

*Code_Saturne[®]:
EDF's general
purpose CFD
software*

Marc SAKIZ - EDF R&D

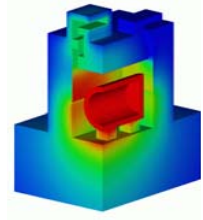
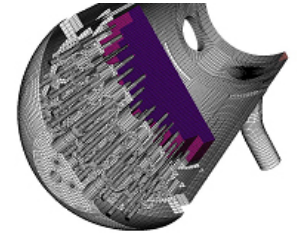
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General elements on *Code_Saturne*

Code_Saturne: main capabilities

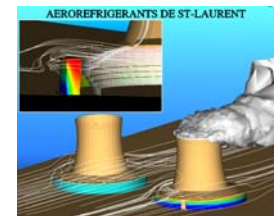
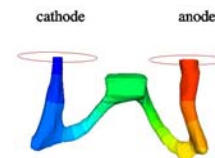
Physical modelling

- Single-phase laminar and **turbulent flows**: $k-\varepsilon$, $k-\omega$ SST, $v2f$, RSM, LES
- **Radiative** heat transfer (DOM, P-1)
- **Combustion** coal, heavy fuel oil, gas (EBU, pdf, LWP)
- **Electric** arc and Joule effect
- **Lagrangian** module for dispersed particle tracking
- **Compressible** flow
- **ALE** method for deformable meshes
- **Conjugate heat transfer** (SYRTHES & 1D)
- Specific **engineering modules** for nuclear waste surface storage and cooling towers
- Derived version for **atmospheric flows** (*Mercurie_Saturne*)
- Derived version for **eulerian** multiphase flows



Flexibility

- **Portability** (UNIX and Linux)
- **GUI** (Python TkTix, Xml format)
- **Parallel** on distributed memory machines
- **Periodic boundaries** (parallel, arbitrary interfaces)
- Wide range of **unstructured meshes** with **arbitrary interfaces**
- **Code coupling** capabilities (*Code_Saturne/Code_Saturne*, *Code_Saturne/Code_Aster*, ...)



Code_Saturne: general features

Technology

- Co-located finite volume, arbitrary unstructured meshes, predictor-corrector method
- 500 000 lines of code, 49% FORTRAN, 41% C, 10% Python

Development

- 1998: Prototype (long time EDF in-house experience, ESTET-ASTRID, N3S, ...)
- 2000: version 1.0 (basic modelling, wide range of meshes)
- **2001: Qualification** for single phase nuclear thermal-hydraulic applications
- 2004: Version 1.1 (complex physics, LES, parallel computing)
- **2006: Version 1.2** (state of the art turbulence models, gui)
- 2008: Scheduled release of version 1.3 (massively parallel, ALE, code coupling, ...)
Released as open source (GPL licence)
Beta versions (1.3.f and following) pre-released

Broad validation range for each version

- **~ 30 cases, 1 to 15 simulations per case**
- Academic to industrial cases (4 to 2 000 000 cells, 0,04 s to 12 days CPU time)
- Linux (workstations, clusters), Solaris, Irix64, Fujitsu VPP, Tru64 (AlphaServer), Blue Gene/L, PowerPC 4 and 5

