HPC SIMULATION AT EDF ENABLING ENERGY CHALLENGES

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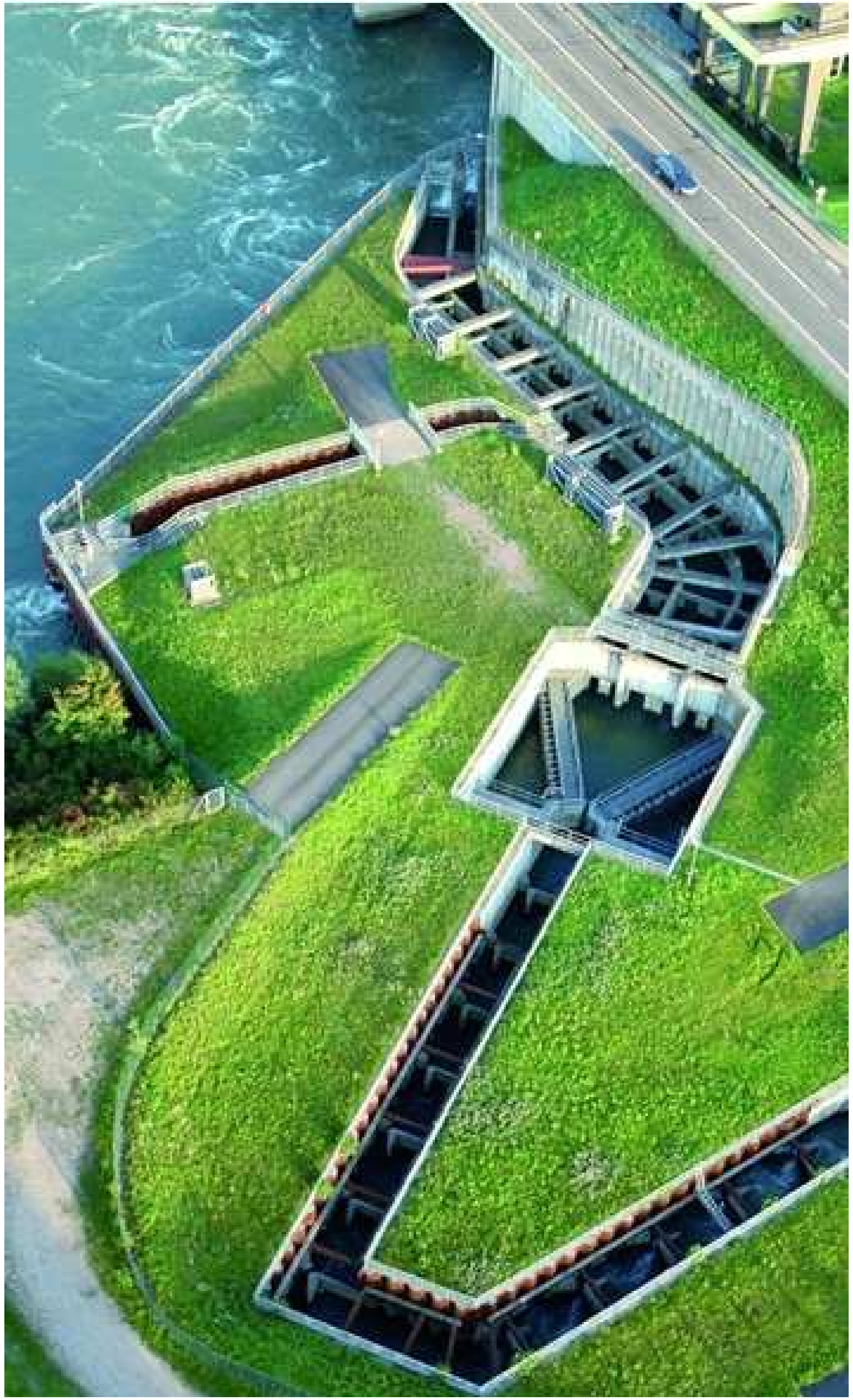


GROUP PRESENTATION
EDF 2014

1

ABOUT US

A global leader in electricity

- Covering the entire business chain:
- generation (from nuclear to renewables)
- networks, sales & marketing, trading
- Expanding in the gas chain, trading and energy services

An international group

- rooted in Europe and committed for the long term
- to partnerships and cooperation agreements
- in high-growth countries

A responsible group

- A Code of Ethics for the entire group
- 11 commitments as a responsible industrial firm, employer and partner

—
1

A GLOBAL LEADER IN ELECTRICITY

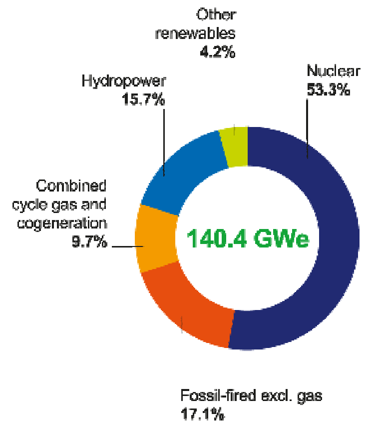
€75.6
billion in sales

39.1
million customers

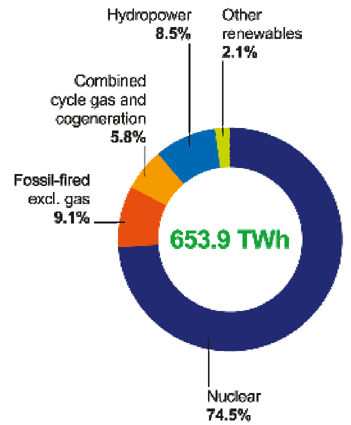
158,467
employees worldwide

85.1%
generation without CO_2

INSTALLED CAPACITY



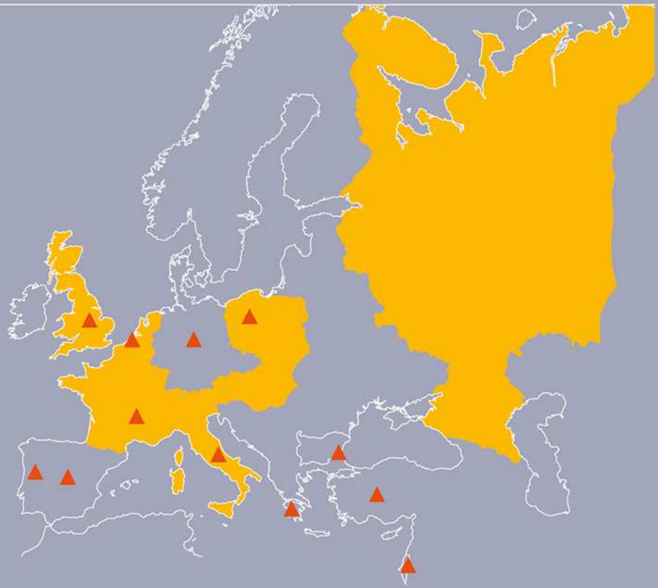
GENERATION



THE EDF GROUP AROUND THE WORLD

(CONSOLIDATED DATA AT 31 DECEMBER 2013)

EUROPE



FRANCE
- 100% — EDF ERDF RTE[1] PEI
- 67% — DALKIA INVESTISSEMENT[2]
- 88.64% — ÉLECTRICITÉ DE STRASBOURG
- 51% — TIRU
- 65% — DUNKERQUE LNG

AUSTRIA
- 25% — ESTAG

BELGIUM
- 63.53% — EDF LUMINUS

HUNGARY
- 100% — EDF DEMASZ
- 95.62% — BE ZRT

ITALY
- 97.4% — EDISON
- 100% — FENICE

NETHERLANDS
- 50% — SLOE CENTRALE HOLDING BV

POLAND
- 99.87% — EDF WYBRZEZE
- 96.51% — EDF POLSKA
- 96.93% — EDF PALIWA
- 49.38% — KOGENERACJA
- 48.59% — ZIELONA GORA

UNITED KINGDOM
- 100% — EDF ENERGY
- 100% — EDF TRADING

RUSSIA
- 100% — FENICE RUS
- 100% — EDF NETWORKS INTERNATIONAL
- 100% — ERDF VOSTOK

SWITZERLAND
- 25% — ALPIQ[1]

ASIA

CHINA
- 100% — FIGLEC
- 35% — DATANG SANMENXIA POWER GENERATION COMPANY[1]
- 30% — TAISHAN NUCLEAR POWER JOINT VENTURE COMPANY[1]
- 19.6% — SHANDONG ZHONGHUA POWER COMPANY[1]

