NUCLEAR OF THE FUTURE INITIATIVES

Experience in developing Digital Twins to support operation and maintenance of french nuclear plants

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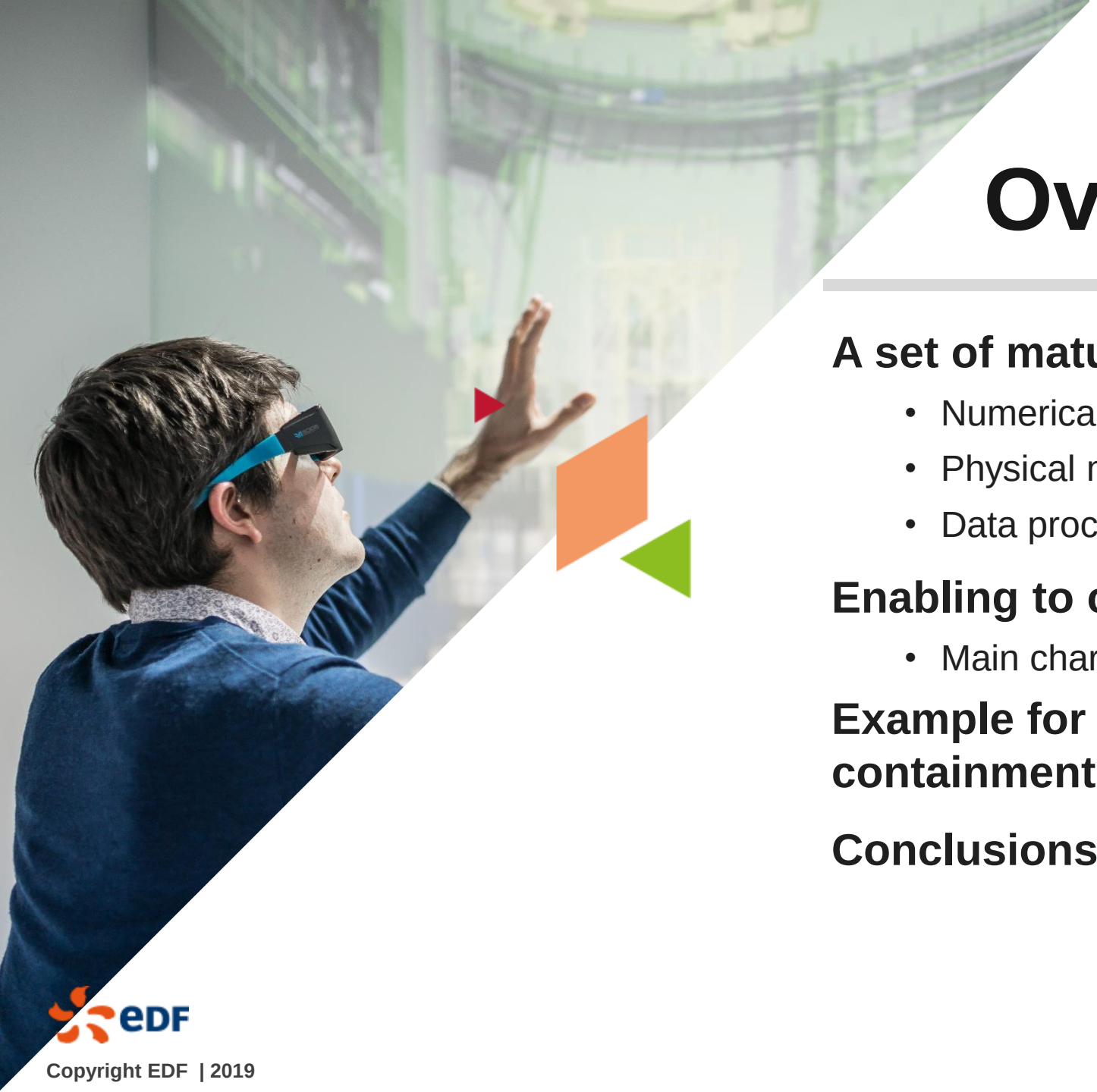


