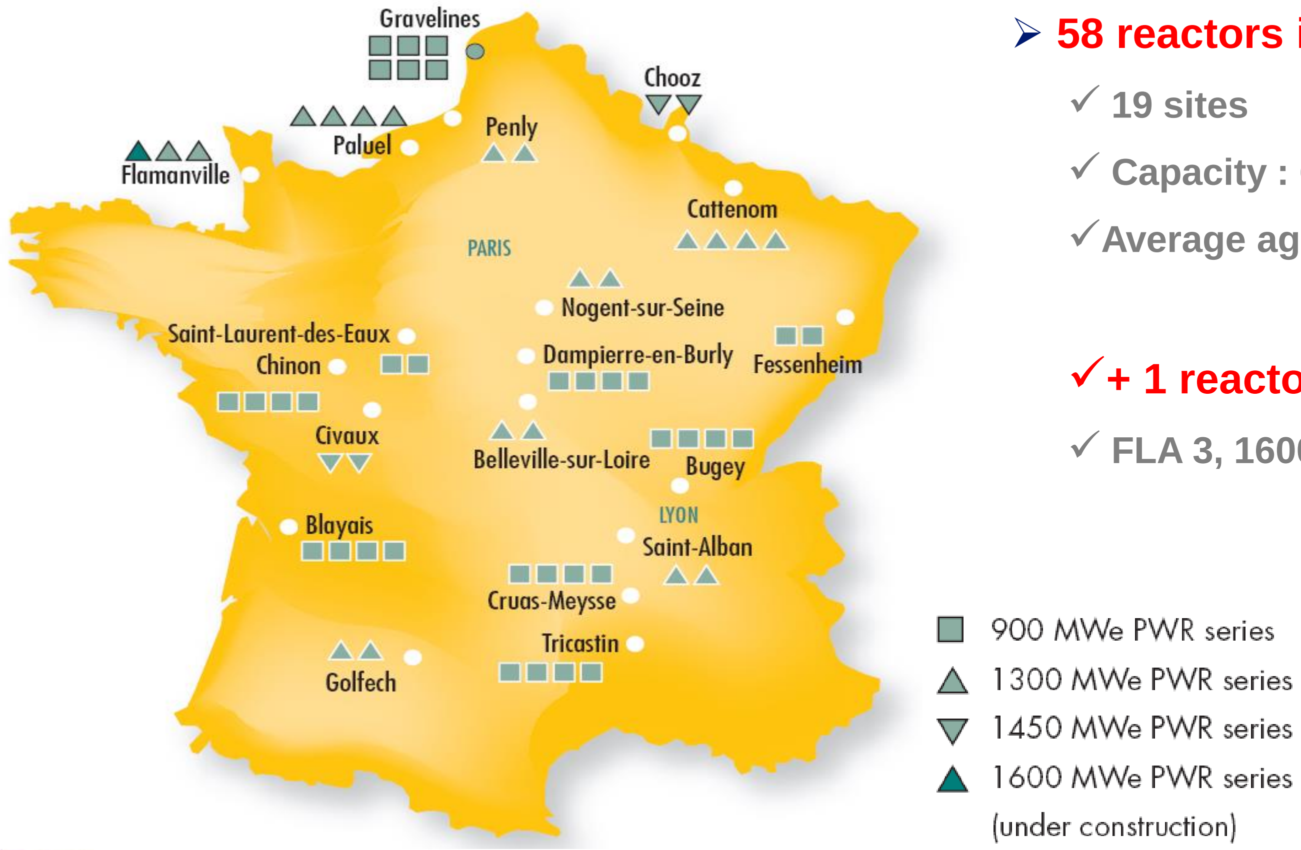
SUMMARY

EDF'S NUCLEAR PRODUCTION IN FRANCE

In operation NPP's	Number of units	Total capacity (GWe)	Average age (years)
PWR 900 MWe 3-Loop	34	30.8	33
PWR 1300 MWe 4-Loop	20	26.4	30
PWR 1450 MWe 4-Loop (N4)	4	6.0	20
Total	58	63,2	



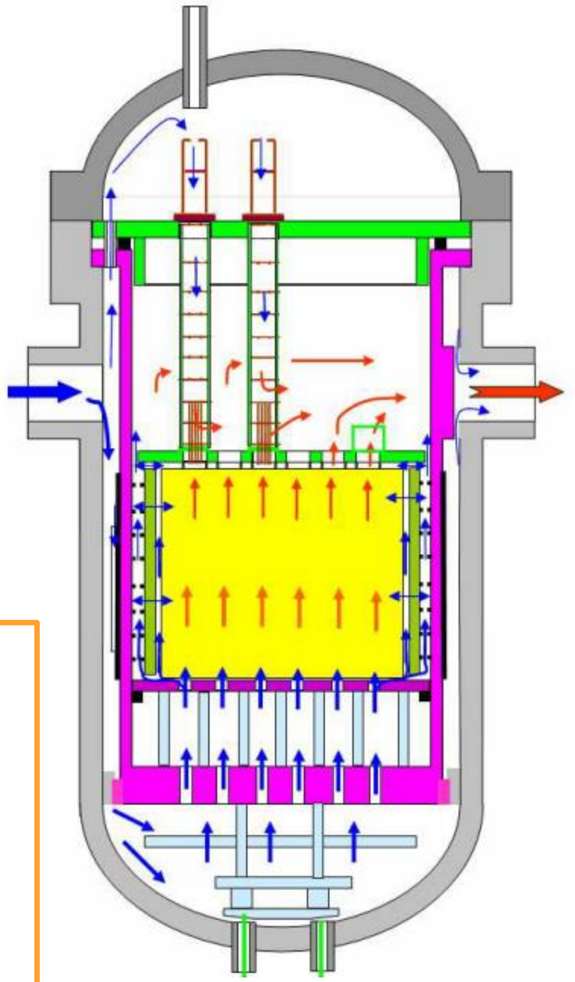
- **58 reactors in operation**
  - ✓ 19 sites
  - ✓ Capacity : 63,2 GWe
  - ✓ Average age : 30 years

- ✓ **+ 1 reactor under construction**
  - ✓ FLA 3, 1600 MWe EPR

REACTOR INTERNALS FUNCTIONS

Reactor internals functions:

- Provide support, guidance and protection of the rod control cluster assemblies (RCCA).
- Provide support and orientation to the reactor core (fuel assemblies).
- Provide a passageway for the distribution of the reactor coolant flow to the reactor core.
- Provide a passageway for support, guidance and protection for in-vessel/core instrumentation.



Reactor Safety functions:

- Reactivity control
- Core cooling control
- Radioactive material containment control