LAOS
- 40% — NAM THEUN 2 POWER COMPANY[1]

VIETNAM
- 56.25% — MECO

NORTH AMERICA

UNITED STATES
- 49.99% — CONSTELLATION ENERGY NUCLEAR GROUP
- 100% — EDF TRADING NORTH AMERICA

SOUTH AMERICA

BRAZIL
- 90% — EDF NORTE FLUMINENSE[1]

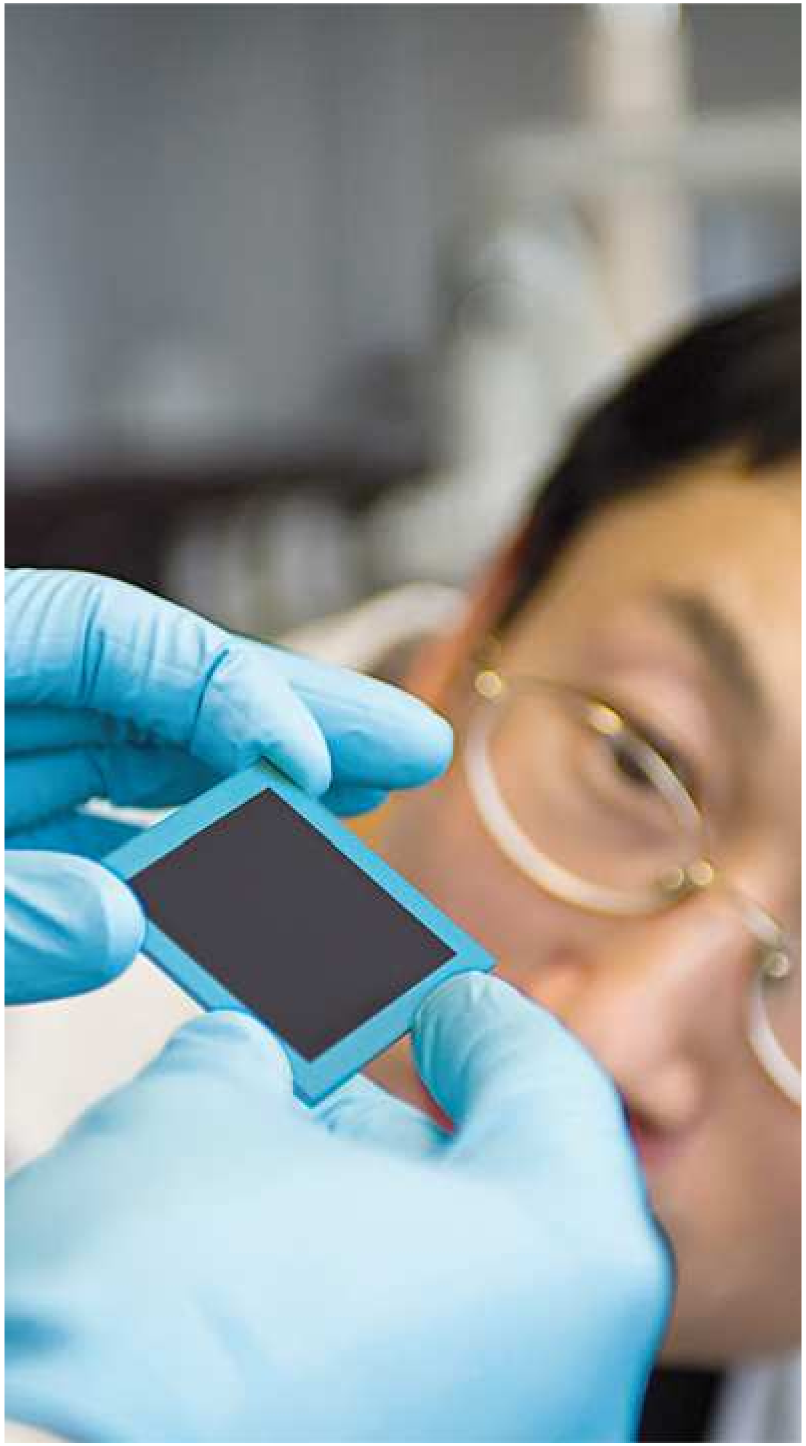
100% — EDF ÉNERGIES NOUVELLES

▲ Presence around the world

(1) Accounted for by the equity method. (2) Under the agreement signed on 25 March 2014 with Veolia Environnement, EDF will take over Dalkia's business activities in France and Veolia will take over Dalkia's international operations, subject to approval by the competent competition authorities.

RESEARCH & DEVELOPMENT

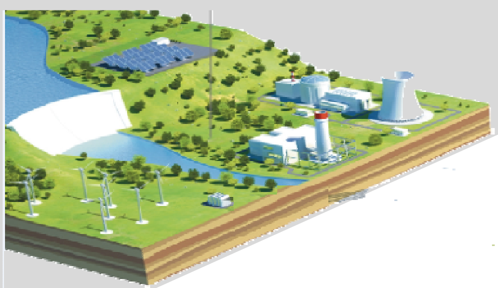
PERFORMANCE
INNOVATION
ENVIRONMENT



PRIORITIES FOR INNOVATING IN ELECTRICITY

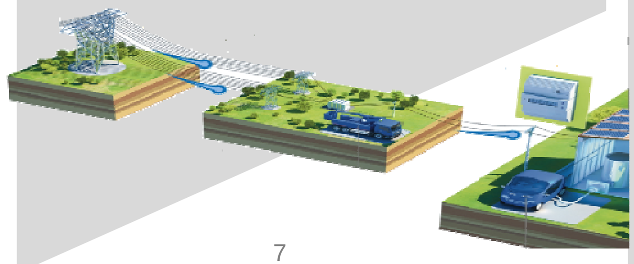
To consolidate and develop a competitive and low-carbon production mix

- To consolidate the group's nuclear asset and prepare its future
- To contribute to the success of renewable energy projects and prepare tomorrow's technologies
- To control and anticipate environmental impacts



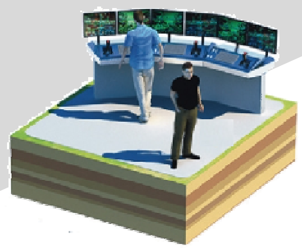
To prepare the electrical systems of tomorrow

- To optimize the lifespan of network infrastructures
- To contribute to the success of smart meter projects
- To develop the advanced management tools of electrical systems
- To anticipate the increase in the intermittent production connected to the network
- To design territorial energy solutions and integrate them into the global system



To develop and try out new energy services for customers

- To improve knowledge of customers starting from data to create new offers
- To promote new electricity uses
- To develop the services of energy efficiency
- To develop offers for cities and territories



R&D: KEY FIGURES

2 100 employees
including :
370 PhD
150 PhD students
200 researchers teaching at universities and advanced engineering schools

More than 553 million
budget in 2014

70 % activity to support performance of Group businesses

30 % activity to anticipate and prepare for the future

15 departments
(expertise, partnerships and project management)

14 joint research laboratories

Partnering with 6 venture capital funds
in the field of clean technologies

10 international Centres
including

3 France

7 Germany, United Kingdom, Poland, China, Italy, USA, Singapour

R&D PARTNERS

A co-development and expertise sharing approach

- International academic support
- Major international partners
- Common Laboratories & Institutes
- National research organisms

AMERICA

CANADA

Hydro Québec

UNITED STATES

MIT – Massachusetts Institute of Technology, EPRI – Electric Power Research Institute, Columbia University

BRAZIL

Eletrobras Cepel

OHTERS TYPES OF COLLABORATIVE RESEARCH

- **European projects**
- **KIC** (Knowledge and Innovation Communities) : Climate, Inno Energy
- **European Industrial Associations :** Nugénia, EASE, E2BA, SEDC, ETI
- **European Technology Platforms & European Industrial Initiatives :** CO2 emission, Smart Grids, Nuclear, Industrial Safety, Construction, Wind
- **Energy European Research Alliance**

EUROPE

JRC – European Commission

GERMANY

KIT, Fraunhofer

ITALY

Milano, Alma Mater Studiorum Università di Bologna Campus di Forlì

POLAND

Consortium d'Universités Polonaises

SWITZERLAND

École Polytechnique Fédérale de Lausanne

NORWAY

SINTEF

FRANCE

ANDRA, CEA, Ifremer, INRIA, Irstea, CNRS, IRSN, CSTB, ParisTech, ONEMA, Dauphine, Schneider Electric, INERIS, INSA, Total, Supélec, ENS, HORIBA

