EDF Ageing Management Program

TECHNICAL AND REGULATORY ISSUES FACING NUCLEAR POWER PLANTS

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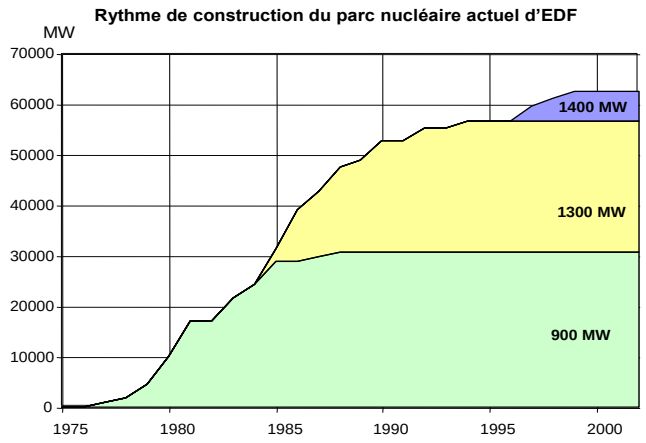
Jean BARBAUD
DIPNN – DTI

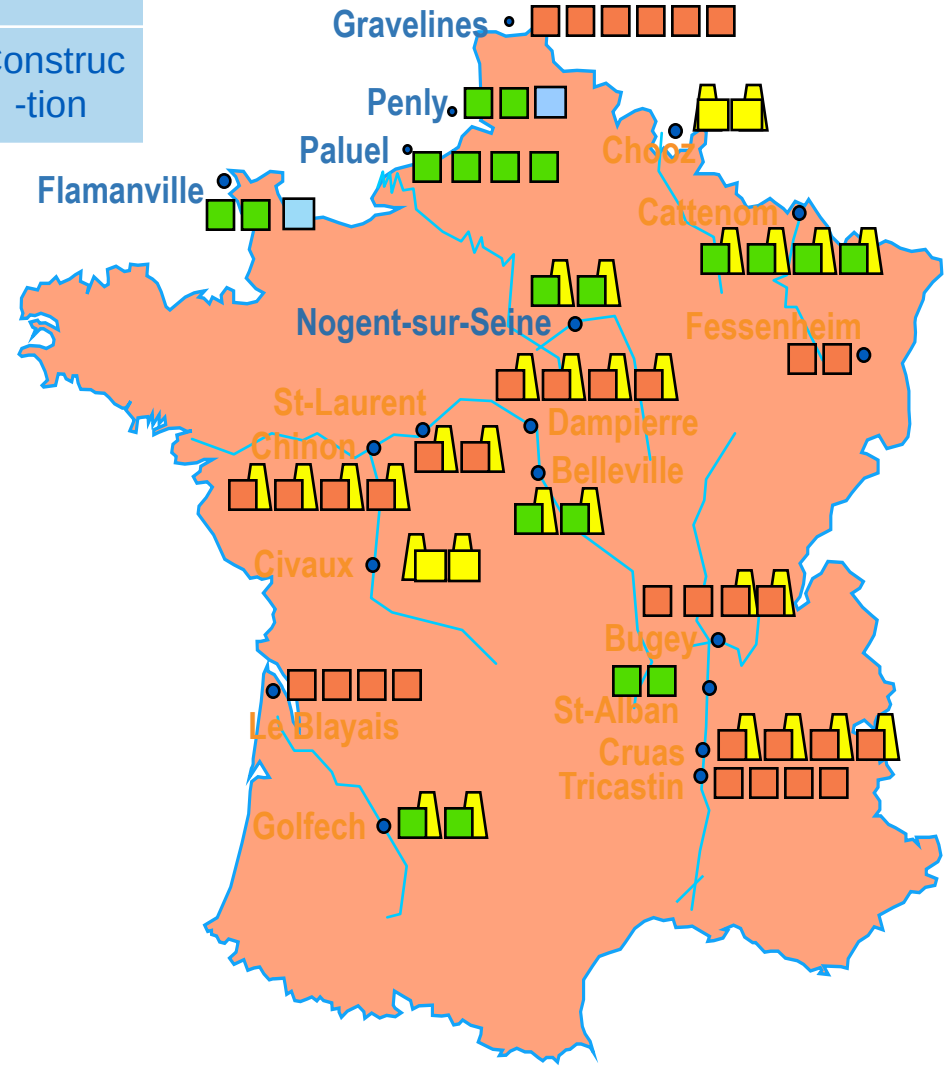
1. EDF PWR Fleet data and LTO context
2. Ageing Management Program
3. Focus on Material Ageing R&D Program
4. Conclusion

