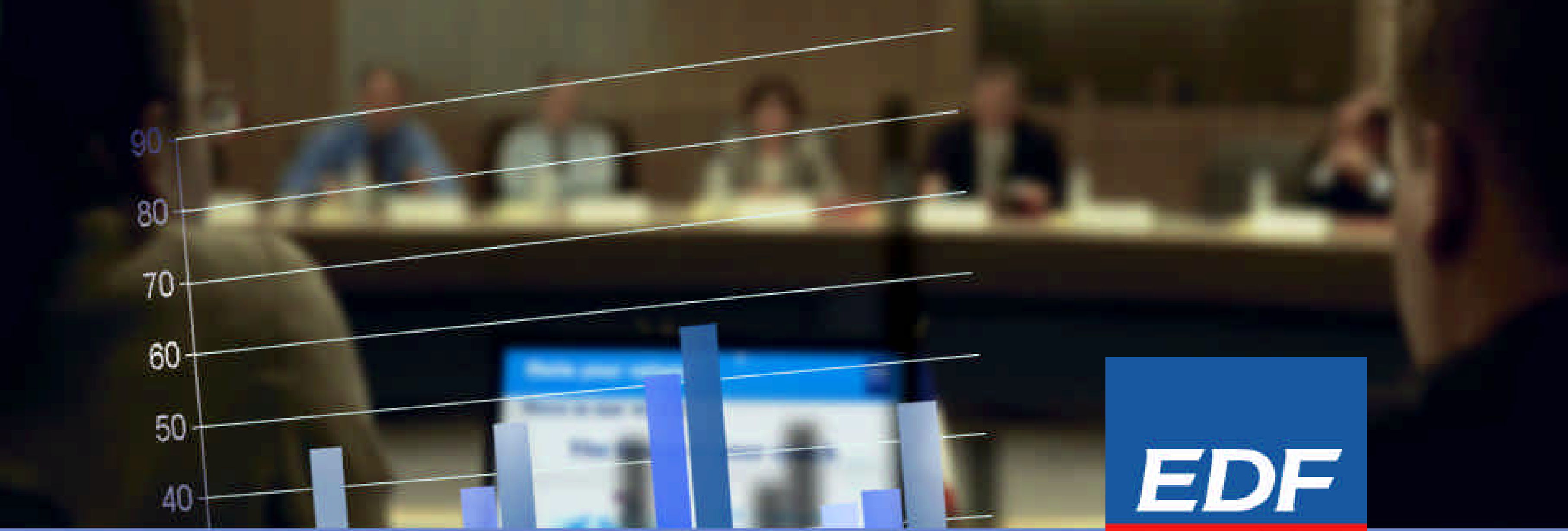
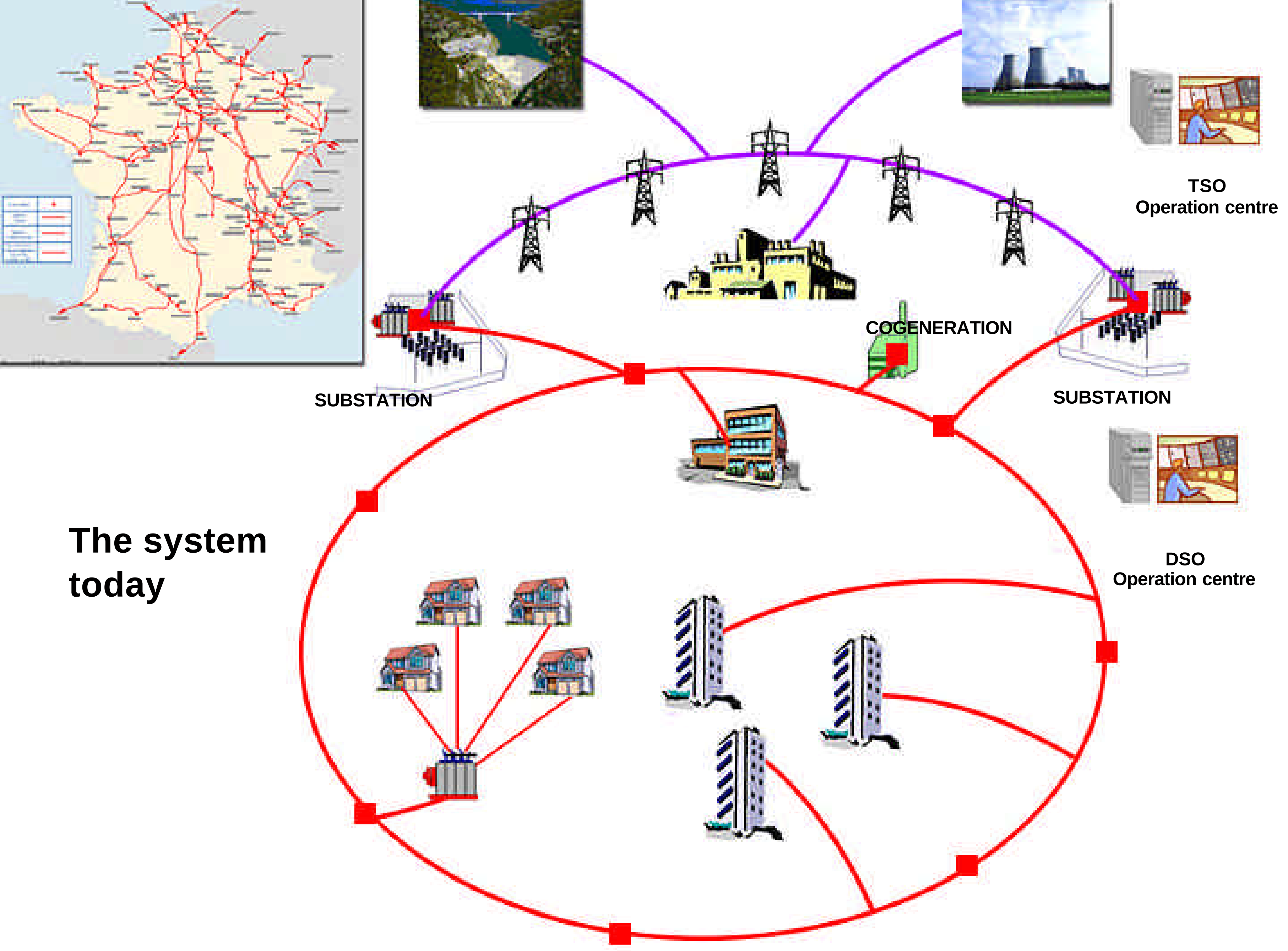