UNITED-KINGDOM

Imperial College London, The University of Edinburgh, Manchester 1824, University of Bristol, Energy Technologies Institute, EPSRC, UCL, University of Strathclyde Glasgow, University of Oxford

ASIA

CHINA

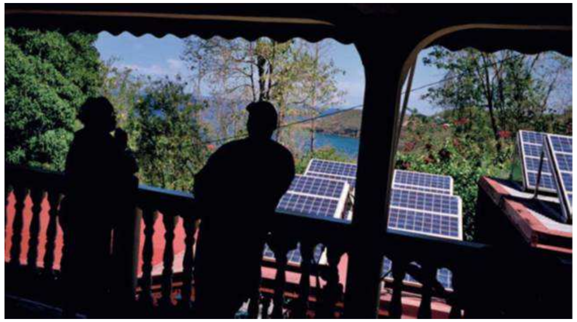
Tsinghua University, 国家电网 State Grid, 中国电力科学研究院, Institute of Electrical Engineering, Chinese Academy of Sciences

JAPON

IEPCO, TEPCO, CRIEPI, The Kansai Electric Power Co., Inc.

eDF

EDF : A leading french player in the energy market, active in **all areas** of electricity from **generation** to **trading** and **network management.**



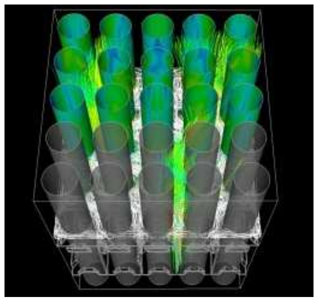
Some contextual elements :

- Plants operated over 40 – 100 years
  - guarantee safety, minimize environmental footprint
  - maintain assets

Figure 2 : Emprise et bathymétrie du modèle 3D.

- Fast changing operating conditions
  - more competitive markets,
  - tougher regulations, ageing, environment

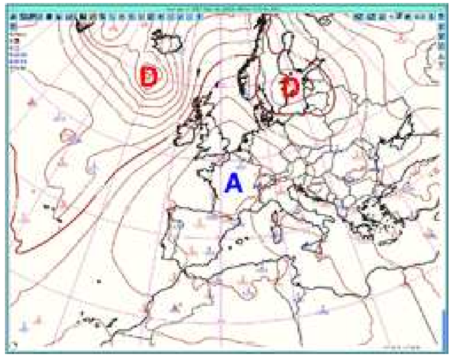
- New business models and services
  - Smart meter
  - Cloud computing
  - Open Data



WHAT DO WE DO WITH HPC ?
INTENSIVE NUMERICAL SIMULATION

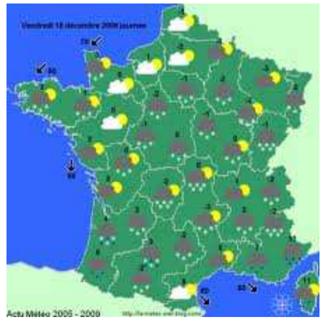
Because :

- An experimental mock up is not always easy/feasable (technical problems, metrology difficulties, scale effect, hight cost)
- We cannot measure everything we want/need



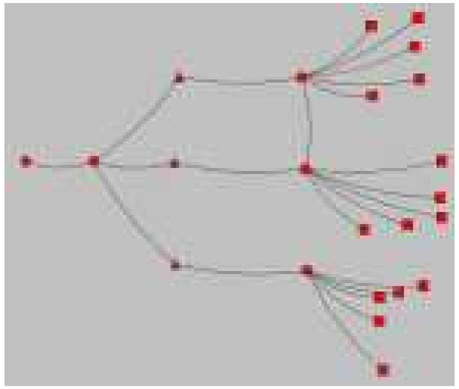
One returns to the laws and parameters for :

- Modelize
- (Numerically) Simulate
- Compute
- Analyse



But do not forget : Numerical simulation and experimental simulation are complementary

HPC ENABLES US ….



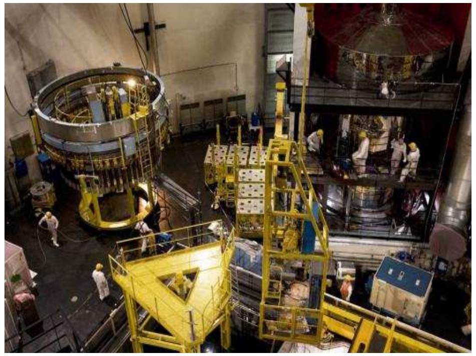
To simulate and then to understand

..to have a better understanding of system's complexity in order

- To comply to new regulations
- To find optimization opportunities

To simulate and then to decide

..to obtain more predictive, more reliable & more trusted simulations of complex real systems in order



- To find new margins
- To help for decision making & business value

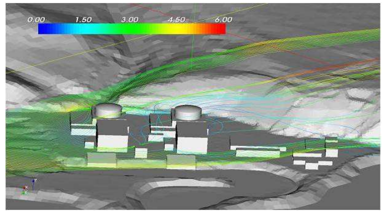
To simulate and then to innovate

..to get more and more refined information in order

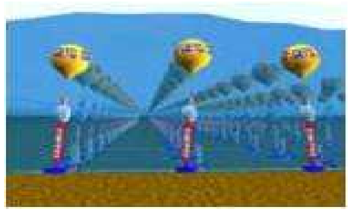
- To open up new areas, new products and services
- To improve methods and methodologies (studies)
- To improve our in-house tools (most of them are Open-Source) : numerical methods, algorithms, models

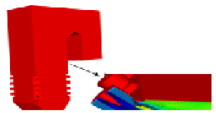
MAIN DOMAINS OF HPC APPLICATIONS (1/2)

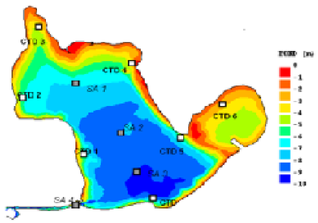
ENERGY PRODUCTION



- Nuclear
  - lifespan of power plants
  - Safety studies
  - Fuel management
- Hydraulics
  - Behavior of engineering structures
  - Optimisation of operations
  - Sediment transport
- Thermal
  - Environmental performance
  - Modelisation of combustion
- Renewable
  - Wind power potential (InShore, Offshore)
  - Photovoltaic process
- Environment
  - Quality of water
  - Qualité of air
  - Natural risks management

