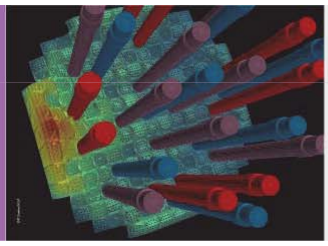

Methodologies for efficient and reliable NPP polymer ageing management

TeaM Cables – Morgane BROUDIN (EDF R&D)
El-Peacetolero – Mohamed BEN CHOUIKHA (Sorbonne Université Paris)

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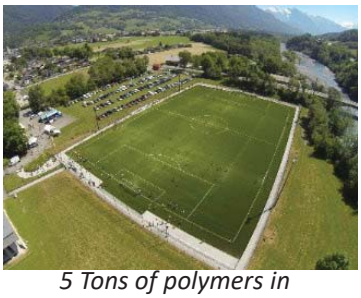
Methodologies for efficient and reliable NPP polymer ageing management

Why do we care about polymer ageing?

- Since 1960, the use of polymer materials has increased dramatically
  - From **10Mt** to **359Mt** in 2018, *i.e*. 3,600% growth in less than **60 years**
- In the French nuclear sector, polymers occupy a share of **16%** by mass compared to **6% 25 years ago**

Polymer needs are real…

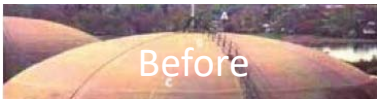
1500 km of cables per NPP including 50 km in reactor building



5 Tons of polymers in reactor building ~ football field

Polymer needs consist in providing…

- Key solutions
  - Cheaper (faster) repair techniques with the same security level
  - Specific materials (much more than ever): gamma stabilization, super hydrophobic
- Justifications "**durability**": obsolescence, duration life extension and set-up non-destructive exams
  - **To schedule preventive and corrective maintenance operations**



Reactor building dom repair Bruce Nuclear Generating Station (Ontario – Canada)

Cable jacket and insulation layer

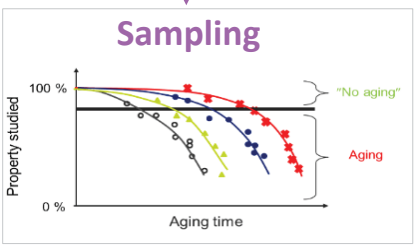
HDPE Pipes EDF NPP SIZEWELL B, UK

How to schedule maintenance operations?

Experimental methodologies

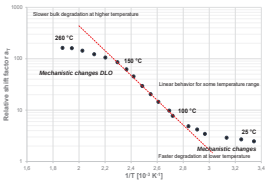
Numerical methodologies

Sampling



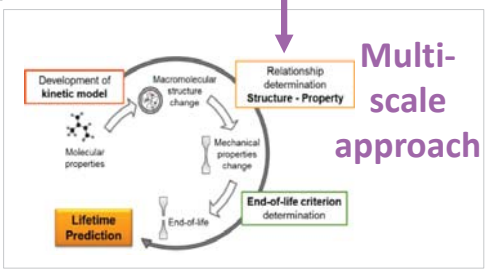
Do Lab tests to chase no ageing indicator

Empirical



Apply Arrhenius law

Kinetic modelling to simulate long term P



Multi-scale approach

Non-destructive exams

How to schedule maintenance operations?

Experimental methodologies

Numerical methodologies

Sampling

Do Lab tests to chase no ageing indicator

Empirical

Apply Arrhenius law

Kinetic modelling to simulate long term P

Multi-scale approach

Non-destructive exams

El-Peacetolero

TeaM CABLES

TeaM Cables in a nutshell

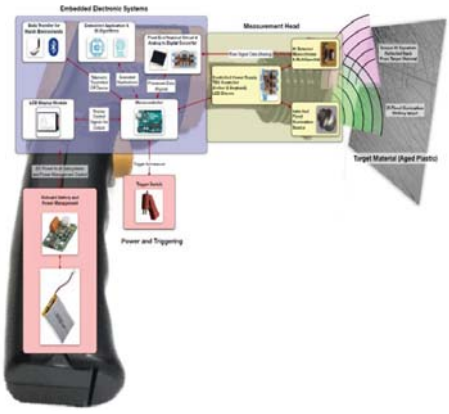
European tools and methodologies for an efficient ageing management of nuclear power plant cables