Numerical simulation at EDF: current state of progress and prospects

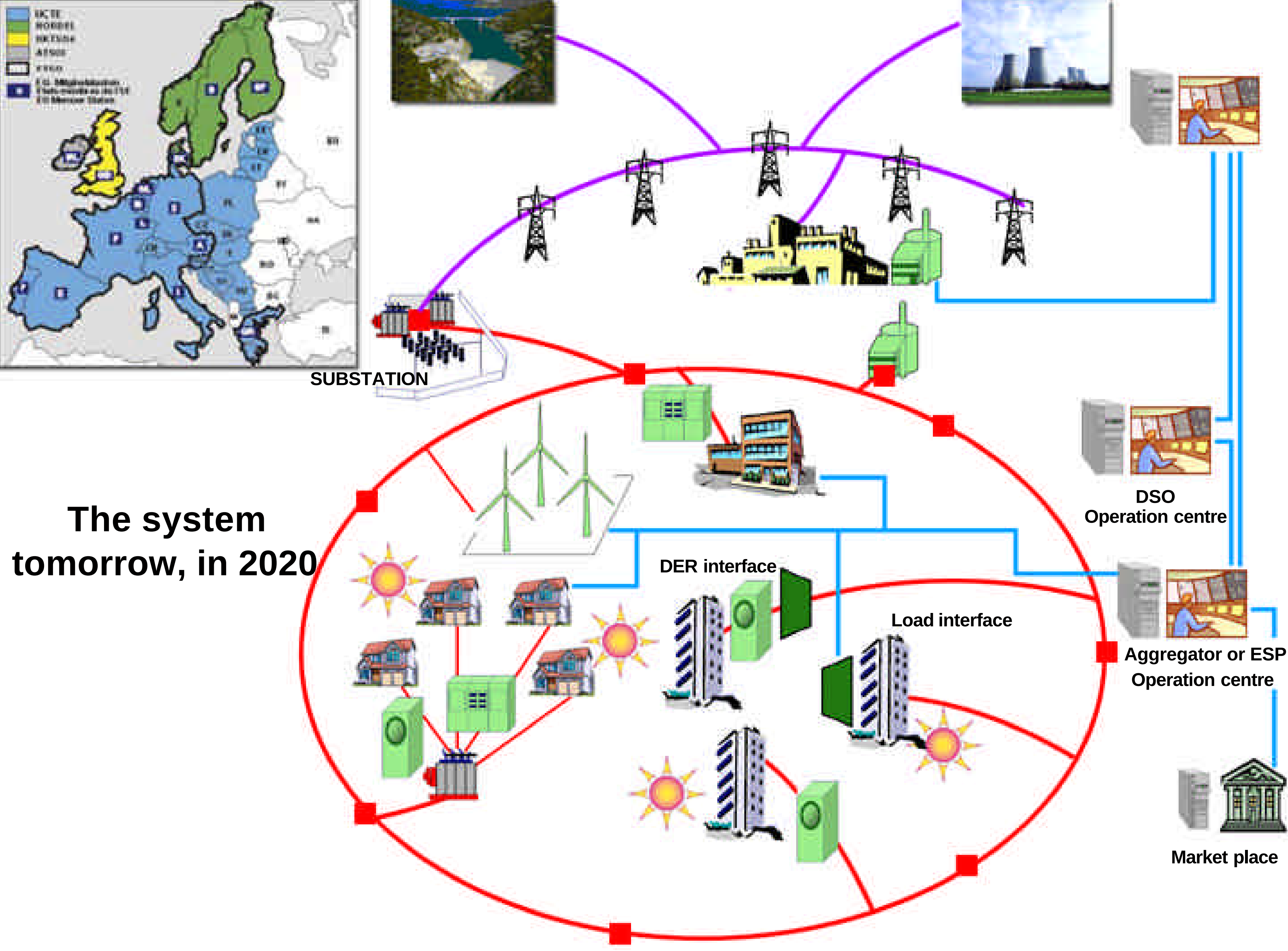
Jean-Yves Berthou, EDF R&D

IliaTech, January 18, 2005

The system today



The system tomorrow, in 2020



the "challenges" of EDF R&D

Regulations and electricity markets

- Supply pertinent tools for market risks and for optimisation of assets
- Understand in order to be a player in regulations for energy markets
- Assess the range of generation means of the future

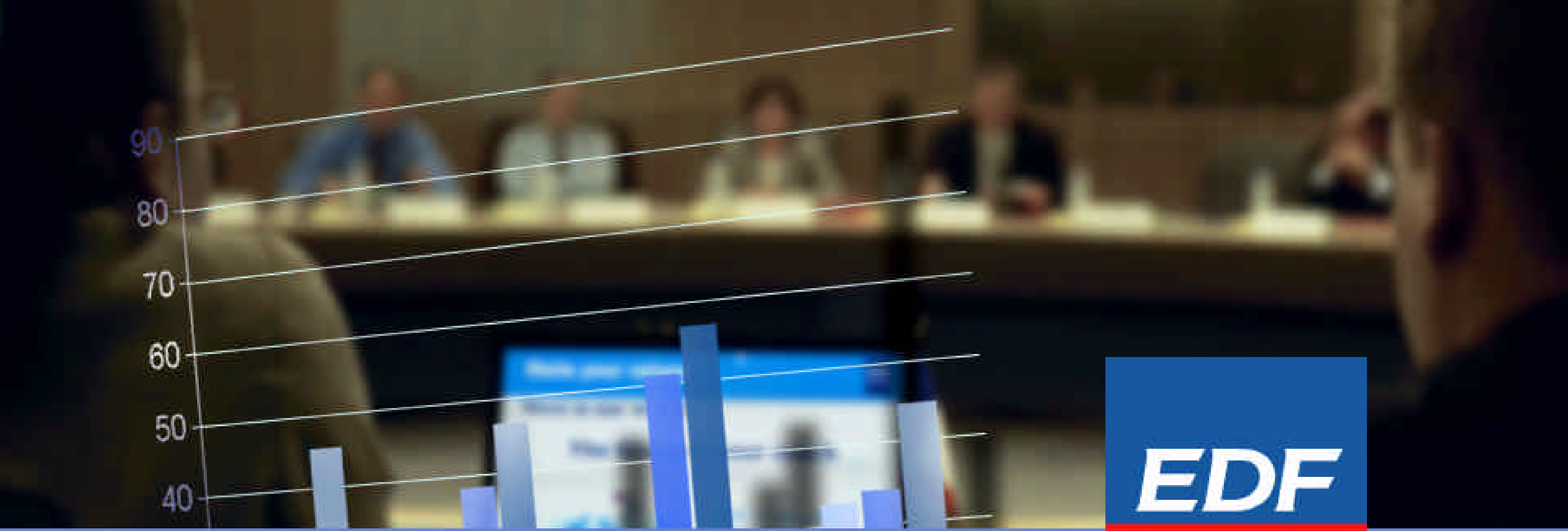
- Simulation 2010
- Acquire command of techniques for assessing impacts on the environment and health
- Invent the intelligent network
- Anticipate the rarity and the sharing of water

