1st international Nonmetallic Research Program

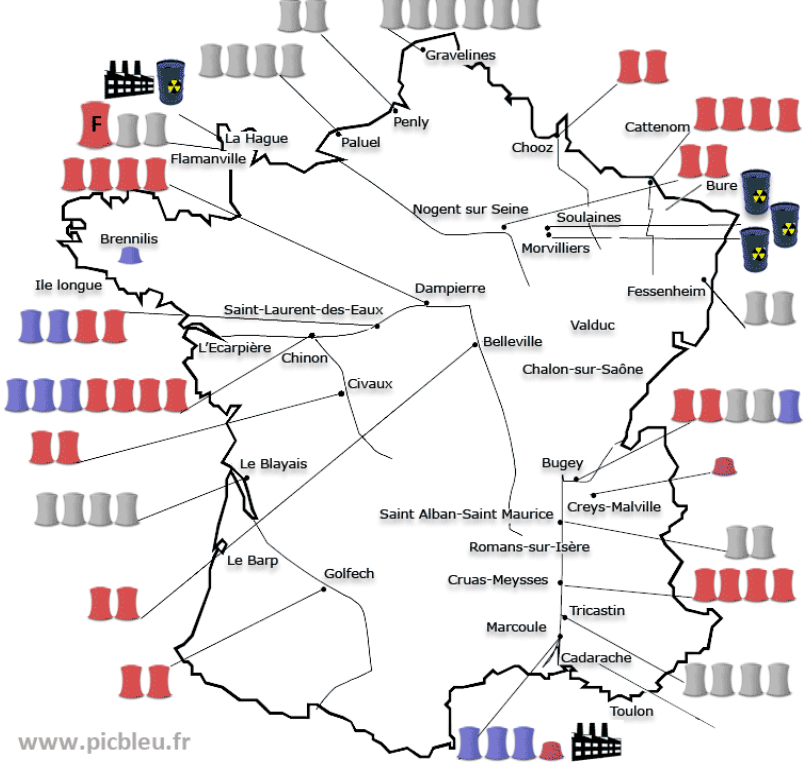
Nonmetallic materials at the service of the nuclear pools maintenance

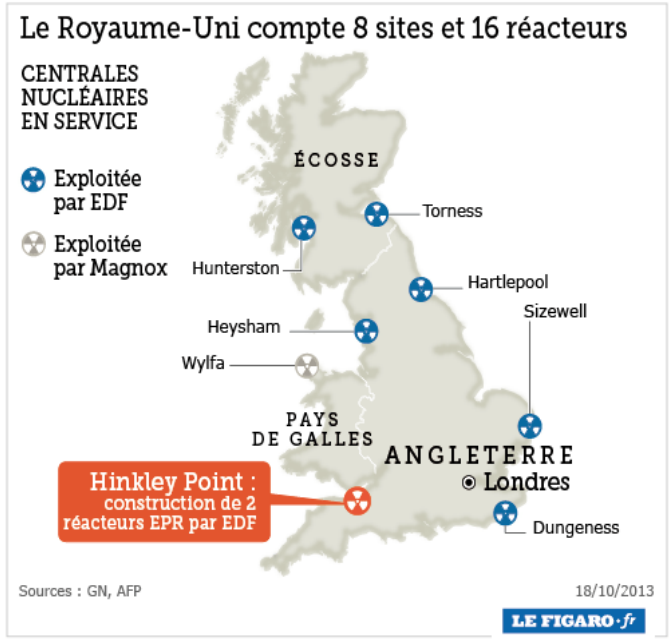
Polymers in Nuclear Applications - 2024
Conference organized by ENERGIFORSK
Stockholm, Sweden, **March 19-20 2024**

Dr. Marc Kuntz, EDF R&D

EDF key figures

- 130,000 Employees in 2020
- 2nd electric company in the world
- Nux, hydro, wind turbine gas, solar power, coal, oil
- NUX in France = 1963 for graphite/gas technology and 1971 for PWR
- FRANCE: 56 reactors under operation (PWR 900MW to 1450MW), 1 under construction (EPR 1750MW)
- UK: 16 reactors under operation, 2 under construction (EPR 1750MW)





EDF key figures

90% carbon-free energy

France installed capacity [MW][9] and production in 2020 [TWh][6]

	Installed capacity [MW]	Production [TWh]
Nuclear	61370	379,5
Hydropower	25466	60,0
Wind power	17391	34,1
Gas	12529	38,6
Solar power	10101	11,6
Coal	2978	1,6
Oil	2897	2,3
Bioenergies	2160	9,9
Total	134892	537,7

Content

1. Role and place of the nonmetallic materials in the nuclear industry
2. Strengths and specificities of Megapol
3. Presentation of the research programs [2019-2022] and [2022-2025]
4. Short term agenda

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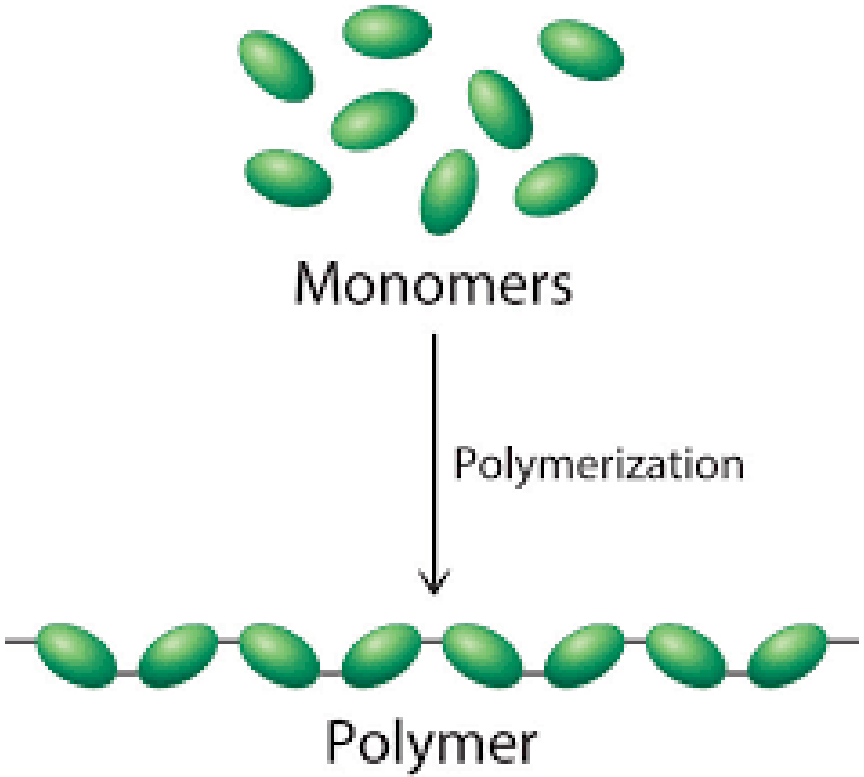
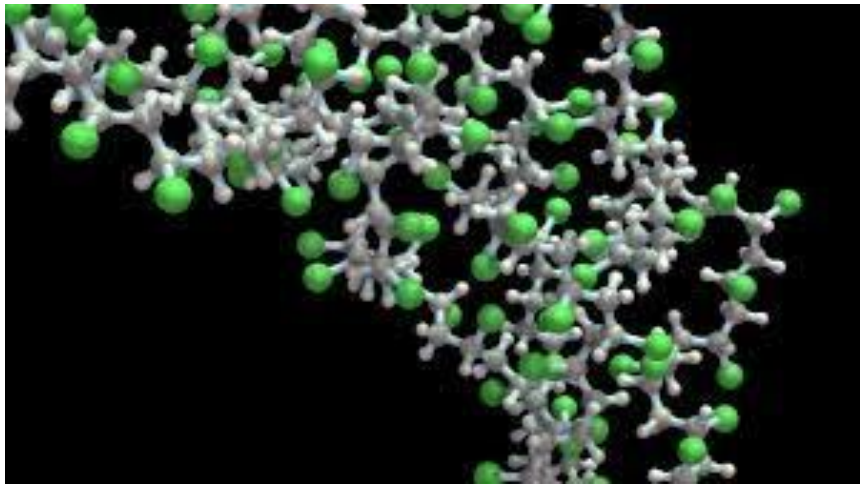
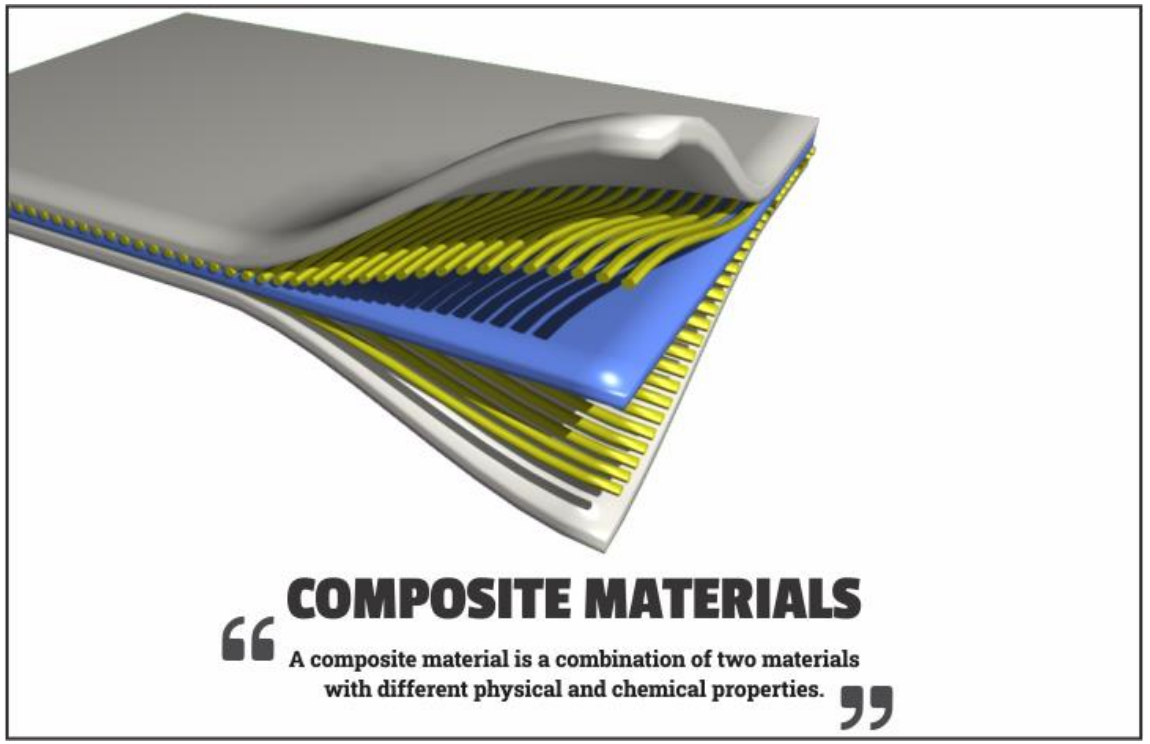
Nonmetallic materials: definition