- H2020 Framework: "Continually improving safety and reliability of Generation II and III reactors"
  - 2017 – 2022
  - 5,5M€ including 4,2M€ financed by EU
  - 13 partners : **from cable manufacturers to utilities through academic labs**
  - Lead: EDF
  - XLPE **insulations**, NPP Cables
  - 3 PhD students (thesis presented) + 1 post-doc student
- A **dedicated end-user's group**
  - EDF, Tecnatom, Engie LaborElec, Airbus, Forsmark, Paks II, NEXANS
- Work plan combines
  - Experimental work packages to obtain data throughout accelerated ageing
  - Highly scientific work packages for the polymer ageing kinetics models

El-Peacetolero in a nutshell

Embedded Electronic solutions for Polymer Innovative Scanning Methods using Light Emitting devices for diagnostic Routines

- H2020 Framework: "Innovation for generation II and III reactors"
  - 2020 – 2023
  - 3,65M€ including 3M€ financed by EU
  - 9 Partners with a **large spectrum of skills** (materials, optoelectronic, artificial intelligence and robotics fields)
  - Lead: Sorbonne Université Paris
  - HDPE/Neoprene **Pipes**
  - 3 PhD students
- Work plan divided into two distinct large blocks of work:
  - Material's ageing and characterization, data generation, AI and algorithms
  - Device itself: LED set up, laser heads and the optoelectronics needed



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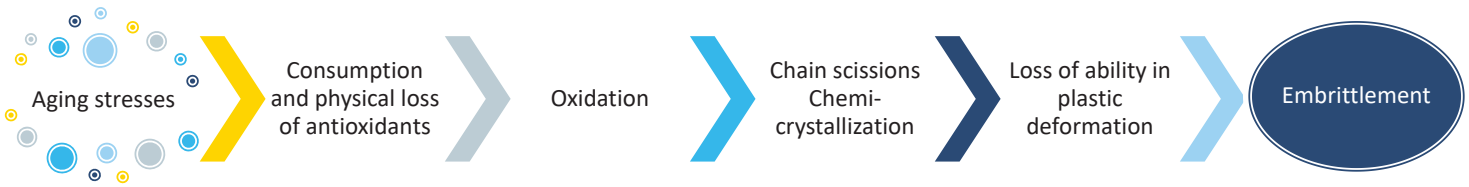
Main scientific challenges?

- Deeper **understanding** of operation-induced **degradation mechanisms**

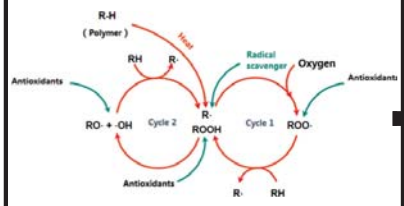


A. Xu, et al., "Physico-chemical characterization of the blooming of Irganox 1076® antioxidant onto the surface of a silane-crosslinked polyethylene", PDST, 2020.
A. Xu, et al., "Thermal ageing of a silane-crosslinked polyethylene stabilised with a thiodipropionate antioxidant" , PDST, 2020.
A. Xu, et al., "Physico-chemical analysis of a silane-grafted polyethylene stabilised with an excess of Irganox 1076®. Proposal of a microstructural model", PDST, 2021.
A. Xu, et al., "Thermal ageing of a silane-crosslinked polyethylene stabilised with an excess of Irganox 1076®", PDST, 2021.

Main scientific challenges?