Sustainable trade

- Experiment with the naturally economical, intelligent building
- Accompany our industrial customers towards performance
- Experiment with energy optimisation solutions for local authorities
- Make access to electricity possible in Developing Countries

Performance of our generation

- Supply tools and expertise for guaranteeing a life span of 60 years
- Understand and simulate the mechanisms of degradation of materials
- Guarantee optimum use of the fuel



Generation management and risk management

EDF R&D

Objective of forward-looking management of generation and of risk

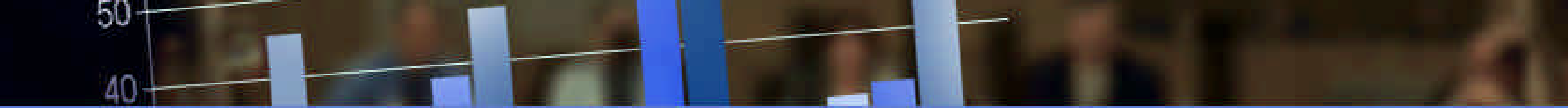
› Determine strategies for using the electricity generation means that optimise specific economic criteria over varied time scales: maximum gain, minimum cost, minimum risk …

- *e.g. Determine the shutdown schedule for the 58 nuclear power stations over a 5 year period that minimises the cost of fuel*
- *Management of energy reserves, stops-starts of units, purchases and sales of energy on markets, etc.*

Difficulties

› Problems of **stochastic** optimisation of **very large scale** (up to several tens of thousands of variables and of constraints) usually in **mixed variables**, i.e. involving continuous and integer variables.