"a substance which has a molecular structure built up chiefly or completely from a large number of similar units bonded together, e.g. many synthetic organic materials used as plastics and resins".



Polymers, a game changer with a rise of technical applications

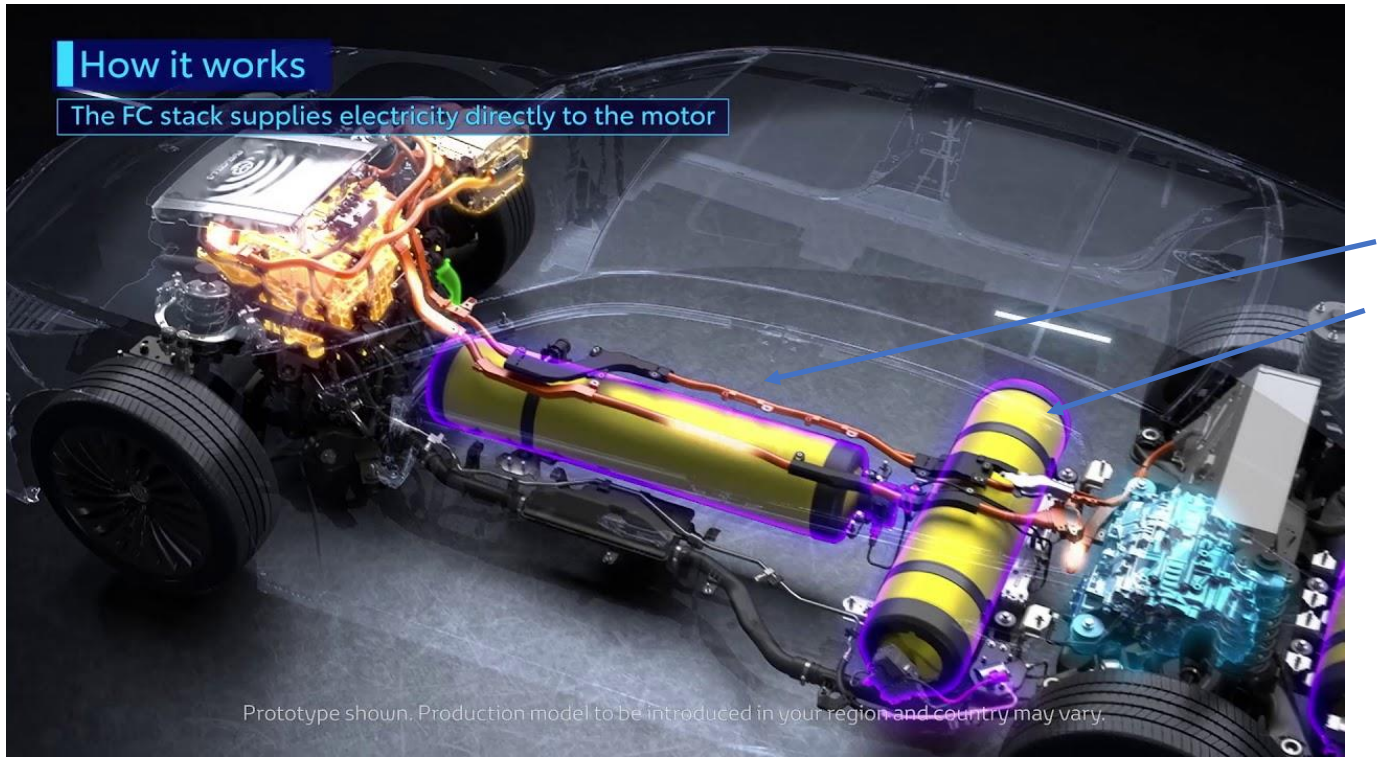
- Some of polymer applications in the Industry are mainly justified through economical purposes

- [80’s – today] – technical aspects taken into consideration to advocate A polymer solution among between several material options

A break-through industrial innovation only feasible with polymers

Toyota MIRAI 2 – 182 HP – 300 kN - 400 mi (650 km)

Pull winding process for composite

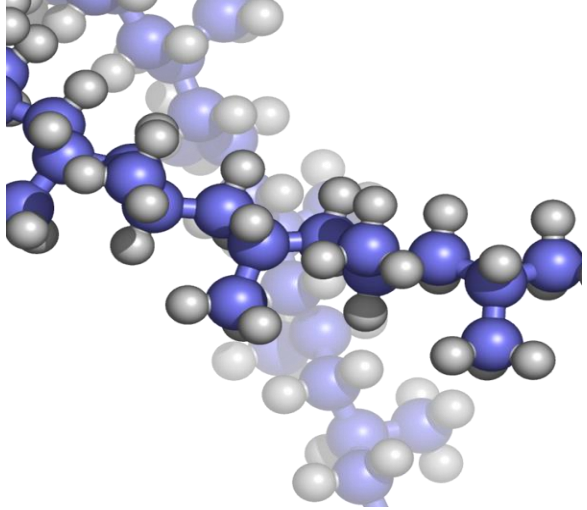


2 reservoirs for H_2 storage, 142 liters, 750 bars and crash test requirements

Nonmetallic materials in the energy sectors, a game changer!