REACTOR INTERNALS FUNCTIONS

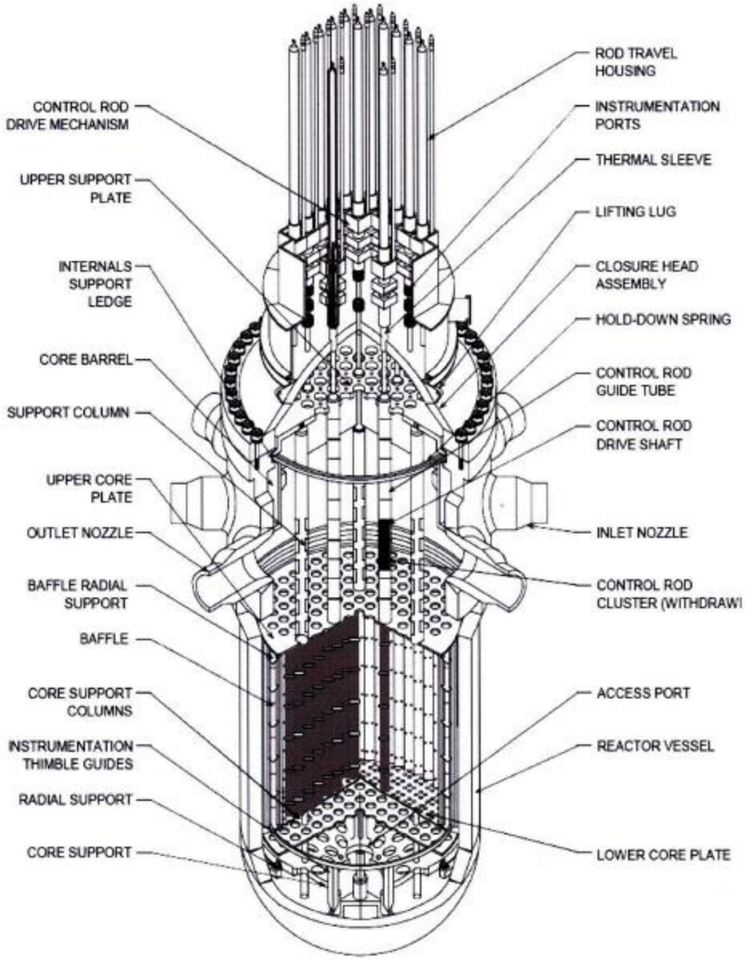


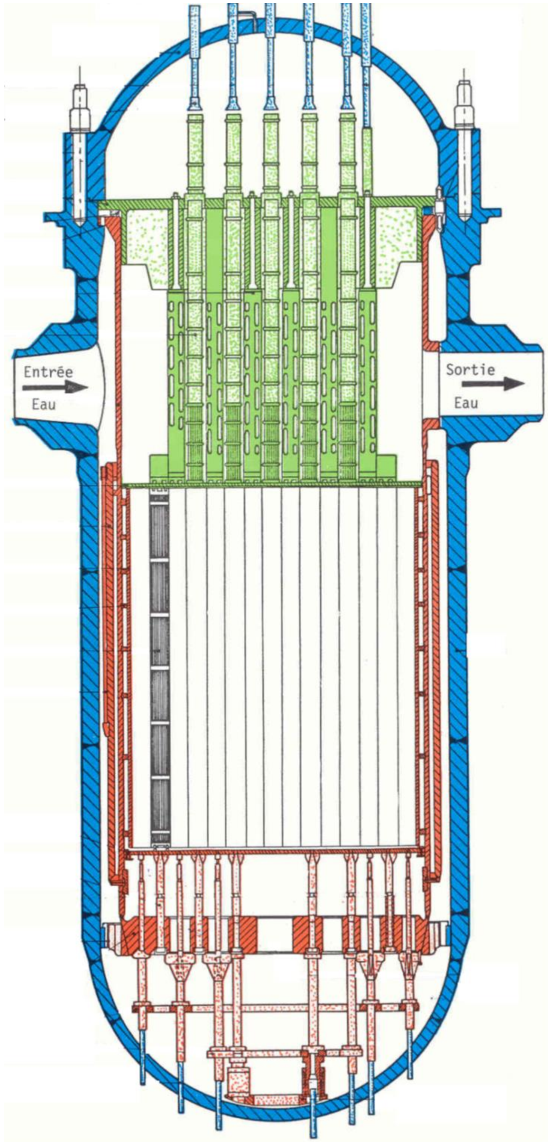
Figure 3-5
Overview of typical Westinghouse internals

<u>3-loop RV Internals</u> :

- Material Temperature : 290 to 355°C

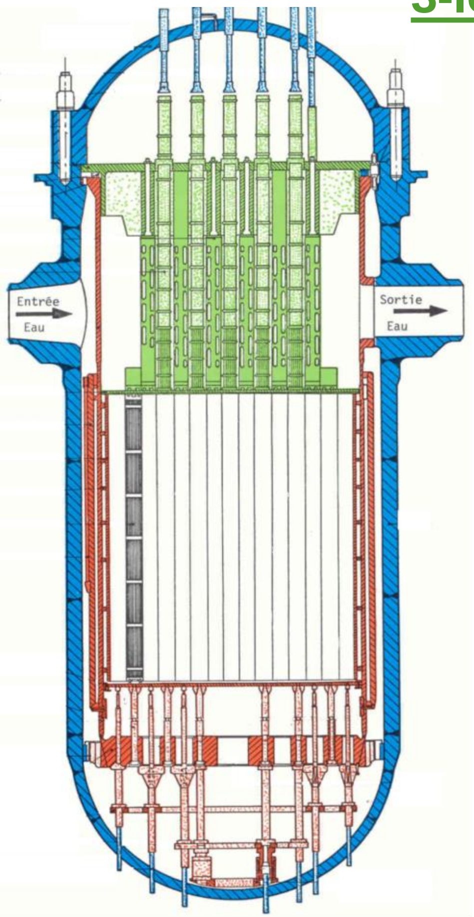
- Upper Internals : 45 tons
- Lower Internals : 90 tons
- Height of Fuel assemblies : 4076 mm

•# Fuel Assemblies : 157
- Core barrel diameter : 3400 mm



REACTOR INTERNALS FUNCTIONS

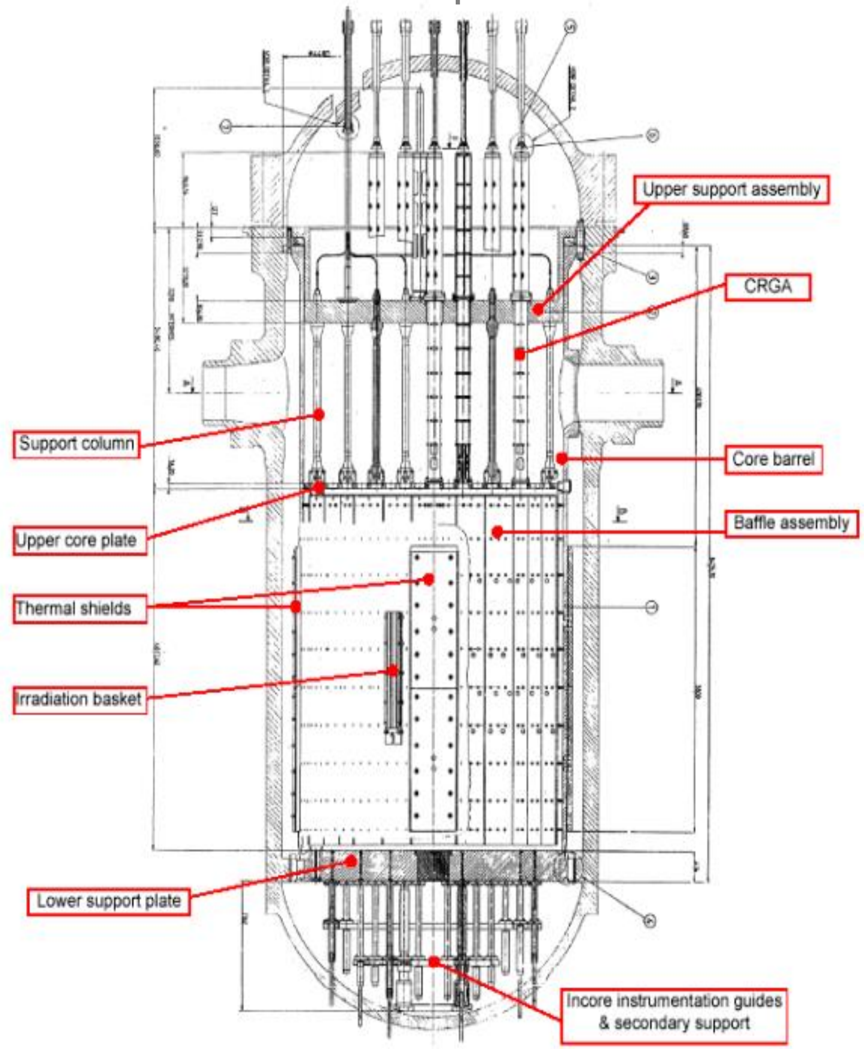
3 loops



3-loop vs 4-loop PWR :

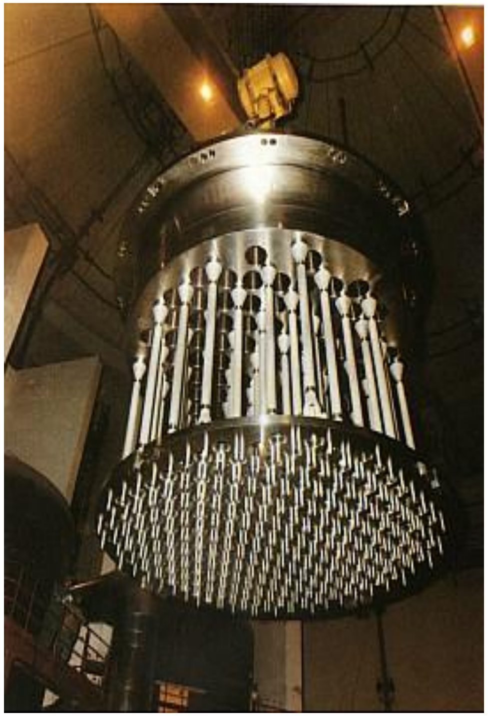
- Temperature into the vessel head plenum (to avoid SCC)
- Upper support assembly plate (less fatigue)
- Baffle assembly (more fuel assemblies)
- Thermal shields (thickness of the water)
- Lower Core Plate (height of the fuel assemblies)