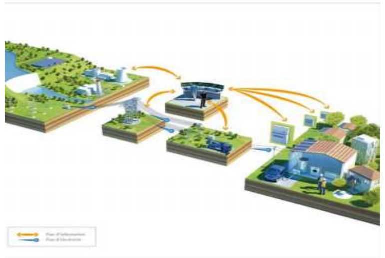


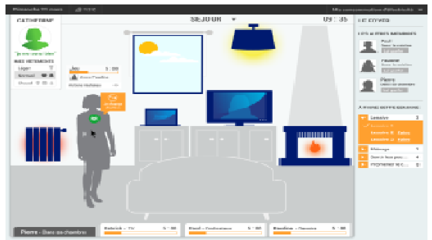




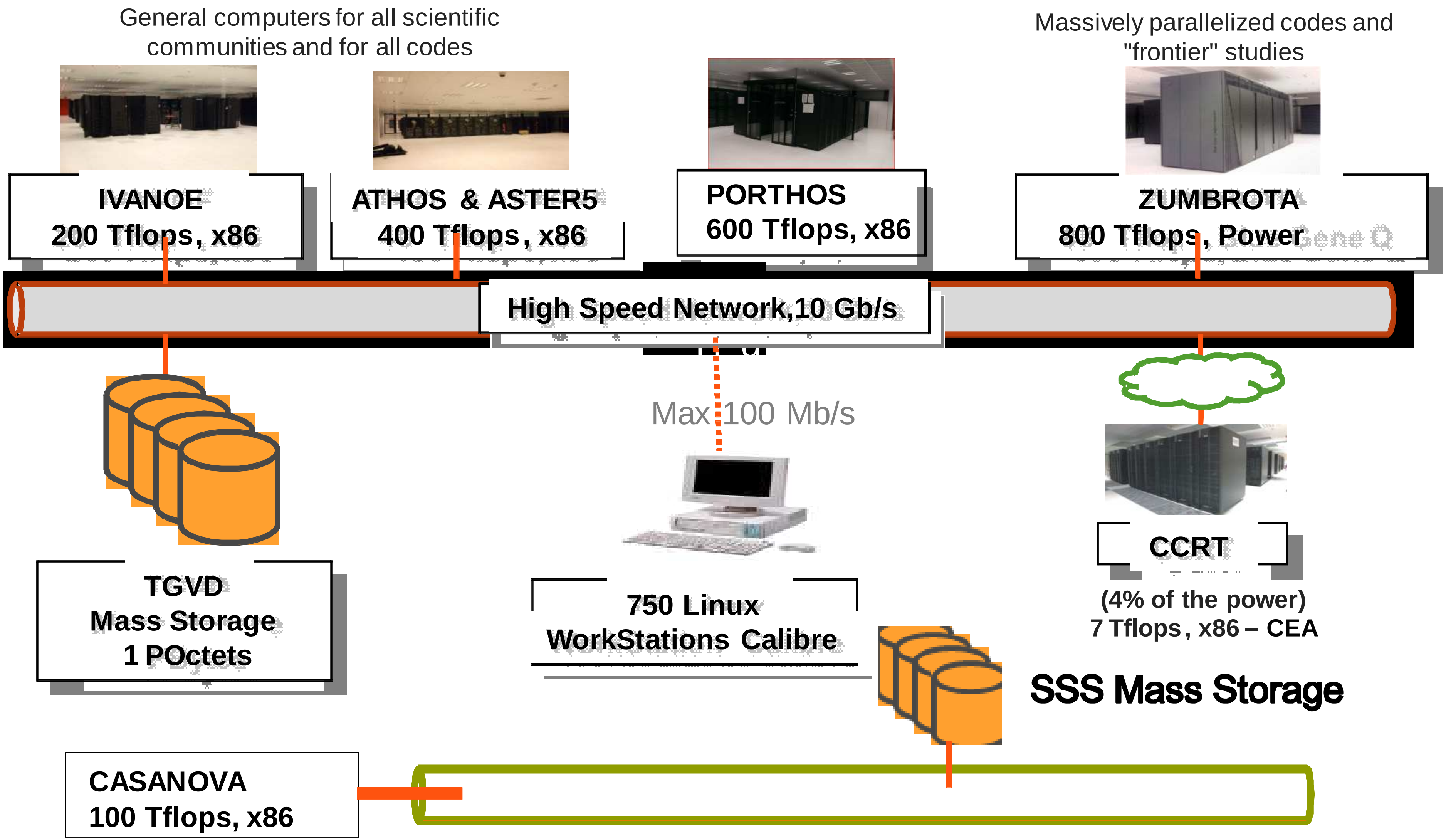
MAIN DOMAINS OF HPC APPLICATIONS (2/2)

- Network / Smarties
  - Smart Grids : Impact of distributed and intermittent power generation on our networks
  - Smart-Cities : Optimization of power ressources, water, waste, ...
- Marketing
  - Knowledge of the load curve
  - Custumer behavior simulation
  - Analysis of customer data
- Energy Management
  - Generation / consumption balance
    - Weekly forecast
  - European Electrical System for 2020, 2030
  - Weather and climate forecast adjustments



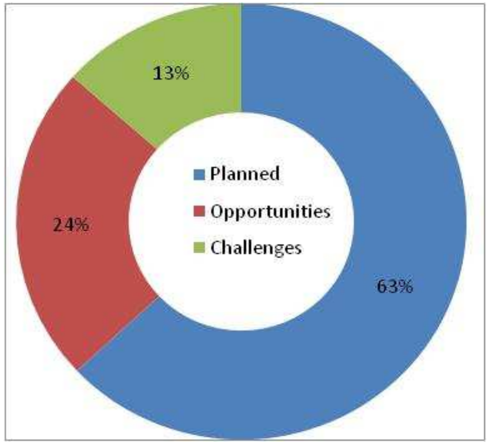


EDF COMPUTING FACITITIES



A MATURITY MODEL FOR HPC USE AT EDF-R&D

EDF R&D Road Map is based on different forecasts of usage of HPC :



Planned usages : simulation for daily studies

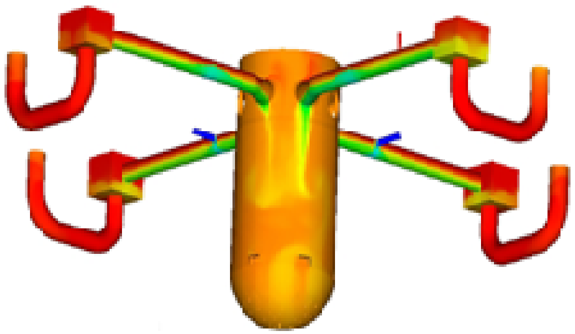
- Projects have already secure the use of HPC. **HPC is required as a necessary step** of the project.
  - Ex: Safety studies, process qualification of non destructive control Contrôle
  - Ex : CFD : 50 Millions cells calculation for a mixing grid of a fuel assembly

Opportunities : simulation to prepare for tomorrow

- HPC is part of the experimental framework of the project, **and HPC is contributing to short term or middle terms benefits**
  - Ex: Microscopic scale simulation of materials
  - Ex : CFD- 1 Billion cells calculation for a whole fuel assembly

Challenges: Simulation to explore new frontiers

- **HPC is part of a scientific research** and should contribute to make major breakthroughs
  - -Ex : CFD- 100 Billion cells calculation of a PWR reactor



HPC timeline – Capability (peak) examples

2003 — **2006** — **2007** — **2013** — **2018**

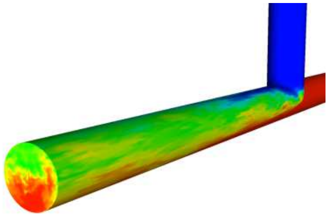
2003

Consecutive to the Civaux thermal fatigue event

Computations enable to better understand the wall thermal loading in an injection.

Knowing the root causes of the event ⇒ define a new design to avoid this problem.

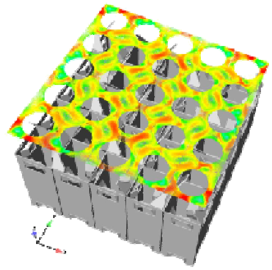
2006



Computation with an L.E.S. approach for turbulent modelling

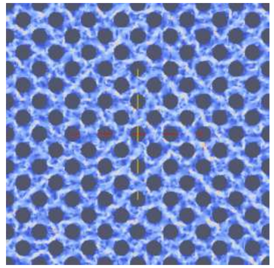
Refined mesh near the wall.

2007



Part of a fuel assembly
5x5 grid experimental mock-up

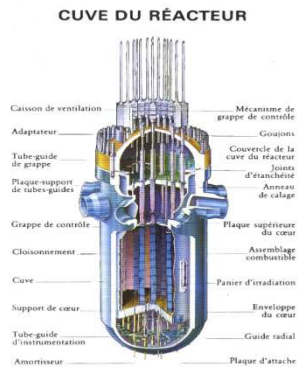
2013



LES of tube bundle

2018

Complete reactor vessel



Computations with smaller and smaller scales in larger and larger geometries
⇒ a better understanding of physical phenomena ⇒ a more effective help for decision making

