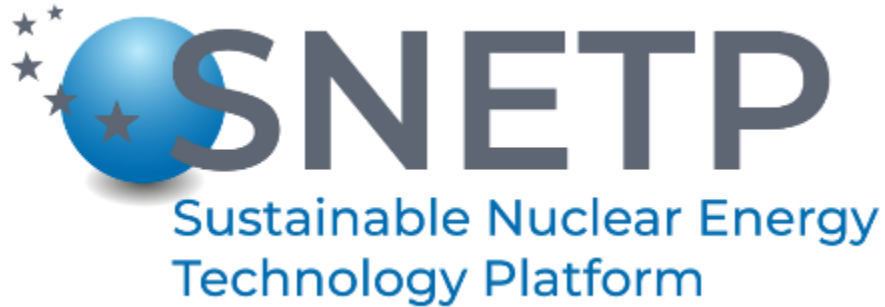




Avec le soutien de



Le pôle de compétitivité du nucléaire civil



# Digital Nuclear Reactor

## *Projet Réacteur Numérique*

*SNETP 2022 – June 2<sup>nd</sup>, 2022 – Lyon (France)*

*Cécile Clarenc-Macé – EDF R&D – Digital Reactor Project - Technical Coordinator and WP4 Leader*



framatome



CORDYS



# Agenda

- ❑ **The project**
- ❑ **Product 1: a platform for studies**
- ❑ **Product 2: a full scale NPP simulator**
- ❑ **« Software as a Service » platform**
- ❑ **First results**



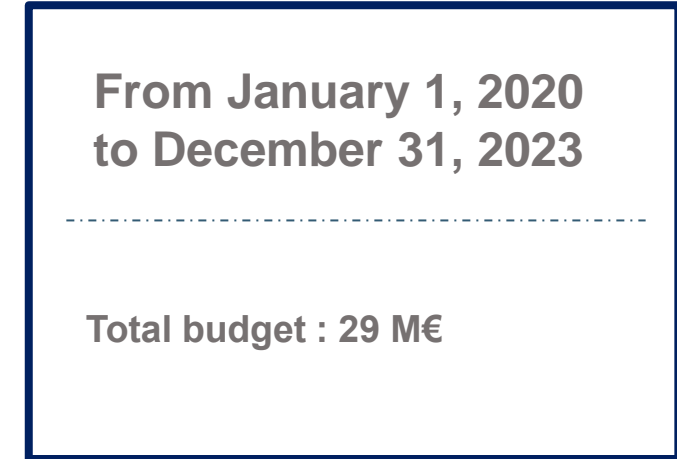
# Digital Nuclear Reactor Initiative

## Partners

## Support

## Clients

## Dates & Budget



*2 Innovative products based on a continuum of models in reactor physics*

### SERVICE PLATFORM FOR STUDIES

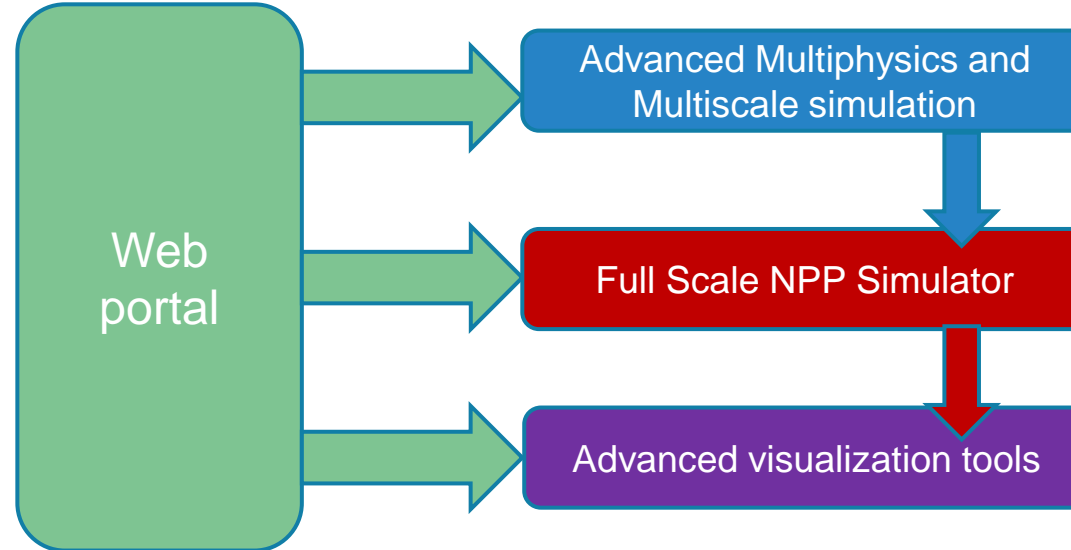
**PROVIDE MULTI-PHYSICAL AND MULTI-SCALE SIMULATION BASED ON COUPLING OF SPECIALIZED CODES TO DEVELOP NEW METHODS AND EXPERTISE**