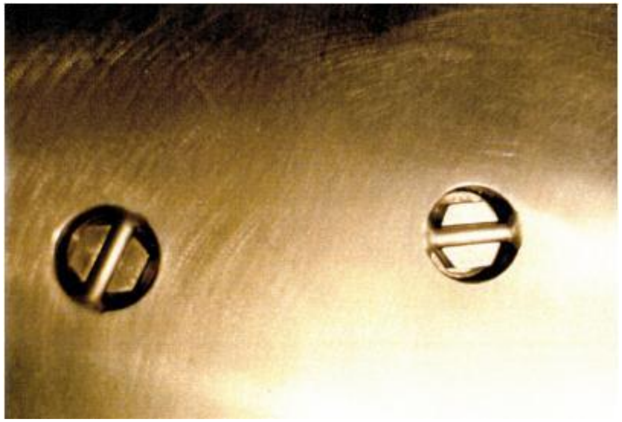
4 loops



REACTOR INTERNALS FUNCTIONS

- **Thin structures (no pression boundary)**
- **Materials : Stainless Steel (304 or 316 Cold Worked)**
- **Vibrations => every pieces must be « screwed or welded »**
- **High temperatures (nearly 350°C – gamma heat)**
- **High Irradiations (some components are very close to the fuel assemblies)**





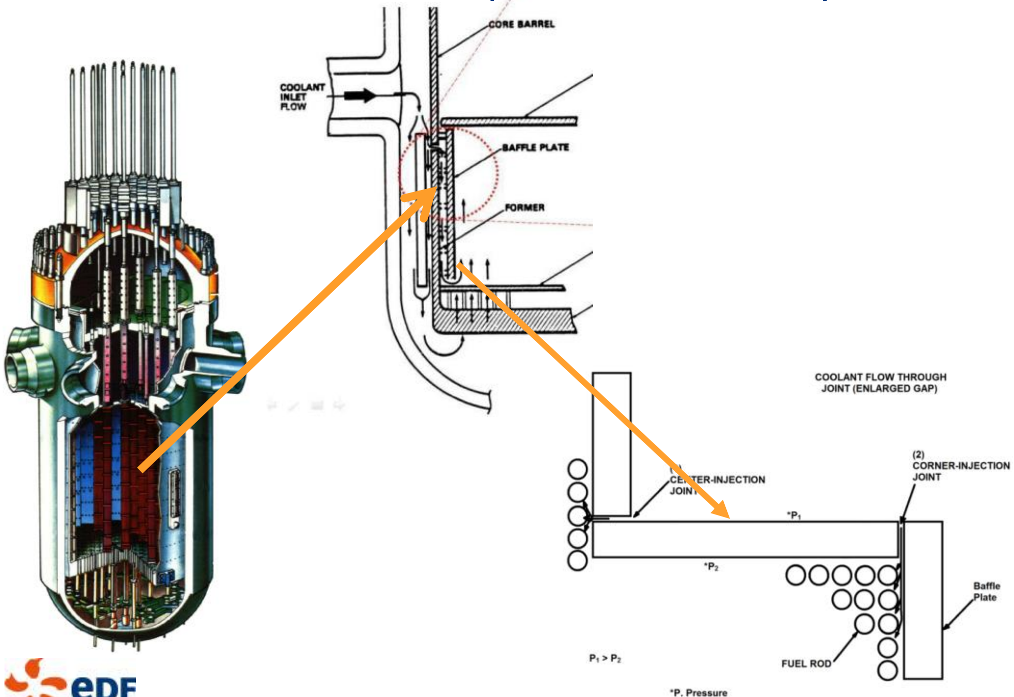
REACTOR INTERNALS FUNCTIONS

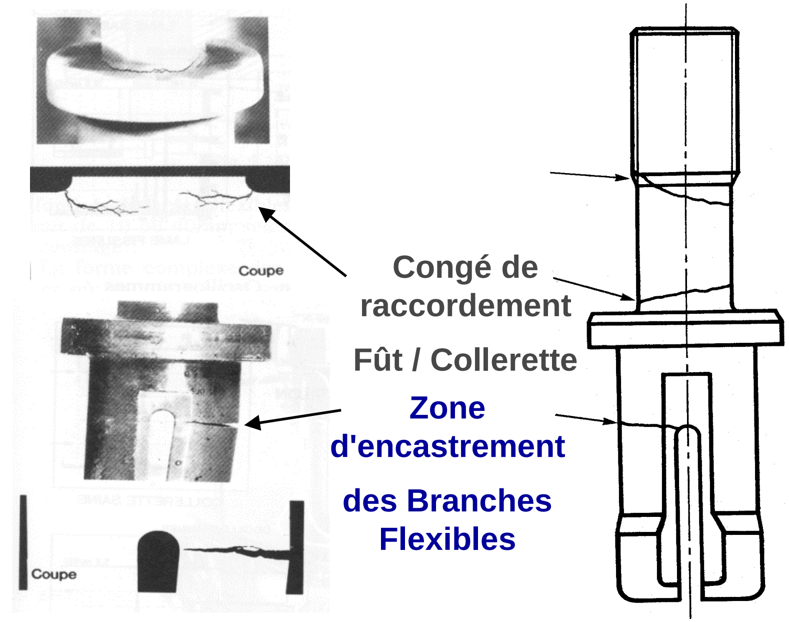
- **The RVI components must fulfil an Ageing Management Program (AMP) in agreement with the French regulation for the NPP third decennial outages and the following decennial outages. As for other Systems and Components, the AMP is carried out at EDF in 3 main steps, which are globally in agreement with IAEA Safety guide NS-G-2.12 on Ageing Management for Nuclear plants :**
  - Selection of Safety Structures, concerned by an ageing mechanism (SSC),
  - Review of all the couples SSC / degradation mechanisms selected by experts and run synthetic analyses on Ageing Analysis Sheets, taking into account maintenance adaptability, difficulty to repair or replace as well as risks of obsolescence,
  - Detailed Ageing Management Reports in order to justify that all the components concerned by an ageing mechanism can operate within the safety criteria during the considered period of operation (10 years).

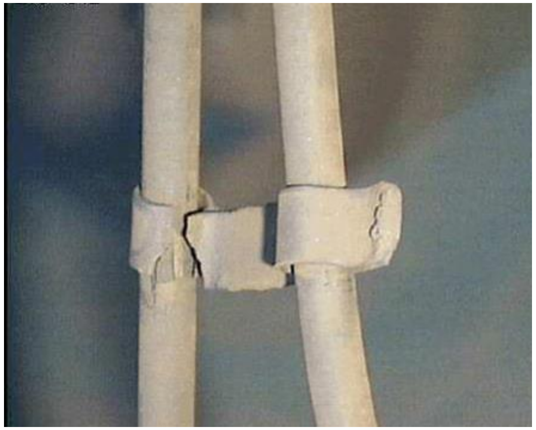
- **Because they don't contribute to pressure resistance, installed RV Internals are not submitted to French regulation on pressurized equipment.**

STATE OF KNOWLEDGE - OE

- **Stress Corrosion Cracking (SCC) :**
  - Baffle jetting (1980) => upflow conversion
  - SCC in the split pins of the guide tubes (1982, Inconel X750)
    => replacement with new pins design since 1990s
  - SCC in the thermocouples clamps (2008, SS 316)
    => extraction of clamps to avoid loose part