10^6 cells	10^7 cells	10^8 cells	3.10^9 cells	5.10^{10} cells
1 of 4 vector processors 2 month length computation	400 processors 9 days	8 000 processors # 1 month	4 000 cores # short test (< 1day)	60 000 cores # 1 month
# 1 Gb of storage 2 Gb of memory	# 15 Gb of storage 25 Gb of memory	# 200 Gb of storage 250 Gb of memory	# 5 Tb of storage 3 Tb of memory	# 100 Tb of storage 60 Tb of memory
Power of the computer	Pre-processing not parallelized Power of the computer	Pre-processing not parallelized Mesh generation	*Mostly resolved* … ibid. … Scalability / Solver	*resolved* … ibid. … … ibid. … Visualisation

eDF

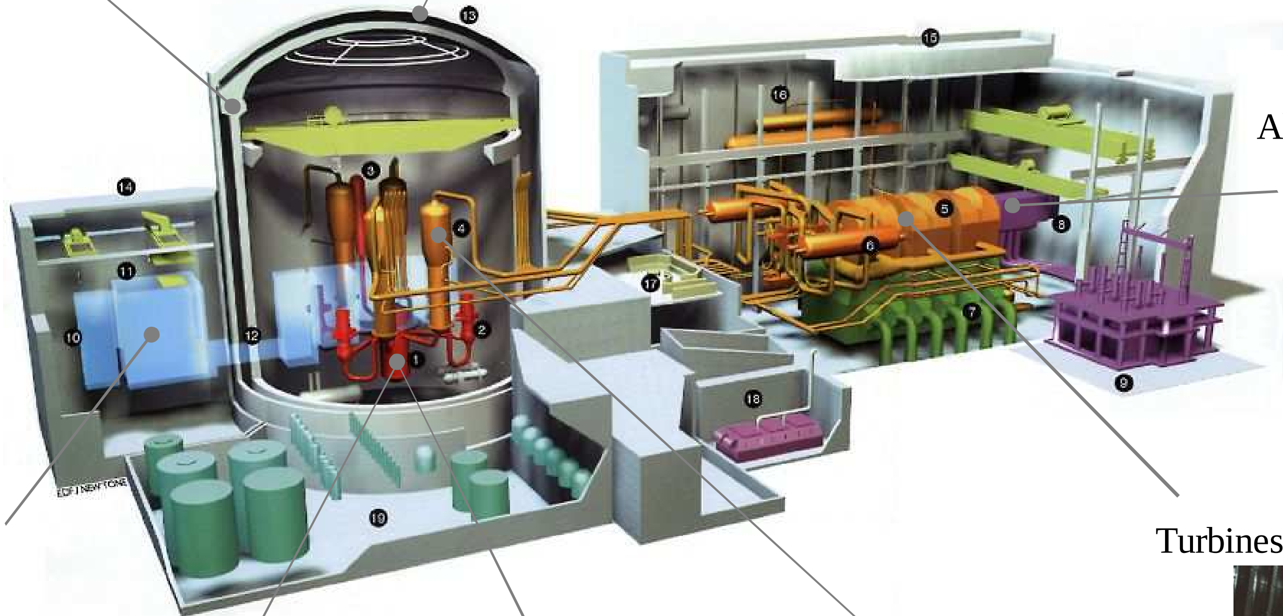
EXAMPLES OF HPC SIMULATIONS

Nuclear power : a safety exploitation

Containment
building tightness

Impact resistance

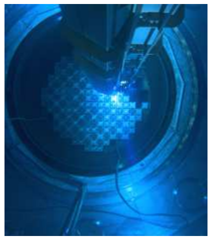
Sismic analysis



Alternators behavior

Dismantling
Storage

Core reactions control



Vessel integrity

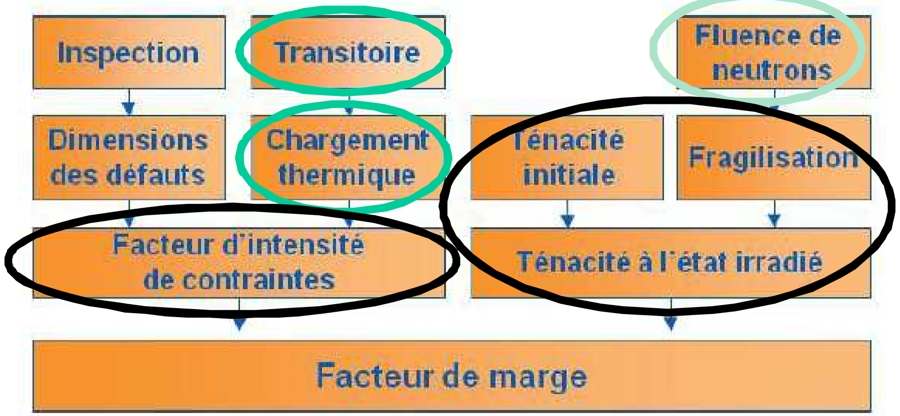
Primary circuit
waterprofness

Turbines behavior

PWR vessel life-time (1/2)

Extending the life of PWR power plants is conditioned by a good behavior of the vessel in service

<u>Issue</u>:Improve the quantification of margins demonstrating the strength of the vessel despite the aging steel embrittlement under irradiation

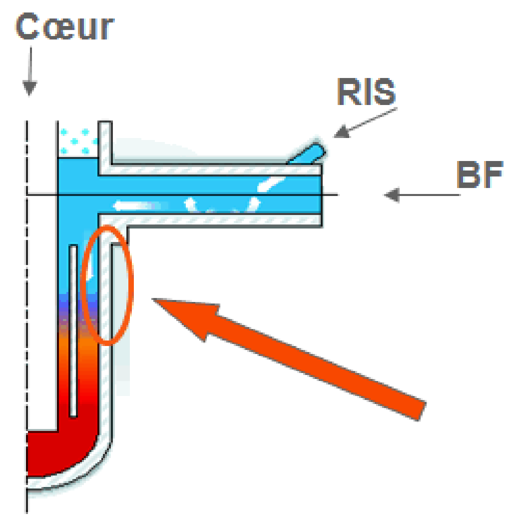


EDF justification Methodology and position of thermal-hydraulic

Thermal-hydraulics neutronics Mechanics Materials

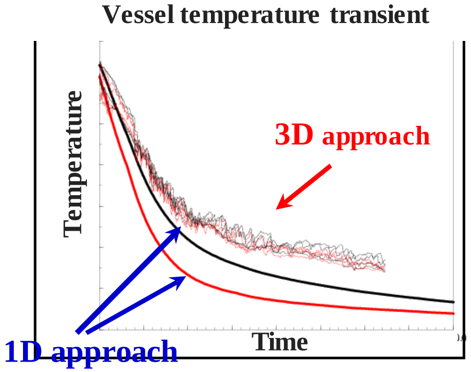
- **Contribution of thermal-hydraulic actions**
  1. Justifications for safety Authorities
  2. **Advanced physical modelisations** in order to reach a better evaluation of the margins

- **Declined by 4 lines of work**
  1. **Experimental Measurements** using HYBISCUS II facility
  2. **CFD codes validation** (*Code_Saturne*, NEPTUNE_CFD)
  3. « Expertise » computations in **real reactor configuration**
  4. **Quantification of the uncertainties** of CFD codes

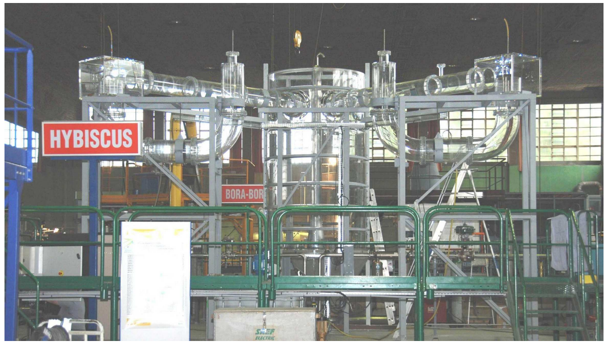


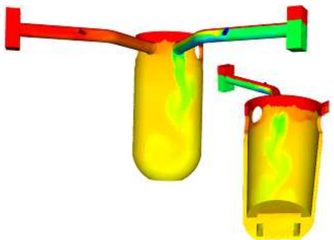
PWR vessel life-time(2/2)

Too much conservatism with 1D approaches



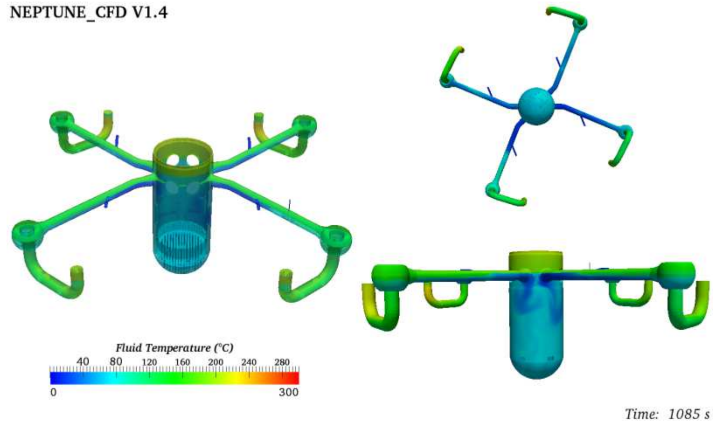
Experimental validation



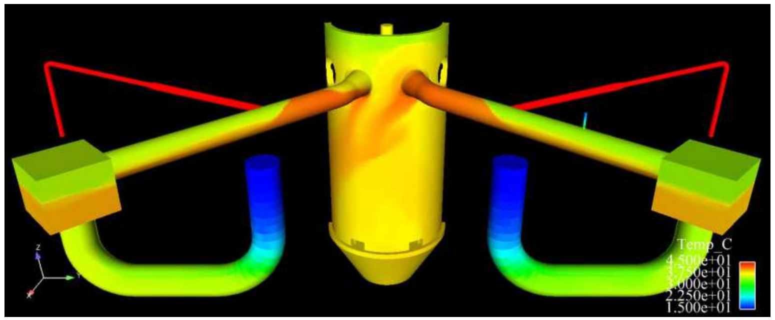


Advanced simulation at the service of reliability

Reactor computation (expertise) (PWR vessel 1300 Mwe)