Overview

A set of mature technologies

- Numerical simulation
- Physical measurements
- Data processing

Enabling to create Digital Twins

- Main characteristics of Digital Twins

Example for O&M of nuclear power plants: containment building Digital Twin

Conclusions & Perspectives

Simulation

Some breakthroughs of the last 30 years

Non linear solvers

Transient algorithms

Advanced constitutive laws

Multi-phase flow

Mesh adaptation

Parallel computation

Multi-physics

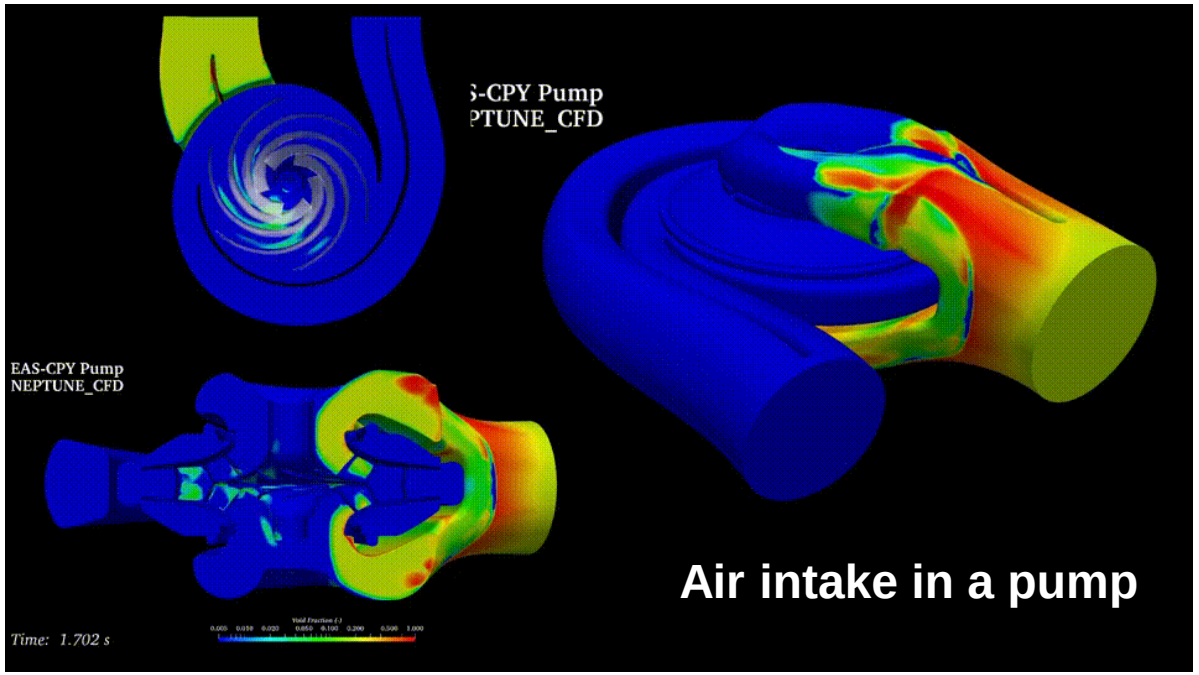
Multi-scale

Probabilistic approaches

Data assimilation

Simulation plat-forms

Environments to develop/run/analyse

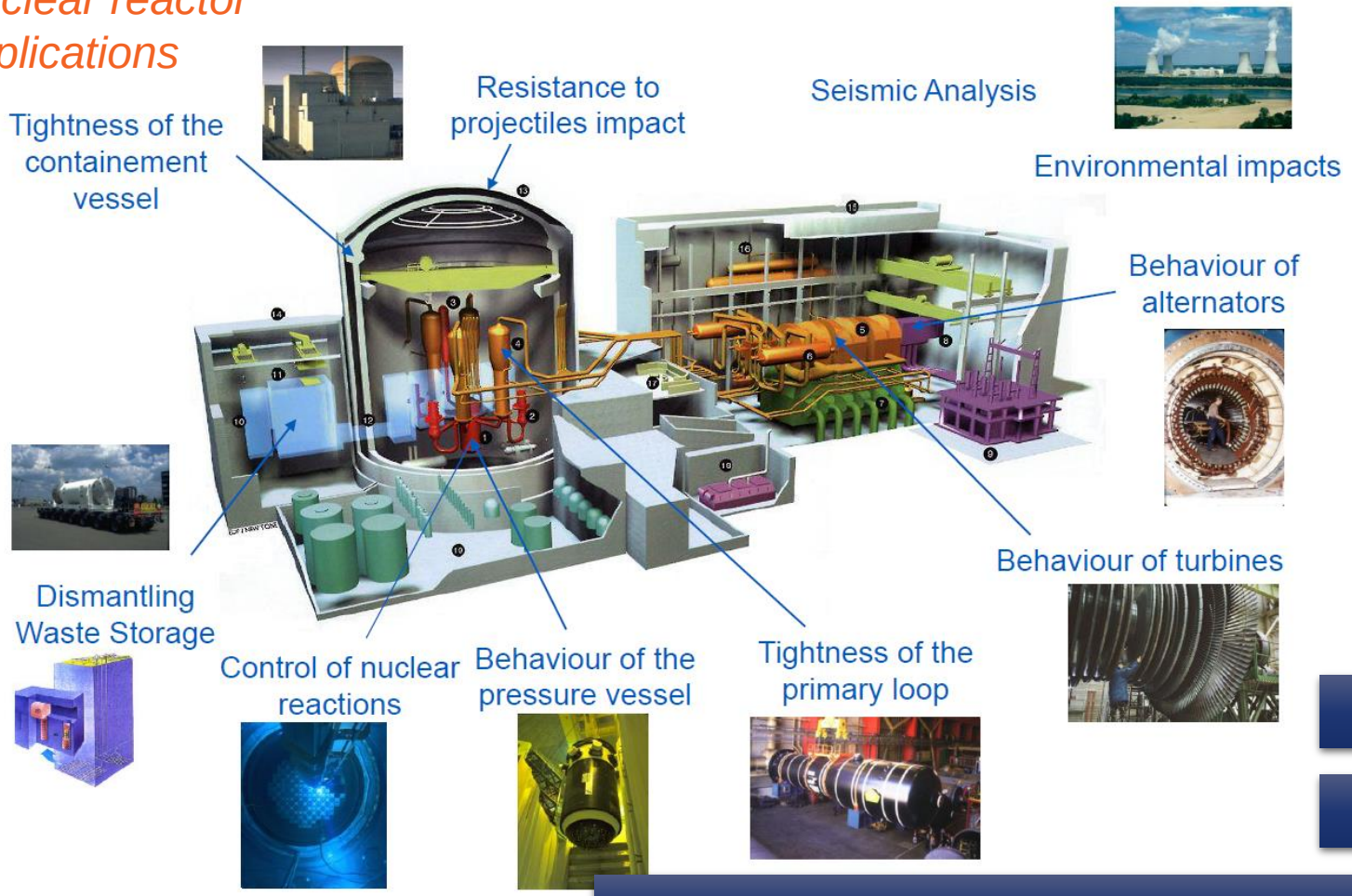


Air intake in a pump

Advanced simulation

A set of skills and tools for various applications

Nuclear reactor applications



- **During the last 30 years EDF R&D and his partners has built a quite comprehensive advanced simulation capacity, based on numerical tolls and methodologies**
- **This asset benefits to all group activities: electricity generation, distribution, services**

OPEN-SOURCE **MULTI-PHYSICS**

HIGH PERFORMANCE COMPUTING

INDUSTRIAL TOOL NEEDED TO BE APPROVED BY SAFETY AUTHORITIES

Physical measurements

No data analysis without data

Different kind of measurements

- For design: geometry, material properties
- For maintenance: actions correctives réalisées
- For process operation: pressure, temperature, flow rates… *online*
- For process monitoring: online or offline
- For control: non destructive control,…