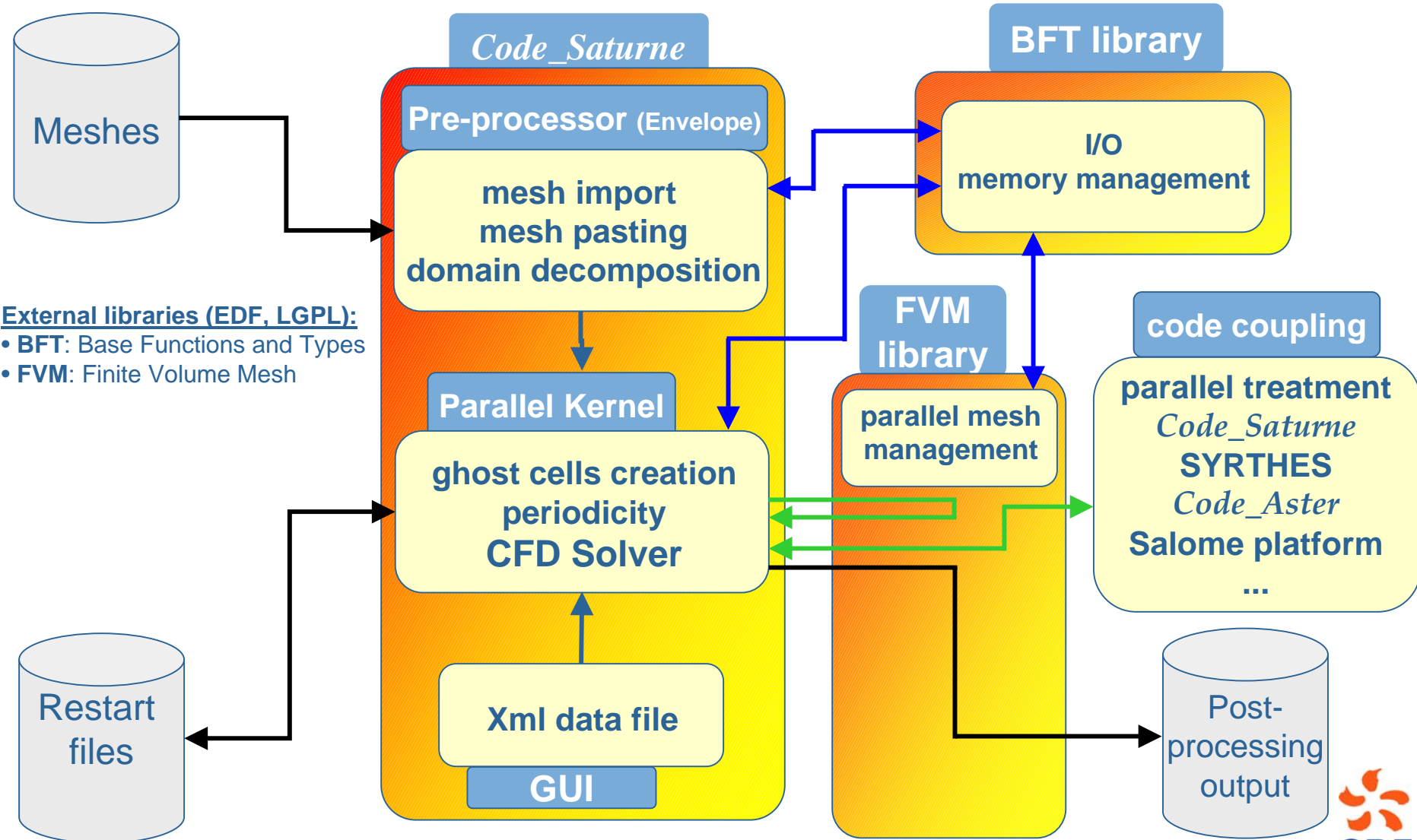
Qualification for single phase nuclear applications

- **Best practice guidelines** in specific and critical domain
- Usual real life industrial studies (500 000 to 3 000 000 cells)