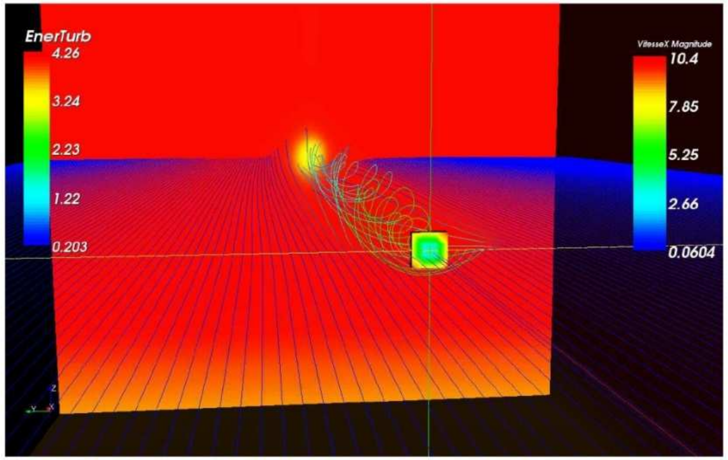
Ivanoé : 3 months.compt. for 1h of physical time
Fluid : 2 millions cells – 20 nodes (140 proc)
Solid : 1 millionscells – 1 nodes (12 proc)



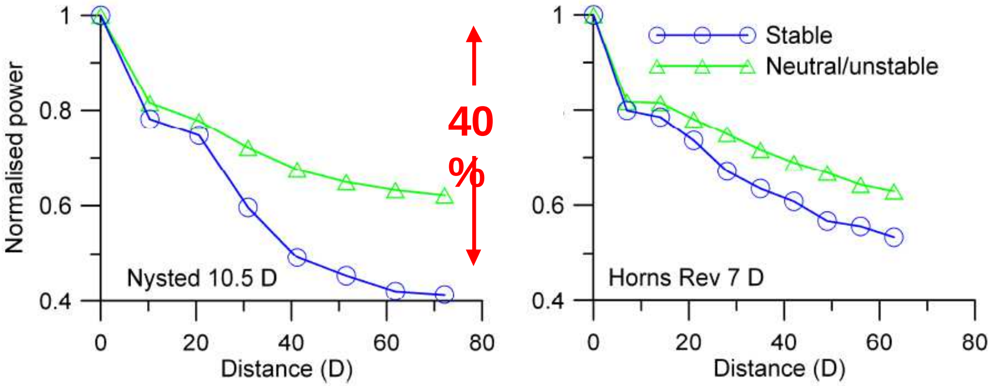
Perspectives

✓Advances physical Modélisation :
Inclusion of condensation phenomenon
✓Parametric calculations :
Estimation of uncertainties

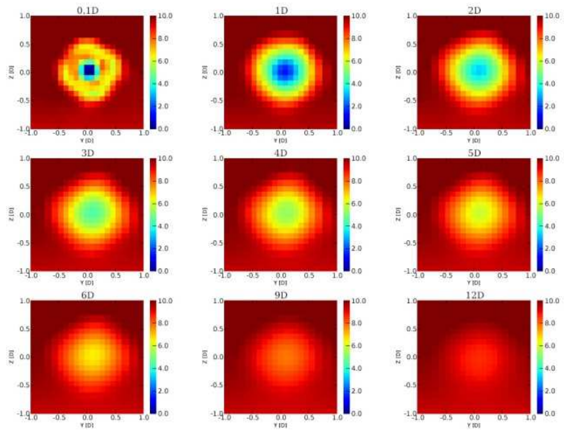
Optimize the placement of windturbines for an improved power production



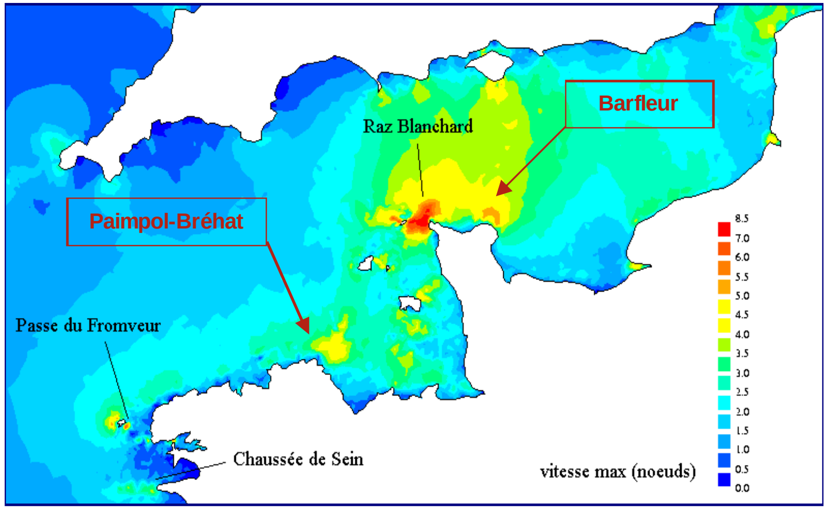
Aerodynamics calculation : loss of production (Code Saturne – EDF)



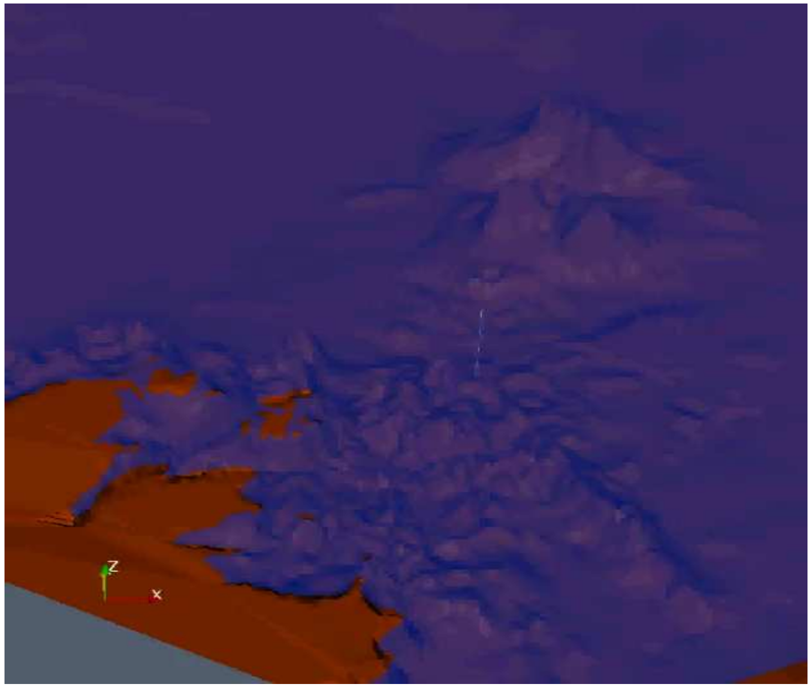
Decrease in production compared to the first machine facing the wind in a windturbines farm depending on weather conditions