EDF PWR fleet

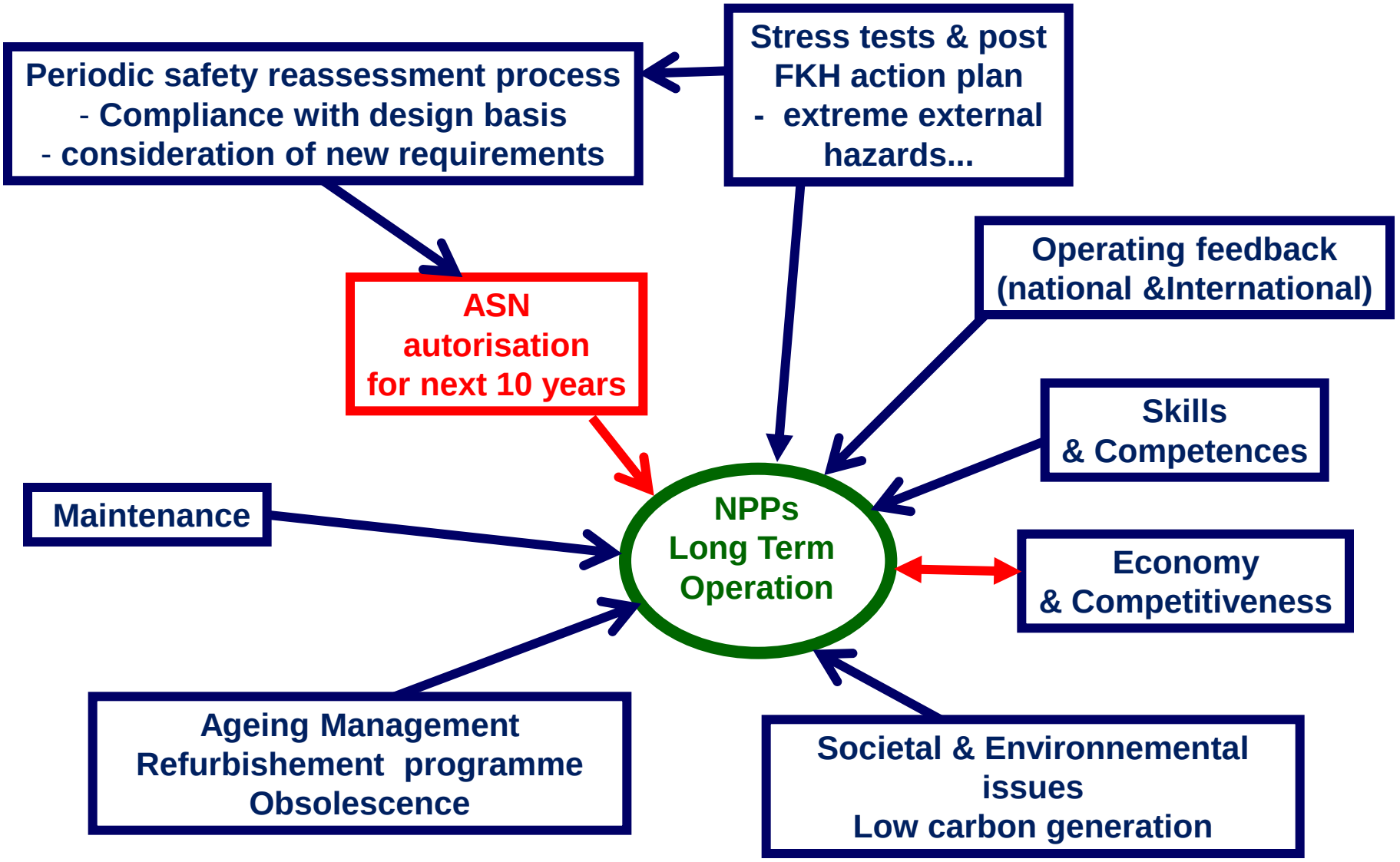
NPP series	900 (3 loops)	1300 (4 loops)	1450 (4 loops)	1650 (4 loops)
Number	34	20	4	1
Average age	34	28	18	Construc -tion