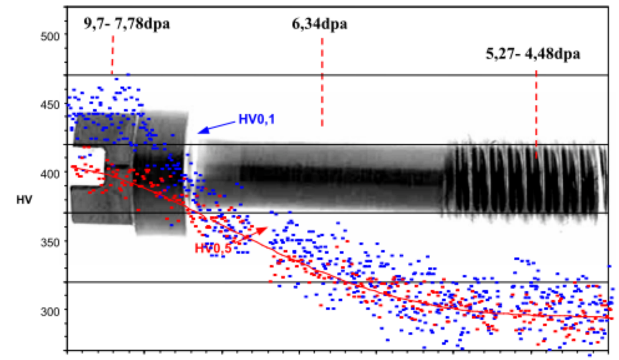


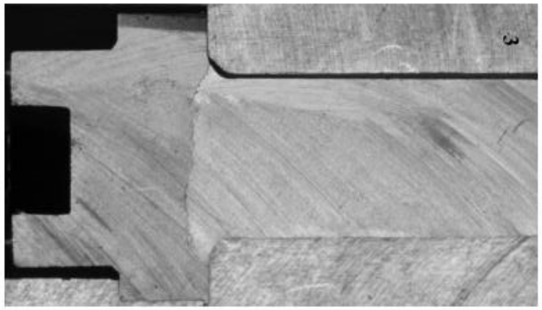


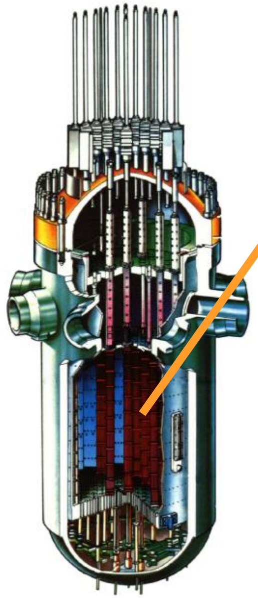


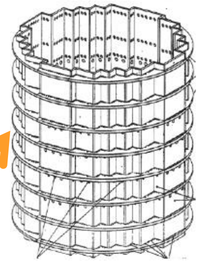
STATE OF KNOWLEDGE - OE

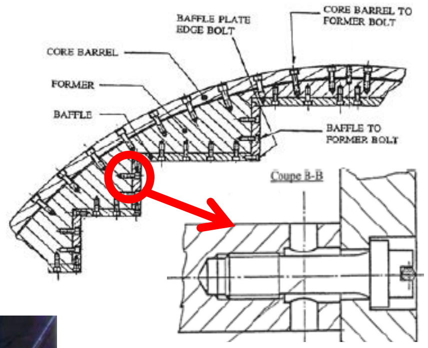
- **Effect of <u>Irradiation</u> :**
  - IASCC on the Baffle Former Bolts (1990s -> today)
    => temperature and irradiation modelling
    => examination on many bolts (10 to 40 dpa)
  - Potential swelling on baffles and bolts
    => ongoing international research (GONDOLE program, R&D modelling…)
  - Loss of ductility, segregation, relaxation…

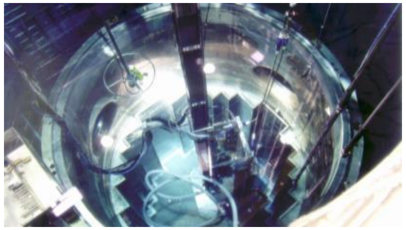


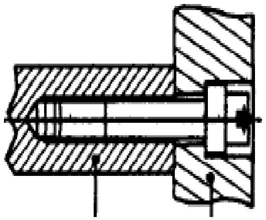






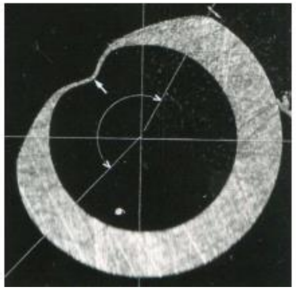


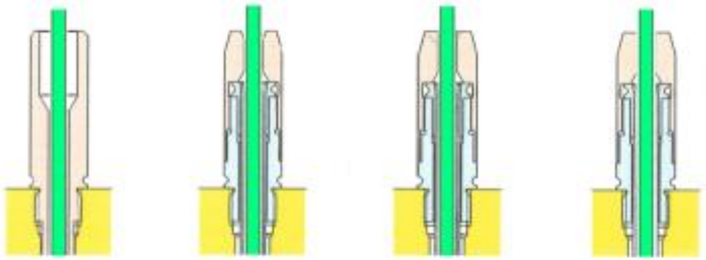




STATE OF KNOWLEDGE - OE

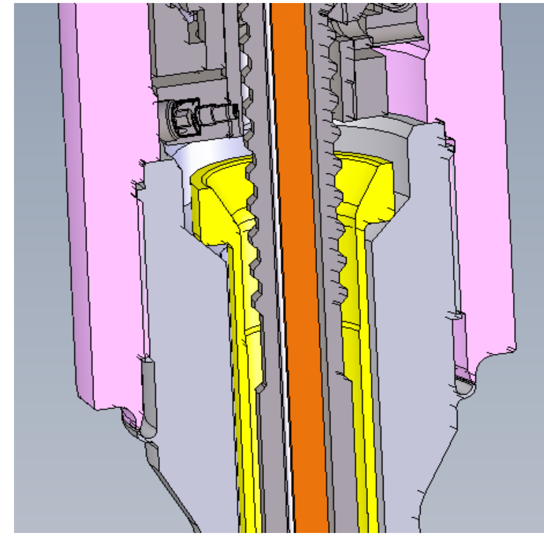
- **<u>Wear</u> of several components :**
  - Wear and leak of the flux thimble tubes (1985-89)
    => raising of the thickness of FTT, lowering the gap between FTT and the lower core plate
  - Wear of some lower core pins (1999)
    => happened on one single plant, no real issue
  - Wear of the stellite surfaces of radial keys (2010)
    => 3D calculations to increase the admissible gap in case of accident (LOCA and seismic conditions)
    => VT-1 on each decennial outage + some wear measurement