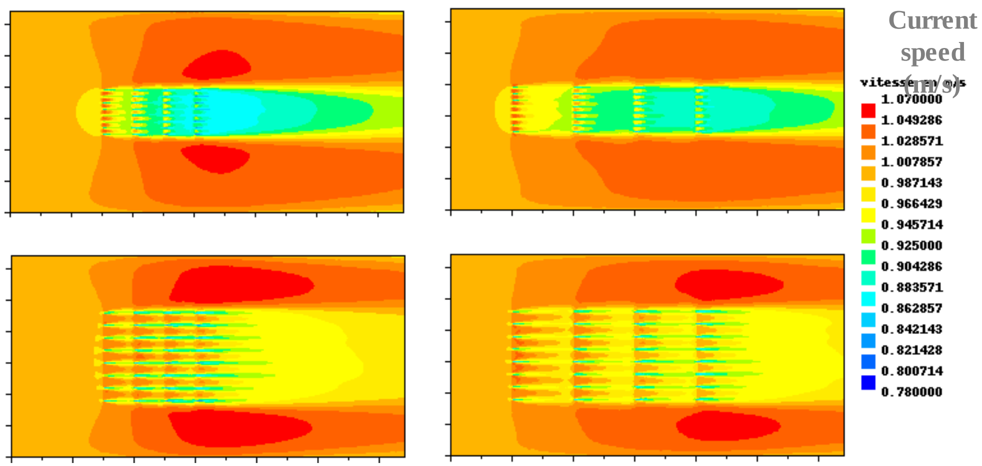
Optimize the placement of marine current turbines for an improved power production



Currents calculation



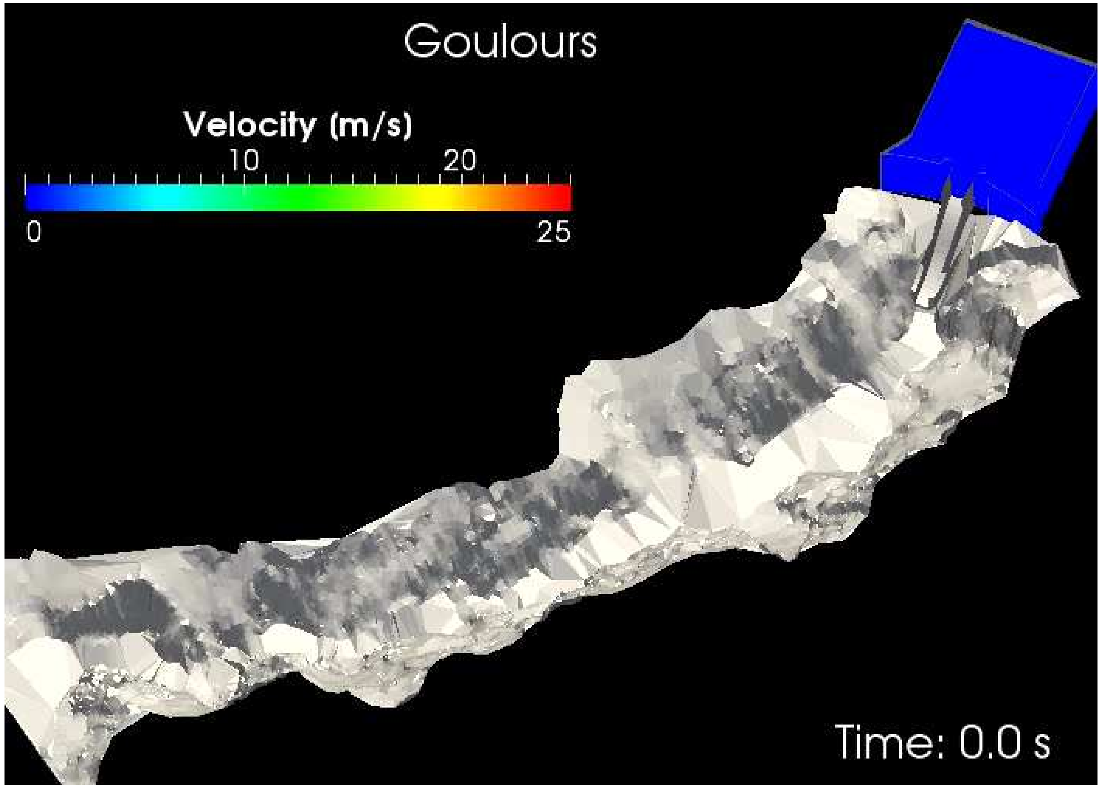
Hydrodynamic study
(spacing of turbines)



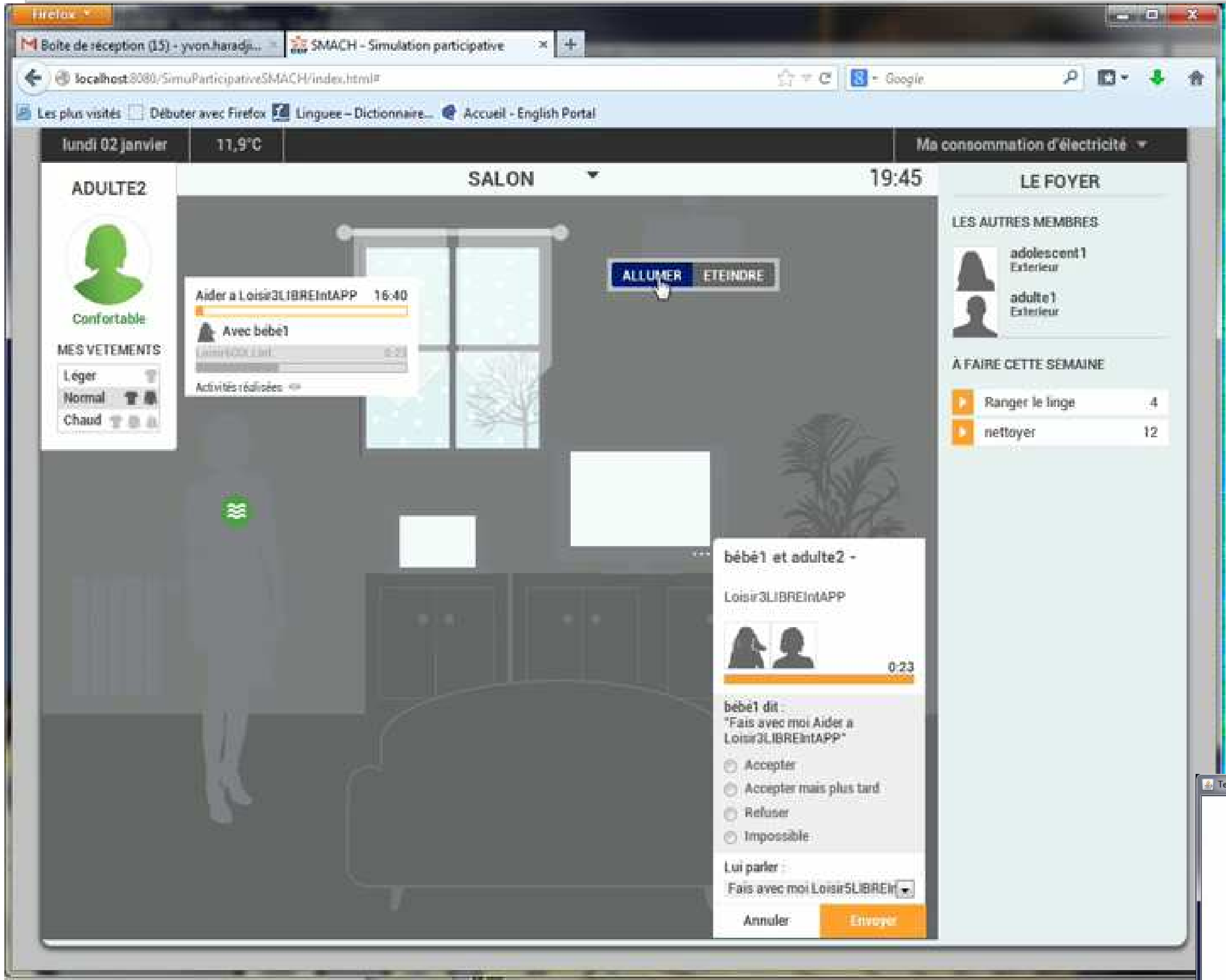
Hydraulics : SPH Simulation

Study of a floodwater spillway:

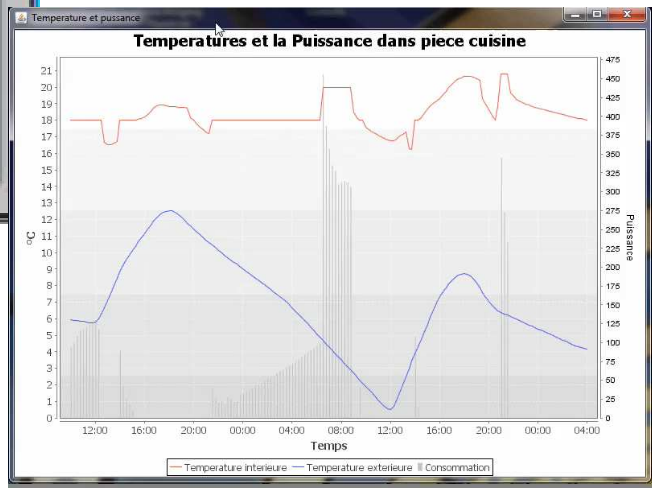
Numerical simulation and experimental simulation complementary