### TRAINING SIMULATOR

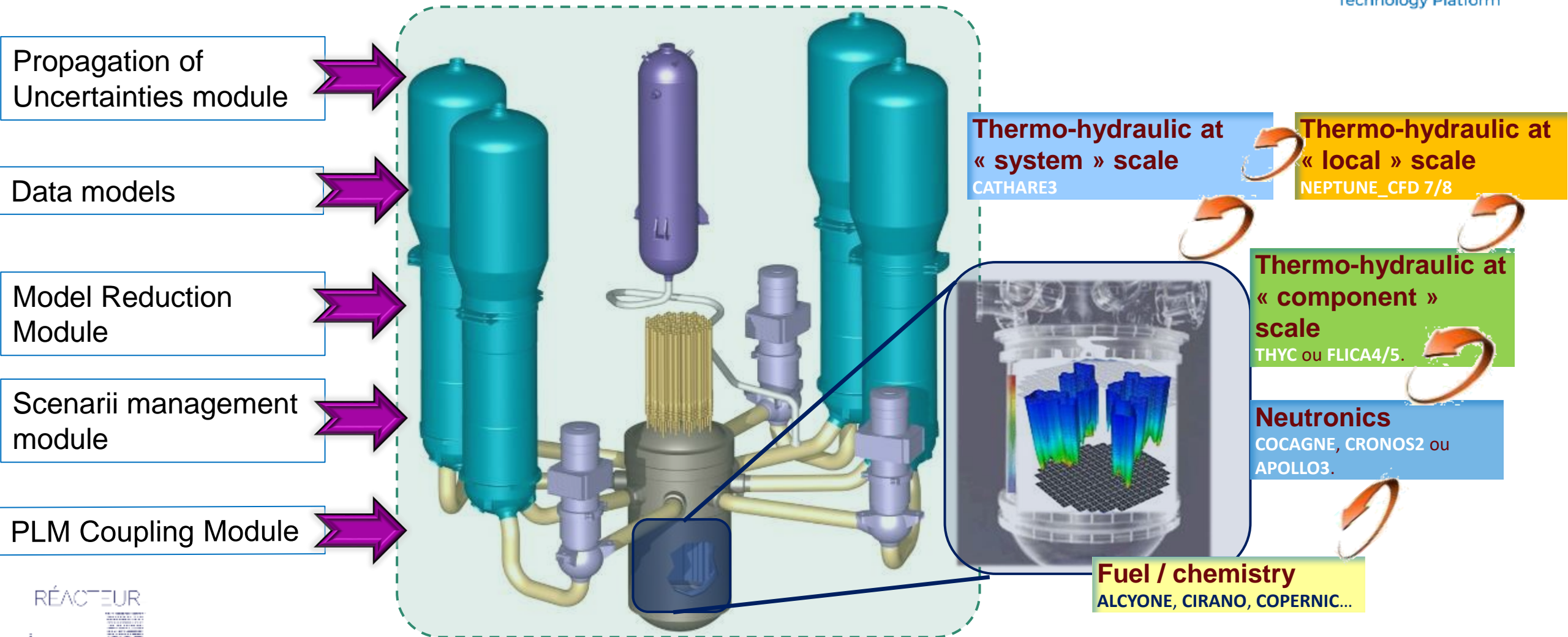
**TRAIN OPERATORS ON A DIGITAL TWIN REPRESENTATIVE OF THE PHYSICAL STATE OF THE NPP AND COUPLED TO PROCESS DATA**

# The digital reactor initiative

- 8 partners involved:
  - CEA, EDF, FRAMATOME, CORYS, ESI Group, AXONE, AFNET-SERVICES, CNRS-CRAN
- Development of the digital twin of a nuclear reactor comprising:
  - A multiphysics and multiscale coupling platform for advanced simulation
  - A full scale simulator
  - Advanced visualization tools
  - A single web portal offering access to all services