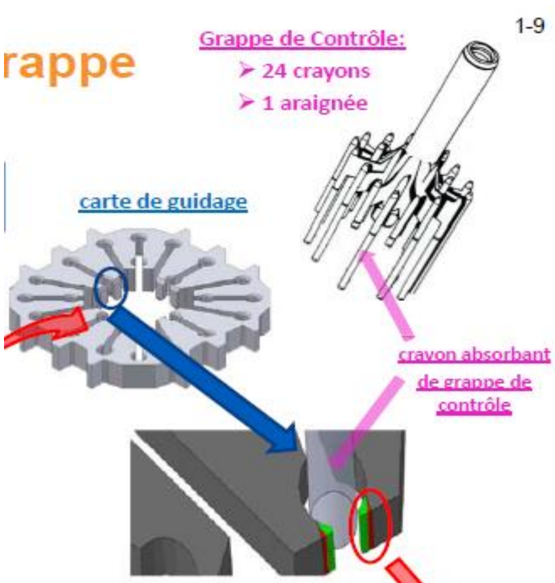


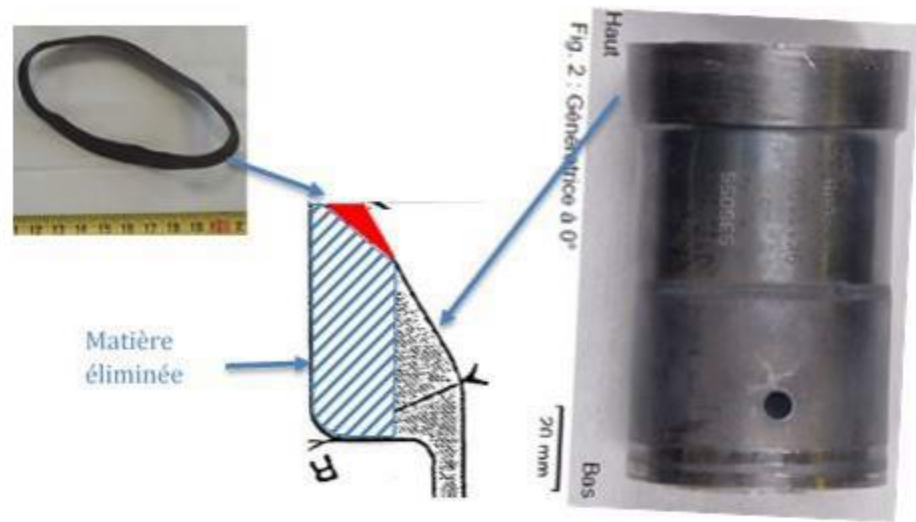
ACCESSIBILITY INTERNAL

STATE OF KNOWLEDGE - OE

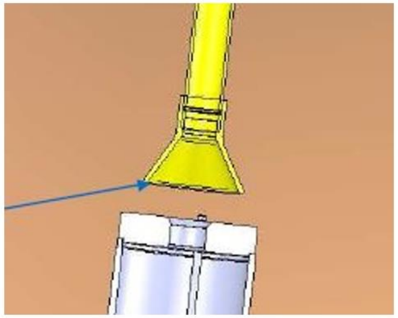


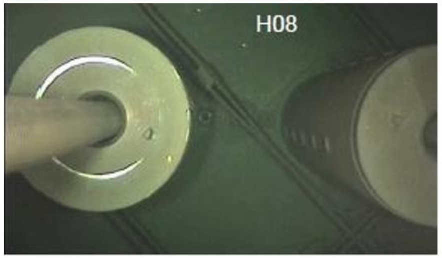
- **Wear of several components :**
  - Wear of guide tubes (2012)
    => wear measurement on 4 central canals
    => replacement of guide tubes
  - Wear of thermal sleeve of the vessel head (2017)
    => lowering measurement under every RV heads
    => replacement of the TS to avoid loose part
    => considering mitigation to stop TS wear and head penetration wear also





OE – THERMAL SLEEVE WEAR

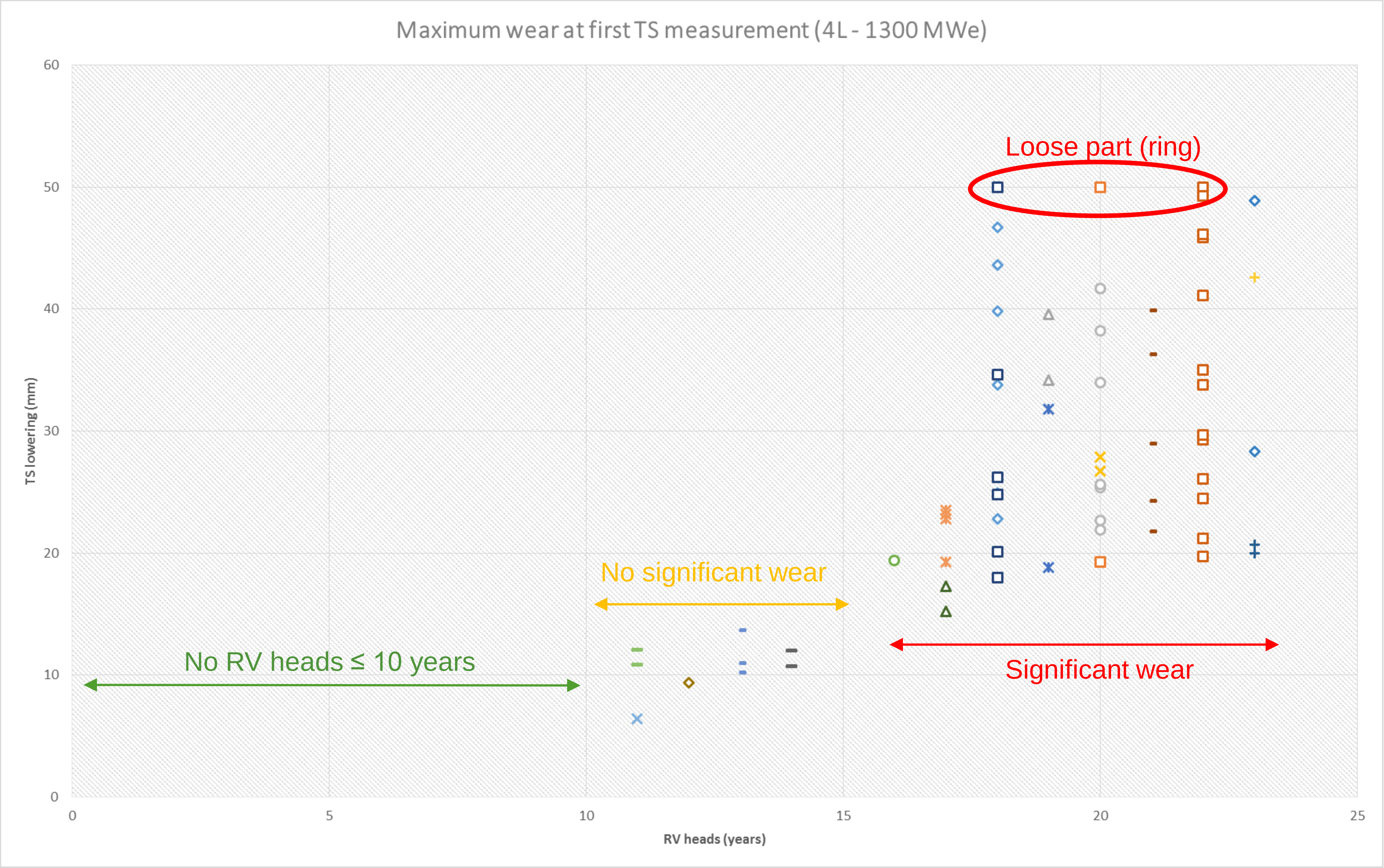




- First quarter 2019, first wear measurement have been performed on each 58 French reactors (3L and 4L)
- Main results :
  - 3L-900 MWe CP0 (T-hot head) : No wear measured
  - 3L-900 MWe CPY (T-cold head) : No significant wear, moderate wear on some TS located in central positions (lowering < 30 mm after 22 years)
  - 4L-1300 MWe (T-cold head) : Significant wear, maximum in H08 (central position) but also significant on TS located near the center or in the periphery including non controlled positions.
  - 4L- 1450 MWe N4 (T-cold head) : No significant wear, moderate wear on one plant, lowering < 30 mm after 22 years
- Second quarter 2019, second wear measurement to come on some 4L-1300 MWe plants

OE – THERMAL SLEEVE WEAR

Main results on the lowering measurement of more than 3300 thermal sleeve



OE – THERMAL SLEEVE WEAR

- **Location on the RV heads, difference between 3L and 4L Plants**

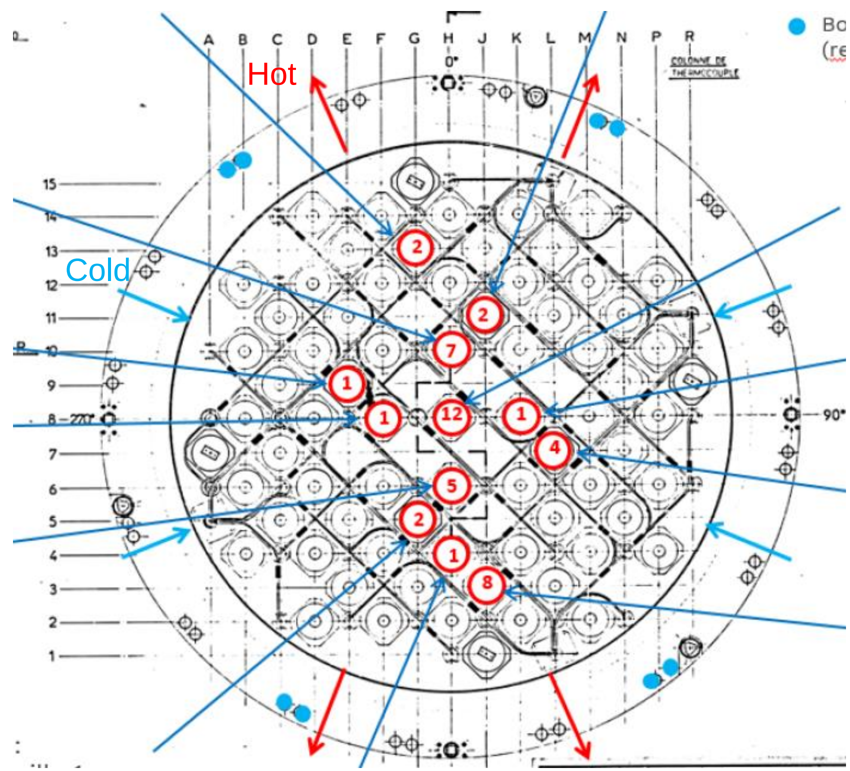
3-Loop

180°

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1																1
2						N22		R1		N21						2
3					PTC		SB2		SB1		SD1					3
4				N11		G22		G1		G21		N11				4
5			SD1		SC		SD2				SC		PTC			5
6		N21		G21		R2		N12		R2		G22		N22		6
7			SB1				SA1 2		SA1 1		SD2		SB2			7
90° 8		R1		G1		N12		SA2 9		N12		G1		R1		8 270°
9			SB2		SD2		SA1 1		SA1 2				SB1			9
10		N22		G22		R2		N12		R2		G21		N21		10
11			PTC		SC				SD2		SC		SD1			11
12				N11		G21		G1		G22		N11				12
13					SD1		SB1		SB2		PTC					13
14						N21		R1		N22						14
15																15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