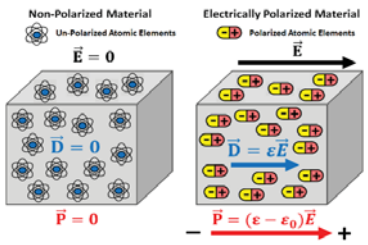
- Deeper **understanding** of operation-induced **degradation mechanisms**
- Using **multi-scale approach** to predict reliable **lifetime**

1 Matrix & degradation species



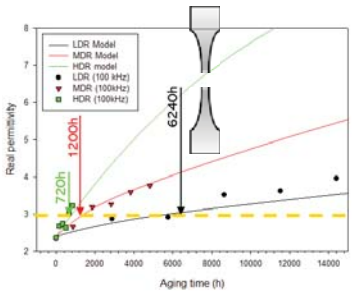
Through kinetic modelling

2 Dielectric permittivity, ε



Refers to the ability of the substance to store energy

3 Define end-of-life criterion



Predict duration life

S. Hettal, et al., "A new analytical model for predicting the radio-thermal oxidation kinetics and the lifetime of electric cable insulation in nuclear power plants. application to silane cross-linked polyethylene", Polymer Deg. and Stab., 2021.
S. V. Suraci, et al., "Multi scale aging assessment of low-voltage cables subjected to radio-chemical aging: Towards an electrical diagnostic technique", Polymer Testing, 2021.
S. Hettal, et al., "Towards a Kinetic Modeling of the Changes in the Electrical Properties of Cable Insulation during Radio-Thermal Ageing in Nuclear Power Plants. Application to Silane-Crosslinked Polyethylene", Polymers, 2021.
S. Hettal, et al., "A kinetic modeling approach for predicting the lifetime of ATH filled silane cross-linked polyethylene in a nuclear environment (under review)", Polymer, 2022.
S.V.Suraci, et al., "Multiscale modelling of permittivity of polymers with aging: how molecular scale properties modify the electrical permittivity" (under review)", Transaction on Dielectrics and Electrical Insulation, 2022.

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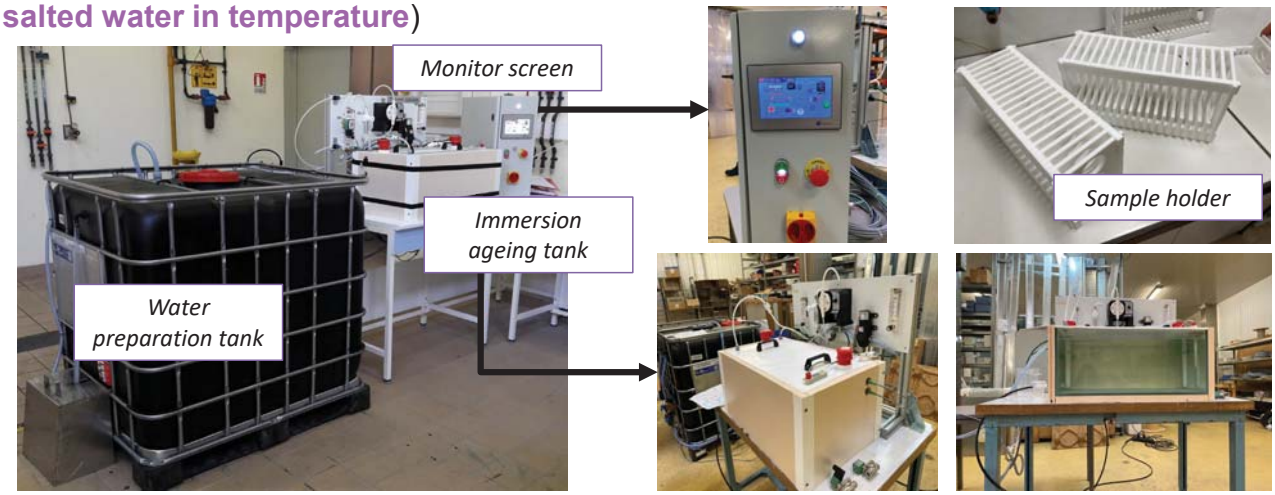
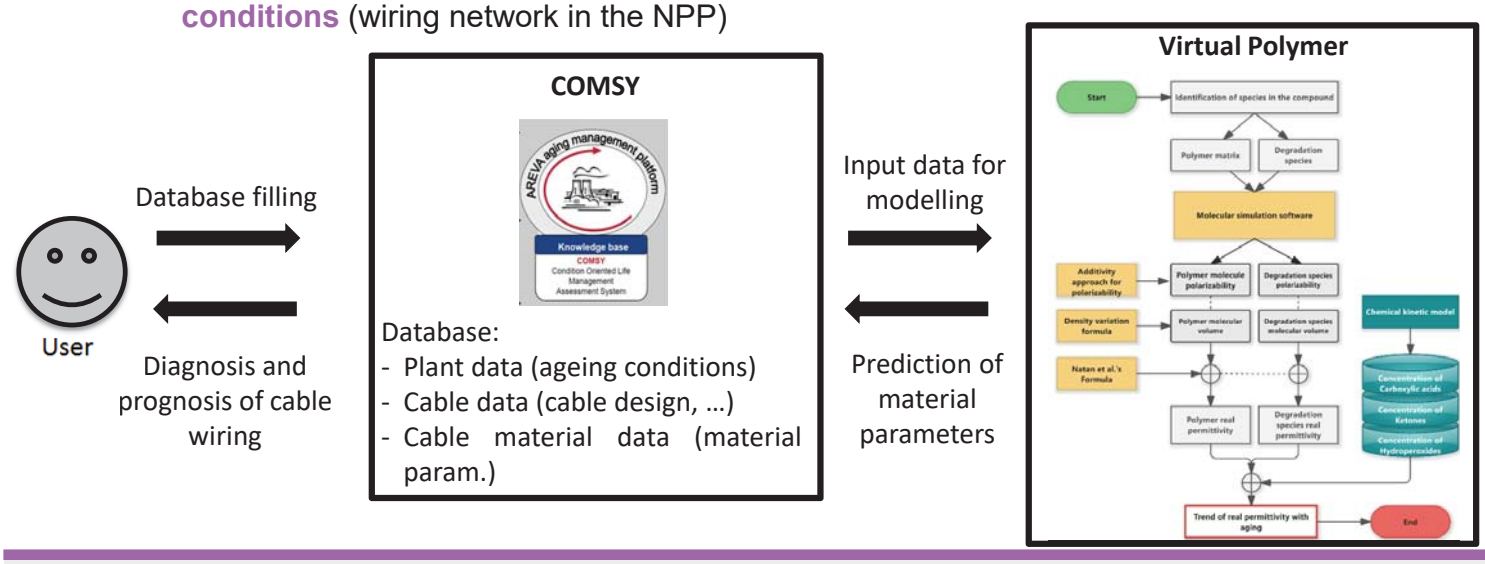
Lessons learnt and follow-up issues