# Product 1: platform for studies

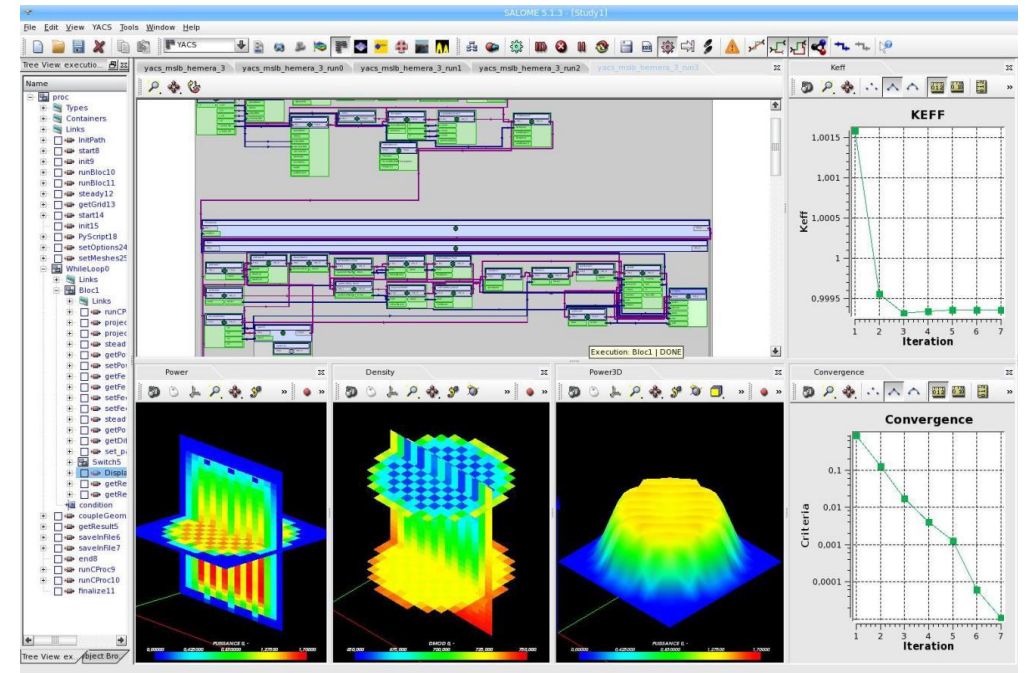
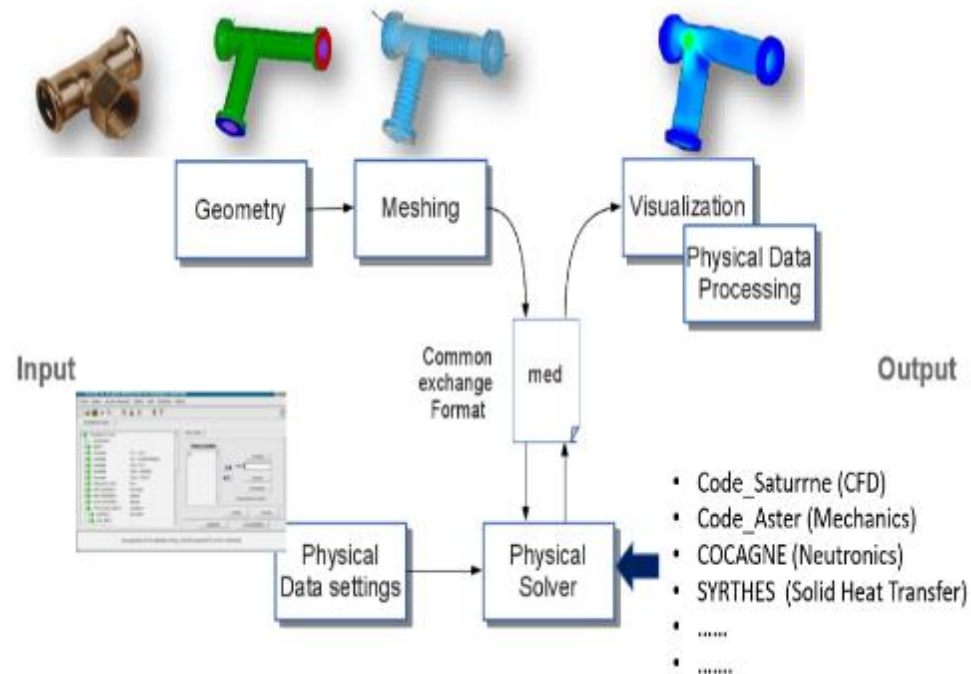




# Multiphysics & Multiscale workbench

**Based on the SALOME open-source numerical platform (EDF/CEA) :**

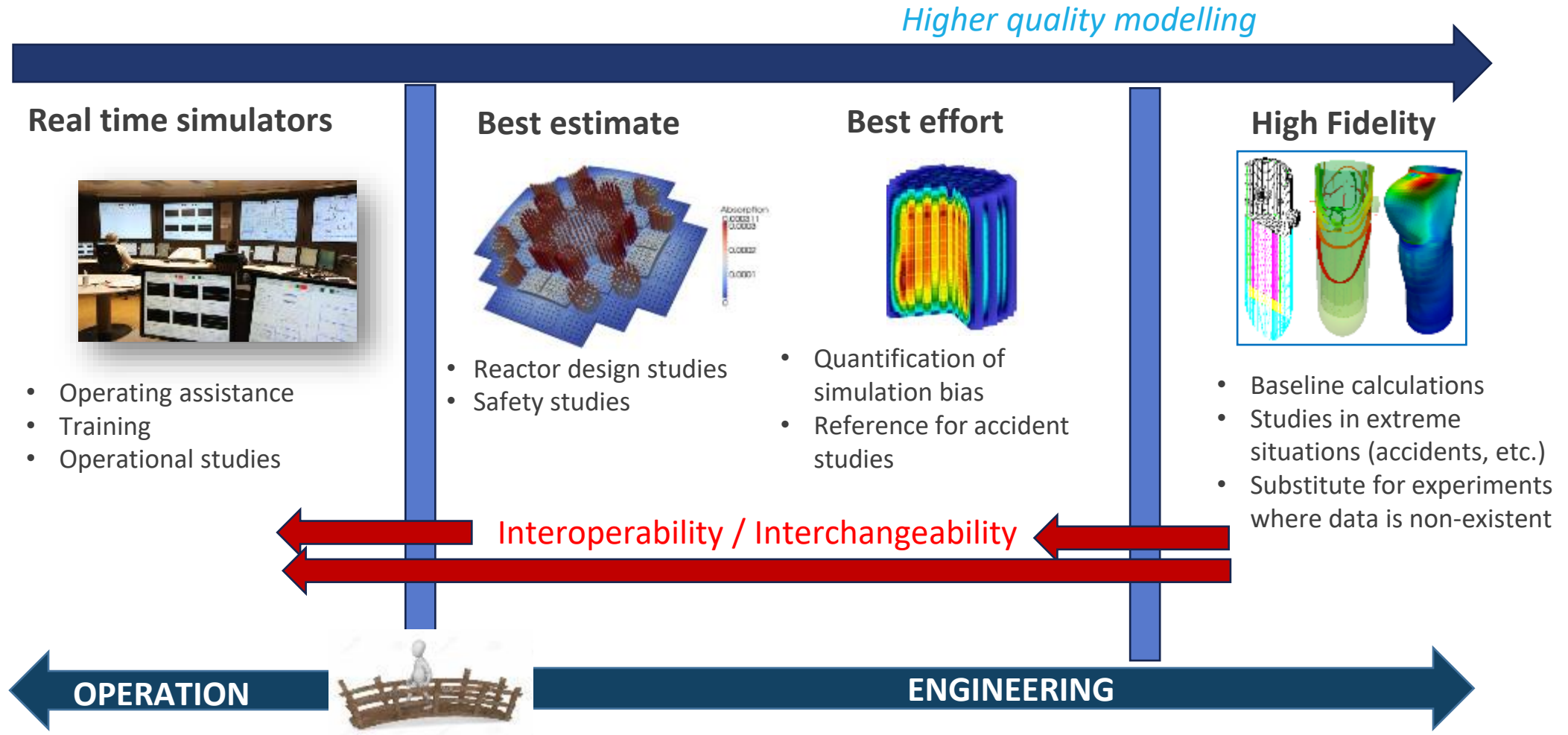
- ❑ Preprocessing tools : CAO modeler, Meshing
- ❑ Proven capabilities of code integration & coupling, including simulation codes approved by French regulator (ASN) as well as external codes
- ❑ Numerous tools : Jobs distribution, parametrical studies, data coupling, mesh interpolation, ...
- ❑ Uncertainties treatment software: OpenTurns, Uranie, GUI Persalys (new!)
- ❑ Advanced postprocessing tools