With a lot of recent progress

- Development of scanners
- Development of tomography
- Development of wireless technologies
- Continuous improvement of sensors (representativeness, reliability, lifetime,…)
- Improvement of related tech: communication, storage, data analysis

Towards Digital Twins

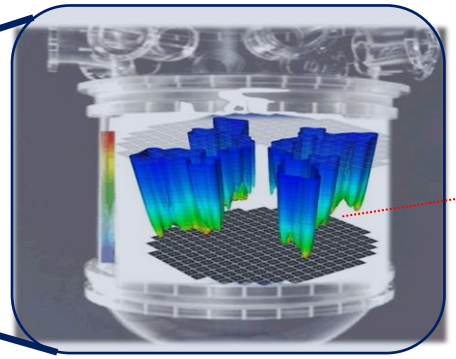
All necessary components are available to build Digital Twins

Real plant

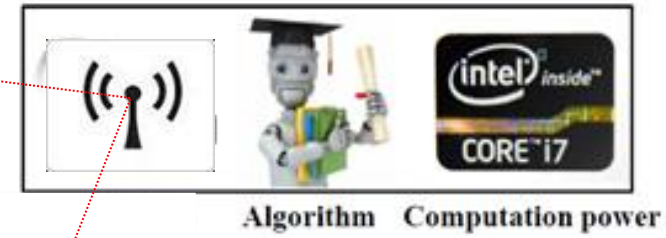
Communication

Sensor

« IoT »



Simulation models



Algorithm Computation power

Data storage and analysis

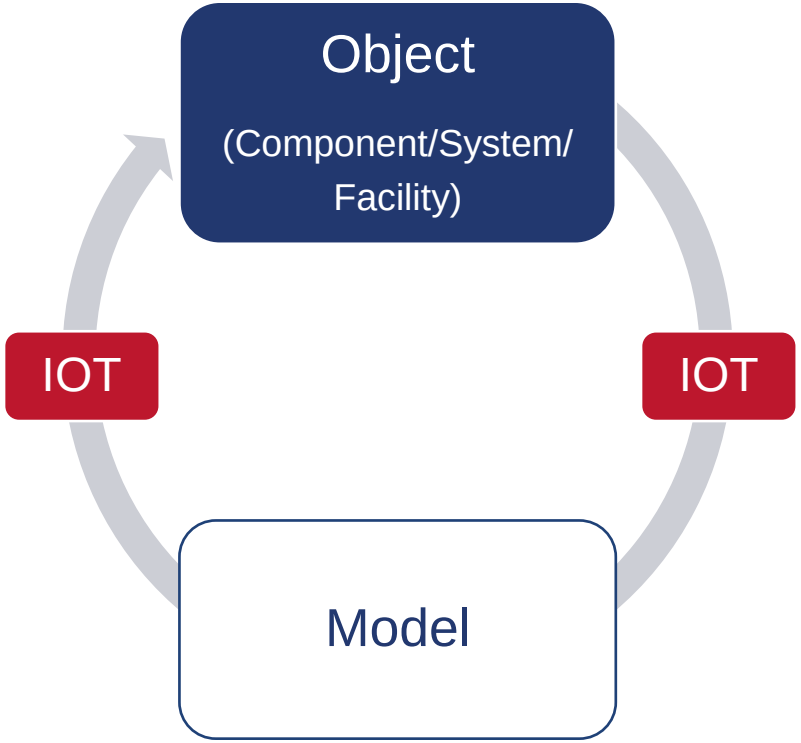
Progress in Data technologies:
- Storage
- Data analytics
- Big Data

What is a Digital Twin ?