Has allowed development of new technologies like Wind turbine or hydro turbine

Optimization of business model (solar farm distribution poles)



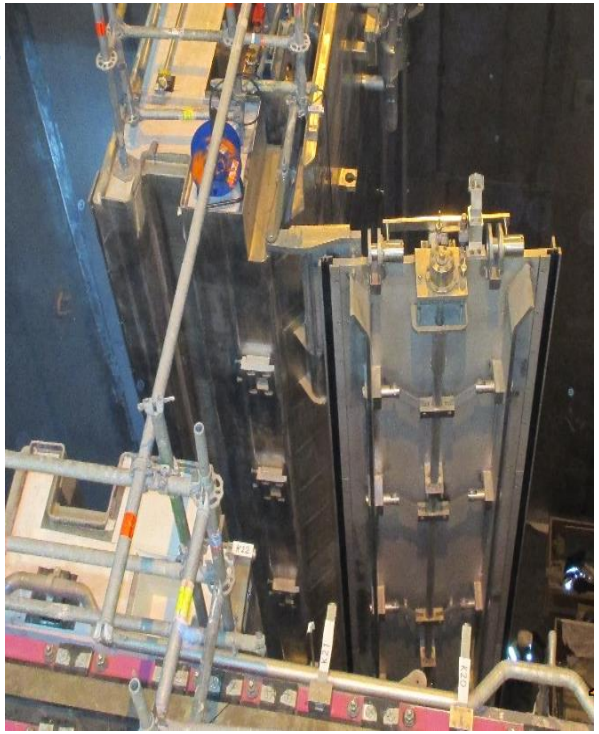
Yes nonmetallic materials can protect !!

Safety-related !!!

Major functionalities of nuclear polymers

- Corrosion protection
- Fire protection
- Decontamination
- Repair concrete and metal
- Seismic protection
- Water tightness
- Airtightness
- Thermal insulation
- Electrical insulation

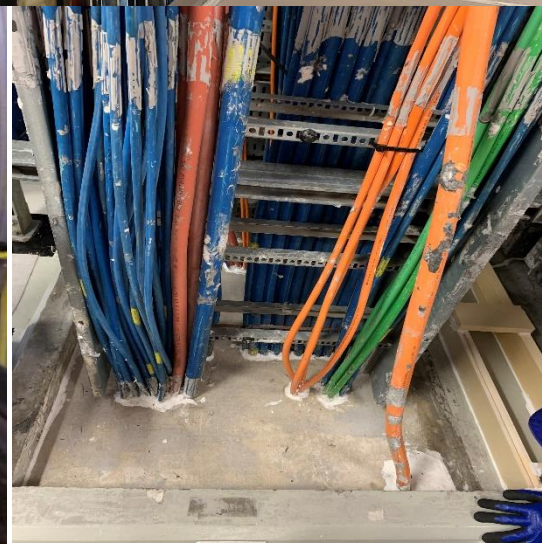
Few ex. of current polymeric projects for new buildings [EDF]



Qualification of the seal of Fla3 cofferdam

UK NPP Evaluation of the compressibility limit of a polymeric backfill (PSE)

Development, qualification and installation of new fireproofing materials (penetration seals and cable ways)



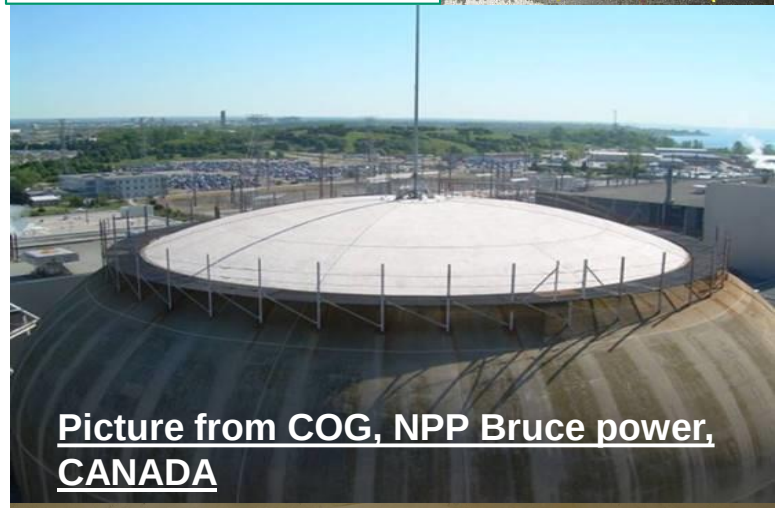
Nonmetallic materials and nuclear sector

- A class of material that is developing in nuclear power, margin for progress
- 5 tones today
- The French nuclear sector gives a good indicator, part has doubled in 25 Years
- Some repairs are only possible with polymers
- **A connection between use of polymers and cost of production for nuclear power**

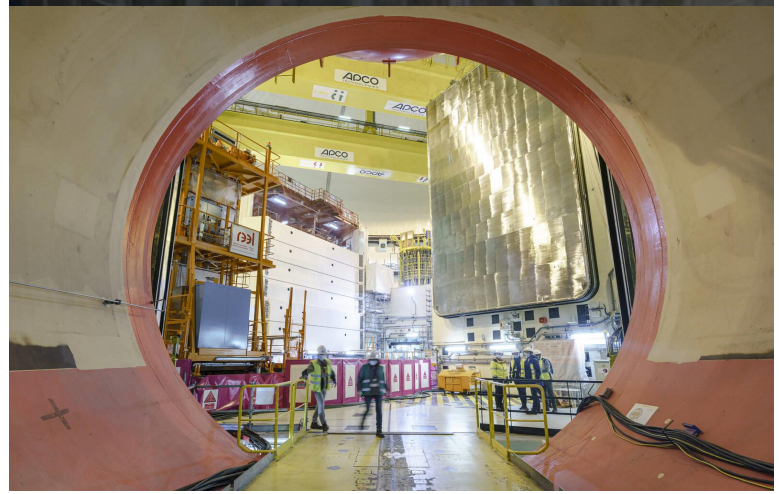
- **On utility' side, polymers needs are real**
  - **New and "Specific" polymers : much more than ever**
    Due to reinforcement of accidental scenario and qualification procedure + polymer-based material have not changed: reduction of operational margin
  - **Key solutions for safe and affordable maintenance**: some maintenance operations are impossible without polymers

STELLANTIS

EDF power plant, DAMPIERRE 2, Cooling tower, damaged area observed – halfway up - Circular composite – carbon epoxy plates -



Picture from COG, NPP Bruce power, CANADA



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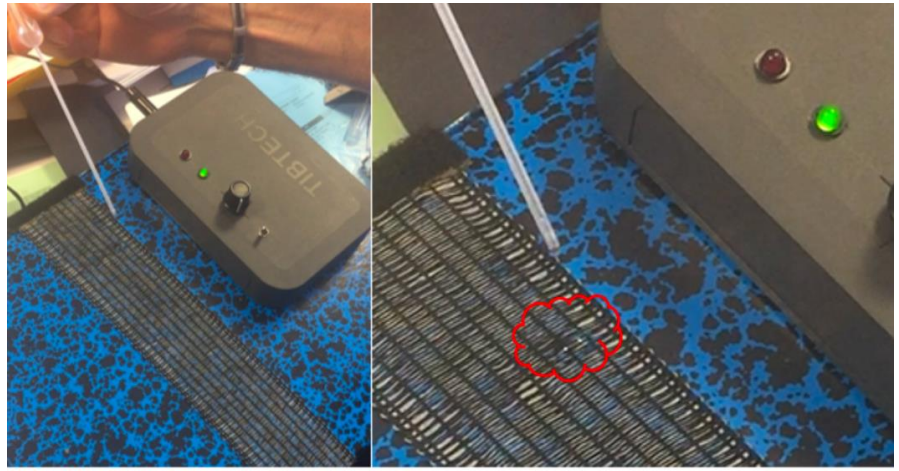
- Non-profit Research Consortium designed by Nuc. people for Nuc. People
  - **To control maintenance costs / cost of the nuclear energy by d**eveloping knowledge about nuc polymer applications
  - To **contribute safely LTO**