- 58 reactors in operation
- 1 reactor (EPR) under construction
- spread out over 19 sites
- Average age : 29 years
- 18 units will reach 40 years before 2020





Long Term Operation: a multi facets challenge



The Periodic Safety Review (PSR) process

- A mandatory process
  - Implemented since the 2nd 10-year outage of 900 MW series
  - Introduced in the French law (TSN) in 2006
  - Common EU practice included in Nuclear Safety Directive
  - To be performed each 10 years
- It includes two main aspects :
  - Compliance assessment with existing safety basis, checking and inspections, assessment of ageing mechanisms, including
    - Basic inspection programs and additional inspection programs
    - Containment test, Main primary circuit hydro test
  - Reassessment and updating of the licensing basis (internal/external events, severe accidents, PSA...), taking into account experience feedback, new knowledge, best international practices & requirements applicable to new NPPs
- Enables to define measures to improve the safety of the plant
  - In practice these measures are implemented during the next 10-year outage (VD in French), which are longer than refueling outages

The Periodic Safety Review (PSR) process

French ASN allows 10 years operation after each PSR:

	VD1 (10 years)	VD2 (20 years)	VD3 (30 years)	VD4 (40 years)
900 MW (34 units)		done	2009 to 2020 (25 units done)	2019 to 2030
1300 MW (20 units)		done	2015 to 2024	2025 to 2034
1450 MW – N4 (4 units)	done	2019 to 2022	2029 to 2032	2039 à 2042

Numerous improvements have already been implemented on the existing NPPs, i.e.:

- Examples of improvements already implemented
- filtered containment venting device (U5-1986),
- H2 passive recombiners,
- containment sump strainers
- back up power supply (LLS, additional diesel or TAC / site),
- spent fuel pool make-up improvements
- seismic upgrade ...

PSR associated to VD4 900 will be the first to need the ASN authorization for the step beyond 40 years (initial design hypothesis)

- EDF Orientation file sent to ASN by end of 2013, with complements up to mid 2014
- Framing Advisory Group meeting in April 2015 ; French ASN position on review program received in April 2016

EDF Modernization program for existing NPPs

- **It will be monitored through a specific project, the "EDF industrial project" ("Grand Carénage") which:**
  - ✓ integrates all modifications issued from the different programs (PSR, Refurbishment program, post Fukushima and all other modification or maintenance programs) with a multi-annual vision
  - ✓ assures the monitoring off all aspects of the program: nuclear safety, availability, economic and financial dimension, industrial resources, internal resources and skills, logistic
  - ✓ Aims at operating the fleet well beyond 40 years, up to 60 years

1. EDF PWR Fleet data and context
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Ageing Management Program Process

- The major objective is to justify that all the components concerned by an ageing mechanism remain within the design and safety criteria.

- The AMP procedure, described in a generic guideline, is carried out in 4 main steps :
  - Selection of structures, systems and components (SSC) concerned by an ageing mechanism
  - Review of all the couples SSC / degradation mechanism selected by experts and synthetic analyses in Ageing Analysis Sheets (AAS)
  - Detailed Ageing Management Reports (DAAR) required for some sensitive components
  - Unit Ageing Analysis Report (UAAR)

- All these reports have to be prepared in agreement with the French regulation.

Ageing Management Program Procedure

- **Step 1 : Selection of Structures, Systems and Components (SCC)**

  - Mechanical components of all safety classes
  - Electrical components (class 1E)
  - Civil engineering structures
  - SSCs not important to safety but likely to affect a SSC important to safety due to an ageing degradation.