The diagram illustrates the C3PO architecture, a central platform for reactor simulation. It features a central green box labeled 'C3PO' containing a 'Main REA dataset' and a 'NeutronicDriver' and 'Thermalhydraulics Driver' connected by a circular arrow. Surrounding this central box are several drivers and datasets:

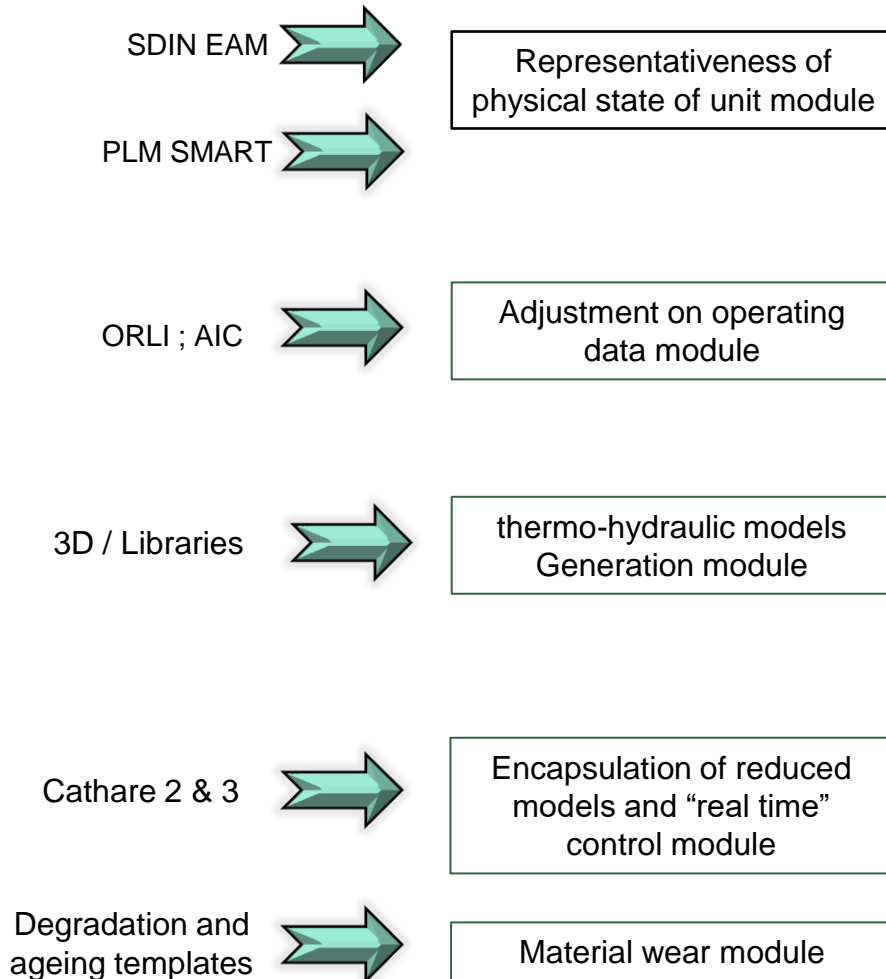
- Top Drivers and Datasets:**
  - Apollo3Driver:** Connected to 'APOLLO3®' (red oval) and 'AP3 generic dataset' (red box).
  - Cronos2Driver:** Connected to 'CRONOS2' (red oval) and 'CR2 generic dataset' (red box).
  - CocagneDriver:** Connected to 'COCAGNE' (red oval) and 'Cocagne generic dataset' (red box).
- Bottom Drivers and Datasets:**
  - Flica4Driver:** Connected to 'FLICA4' (red oval) and 'FL4 generic dataset & prepro' (red box).
  - ThycDriver:** Connected to 'Thyc' (red oval) and 'Thyc generic dataset & prepro' (red box).
  - Cathare3Driver:** Connected to 'CATHARE3' (red oval) and 'CAT3 generic dataset & prepro' (red box).
- Central Drivers:**
  - NeutronicDriver:** Receives input from the top drivers and outputs to the 'Thermalhydraulics Driver'.
  - Thermalhydraulics Driver:** Receives input from the bottom drivers and outputs to the 'NeutronicDriver'.
- Data Flow:**
  - Data in:** A cloud icon labeled 'Data in' feeds into a blue box labeled 'EFICAS' containing 'Technological data', 'Model data', and 'Scenario data'.
  - FactoryBuilder:** Indicated by dashed blue arrows connecting the datasets to the central C3PO box.
  - MEDCoupling:** A box labeled 'MEDCoupling' with the 'SALOME' logo is connected to the 'Thermalhydraulics Driver'.
- Outputs:** A large grey arrow points from the central C3PO box to a grey box labeled 'Outputs' containing:
  - MED Fields:** A 3D visualization of a reactor core.
  - Scalar values:** A line graph showing 'Core Axial Ratio (C3PO)' over 'Time (s)'.