- DNA: International, Transdisciplinary, innovative
- Representative of the nuclear sector (PWR, BWR, CANDU, VVER, >80% of the power plants currently in operation around the world
- **Starting with 5 members, a growing-up consortium**, attractive, more powerful, more financial means, more research
- **Megapol's drivers**
  - **makes the research more affordable** "You pay what you get for" & "Free to pick what you need"
  - **Short-term outcomes dedicated to each member (based on use cases)**
  - **Able to develop nuclear innovations (materials, new NDE) for new buildings and existing fleet**
  - **Able to capitalize feedback, knowhow and knowledge for the community**

Formalism and Outcomes for members, 4 ways to generate value

- **Capitalization of know-how: extension of use**
- **Innovation: emergency repair, leak detection with tape:**
- **Benchmark: test of several decon solution, test of fireproofing materials**
- **Bibliographic research: composite in the nuclear sector, geopolymer applications**



Membres & Partners

MEGAPOOL

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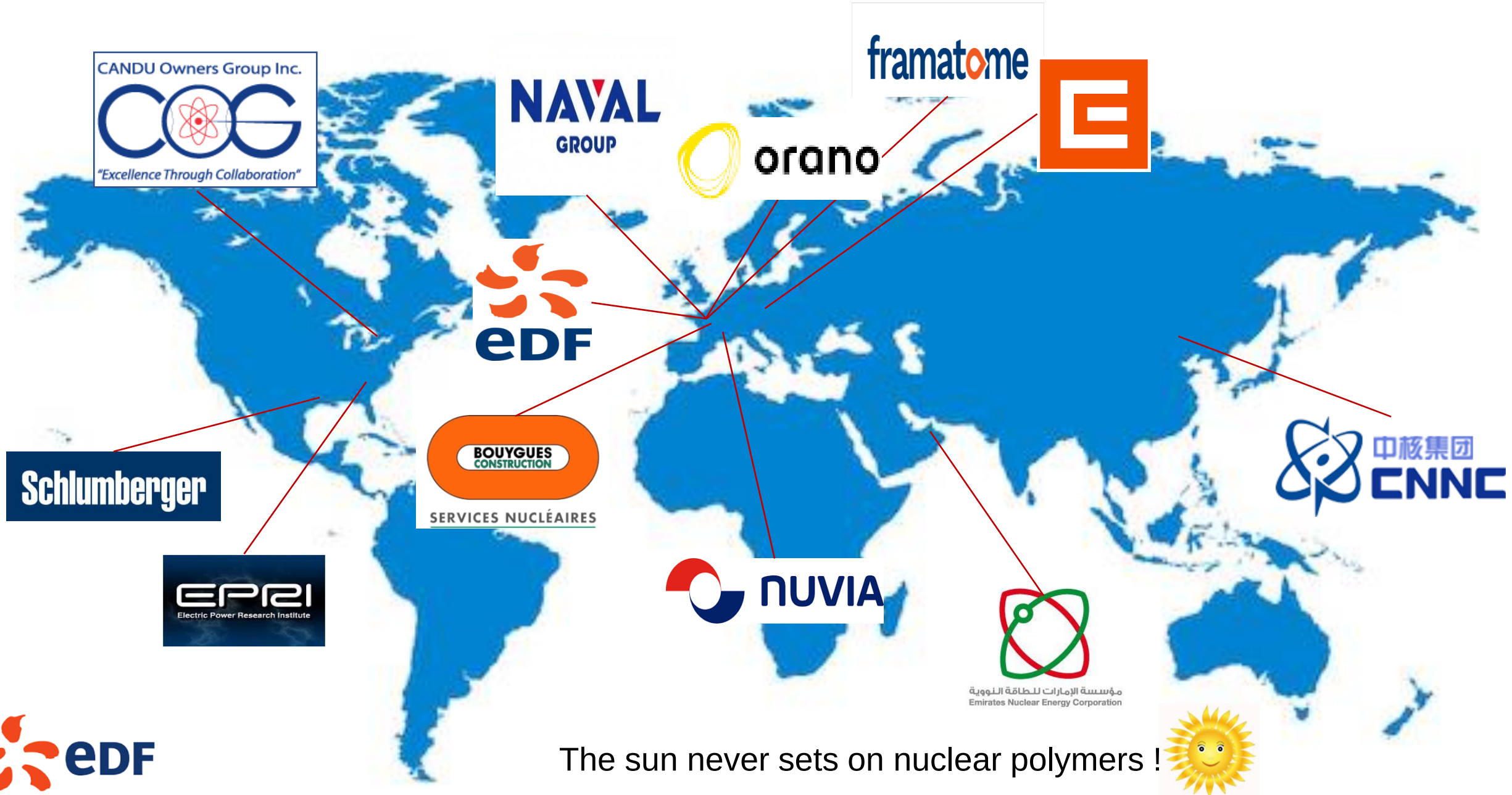
Megapol Membres & Partners



EDF

The sun never sets on nuclear polymers !

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Phase 1 [2019-2022] – 6 studies, 10 deliverables

Del	Title	Number / Megapol reference	Publication date or current status
D0	Compilation of input data related to the 3 Megapol deliverables (D1, D2 and D3) scheduled for 2020	6125-2012-2020-01571	July 6th 2020
D1	Aging and justification of service life extension of nuclear elastomers	6125-2112-2021-00353	May 5th 2021
D2	Underwater emergency repair of the nuclear pools with polymers	6125-2112-2021-00935	August 3rd 2021
D3	Superhydrophobic surface engineering for performance enhancement of nuclear components	6125-2112-2021-01451	September 9th 2021
D4	Compilation of input data related to the deliverable D4: state of the art for modeling the aging of nuclear polymers	6125-2112-2021-02684	September 27th 2021
	How the modeling of the polymer's ageing can constitute an interest for the maintenance in the nuclear sector. Deliverable D4 - Megapol Research Program Phase 1	6125-2112-2021-02560	Oct. 10th 2022
D5	Compilation of input data related to the deliverable D5: state of the art for nondestructive examination of nuclear polymers	6125-2112-2021-02689	September 27th 2021
	Monitoring the aging of polymer components installed in the nuclear sector by setting up non-destructive examination. Deliverable D5 - Megapol Research Program Phase 1.	6125-2112-2022-02224	Will be sent to members on dec 15th
D6	Compilation of input data related to the deliverable D6: development of a polymeric fabric for leak detection in the nuclear sector	6125-2112-2021-02694	September 27th 2021
	Development of polymeric fabrics for leak detection in the nuclear sector	6125-2112-2022-00782	Nov. 10th 2022