- **Accelerate** YES but **keep** the **representativeness** of the **degradation mechanisms** observed in **NPPs conditions**
  - Setting up a dedicated accelerating aging loop within the framework of El-Peacetolero project considering numerous environmental factor (**immersion in chlorinated and salted water in temperature**)



Lessons learnt and follow-up issues

- **Capitalization**!
  - A novel "**TeaM Cables tool**" has been developed integrating the **multiscale model** and providing the **residual lifetime of cables** knowing **material** data and the **exposure conditions** (wiring network in the NPP)



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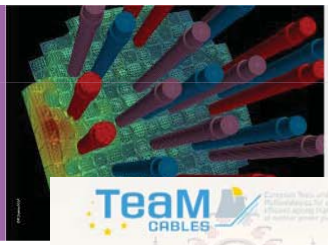
Conclusions – to be continued…

- The combination of these 2 projects allows to **provide non-destructive and predictive tools**, that can help assessing the reliability and functionality of the **polymer's-based components such as cables or pipes**

- Predictive tool
  - TeaM Cables highlights the importance of **ageing models' choice** (**multi-scale approach** *vs*. empirical approach), but also the need to **crosscheck** the results with **data from in service inspections**, which allows for **predictive maintenance** (as opposed to scheduled maintenance)

- NDTs
  - El-Peacetolero tool will be an **innovative TRL7 product** that will **have demonstrated a real use in a safety critical industry**
  - Within TeaM Cables EU H2020 project, **dielectric spectroscopy** already shown **promising results** to evaluate the **degradation rate** for portions of the **cable**



FISA 2022

30 May - 3 June 2022
Lyon, France

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