- *In this field lie problems among the hardest in the discipline*



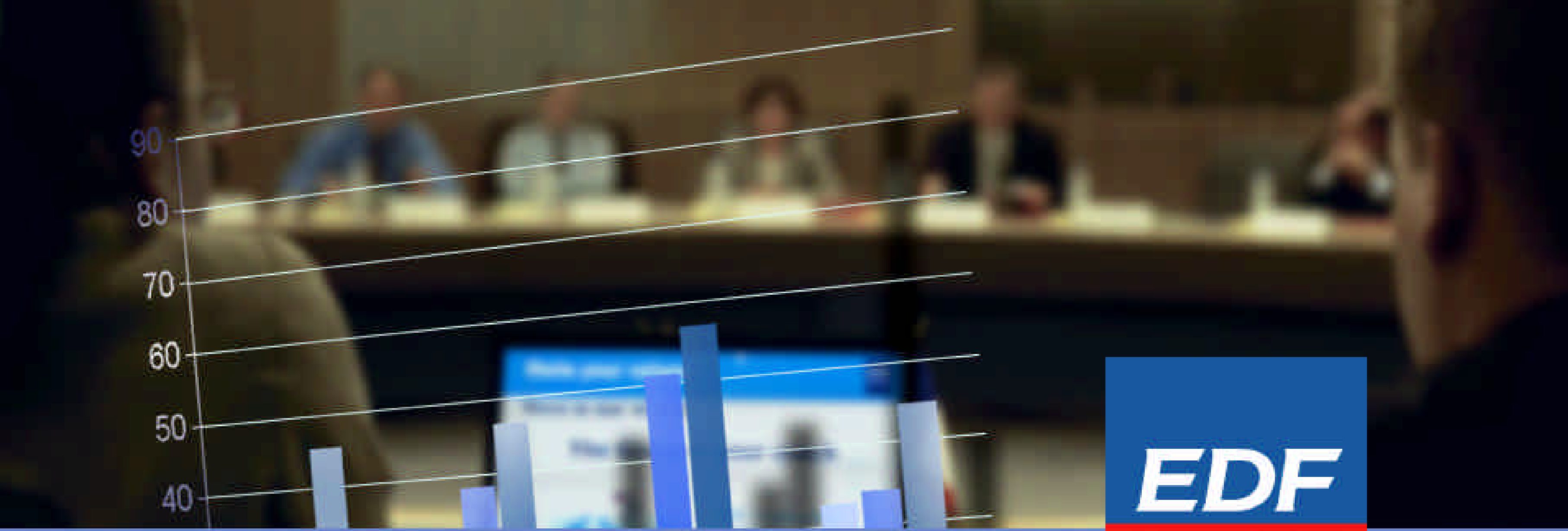
High-Performance Computing Needs

necessity of improving the models and the simulations

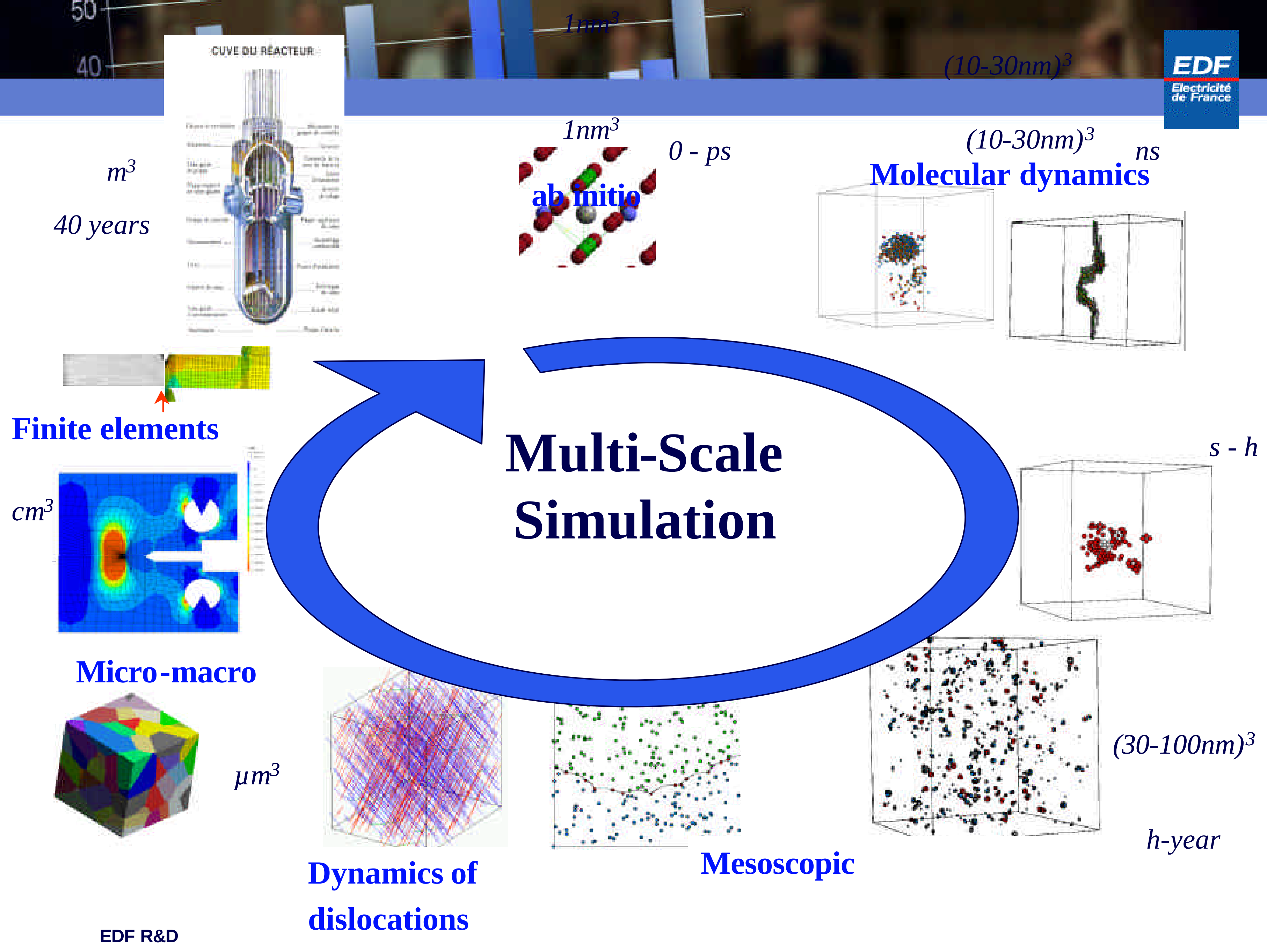
- Optimisers:
  - *Hone down the representation of the hazards.*
  - *Generating facilities represented in much more detailed manner*
- Simulators:
  - *Go from a few hundred to several thousand hazard scenarios.*
  - *Take account of finer constraints: start-up costs, "dynamic" constraints …*

Performance needs that are increasing very quickly

- Today: a few hours on a workstation
- The preceding increase in complexity (fineness of representation and massively parametric studies) represents gains in computing power by factors of from **100 to 1000**
- Necessity for massively parallel architectures



Materials simulation


Multi-Scale
Simulation
CUVE DU RÉACTEUR
m3
40 years
Finite elements
cm3
Micro-macro
μm3
Dynamics of
dislocations
1nm3
0 - ps
ab initio
(10-30nm)3
ns
Molecular dynamics
s - h
(30-100nm)3
h-year
Mesoscopic
EDF
Electricité de France
50
40
EDF R&D

Materials simulation: high intensive parallel computing needs

ab initio

-Computing (interactions between two vacancies or between a vacancy and a carbon atom): from 200 to 500 hours CPU (parallel machine of the CCRT (Computing Centre for Research and Technology) for 128 atoms.

-Study of the various possibilities for interaction in terms of energetics and in terms of mobility of the defects: 10 to 100 times more computing

-Computing of complex defects (interstitials): computing 1000 times longer

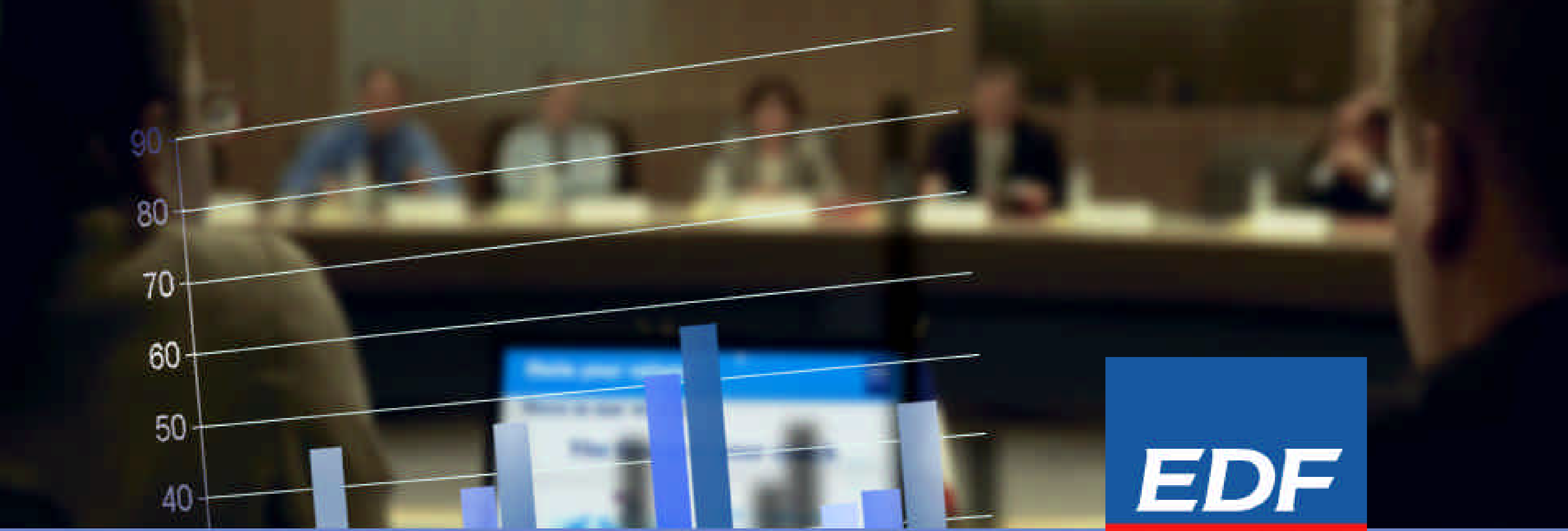
-Studies of agglomerations of point defects or core effect of dislocations: requires 500 atoms and computing 50 times longer