[2022-2025] Research Program

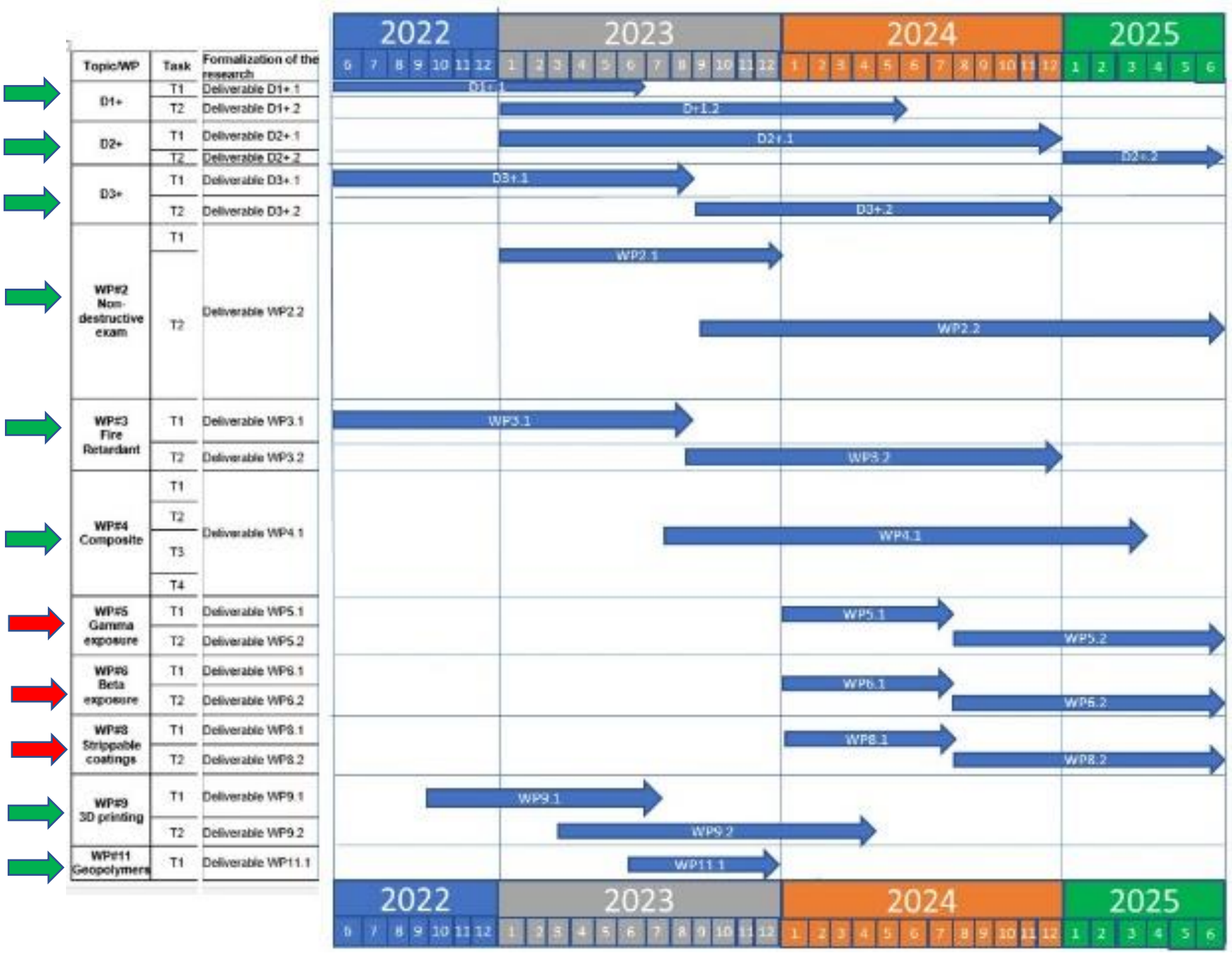
Topics	Section	Scope / target	Type of study	Expected outcomes
D1+. Aging of nuclear elastomers	LTO	Justification of service life extension of nuclear elastomers	Experimental work based on component testing “in-service requalification”	Guideline to get more than 10 years of extra time in service
D2+. Underwater emergency repair	SAFETY	Repairing from the surface a leak of the floor that overpasses the drainage system, fast and efficiency Seismic or fallen objects (used fuel containers)	Experimental development in full scale pool	Having a proven solution at disposal, knowing limitations, knowing how to industrialize
D3+. Superhydrophobic surface engineering	LTO (Performance of the plant)	Improving functioning Durability of solution	Survey, tests of solution	Benchmark of solutions
WP2. NDE	LTO	Evaluation of applicability of several technics for follow-up ageing polymers (55 aged materials) Thz, indenter, light emitting, hyperspectral imaging	Experimental work	Round robin; knowledge
WP3. Fire	SAFETY	Inventory of fireproofing material applications and expected level of performance. Comparative fire testing Development of new applications, possibly fire upgrade of existing polymers and composites	Survey, comparative tests, prospective new applications	Round robin; knowledge

[2022-2025] Research program

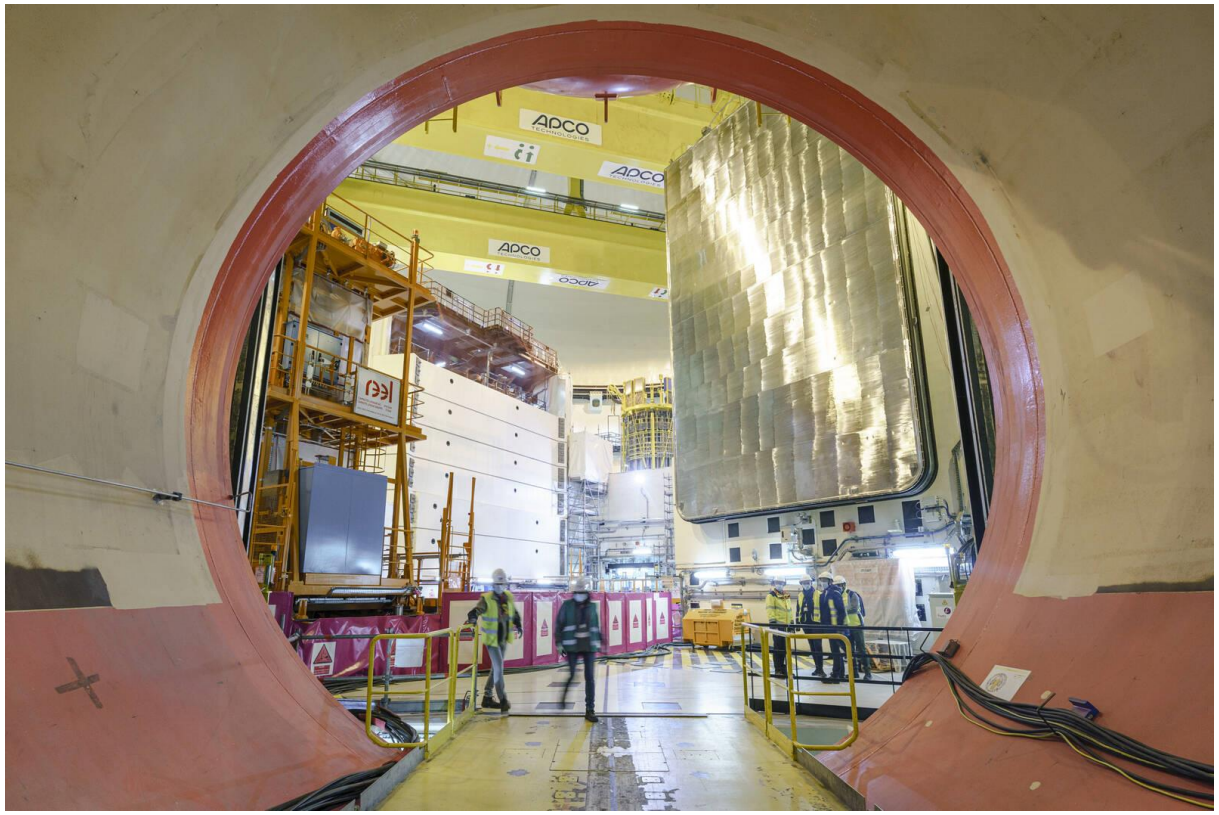
Topics	Section	Scope	Type of study	Expected results
WP4. Composite applications	LTO	Compilation of composite repairs realized and existing composite applications for all nuclear power plant designs New applications investigations	Survey and bibliographic study	Knowledge, Feedback of the nuclear sector, prospective new applications
WP5. Gamma stabilized polymers	LTO	Formulation of a gamma-stabilized elastomeric grade for nuclear application Test of the gamma-stabilized elastomeric grade to evaluate gain	Survey, bibliographic study, test	One grade of elastomer gamma stabilized in accordance with existing application- proven gain
WP6. Beta stabilized polymers	LTO	Formulation of beta-stabilized polymers for nuclear applications Test of the beta stabilized polymer grade defined in task 1	Survey, bibliographic study, test	One grade of elastomer beta stabilized in accordance with existing application-proven gain
WP8. Decon polymeric process	LTO	Test of commercial solutions for 3 applications Development of new applications of strippable coating for Megapol2 members	Survey, test and prospective new applications	Benchmark of solutions, prospective new applications
WP9. 3D printing	LTO	Inventory of 3D printable components for the nuclear sector that constitutes value for maintenance program. Manufacturing and test of 3 applications	Survey, state-of-the-art, manufacturing and test	Knowledge about new technologies, Prospective new applications
WP11. Geopolymers	LTO, SAFETY	State-of-the art for geopolymer applications for nuclear sector.	Survey, bibliographic study	Knowledge about new technologies, Prospective new applications