➔ **Around 70 components or group of components or structures selected**

➔ **Around 50 degradation mechanisms of components or structures considered**

Ageing Management Program Procedure

- **Step 2 : Review of all selected couples SSC /ageing mechanism : Ageing Analysis data Sheet (AAS)**

  - Analysis of ageing mechanism concerning each of the selected SSCs, potential or encountered
  - Consequences of the mechanism on the SSC and its safety function
  - Availability of the routine maintenance program and of the operation procedures
  - Difficulty to repair or to replace the SSC
  - Risk linked with obsolescence

For each couple [SSC / Ageing mechanism] an Ageing Analysis Data Sheet is written (near 600 sheets on the whole for 900 MW series)

Ageing analysis data sheet (AAS)
Final status principle

	Encountered mecanism			Potential mecanisme		
Maintenance and Operation	**Adapted**	**Adaptable**	**Difficult to adapt**	**Adapted**	**Adaptable**	**Difficult to adapt**
Repair and replacement difficult	**2**	**2**	**2**	**0**	**1**	**2**
Repair or replacement not difficult	**0**	**1**	**2**	**0**	**1**	**1**

Status 0 : Ageing under control, without any other information needed

Status 1 : Temporary state – complementary instruction is needed (30 for 900 MW series)

Status 2 : An Ageing Management Detailed Report is required (29 for 900 MW series)

Ageing Management Program

Step 3: (for components with ageing data sheets in status 2) : Generic Detailed Ageing Analysis Reports (DAAR)

Content :

- Design basis : regulation, codes & standards, specifications and guidelines
- Description of the component and operating experience : design, materials, fabrication process, water chemistry, operating conditions and feedback experience
- **Ageing mechanisms, scientific knowledge, damage rate and fitness for service analysis, surveillance and ISI, mitigation , repair process,**
- Industrial capacity and obsolescence: repair, replacement, tools availability
- Output : Synthesis and Specific Component Ageing Management Program, including surveillance, maintenance, modification, operating conditions, R&D actions

Ageing Management Program

12 Detailed Ageing Analysis Reports (DAAR)

- Reactor Pressure Vessel
- RPV internals
- Steam generator
- Pressurizer
- Main coolant line of reactor cooling system
- Auxiliary lines connected to reactor cooling system
- Main coolant pump

- Containment
- Other nuclear civil engineering structures
- Electrical penetration in the containment
- Electrical cables
- I&C systems

Ageing Management Program

Step 4 : Each NPP is in charge of its Unit Detailed Ageing Analysis Report (DAAR)

The Unit Ageing Analysis Report :

- is based on Detailed Ageing Analysis Reports and Ageing Analysis Sheets,
- its conclusion is the ageing action plan of the unit
- is approved by the Plant Technical Committee and signed by the NPP Site Manager
- is sent to Nuclear Safety Authority before each 3rd 10Y outage
- is updated after each 10Y outage in order to include maintenance activities, modifications, inspection and test results

10 units received prescriptions from the Nuclear Safety Authority for their operation till their 4th 10Y outage : Tricastin 1-2-3, Fessenheim 1-2, Bugey 2-4-5, Dampierre 1-2

Ageing Management Program Review

- The AMP is regularly reviewed
  - Through an annual examination of ageing analysis data sheets :
    - to take into account national and international feedback experience
      + information coming up from the plants
    - to be consistent with evolution of operation procedures and maintenance strategies,
    - to implement new results from R&D on going programs
    - to possibly complement the list of SSCs and of ageing mechanisms .
  - Through a 5-year examination of the 12 Detailed Ageing Analysis Reports

The results of this periodic review are required by French Safety Authority

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Material R&D Program

The major objectives of the Materials R&D Program are:

- To ensure that all the pertinent ageing mechanisms are evaluated (including possible mechanisms),
- Increase the knowledge in the areas and technical fields when required,
- Avoid penalising extrapolations due to a lack of data,
- Acquire needed data for equivalent 60 year ageing to check they remain within the design and safety criteria.

Approach:

- Ageing R&D Programs for all areas sensitive to ageing or degradation mechanisms
- Representative materials

  (archive or sampled materials or removed components or dedicated mock-ups)
- Ageing in furnaces (thermal ageing) or experimental reactors (irradiation) or loops (corrosion)
- Materials tested after equivalent 60 years ageing time,
- Mechanical data (toughness, tensile, fatigue...), CSC data (initiation and propagation), corrosion rate, etc.