-Expected gains: CPU power, memory and also algorithmics (methods of order N: computing power linear with size)

Increase in needs for the entire chain

- Molecular dynamics (description of more complex potentials)

-Dynamics of the dislocations and simulation of the micro-structures



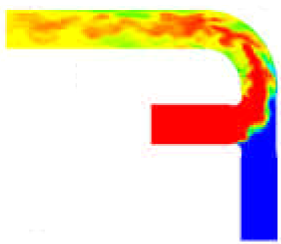
Thermo-hydraulics

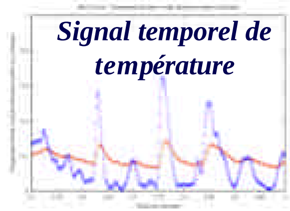
Pushing the limits of modelling towards the tiniest of scales

To obtain more precise models, on the basis of

- sound hypotheses verified by small scales
- experimental or numerical results

on (“analytical”) elementary phenomena



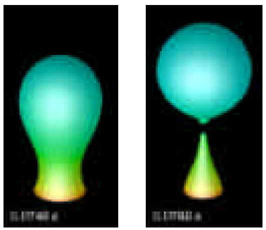


LES (Large Eddy Simulation): a path to local and instantaneou information: providing hydraulic loading lying behind problem structures

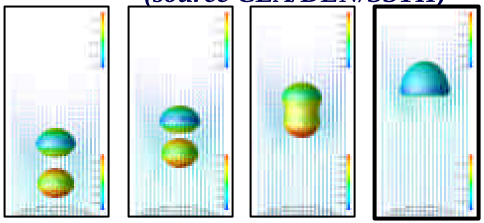
- Acoustics (*Code_Saturne Eole*)
- Vibration, fretting (*Code_Saturne Code_Aster*)
- Thermal fatigue (*Code_Saturne Syrthes Code_Aster*)

Diphasic DNS (Direct Numerical Simulation) : a supplement to physical modelling

- Understanding boiling: first computations in 2004



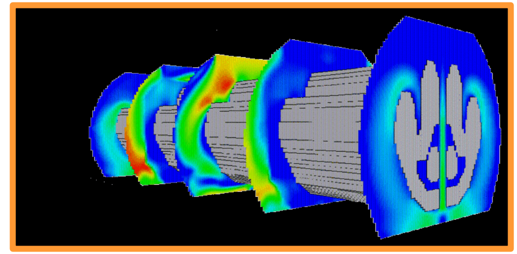
(source CEA/DEN/SSTH)

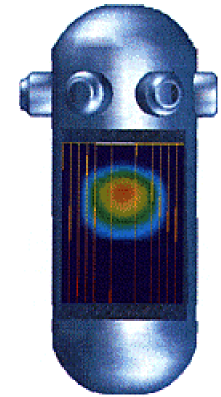


The same need for major resources:

- Long computations (transients, statistics computations…)
- Fine meshing (small structures, numerical convergence…)

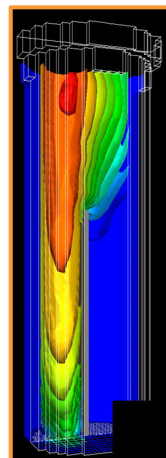
Coupled physics: a few examples





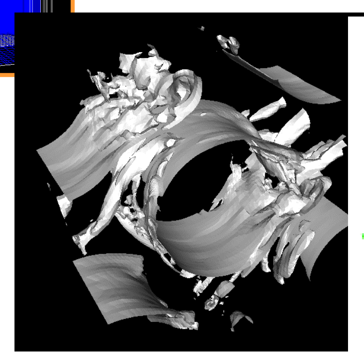
- computing for designing reactor cores (neutronics/thermohydraulics coupling)

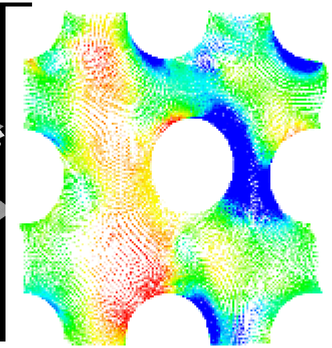
- computing for reloading, computing for accident scenarios (e.g. steam pipe burst: system/component/neutronics coupling),



- computing for dimensioning for heat exchangers, steam generators, condensers, for reducing maintenance costs,

- studies for in-flow vibration (steam generator banks of tubes, fuel assemblies, and control clusters): hydraulics – mechanics coupling





Software platform and architecture for numerical simulation

EDF R&D

Software platform and architecture for numerical simulation

Major simulation codes: state of the art at the end of the nineteen nineties

Architecture heterogeneous: limits their coupling possibilities

Re-use of code portions (components) is generally impossible

Lack of flexibility: limits their field of application

Not all of them take advantage of the performance of current machines (graphism, parallelism, distribution)

Heterogeneity of the simulation environments limits their diffusion and restricts the reduction in research lead times and costs

Software platform and architecture for high-performance computing

Identified numerical simulation needs: increasing specialisation and complexity

Separation of the physical disciplines: mechanics, neutronics, fluid mechanics, molecular dynamics, ...

But need for coupling in studies and for broadened interaction with the "technical" disciplines: CAD, meshing, uncertainties, data assimilation

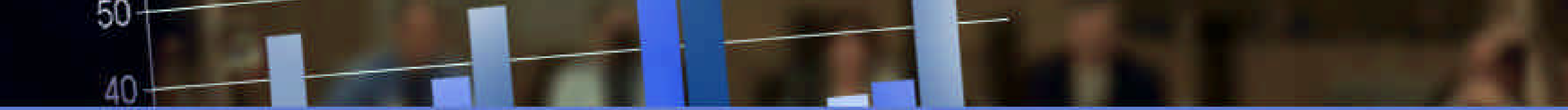
=> Definition of a common software architecture and a new generation of codes

Software platform and architecture for high-performance computing

Need to have tools for taking charge of the coupling: by providing integration mechanics for facilitating

- › Development of integrated tools: CAD-Computation-Visualization, ...
- › Development of trade applications
- › Production of ambitious multi-physics applications
- › Interactive 3D visualisation, parallel computing