No standard definition but a set of common features

The Digital Twin of an industrial component or system (« object ») is a digital image of it, based:

- On a virtual representation relying either on the physics (model centric) or on a data analysis (data centric), or on both
- On a connection with the real object, allowing the twin to be updated with the received data

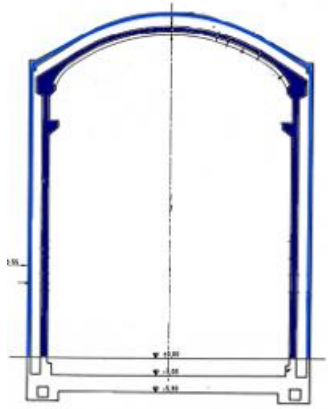


The value raised by a Digital Twin comes from its own features:

- **Individualize** decisions according to *each* object
- **Extend** the observation domain (limited in the real world) to the whole model
- **Forecast** the future object behavior based on an optimal knowledge of its state at each time

Containment building Digital Twin

An example for O&M optimization of nuclear power plants



1300 MW NPP double wall containment

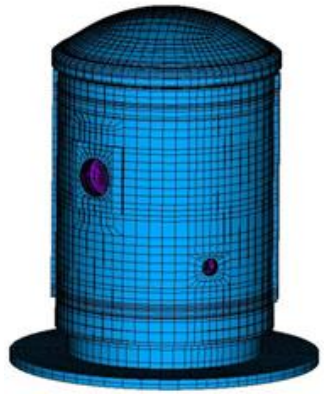
What is at stake ?

- Containment shall respect leakage threshold
  - A test is performed every 10 years to measure containment leakage rate
  - A polymer coating can be placed on the surface of the internal wall to reduce leakage. Nevertheless, this preventive maintenance operation is expensive and should be optimized