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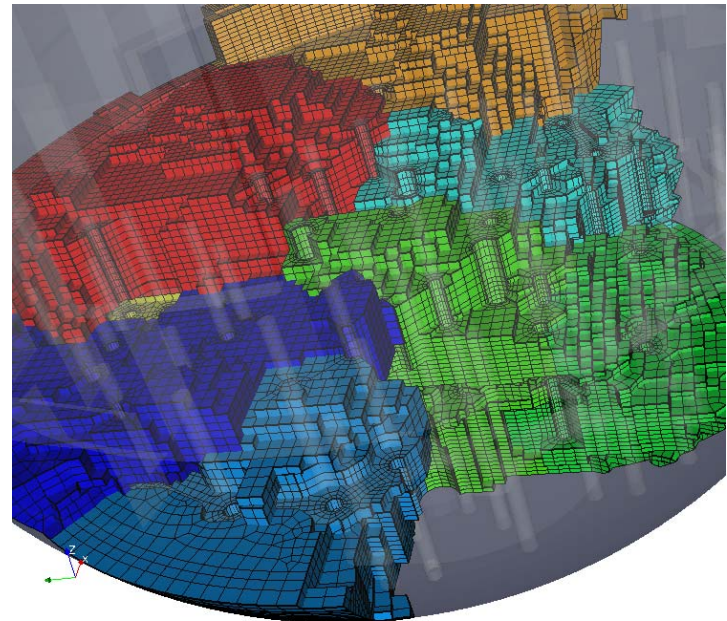
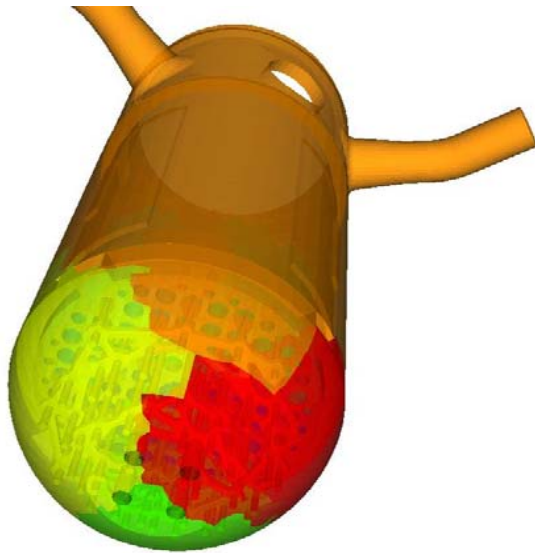
Basic software architecture characteristics of *Code_Saturne*

Code_Saturne elements



Parallelism

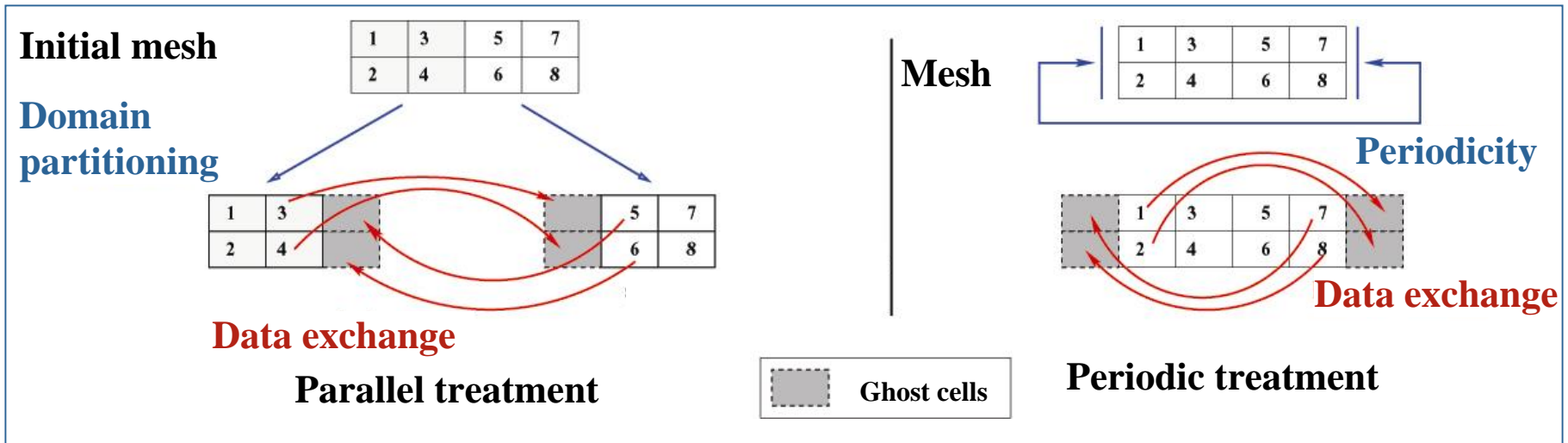
Classical domain splitting using MPI



PWR lower plenum decomposition (Metis)