# One ambition: ever more robustness and precision on a wider scope of use





# Product 2: Full Scale NPP Simulator



## OPERATION BENCH

based on SIRENE 1300

## ADVANCED VISUALISATION



Requirements Monitoring  
(STE)

Operator guidance &  
procedure validation

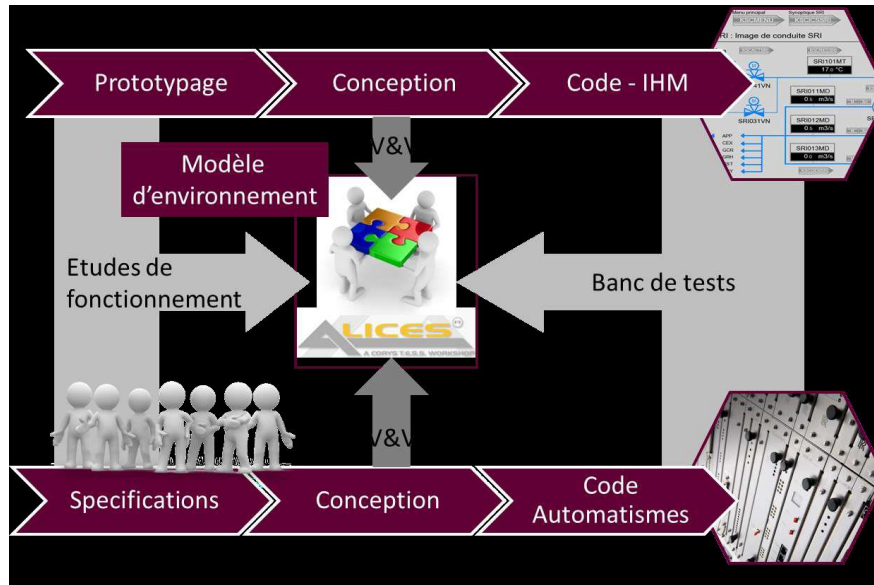
# Full Scale workbench backbone

## Based on ALICES platform (Corys):

- ❑ A digital platform which can use international standards (such as FMI) for a Plug'N'Play model integration
- ❑ A complete set of tools to handle a full-scope simulation of a nuclear reactor
- ❑ Used as backbone of operators' training simulators
- ❑ Used also for design and optimization studies

## Connected to advanced visualization tools based on Unity:

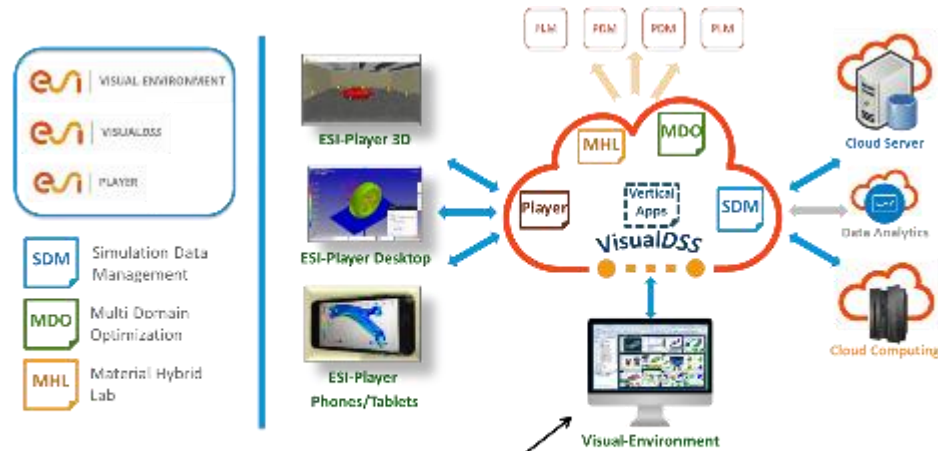
- ❑ Idea: use of metaphors, techniques used a lot in games and movies industries.
- ❑ EDF has some experience in this domain with MINERVE application and plans to upgrade it using up-to-date technology.