Main Materials R&D Programs
Mechanisms taken into account (1/2)

1 Embrittlement mechanisms

- **Neutron embrittlement : RPV steel and welds, internals**
- **Thermal ageing : CASS, Austenitic SS welds and dissimilar welds, Martensitic Stainless Steels, Low Alloy Steels and C-Mn steels**

2 Corrosion

- **Stress Corrosion Cracking** *(Irradiation Assisted)* **of RPV Internals**
- **Stress Corrosion Cracking of cold work austenitic Stainless Steels** *(316L)*
- **Stress Corrosion Cracking of Nickel base alloys: Alloy 600 and welds**
- **Boric Acid Corrosion…**
- **FAC in secondary circuit,**
- **…**

Main Materials R&D Programs
Mechanisms taken into account (2/2)

3 Fatigue

- Low Cycle and High Cycle fatigue (Thermal Fatigue)
  - Mixing areas
  - Better evaluation of stratification loads with a Fatigue Assessment Device
- Environmental Assisted effects:
  - Mainly for austenitic stainless steels

4 Degradation with loss of material: Wear

- Impact Sliding Wear

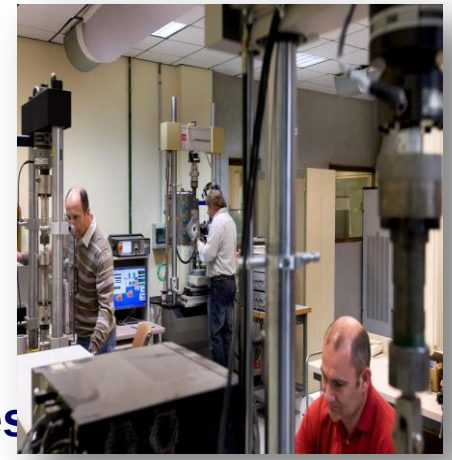
5 Degradation of non metallic material

- Polymers: Physical Ageing, Chemical Ageing…
- Concretes:
  - Swelling (Alkali Silicate Reaction…)
  - Creep…

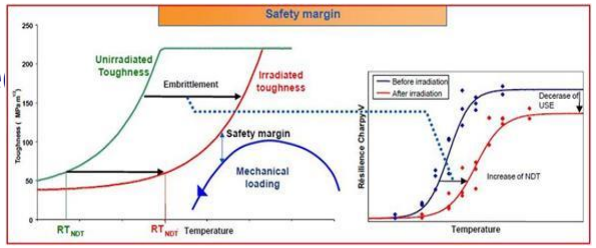
The Materials Ageing Institute for R&D relative to plant life extension

- **Need for Predictive Capability for**
  - **- Inspections**
  - **- Mitigations**
  - **- Replacement**
- **Through Mechanistic understanding of ageing processes**

Materials Ageing Institute



- **11 Members (Utilities...) representing 66% NPPs**
- **80 Researchers and technicians involved**
- **20 universities / scientific institutes associate**
- **11 M€ annual budget in 2013**
- **35 M€ total EDF's Investment (2008-2016)**
- **250 participants yearly in the E&T program**
- **12 main projects**



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Conclusion and perspectives on EDF LTO strategy

LTO will bring additional value to existing NPPs as a tool to produce safe, reliable, economical, clean and low carbon electricity,

LTO constitutes a challenge which multiple aspects. Among the most importants:

- Continuous improvement of safety to reduce gaps with new NPPS, mainly through PSR process
- Adequate management of Ageing and obsolescence

Lifetime extension (up to 60Y) should be reasonably achieved owing to :

- Adequate maintenance strategy and program
- Complementary analysis for non-replaceable components : RPV and containment building.
- Extensive R&D Programs to support this analysis