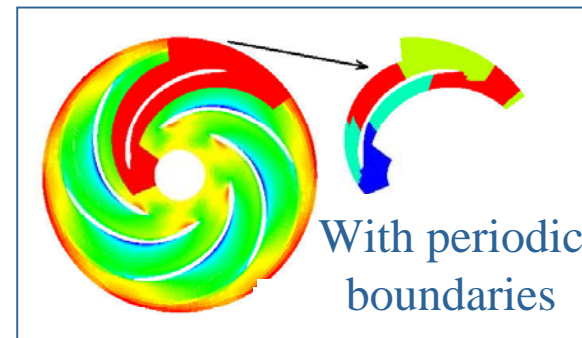
Parallelism - periodicity

Parallelism and translation periodicity: data exchange

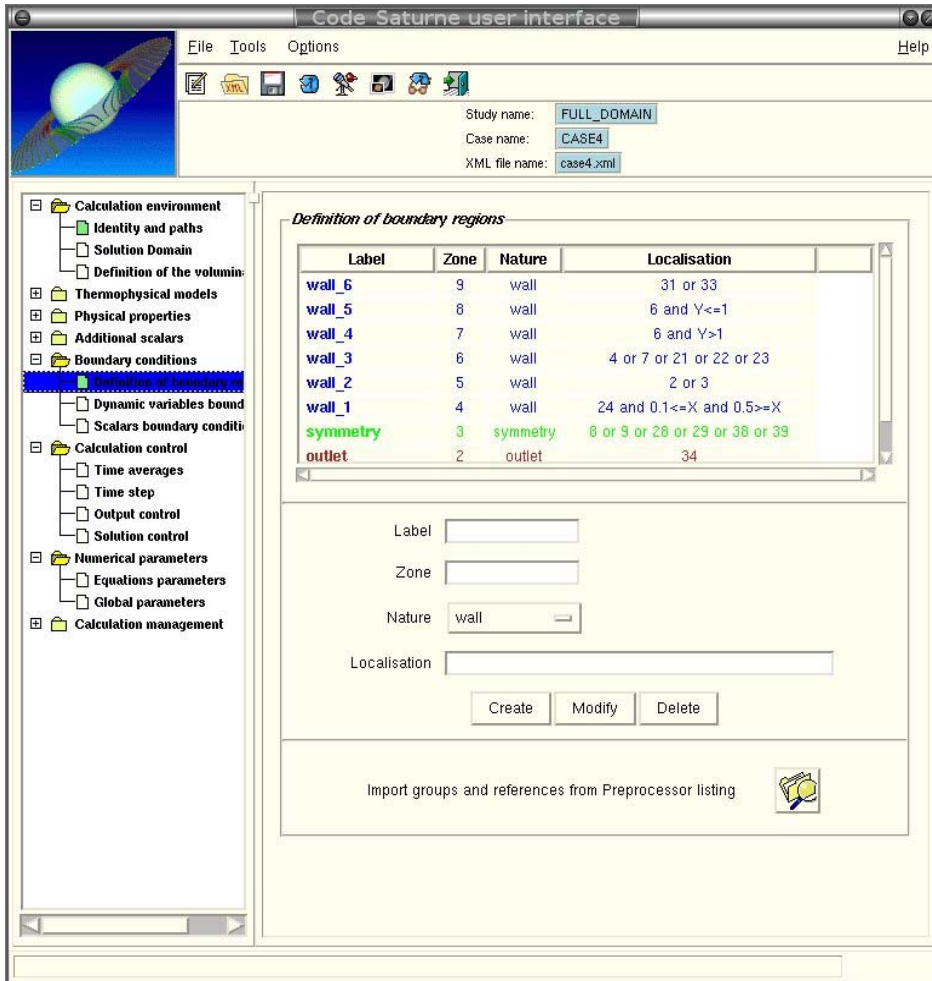


Rotation periodicity: similar but implementation is more complex

- Vectors and tensors rotation required (component coupling)



Environment and documentation



Environment

- Pre-requisite: compilers
 - C (cc, gcc, xlc, icc, ...)
 - FORTRAN (f77, g77, gfortran, frt, f90, xlf, ifort, ...)
- Pre-requisite for parallel computing:
 - MPI: lam, openmpi, MPICH2
 - Metis or Scotch for better load balancing (optional; linked with the Preprocessor)
- Pre-requisite for Graphical User Interface:
 - Python
 - Tcl/Tk, Tix
 - Xml2
- Optional data exchange libraries:
 - MED, HDF5
 - CGNS
- Misc.:
 - Zlib

Documentation

- Quality Assurance
- Online user and programmer's guides
- Support hot-line: saturne-support@edf.fr (no warranty)
- Internet home page:
http://rd.edf.com/code_saturne

3

General capabilities of *Code_Saturne*

Supported meshes

Mesh generators

- **Simail**: easy-to-use, with command file, but no CAD
- **I-DEAS Master Series**: powerful, CAD, no Linux version
- ICEM-CFD, GAMBIT
- IGG-HEXA (NUMECA), Comet-Design (STAR-CCM),
- Harpoon, GMSH...