Detailed program

- 3-year program
- Program defined and voted by members in terms of schedule, budget, confidentiality and contractor
- Program cannot be changed or amended
- 11 topics / 20 deliverables



Application of innovative polymers in the nuclear sector



Pictures from EDF,
gasket gamma-stabilized of the access hatch

Figure 1

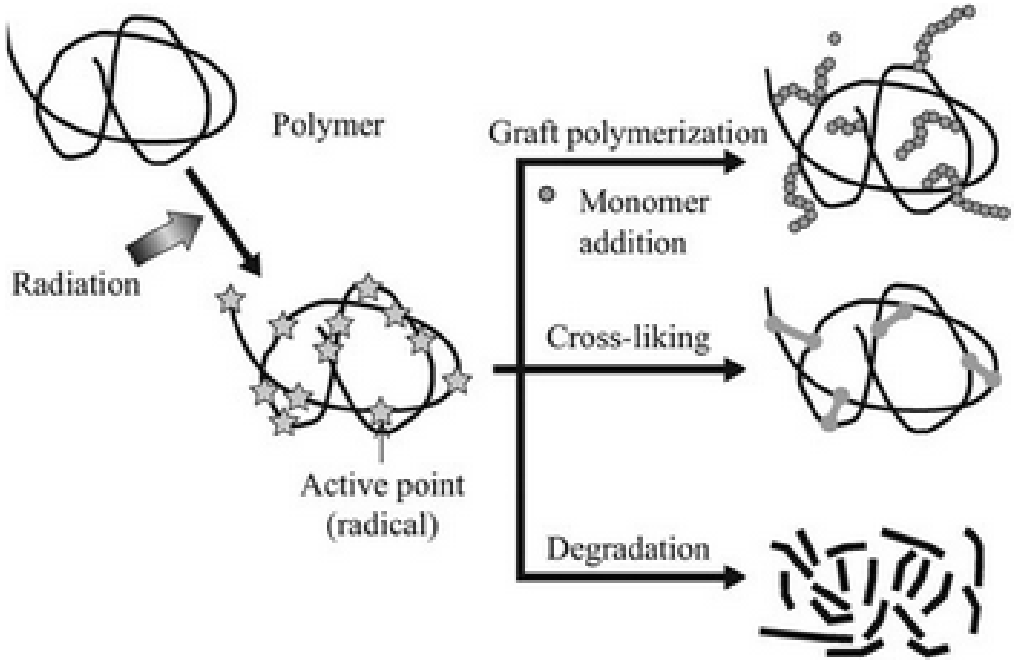


FIGURE 1. The effect of high energy (gamma) irradiation on polymers in different manner (Tamada and Maekawa, 2010).

HIGHLIGHTS

D1- Ageing and service life extension of elastomers

INTRODUCTION

- Elastomers are widely involved in nuclear installations
- Service conditions produce ageing effects and reduce longevity however additional margin exists. In this sense, this deliverable has been proposed.
- Contributors: COG, EPRI, FRAMATOME, Naval Group, EDF:

  5 industrial cases of use and 3 materials to consider
- This study aims to set up 4 ways (strategies) to justify extending the service life of components without impact on safety level.
- What is A Strategy ? Experimental or modelling approach based on EDF's experience or bibliographic research, associated to acceptance criteria that allow justifying an extension of service life.

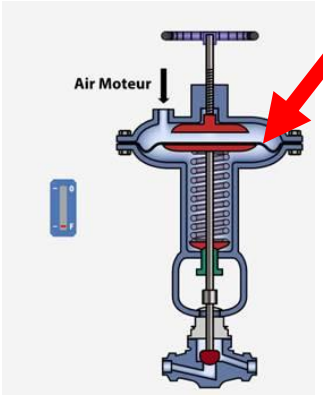
	EPRI	COG	EDF	FRAMATOME	NAVAL Group
Materials of case study	Silicone	EPDM	EPDM	EPDM	FFKM

FOCUS ON THE EDF CASE STUDY

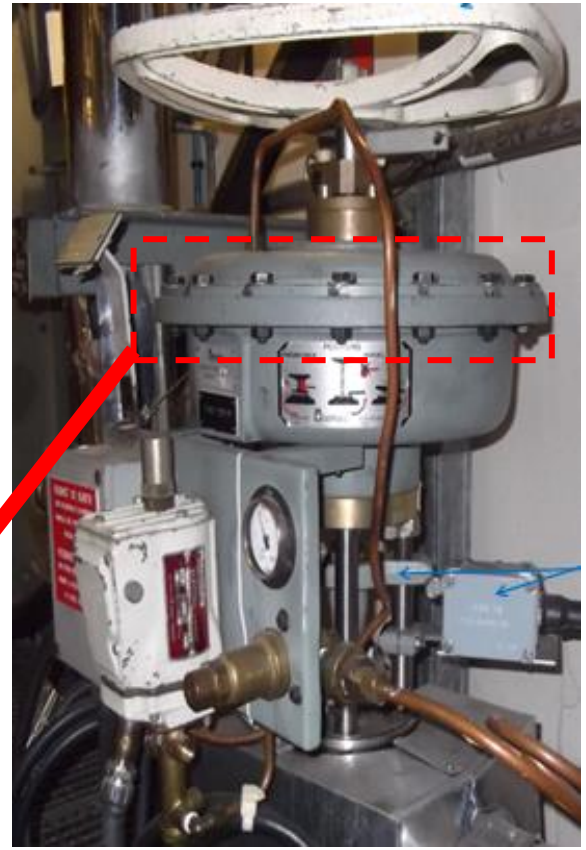
Application

Industrial case	Pneumatic valve actuator diaphragm (SEREG)
Operating mode	Use of air pressure to operate the valve
Qualification procedure	K3AD (EDF procedure) ASTM C1068 - 15

Main operating air leaks identified



Operating mode

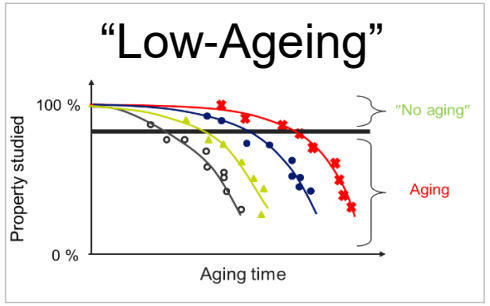


THE 4 STRATEGIES

In order to justify service time increase

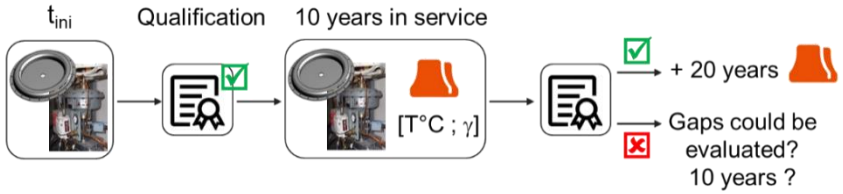
2 Experimental approaches

"Low-Ageing"



Do Lab tests to chase no ageing indicator

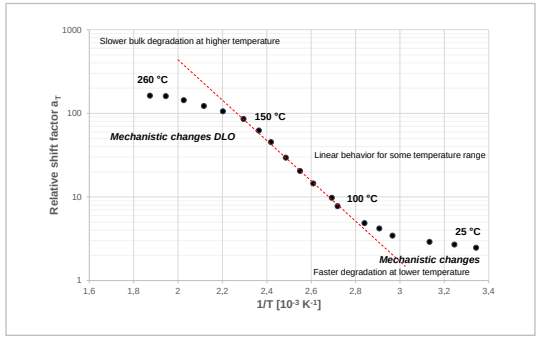
Re-qualification



Do additional testing based on qualification

2 Numerical approaches

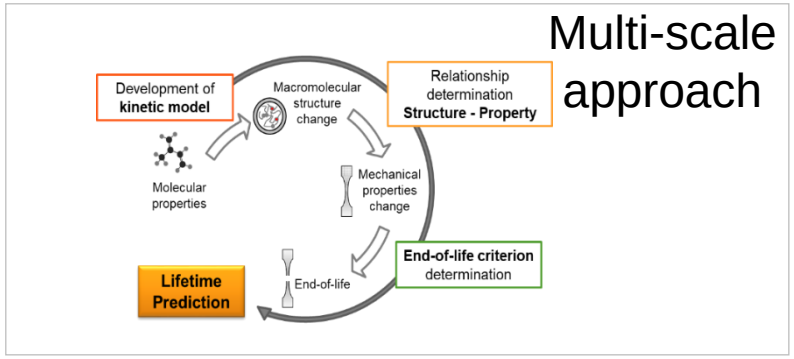
Empirical



Apply Arrhenius law to extrapolate P beyond service time

Kinetic modelling to simulate long term P

Multi-scale approach



OUTCOMES OF D1

- Proof that 3 to 15 years of extra time are conceivable and justifiable
- Applicable within 3 to 5 years
- On EDF side, huge cost-saving effect: ongoing calculation conducted by EDF Engineering branch –
- 12 months, 40 k$ per member.