0°

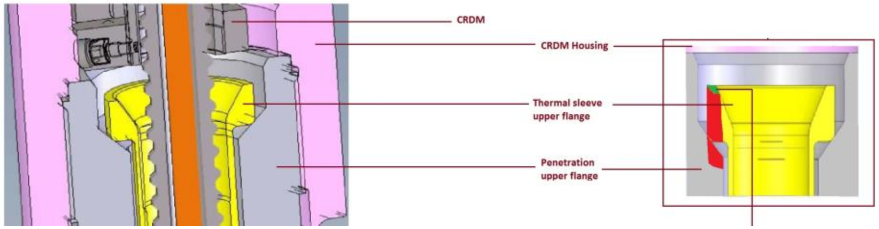
4-Loop



OE – THERMAL SLEEVE WEAR

- Immediate replacements performed during these inspections:
  - 2017/12 initial event 4L-1300 MWe BEL2 : 15.5 EFPY (20 years calendar age)
  - 2018 - 4L-1300 MWe NOG1 15.3 EFPY - Same issue as in Belleville, flange completely worn, control rod jammed, presence of the metal ring, the TS was supported by the GT.
  - 2018 - 4L-1300 MWe SAL1 (17.3 EFPY) - marks on the top of the GT but flange not completely worn
  - 2018 - 4L-1300 MWe PAL3 (14.4 EFPY) - marks on the top of the GT but flange not completely worn
  - 2018 - 4L-1300 MWe BEL 1 (2000 – 14,2 EFPY) - significant wear but no loose part/complete wear
  - 2019 - 4L-1300 MWe PAL 4 (1996 – 17,4 EFPY) – significant wear but no loose part/complete wear
  - 2019 - 4L-1300 MWe FLA 2 (1998 – 15,7 EFPY) - significant wear but no loose part/complete wear

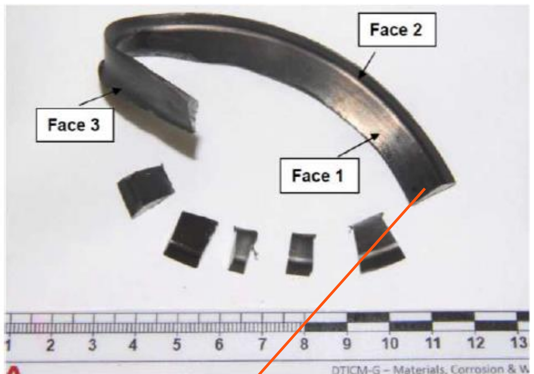
- All the TS replacements have been achieved using a complete CRDM removal
- EDF is still working on the best way to optimize its maintenance and inspection strategy :
  - A mechanical criterion is taken into account (39 mm max for TS lowering). On going studies for justifying penetrations without TS in locations without rods.
  - The wear rate for extrapolated values is based on each RPV head and TS location specific measurements.

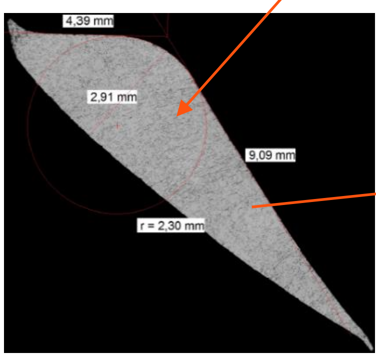


OE – THERMAL SLEEVE WEAR

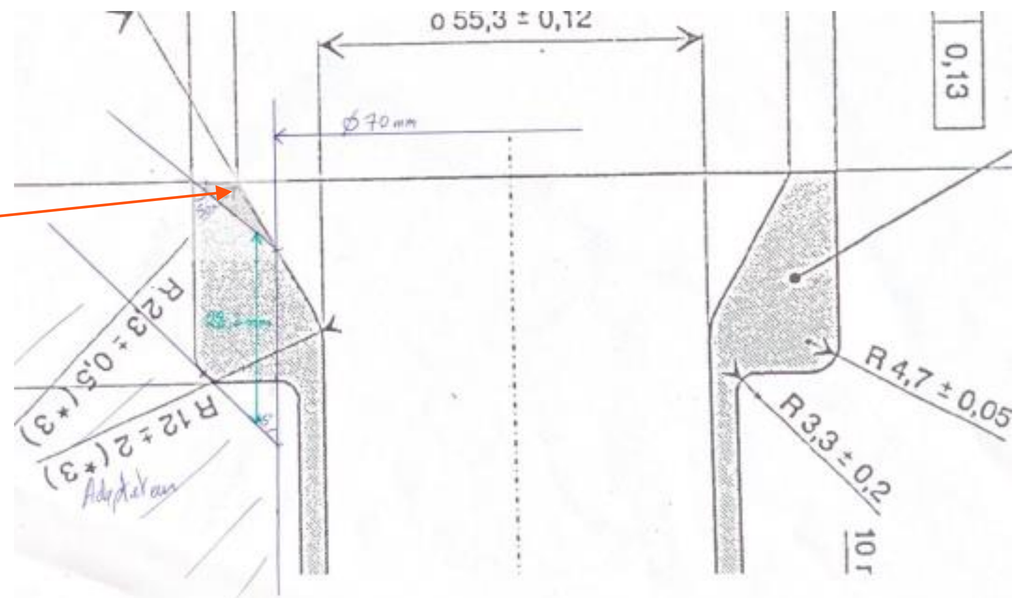
- **Expertise of the loose part (ring), from Belleville 2 thermal sleeve**