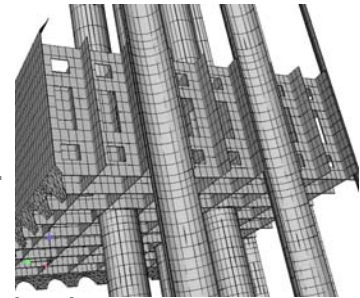


Formats

- Above mentioned mesh generators + MED, CGNS, EnSight Gold...

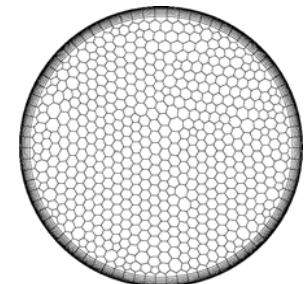
Cells: arbitrary arrangement of polyhedra of any type

- For example: tetrahedra, hexahedra, prisms, pyramids, n-faced polyhedra, ...

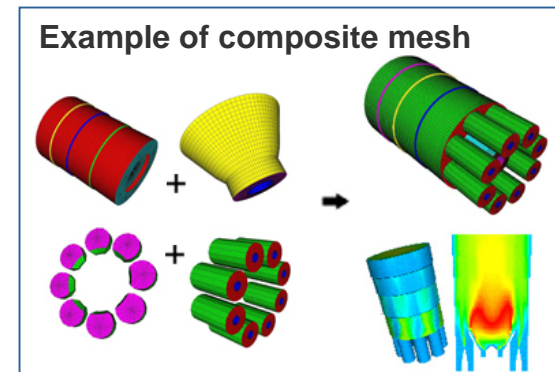
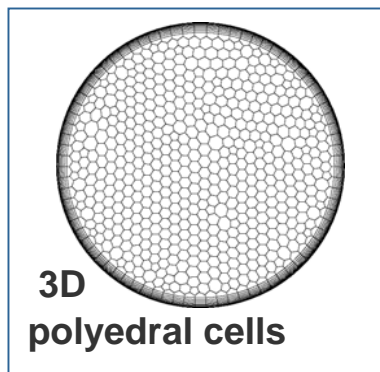
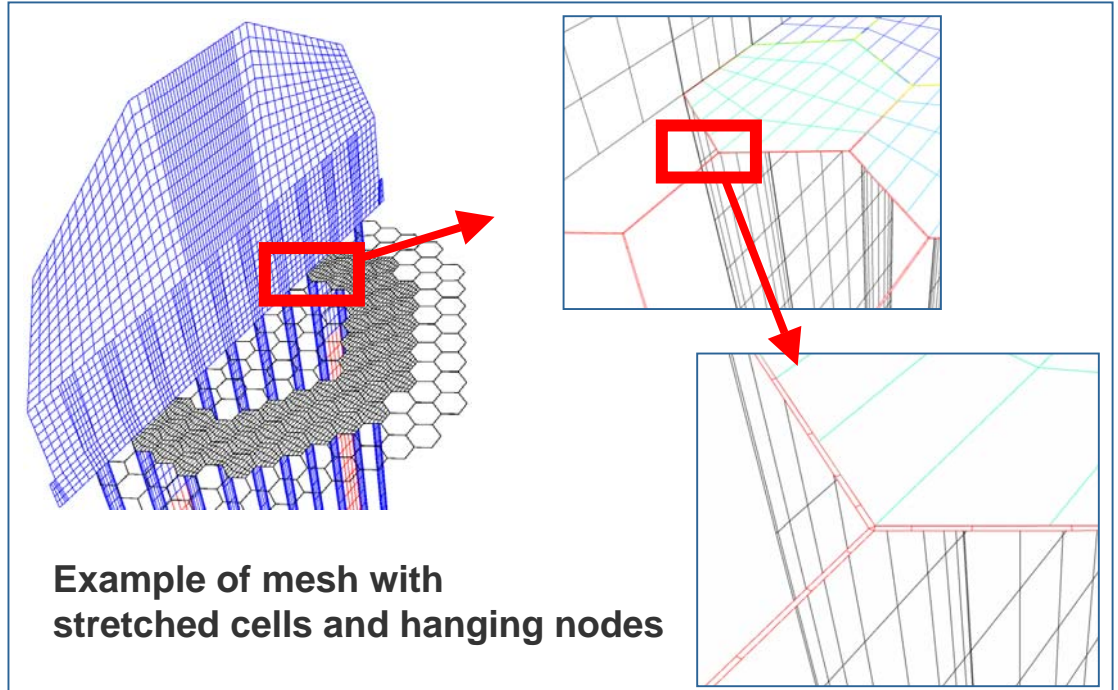
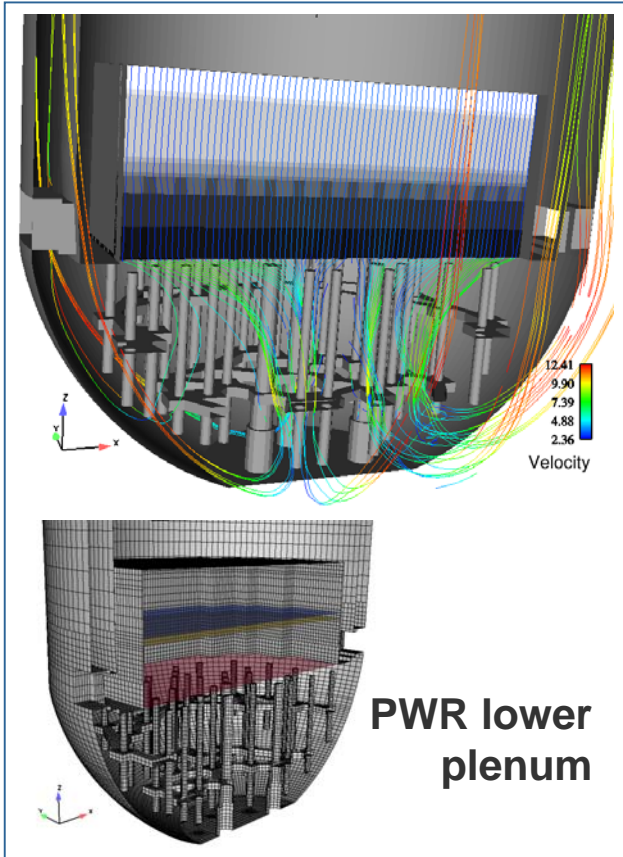


Arbitrary interfaces: « any type of mesh / format » + « any type of mesh / format »

- Meshes may be contained in **one single file or in several separate files**
- **Order of meshes has no influence**
- Arbitrary interfaces can be selected by **mesh references**
- Expertise may be required if arbitrary interfaces are used:
 - in critical regions
 - with LES
 - with very different mesh refinements
 - on curved CAD surfaces