CONTINUATION IN D1+

- Carrying out of functional test on membrane to define and consolidate threshold values (+10 years of service time)
- Report under review (to be issue in April)

Scale	Property / feature	Method	Criteria		Extra Time if all criteria are fulfilled
Molecular scale	Oxydation products C=O	IRTF	C1	$[CO]_t = 0$ or $[CO]_i$	**Extension →**
	Oxidative induction time (OIT)	DSC	C2	OIT ≥ 5 minutes	**½ time already spent in service**
Macromolecular scale	Crosslinking rate (X) Scission rate (S)	Swelling	C3	X = ± 10 % of initial value	**Max 6 years**
			C4	S = ± 10 % of initial value	**Then set up**
Macroscopic scale	Elongation at break	Tensile test	C5	$e_{R\,nom}$ ± 25 % of initial value	**Case 1 for 3 years**
	E-Modulus		C6	E = ± 25 % of initial value	**Or**
	Shore hardness	Indenter	C7	Value = ± 10% of initial value	**Case 2 For ½ time or 6 years**

3.4 Emergency repair?

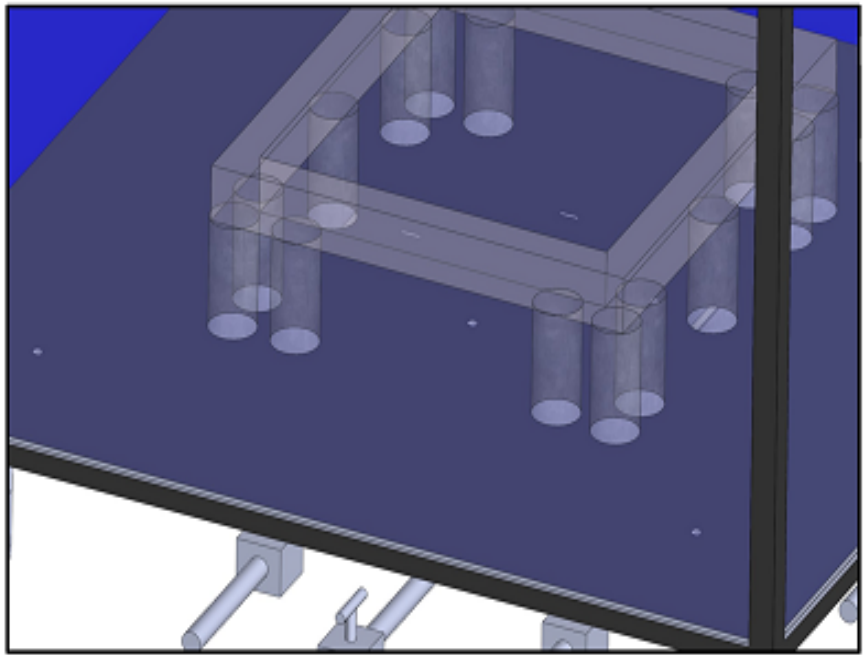
Fixing leaks in a nuclear pool, widely above the drainage system capability, in few minutes without emptying the water or sending divers ➔ never been addressed

Challenge was:

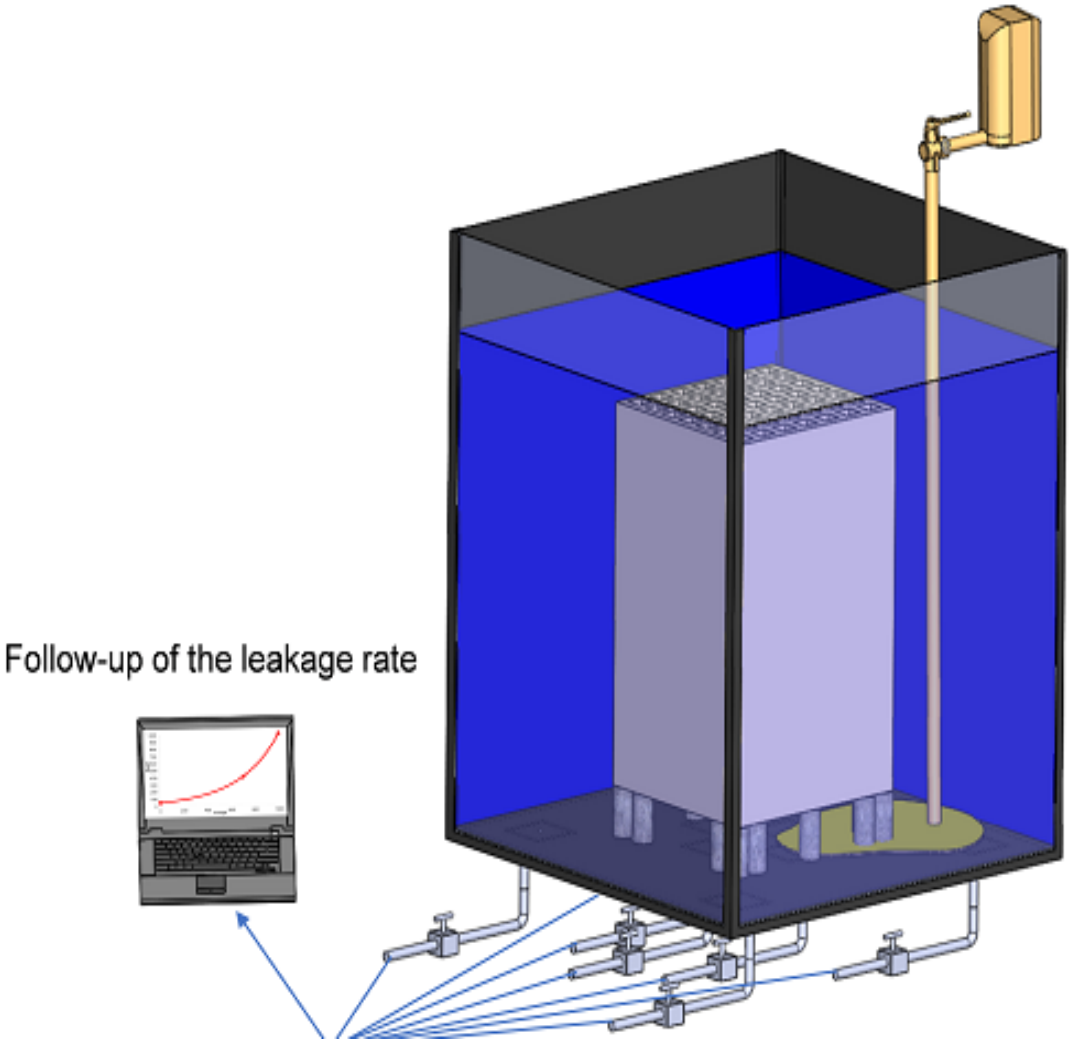
Is it possible to fix “severe” leaks of a nuclear pool bottom in a few minutes from the surface?