Examens visuels





INOX 304L



OE – THERMAL SLEEVE WEAR

- **Expertise of the thermal sleeve and the head penetration**

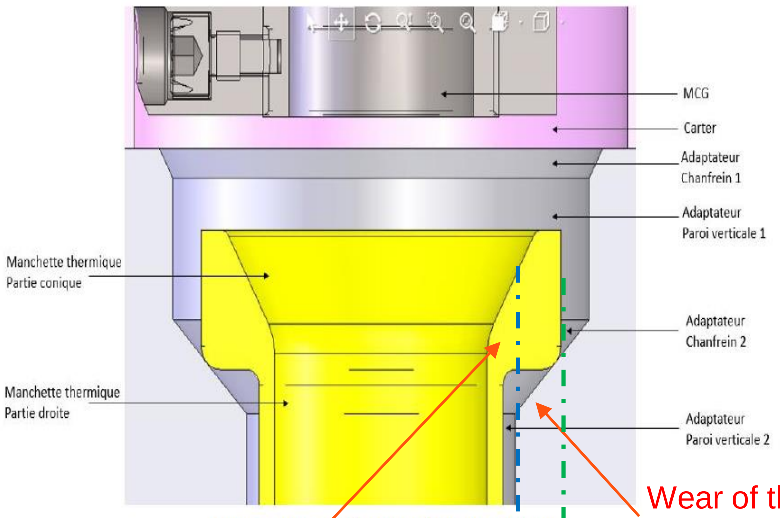


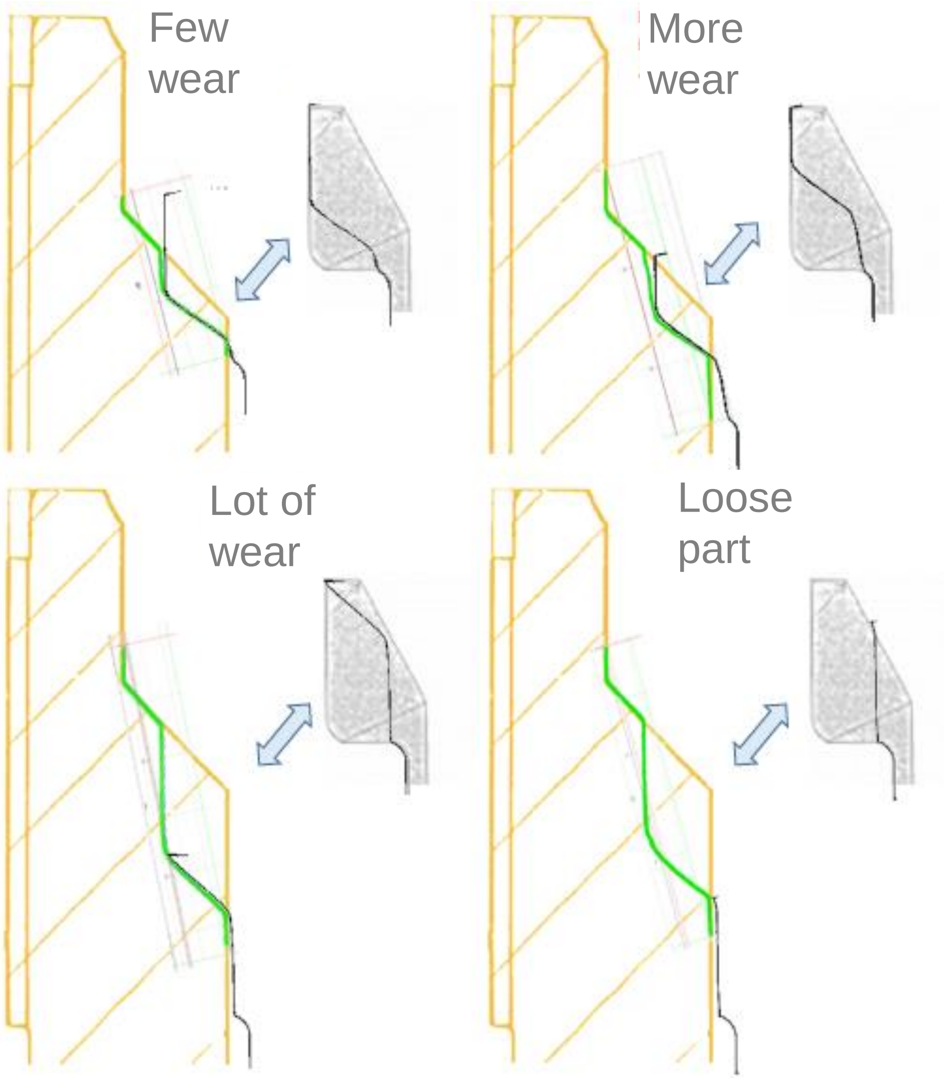
Schéma 1 : schéma MCG/adaptateur/manchette thermique.

Wear of the penetration

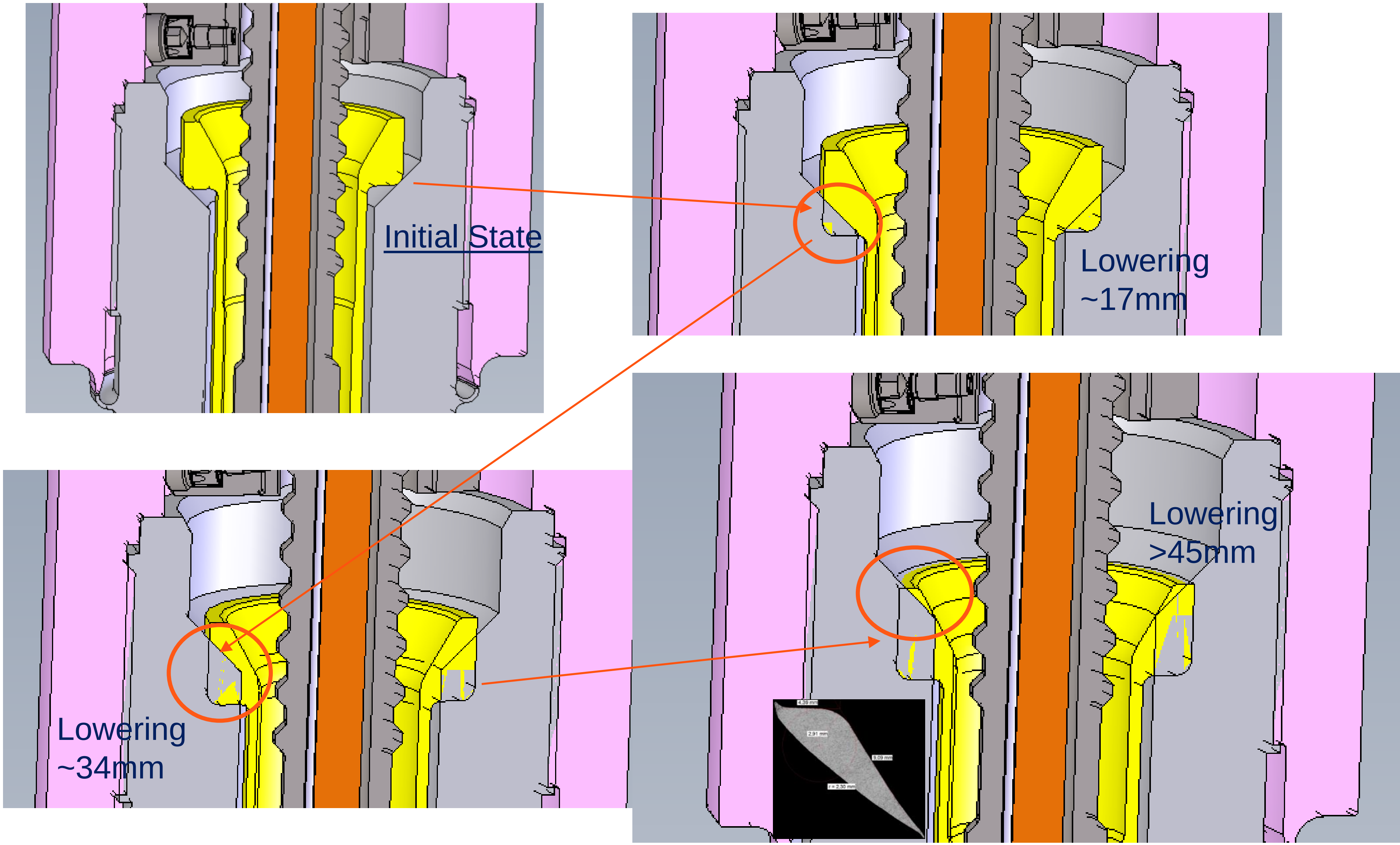
Wear of the TS

OE – THERMAL SLEEVE WEAR

- **The expertise of <u>17 thermal sleeves and head penetrations</u> led to the reconstruction and knowledge of the different phases of wear (lowering between 20 to 50mm)**
  - The wear surfaces of the thermal sleeves have globally the same characteristics, on each lowering
  - Thin circular traces on all wear surfaces, smooth and without noticeable scaling
    => an **abrasion wear mechanism** (producing an effect similar to that of a machining) between the thermal sleeve and the head penetration under the effect of a <u>rotating and/or ball-bearing movement</u> of the thermal sleeve.