=> Design and production of a common generic simulation platform



P@L/SALOME Project: A common software architecture

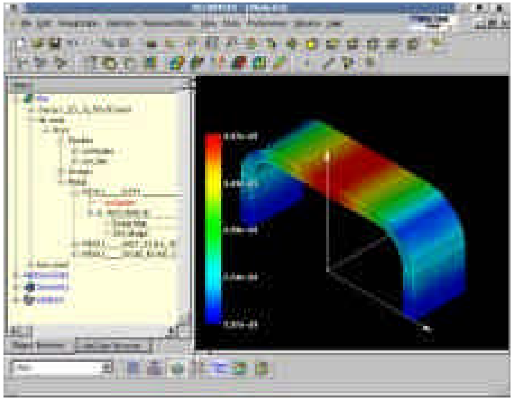
Adoption of a common “component” architecture

- Common methodology for interfacing the disciplinary components
- Choice of a common control language: Python
- Architectural choice for assembling components
- Distribution of computing: CORBA

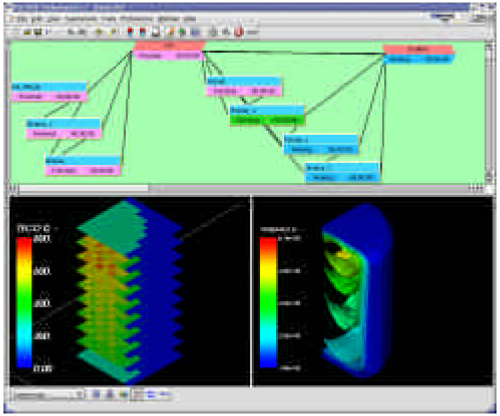
Definition of common data exchange model: MED (DEM)

- Catalogue
- Data model
- Library for data production and data consumption

P@L/SALOME Project: a common generic simulation platform



- *Facilitate interoperation between CAD modelling and computing codes*
- *Facilitate implementation of coupling between computing codes in a heterogeneous distributed environment*
- *Provide a generic user interface that is user-friendly and efficient, and that contributes to reducing the research costs and lead times*



- *Facilitate re-use of code portions*
- *Pool production of non-critical developments (pre and post processors) in the field of numerical simulation*

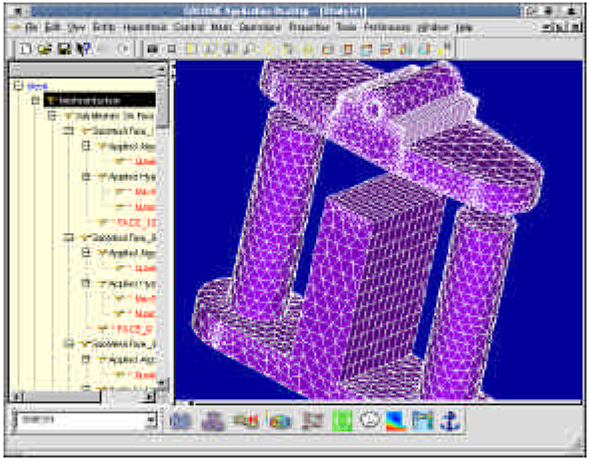
P@L/SALOME Project: an Open Source effort

Structural analysis
CFD
Acoustic
Hydrodynamic
Neutronic
Thermo-hydraulic
Electro-technical
CEM
…

SALOME 1 & 2: RNTL 2001-2005

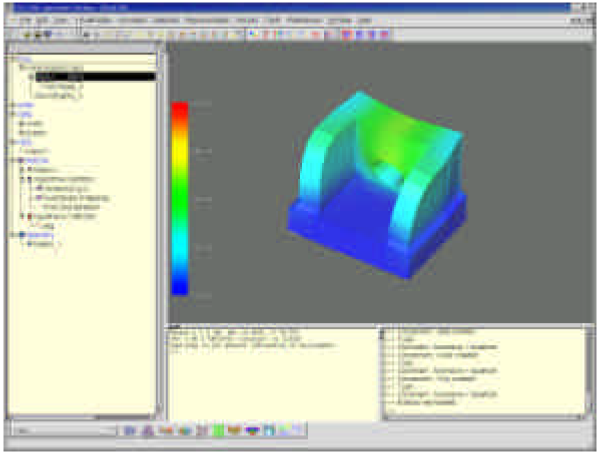
Consortium of 9 & 21 Open Source partners,
www.salome-platform.org

P@L/SALOME Project: an Open Source effort



www.salome-platform.org *: V 2.0 July 2004*

SALOME 1& 2 : 50 + 100 Ing.year



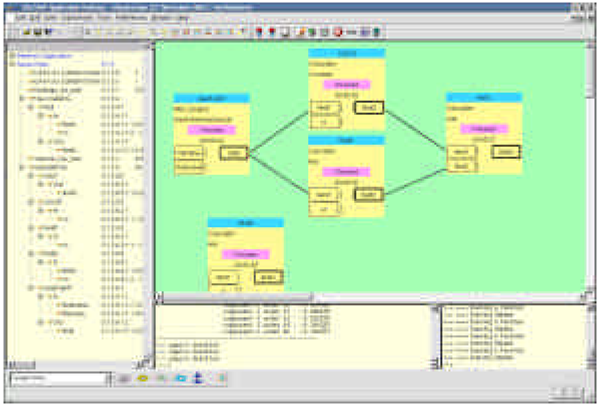
EDF/CEA ***P@L/SALOME*** *project (2001-2005) : 100 Ing.year*

P@L/SALOME Project: challenges to be taken up for HPC:

› Generating and managing distributed meshing

› Supervising coupling of parallel components: distributed data exchange

› Visualising large volumes of data

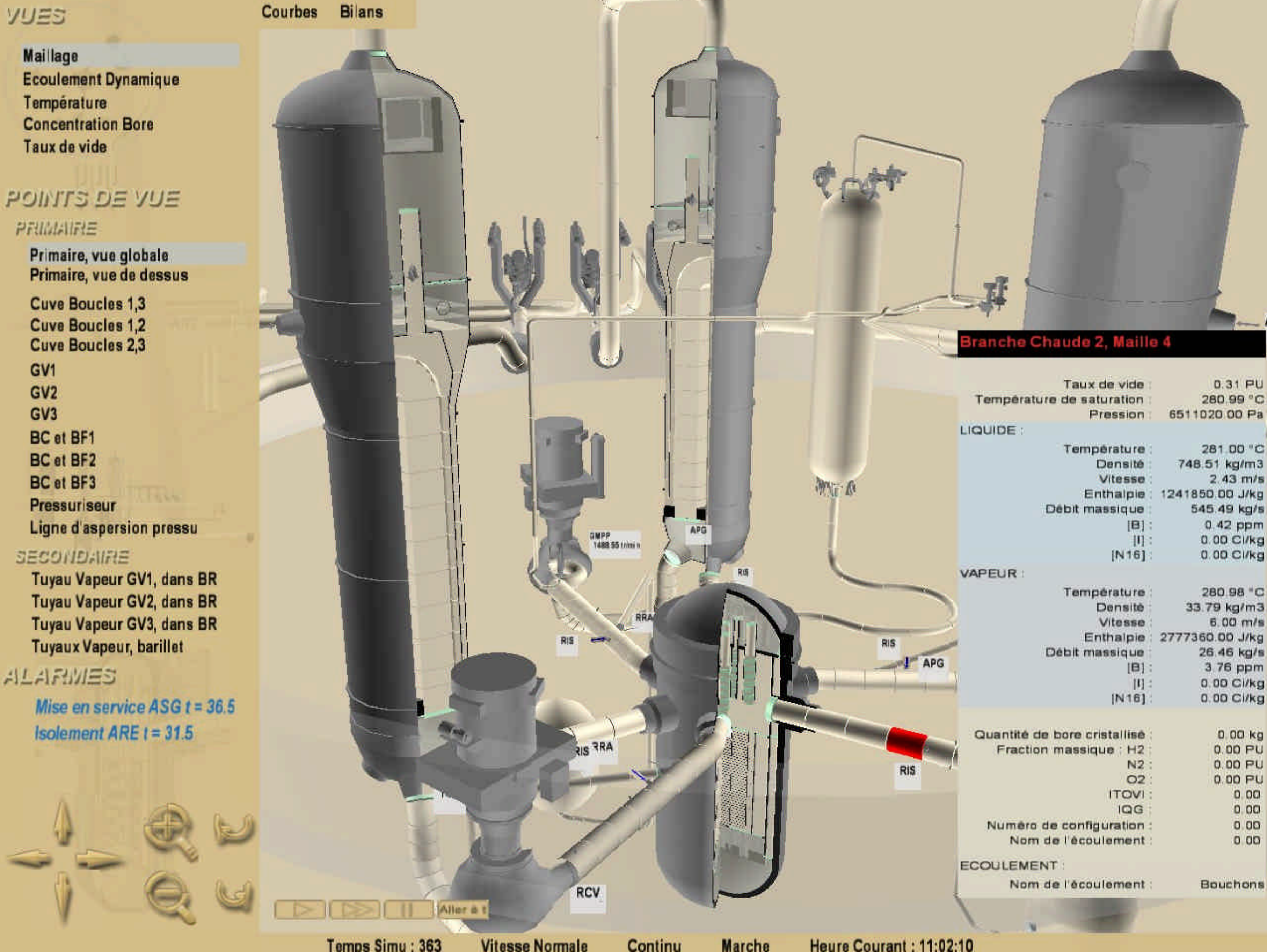


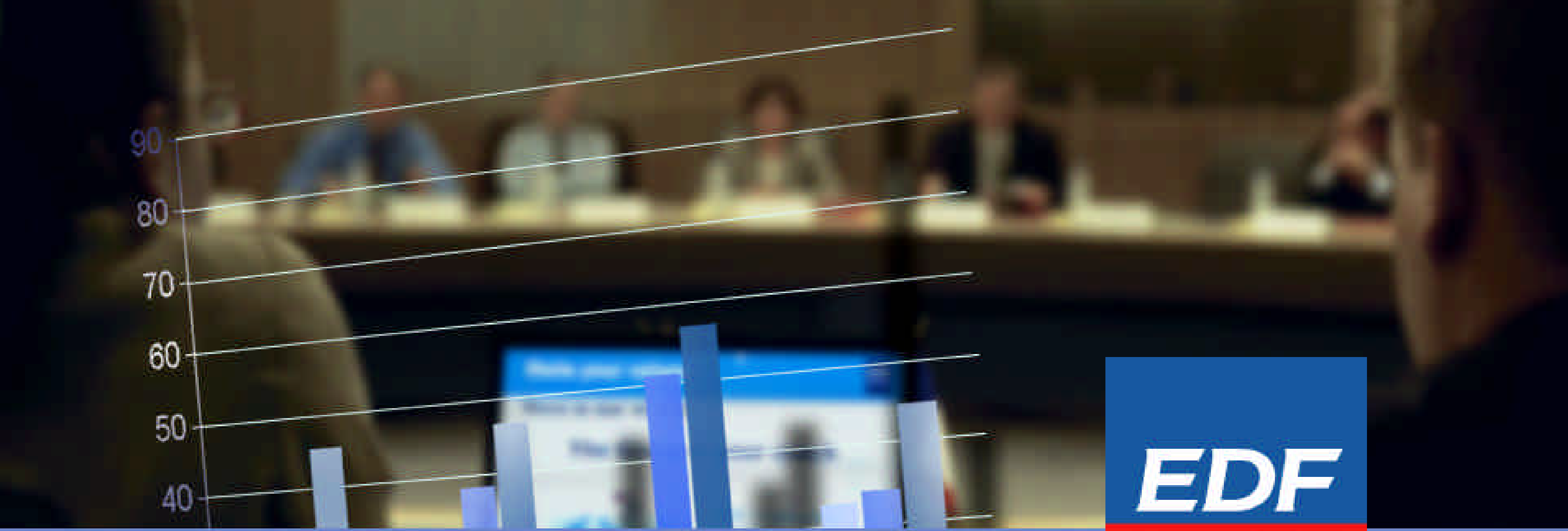
› Remote visualisation and collaborative work

› Interaction between visualisation and computing supervision

› Controlling heterogeneous computing resources (from the workstation to the HPC computer)