Thank you
for your attention

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Appendixes

EDF Step 1 : Selection of Safety class components

	COMPONENTS / STRUCTURES
100	Primary system
101	RPV
102	RVI
103	CRDM
104	PRESSURIZOR & SURGE LINE
105	PRESSURIZOR SEBIM SAFETY VALVE
106	SG
107	MCP
108	MCL
109	AUXILIARY CONNECTED LINES
110	VALVES & CHECK VALVES
200	Secondary system
201	MSIV
202	SG SAFETY VALVE
203	SECONDARY SYSTEM PIPINGS
300	Other nuclear components
301	OTHER NUCLEAR PIPINGS (class 2-3…)
302	FIRE PROTECTION PIPING
303	PUMPS
304	AFW TURBOPUMP
305	TURBOALTERNATEUR LLS
306	NUCLEAR HX
400	Non nuclear components
401	TANKS
402	AUXILIARY PIPINGS
403	VENTILATIONS
404	HANDLING DEVICES
405	SERVICE WATER FILTERS
500	cables
501	ELECTRICAL CABLES
502	CABLE WAYS
503	MINERAL and COAXIAL CABLES

	COMPONENTS / STRUCTURES
600	Electrical components
601	EMERGENCY DIESEL GENERATORS
602	ELECTRICAL PANNEL
603	MV and LV MOTORS
604	CONVERTORS (INVERTERS and LOADERS)
605	ELECTRICAL BATTERIES
606	MAIN TRANSFORMERS
607	AUTOMATIC RELAIS
608	ELECTROVALVE JACOUMATIC
609	CONNECTORS AIR-LB
610	RAYCHEM CONNECTIC
611	CONNECTORS K1 (seismicly design)
700	Instrumentation
701	EX CORE NEUTRONIC MEASUREMENT
702	POSITION DETECTOR
703	ON-OFF CAPTOR
704	TEMPERATURE PROBE
705	IN-CORE THERMOCOUPLE
706	HYDROGEN-METER
707	ANALOGIC FLOW-METER
708	UT FLOW-METER
709	ANALOGIC PRESSURE TRANSMITTER
710	UT TRANSMITTERS
711	KRT PROTECTION CHANNEL
712	REGUL ROD POSITION MEASUREMENT
713	PROTECTION RELAY
714	COUNTER
715	RPV LEVEL MEASUREMENT
716	AUTOMATIC SCRAM INSTRUMENTATION
800	Control components
801	CONTROL ROOM / EMERGENCY PANNEL
802	OTHER CONTROL COMPONENTS

	COMPONENTS / STRUCTURES
900	Civil engineering structures
901	CONFINEMENT BUILDING
902	PIPE PENETRATION
903	ELECTRICAL PENETRATION
904	MATERIAL and PERSONAL HATCH
905	NUCLEAR CIVIL ENGINEERING STRUCTURES
906	BUILDINGS and STRUCTURES
907	REACTOR BUILDING and FUEL POOLS
908	FIRE PROTECTION
909	SITE STRUCTURES
910	BONA CONCRETE PIPINGS
911	COOLING TOWERS

1000	No-metallic no-concrete materials
1001	Polymers
1002	Oils

Around 70 components or group of components or structures

EDF Step 1 : List of degradation mechanism

sigle	mechanism	domain
ABR01	General abrasion	All materials
CAR01	Carbonatation	Concrete
CER01	Erosion-Corrosion (FAC)	Carbon and low alloy steels
CIC01	Intercristallin corrosion secondary water	Alloy 600 tubes
CIC02	Intercrystalline corrosion	Austenitic Stainless Steels
COR01	Boric acid corrosion	Carbon and low alloy steels
COR02	Corrosion concrete rebars	Reinforced concrete
COR03	Boric acid corrosion	Stainless steels
COR04	Waterline corrosion	All Steels
COR05	General corrosion	All materials
COR06	Atmospheric corrosion	Ferritic/ austenitic DMW interface
CPI01	Pitting corrosion	Carbon and low alloy steels
CPI02	Pitting corrosion	Stainless steels
CSC01	PWR stress corrosion	Ni-based alloys type 600
CSC03	PWR stress corrosion	Nickel based alloy welds 82-182
CSC04	PWR polluted water stress corrosion	Austenitic Stainless Steels
CSC05	PWR stress corrosion	Cold worked Austenitic Stainless Steels
CSC06	Nominal PWR water stress corrosion	Carbon and low alloy steels
CSC07	Nominal PWR water stress corrosion	Austenitic Stainless Steels
CSC02	Secondary stress corrosion	Austenitic Stainless Steels
CSC08	PWR stress corrosion	Ni-based alloys type 750
CSC09	Irradiated Stress Corrosion cracking (IASCC)	Austenitic Stainless Steels of RVI
DEC01	Ductile tearing	Alloy steels
DEC02	Ductile tearing	Cast austenitic duplex stainless steel
DEC03	Ductile tearing	Austenitic Stainless Steels of RVI
DEF01	Plastic Shakedown	All steels
ECA01	Erosion Cavitation	all steels
ERO01	Erosion	All materials