OE – THERMAL SLEEVE WEAR



ONGOING RESEARCH – RV INTERNALS

- **RV Internals components can be classified in 3 types :**

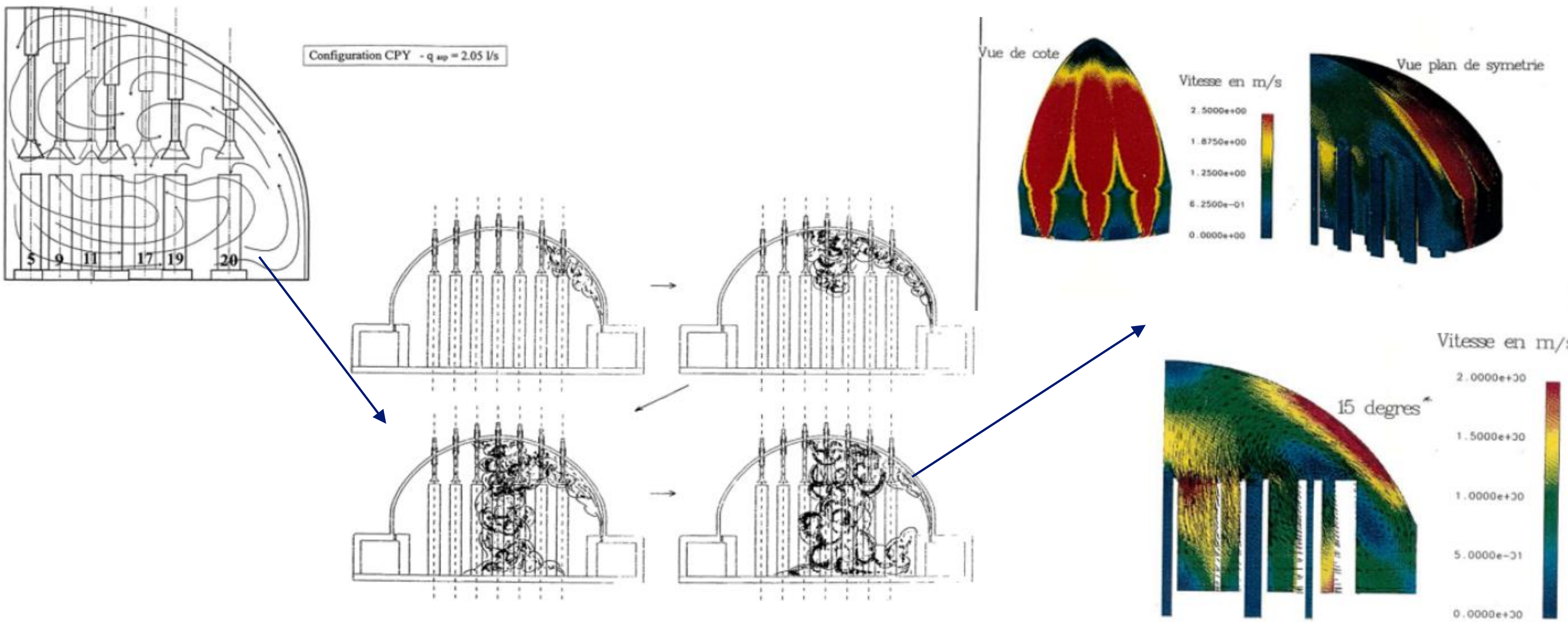
- **Components with well known degradation, from a long time :**
  - Split pins of the guide tube, thermocouple clamps : SCC
  - Flux Thimble Tubes : wear
  - Guide tube : wear

- **Components with degradation from a long time, needing more knowledge :**
  - Bolts and baffles : IASCC, swelling and other irradiation material degradation

- **Components with rather “new” degradation, needing more knowledge :**
  - Radial key / clevis : wear on stellite surfaces
  - Thermal sleeve : wear on SS 304, thermohydraulic under the vessel head

ONGOING RESEARCH – THERMAL SLEEVE

- **Modelling and mechanical testing to understand :**
  - The initiation of the rotating and/or ball-bearing movement of the sleeve
  - The wear mechanism and the kinetics during the different steps
  - The location of the thermal sleeves worn in the RV head



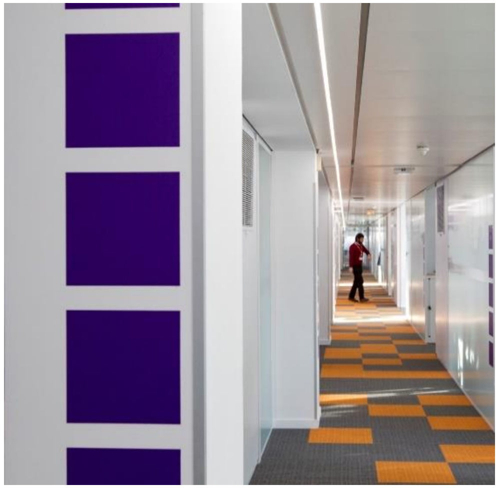
ONGOING RESEARCH – IRRADIATION

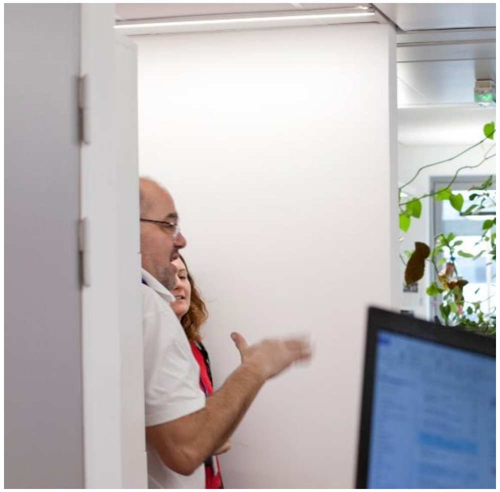
- **Objectives**
  - Loadings: **determine the neutronic and thermal gradients on the Internal structures.**
  - Material properties: **advance in our understanding of material degradation mechanisms to better predict ageing kinetics.**

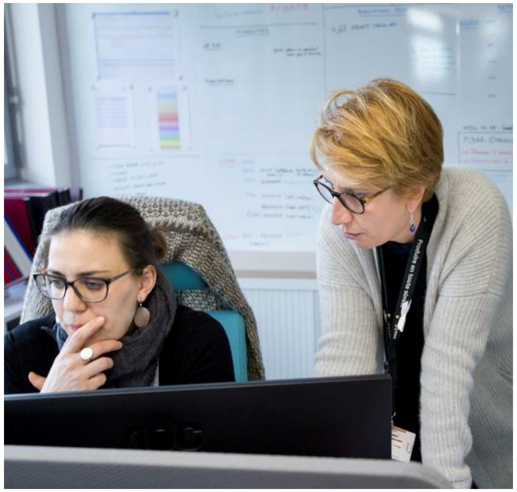
- **Approach**
  - Loadings
    - ✓ **Neutronics and thermo-hydraulics calculations to determine doses and temperatures of the components.**
  - IASCC
    - ✓ **Improve understanding of IASCC through both experiments and microstructure analysis (decommissioned components or experimentally irradiated samples).**
  - Swelling
    - ✓ **Determine PWR conditions leading to void swelling through simulations and observations.**
    - ✓ **Understand swelling mechanisms due to neutron irradiation through microstructure investigations.**

LTO - CONCLUSION

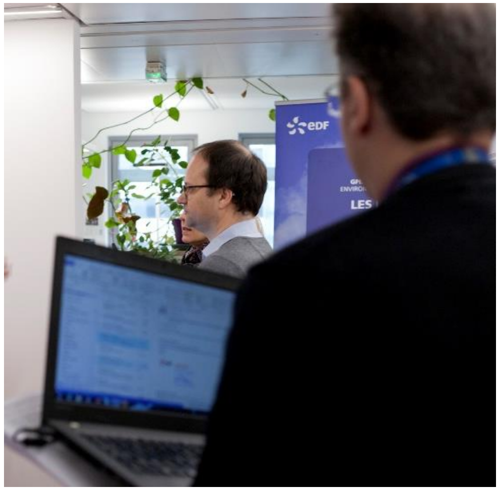
- **Improved safety and competitiveness of the NPP fleet are the main objectives of EDF lifetime policy in the frame of lifetime extension from 40 to 60 years.**
- **In this context, a detailed and systematic ageing management program (AMP) has been developed to review the ageing consequences on SSCs important to safety, applied since the 3rd 10-year safety review of 3L and 4L reactors.**
- **An effective maintenance policy (routine and exceptional) associated with qualified in-service inspections has been implemented, based on integrated feedback experience.**
- **Exceptional maintenance operations, such as guide tubes, split pins, CRDM and baffle bolts, are an illustration of EDF lifetime management policy, designed to prepare major industrial investment in the plant life extension context.**







Projet REX
La DI REX (DI 135) pour prescrire les fondamentaux du projet REX sous forme :
• d'un corpus de règles organisationnelles (locales et nationales) et de règles méthodologiques qui forment l'enveloppe de la DI.
• complété par un ensemble de guides d'application :
→ pour accompagner les règles organisationnelles
→ par domaine technique, reprenant les critères de capitalisation et d'analyse existants dans les prescriptifs actuels.
DI REX



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Thank you