› Storage of large volume of distributed data


VUES
Courbes
Bilans
Maillage
Ecoulement Dynamique
Température
Concentration Bore
Taux de vide
POINTS DE VUE
PRIMAIRE
Primaire, vue globale
Primaire, vue de dessus
Cuve Boucles 1,3
Cuve Boucles 1,2
Cuve Boucles 2,3
GV1
GV2
GV3
BC et BF1
BC et BF2
BC et BF3
Pressuriseur
Ligne d'aspersion pressu
SECONDAIRE
Tuyau Vapeur GV1, dans BR
Tuyau Vapeur GV2, dans BR
Tuyau Vapeur GV3, dans BR
Tuyaux Vapeur, barillet
ALARMES
Mise en service ASG t = 36.5
Isolement ARE t = 31.5
APG
RIS
RRA
RIS
APG
RIS
RRA
RIS
RCV
Aller à t
Branche Chaude 2, Maille 4
Taux de vide : 0.31 PU
Température de saturation : 280.99 °C
Pression : 6511020.00 Pa
LIQUIDE :
Température : 281.00 °C
Densité : 748.51 kg/m3
Vitesse : 2.43 m/s
Enthalpie : 1241850.00 J/kg
Débit massique : 545.49 kg/s
[B] : 0.42 ppm
[I] : 0.00 Ci/kg
[N16] : 0.00 Ci/kg
VAPEUR :
Température : 280.98 °C
Densité : 33.79 kg/m3
Vitesse : 6.00 m/s
Enthalpie : 2777360.00 J/kg
Débit massique : 26.46 kg/s
[B] : 3.76 ppm
[I] : 0.00 Ci/kg
[N16] : 0.00 Ci/kg
Quantité de bore cristallisé : 0.00 kg
Fraction massique : H2 : 0.00 PU
N2 : 0.00 PU
O2 : 0.00 PU
ITOVI : 0.00
IQG : 0.00
Numéro de configuration : 0.00
Nom de l'écoulement : 0.00
ECOULEMENT :
Nom de l'écoulement : Bouchons
Temps Simu : 363
Vitesse Normale
Continu
Marche
Heure Courant : 11:02:10



EDF
Electricité de France

Hardware infrastructure for high-performance computing

EDF R&D

Hardware infrastructure for high-performance computing

3D multi-physics, multi-scale HPC scientific computing, necessary renovation:

- › Parallel HPC computers in partnership with the centres of excellence in France
- › Department computing servers to the hardware and software reference frame of the firm and adaptable to application needs
- › Engineer’s workstation: single LINUX/office automation workstation with high-performance and user-friendly access to and from external partners
- › Files servers, storage servers
- › Networks (local, inter-site, RIN, towards the outside)
- › HPC visualisation tools: wall of images, virtual reality

Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : HPC Resources

CCRT (Centre de Calcul Recherche et Technologie) :

common Computing Center located at CEA BIII

Partners : CEA, EDF, ONERA, TURBOMECA, SNECMA

Access HPC computing power : 3,6 Tflops (at the end of 2004

- HP SC 45 : 960 processors, 2,4 Tflops
- HP Opteron cluster : 228 processors, 0,8 Tflops
- NEC SX6 : 48 processors, 0,4 Tflops

Estimated : > 20 Tflops in 2006, >200 Tflops in 2009

Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : Workstations and clusters

- Development of a Linux EDF “distribution”
- Specialization of EDF “distribution” for particular project needs
- Linux on workstation and clusters part of the enterprise technical referential
- Organizing support and administration of Linux solutions
- Training of administrators and users
- Introduction to Open Source culture : open source software more and more used

Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : Workstations and clusters

Engineer's workstation : Linux + (Vmware/Windows) + (Vmware/LINUX+VPN)

> 400 Linux workstations in 2004

> 1000 workstations in 2006

Clusters :

> 10 clusters in 2004, from 16 to 64 processors

> 20 clusters in 2006, from 16 to 200 processors

Hardware infrastructure for high-performance computing

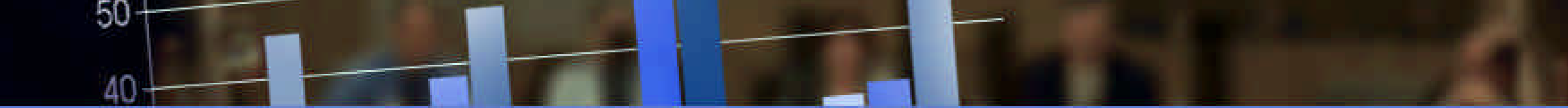
CALIBRE/OSIS Projects 1999-2005 : clusters and cluster federation

Collaboration EDF/IRISA-Paris Project

Providing a Single System Image for clusters : make usable CPUs, memories, devices and disks as a global resource

State of the art clustering tools: fault tolerance (hardware and software), checkpointing, dynamic load balancing, scheduling policies, OpenMP on clusters, extensibility (cluster federation)

Validation in industrial environment : 2005



Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : clusters and cluster federation

- Linux Clusters are now proved industrial target machines
- Clusters are part of a continuum of computing power : between workstation and HPC computers
- Constraints :
  - › Deployment of a unique cluster solution (administration)
  - › The evolution of clusters does not depend of vendors roadmap
  - › Portability between clusters and between workstations and clusters
  - › Availability of state of the art clustering tools

But, how to combine :

A common Linux distribution for workstations and clusters AND, keep the possibility to buy from different vendors?

Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : clusters and cluster federation

A solution ?

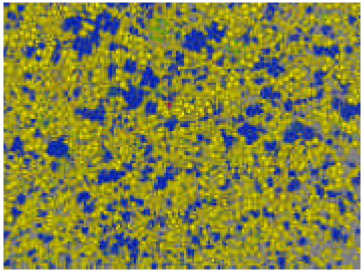
- Introducing EDF constraints into a largely, robust, state of the art Linux software suite for clusters : compatibility with exploitation tools, SSI Kerrighed OS, …
- Convince vendors to sell machines compatible with this software suite => make call for tenders where the compatibility with the software suite is required
- Training administrators : using the software suite for defining “EDF cluster distribution” for production clusters

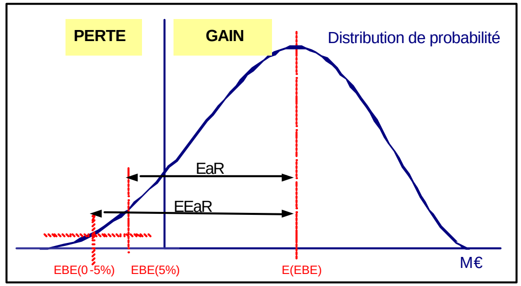
Hardware infrastructure for high-performance computing

CALIBRE/OSIS Projects 1999-2005 : clusters and cluster federation

A collaboration between ONRL, IRISA, EDF (2004/2006):

- Integration of EDF needs into the OSCAR toolbox
- Construction of a WP OSCAR-SSI : availability of the Kerrighed system into OSCAR, V1.0 for SC04
- make OSCAR toolbox adapted to industrial needs and available on commercial clusters





Simulation 2010 challenge

- Software platform and architecture for numerical simulation
- Hardware infrastructure for high-performance computing
- Applied mathematics for HPC
- Uncertainties computing and data assimilation
- 3D visualization