## Project aims' for both training and engineering:

- ❑ Ease the update of simulator's configuration along with maintenance operations
- ❑ « digital twin »: Simulator is mirroring the actual NPP state using data assimilation
- ❑ Include ageing modeling
- ❑ Include smart functions like « operation rules monitoring »

# SaaS Platform for end-users

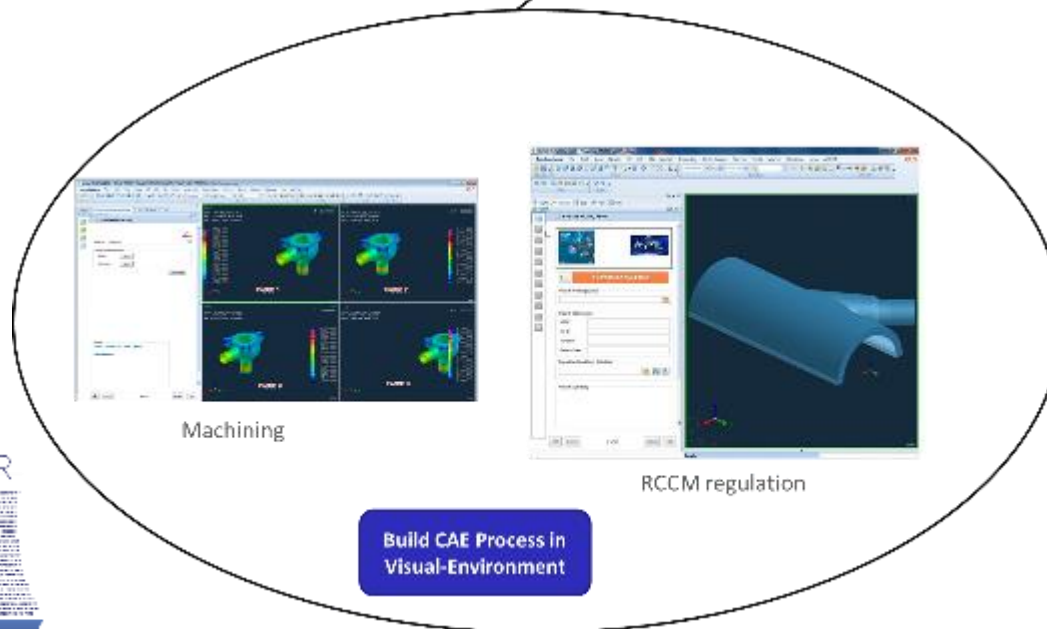


## Based on Visual DSS platform (ESI Group):

- ❑ Multi-Domain Computer Model Management
- ❑ CAE Process Automation
- ❑ Project Workflow Management
- ❑ Simulation Content Management
- ❑ Systems Integration Framework
- ❑ Reporting and Decision Support

## Project aims' for this platform:

- ❑ Allow personalization with new simulation workflows
- ❑ Ease the access to various simulation software
- ❑ Unify entry data collection