Approach & mock-up

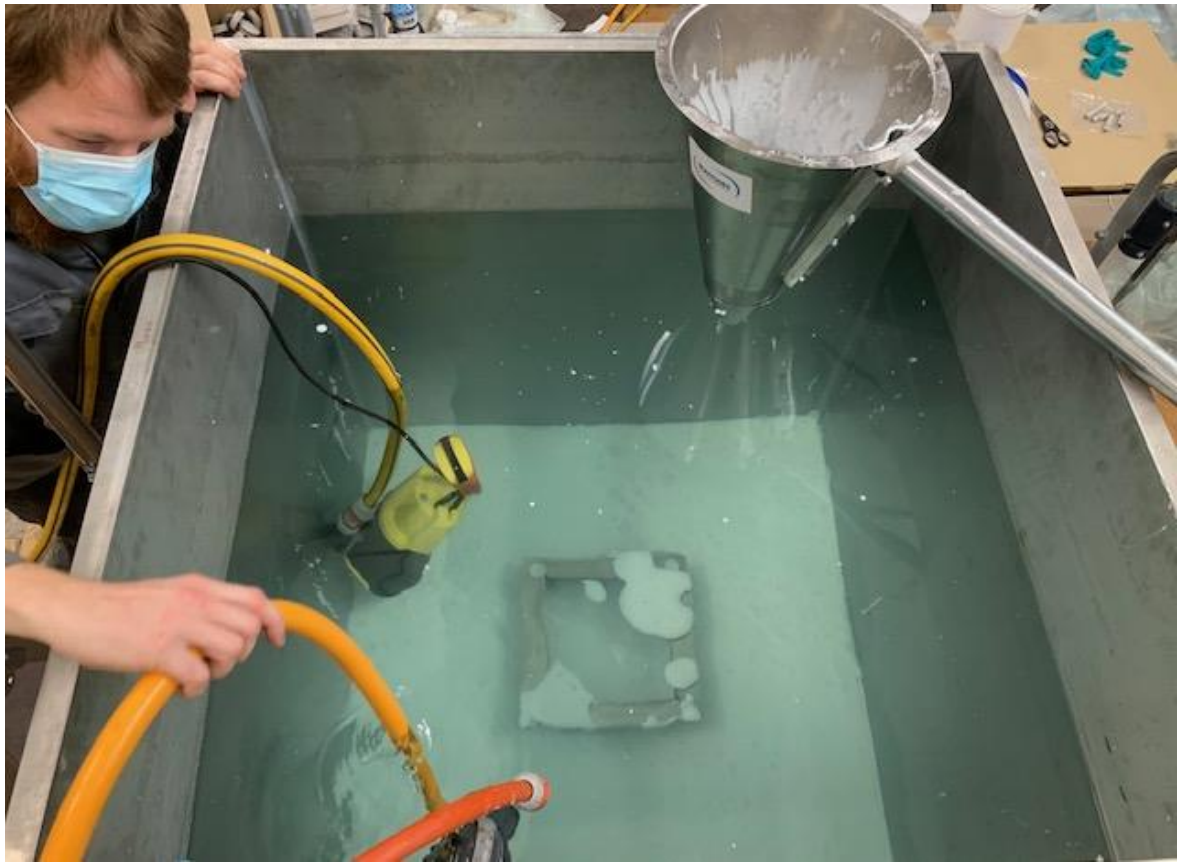
Emergency polymer repair for spent fuel pool bottom,
a self-smoothing and hydro-curable material applicable from the surface



Enlargement of the lower part of the mock-up,
visualization of through-wall defects



Team and mock-up



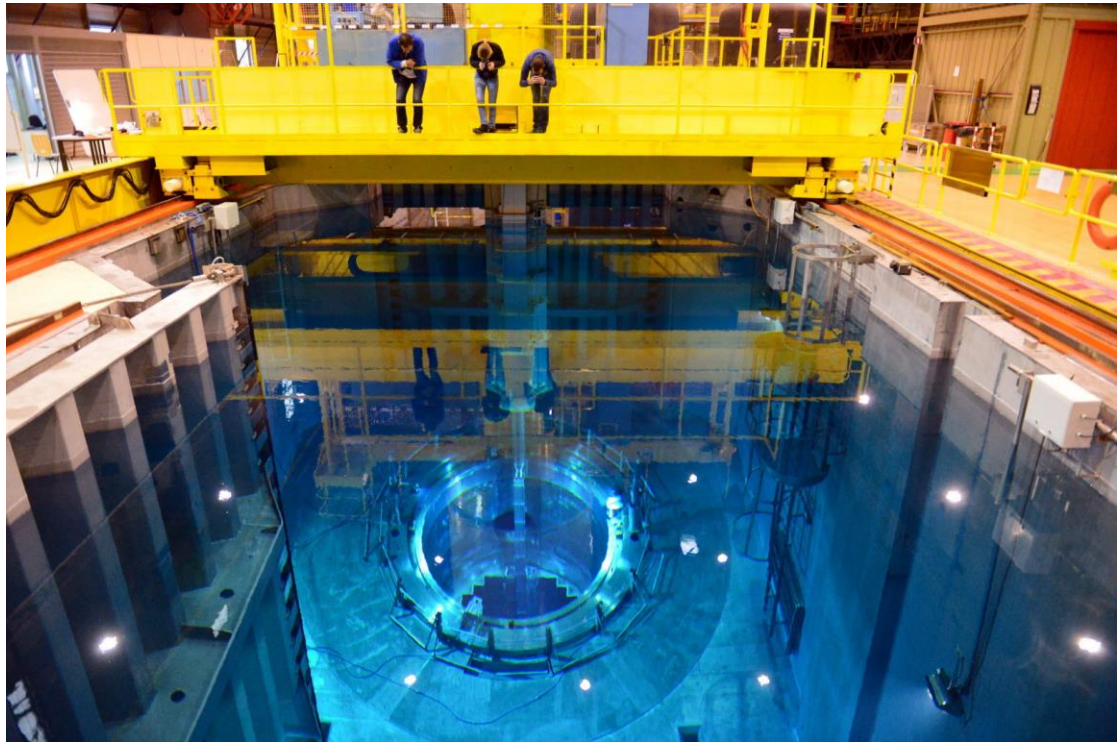
- 40 kg per square meter (80 pounds for 10 square feet)
- 2-inch thick
- Peelable

Lessons learned

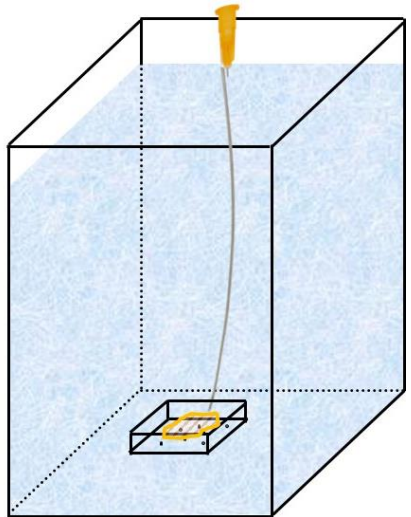
- Leaks were initially up to 500 gal/h (2000 l/h)
- 5 minutes to apply directly the polymer from the surface
- leaks stop after 7 minutes
- Polymer is peelable and removable 20 minutes after repair
- No residue of the polymer into the defect when removed

D2+, Continuation of D2

Fissures (mm)	Débit de fuite (L/h) à 14 m
1 x 18	2189
1 x 23,5	3 773
2 x 5,5	60 370
2 x 9	2 189
2 x 11,5	3 506
Trous (mm)	Débit de fuite (L/h) à 14 m
Ø 4	1 055
Ø 5	2 577
Ø 6	5 344
Ø 10	41 233
Ø 20	659 734
Ø 30	> 1 000 000
Ø 50	> 1 000 000



Sept 4-5 2024 nonmetallic repair application in immersion on mock-up (silicone and geopolymer)



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Short-term agenda

- 2nd Phase of Megapol collaborative research program until 2025
- New members / partners welcome
- 5th Program committee to be held in Vienna, @ the International Atomic Energy Agency (IAEA) = 2 day-MGP meeting + polymer conference “innovative non-metallic materials for the nuclear sector”
- Sept 4-5 2024 CETIC - you are welcome