sigle	mechanism	domain
FAT01	Fatigue	Ferritic / austenitic steels
FAT02	Vibration fatigue	All material
FAT03	Fatigue corrosion	Carbon and low alloy steels
FAT04	Environmental fatigue	All steels
FLA01	Buckling	All materials
FLU01	Radiation creep	Austenitic Stainless Steels of RVI
FSI01	Radiation embrittlement	Low alloys RPV steels
FSI02	Radiation embrittlement	Austenitic Stainless Steels of RVI
GON01	Swelling	Irradiated stainless steels (RVI)
HYD01	Hydrolyse	Composite piping
INS01	Gross plasticity - Plastic collapse	All steels
POL01	Ageing of Polymers	Polymers under nominal env.
POL02	Ageing of Polymers	Sheath and insulater of cables "hot points"
POL03	Ageing of Neopren	Anti-vibration devices
RAG01	Alcali-réaction	Concrete
REL01	Cable pre-stress relaxation	Pre-stressed concrete
RET01	Shrinkage	Pre-stressed concrete
RUP01	Brittle fracture	Carbon, low alloy and martensitic steels
RUP02	Brittle fracture	Carbon and low alloy steels
TAS01	Settlement	Ground
USU01	General wear	All materials
USU02	Shock and slidding wear	Core instrumentation thimble
VIE01	Ageing	I & C
VTH01	Thermal Ageing	Carbon and low alloy steels
VTH02	Thermal Ageing	Martensitic stainless steels
VTH03	Thermal Ageing	Austenoferritic duplex cast stainless steels
VTH04	Thermal Ageing	DMW - dilution / interface area
VTH05	Thermal Ageing	Stainless steel welds

Around 50 degradation mechanisms of components or structures

Materials R&D Program in support of Ageing Management

- **Steam generator**

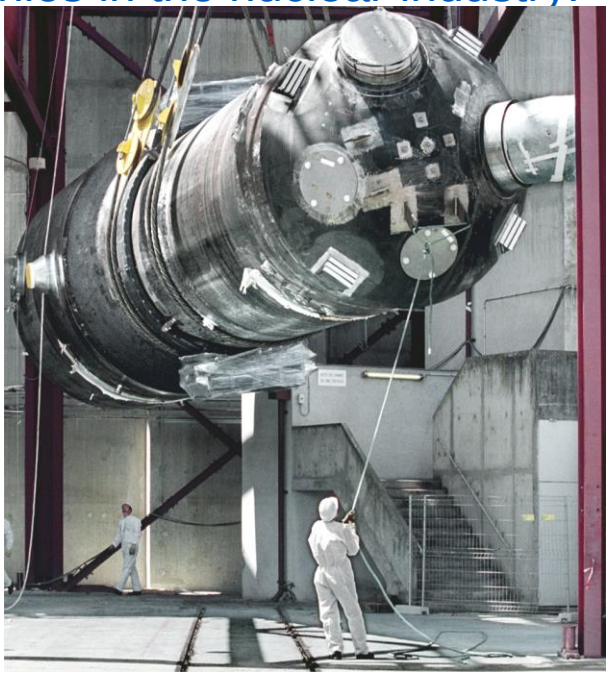
Sherlock Project:

In the frame of EDF R&D (Material Ageing Institute), 2 steam generators would be retired and examined in order to improve the understanding of ageing mechanisms.

Sherlock will have an 8-year program of activities, called the “Core Program” that was developed by EDF R&D with external participation of utilities, organisations representing utilities, vendors and other companies in the nuclear industry.

The extend of the examinations and samplings depends on:

- Decontamination solutions
- Feasibility to perform the examinations without degradation of the materials (due to decontamination and sampling)



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Material Program