$1000\ m^2 \approx 5\ M€ + 15$ working days

=> R&D program to bring an innovative solution

Real Space : VERCORS mock-up



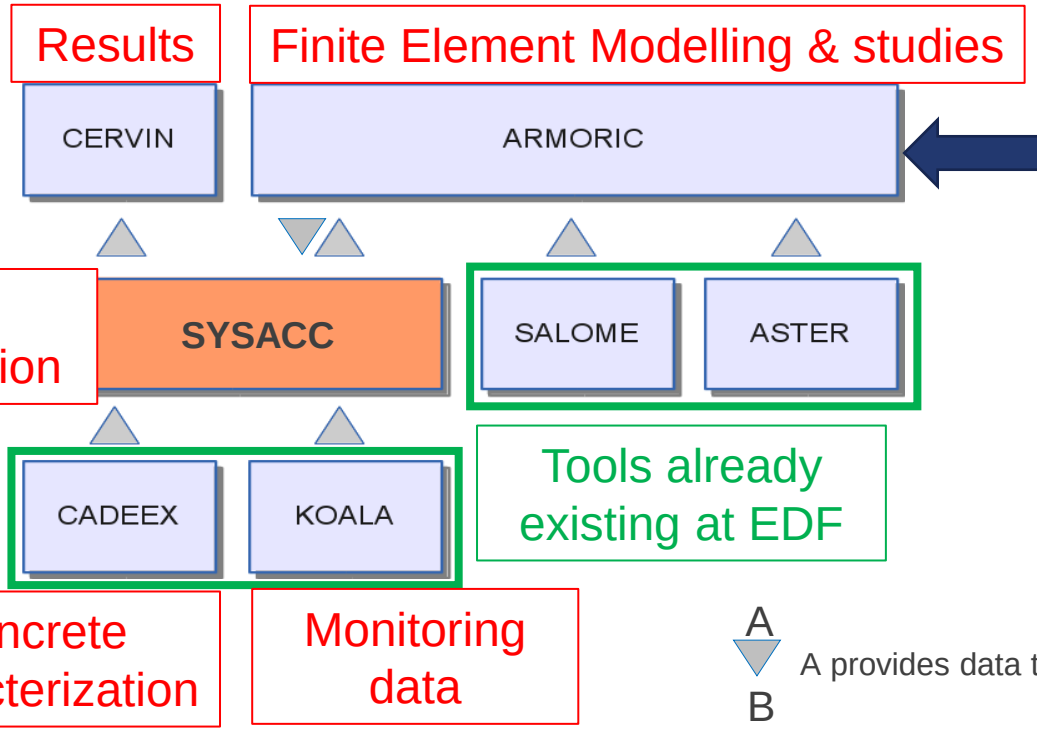
Virtual Space : its Digital Twin

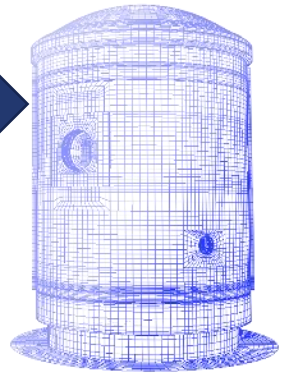
Digital Twin: a software ecosystem around VERCORS

3 specific tools were developed especially for VERCORS :

1) **SYSACC** : requirement for structuring (data models) and keeping the data (database)
2) **ARMORIC** : coherence and capitalization of the studies process
3) **CERVIN** : rapid accessibility to study and test results

Civil engineer

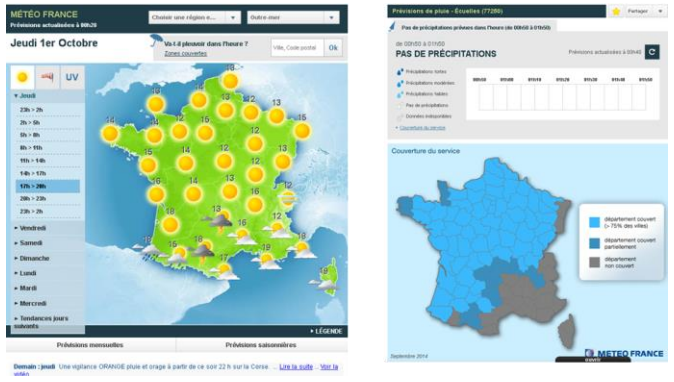


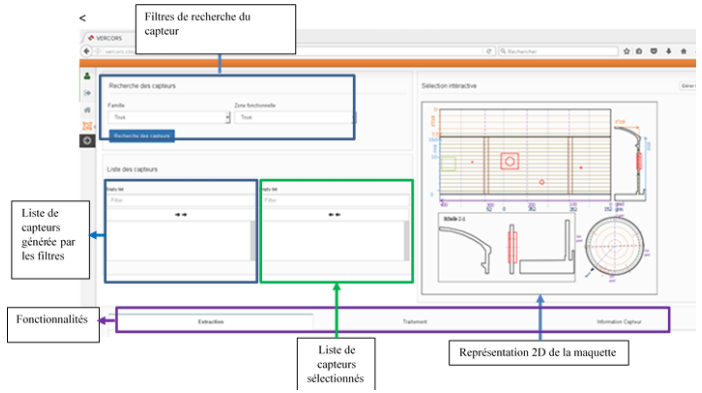


Researcher

An "interoperable" organization built around VERCORS to last until the end of the experiment

Results: forecasting the ageing and predict effect on leaks





- Ageing of VERCORS (Pre-stress, Decennial Tests)
- **Leakage prediction of VERCORS**

Extrapolation to real containement buildings to optimize maintenance works

Concluding remarks

- Digital Twins form a new stage of engineering and analysis tools, to tackle more and more complex systems
- Already successfully used to support different objectives related to design/operation/maintenance/end of life of an industrial “asset”
- A successful example has been shown in the field of maintenance optimization of big components of nuclear plants, others are currently under development
- This raises new scientific, technical and organizational challenges
  - Handling and maintaining the inherent complexity (sensors, communication, data, simulation tools)
  - Beware of multi-purpose digital twin
  - Real time with detailed physical models
  - Capability to “update” the twin in real time
  - Acceptability: users, regulators