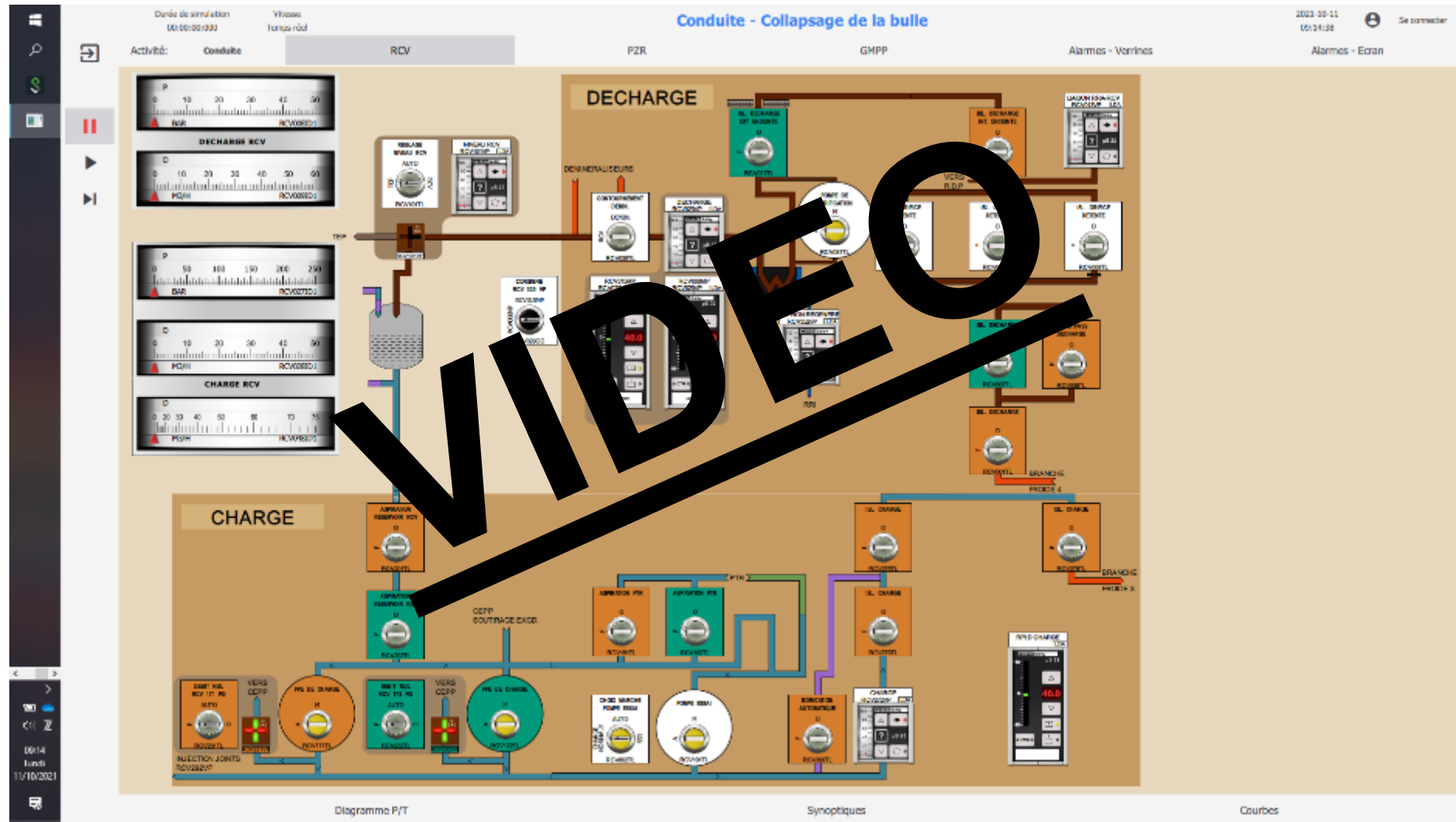


# First results : demonstrators

- ☐ Platform for studies:
  - ☐ Two use cases in progress: Rod Ejection Accident and Islanding
  - ☐ Interchangeability and physical couplings work well 😊
- ☐ Full scale simulator:
  - ☐ Training prototype available for « Pressurizer steam bubble collapse » (see video)
  - ☐ Very good feedback from operators 😊
  - ☐ Work in progress on: model reduction, wedging with operational data,...
- ☐ SaaS platform:
  - ☐ First « PoC » available for parametric studies (using Salomé and code\_saturne) 😊
  - ☐ Next steps: connect to Visual DSS
    - ☐ The training prototype
    - ☐ Then the platform for studies
    - ☐ And provide access to Salomé platform