Energy and human behavior



Evaluation of the impact of human behavior to the energy comsuption using a multi-agent method

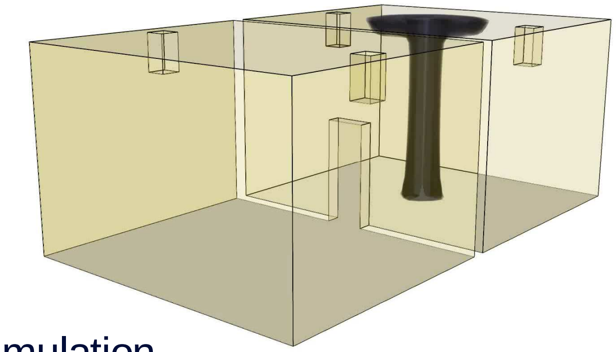


Example : transiant use of energy by a whole family

eDF

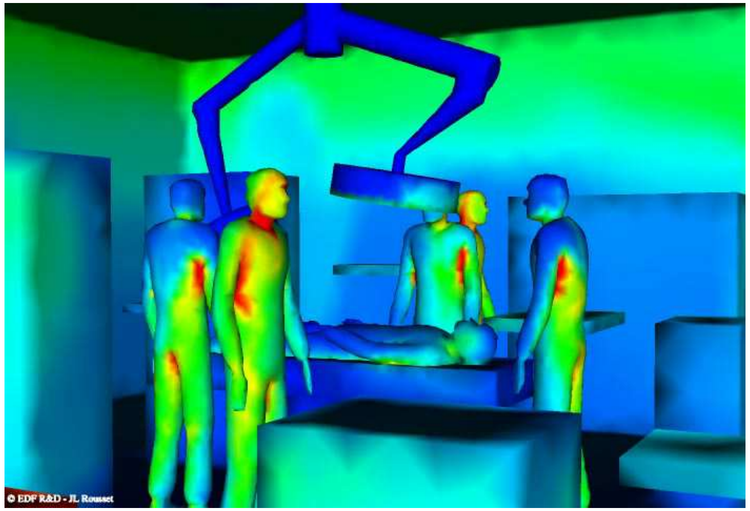
NUMERICAL SIMULATION AND EXPERIMENTAL SIMULATION COMPLEMENTARY : CODE VALIDATION (EX : *Code-Saturne* CFD CODE)

OTHERS APPLICATIONS

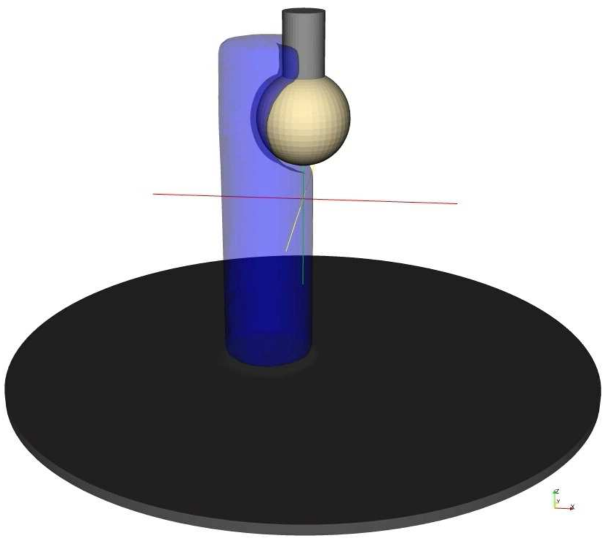


Fire simulation

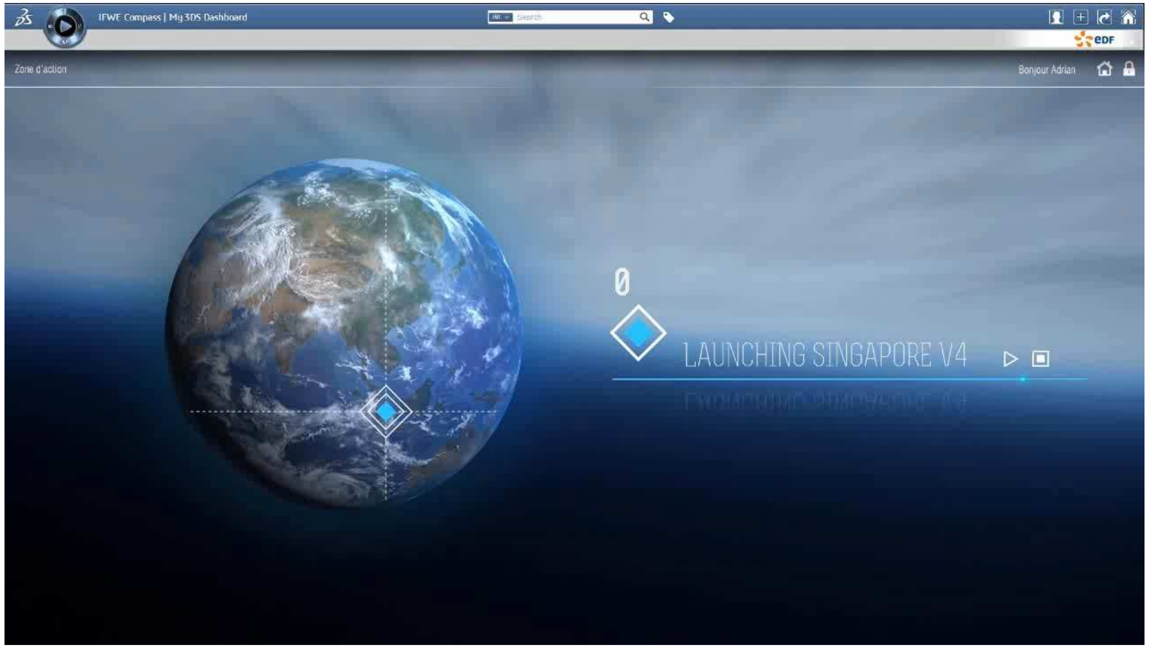
Time = 6 s



Hospital : air flow simulation



Electric arc simulation



Smart city

SOME FUTURE CHALLENGES FOR SIMULATION (1/2)

- Simulation of multi-scales and/or multi-physics phenomena
  - Ex : simulation of flow behaviour inside a PWR core vessel and its consequences : Thermal-Hydraulic + Neutronic + Mechanics
  - Ex : simulation of a whole primary circuit of a nuclear power plant (vessel, steam generator, pressurizer,…) : Thermal-Hydraulic + Mechanics + Chemistry

- Probabilistic simulation : the use of uncertainties / calibration / assimilation methods
  - Ex : evaluation of seismic fragility curves of nuclear componants
  - Ex : impact of intermittency on the network

    → Can lead to a factor 10 to 1000 of needed computing ressources

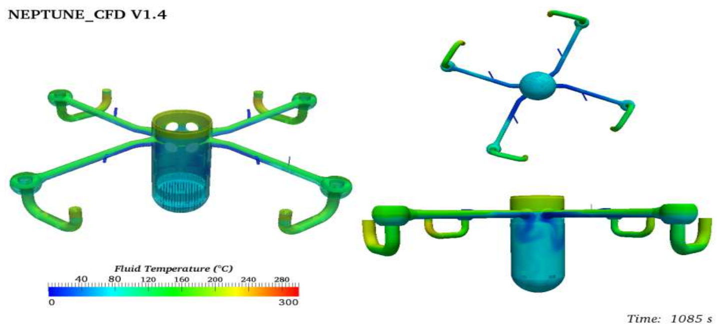


Figure 2 : Emprise et bathymétrie du modèle 3D.

SOME FUTURE CHALLENGES FOR SIMULATION (2/2)

- Pre-prossessing of input data and post-processing of simulation results
  - What future tools to mesh complex geometries in a refined and simple way?
  - What future tools to visualize a deluge of results (including uncertainties)?

- Connection between HPC and Big Data (Data Analytics)
  - Real time calculation and analysis
  - Analysis of significant data
    - Ex: Smart meter data (Linky)

Thank You