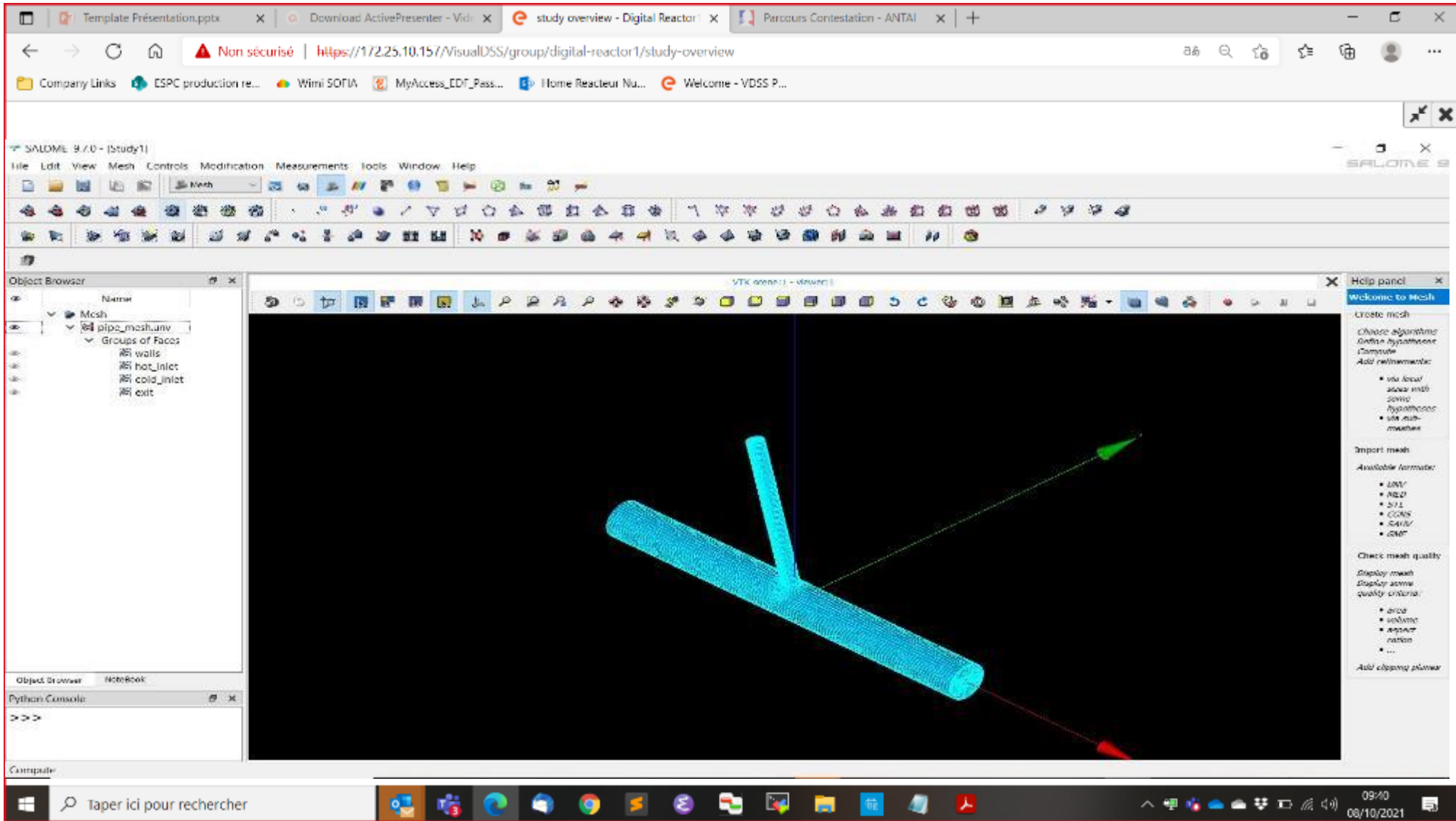


# Full Scale Simulator : training prototype

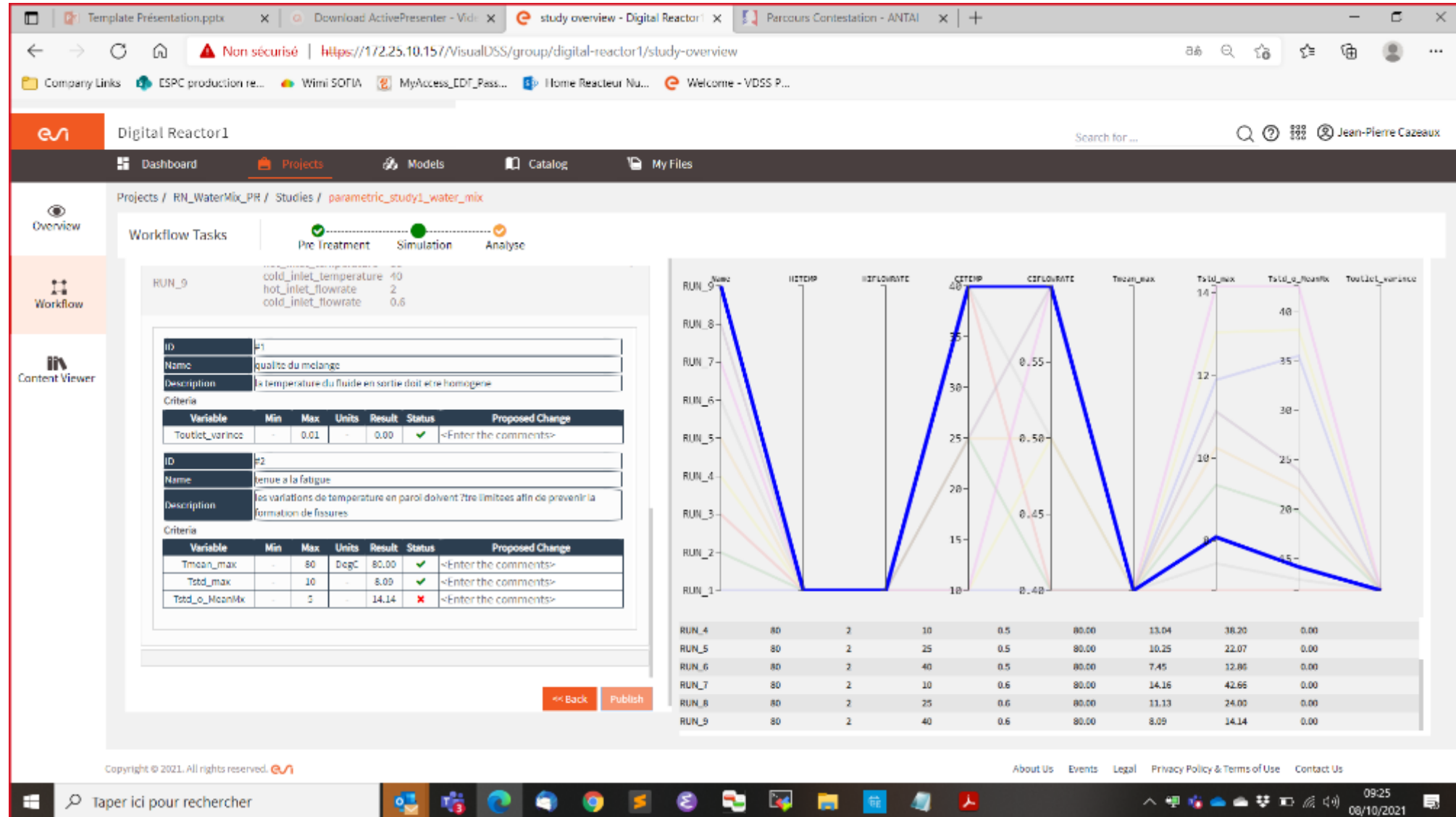




# SaaS platform : simulation study using Salome



# SaaS Platform : parametric study





*Thank you for your attention*