Mesh examples

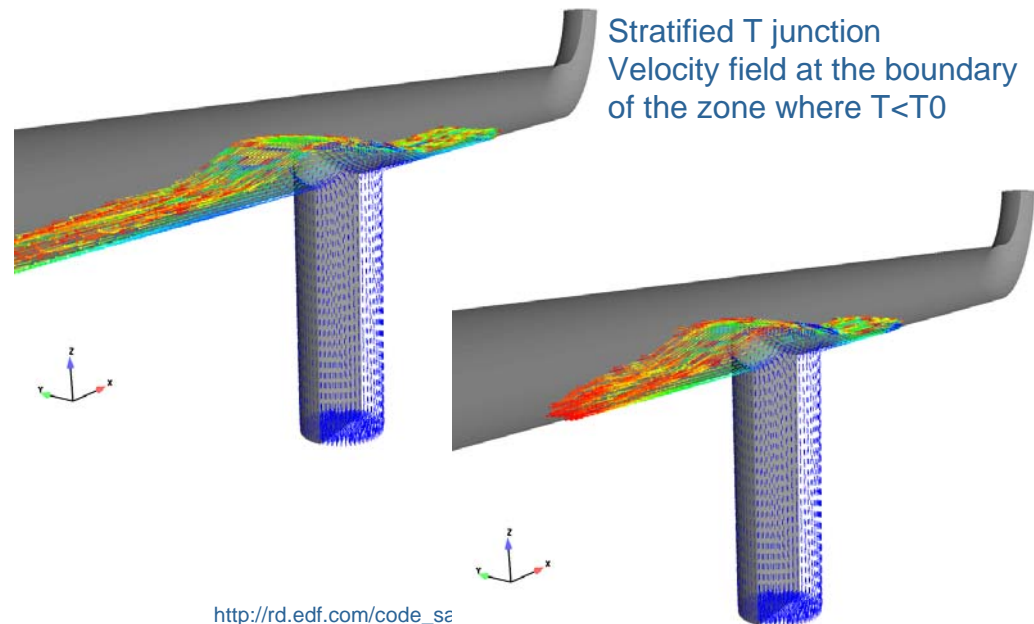
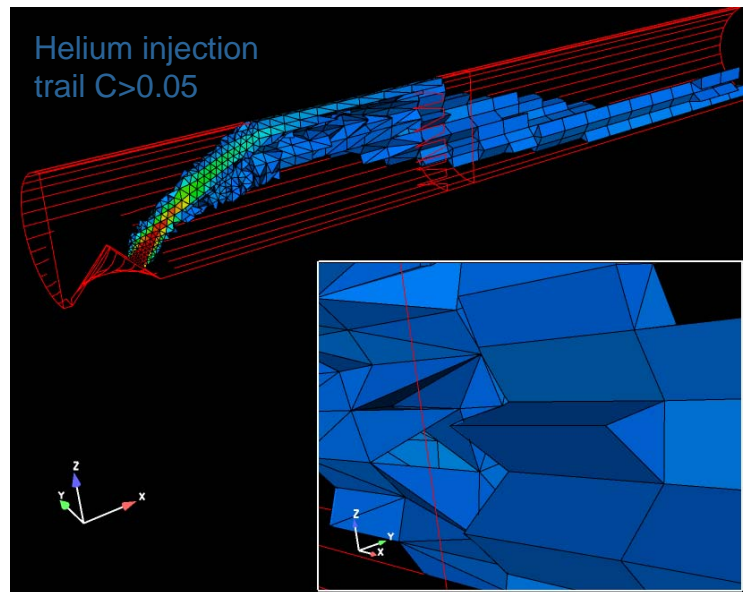


Advanced post-processing capabilities (FVM library)

FVM library capabilities

- fully parallel treatment
- post-processing files written while calculation is running
- optional discard of non-standard polygons or polyhedra
- optional tessellation of non-standard polygons or polyhedra → adaptation to format or post-processing tool features

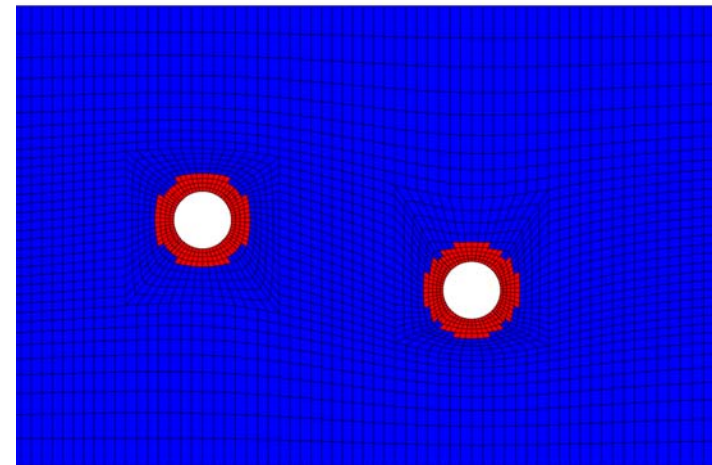
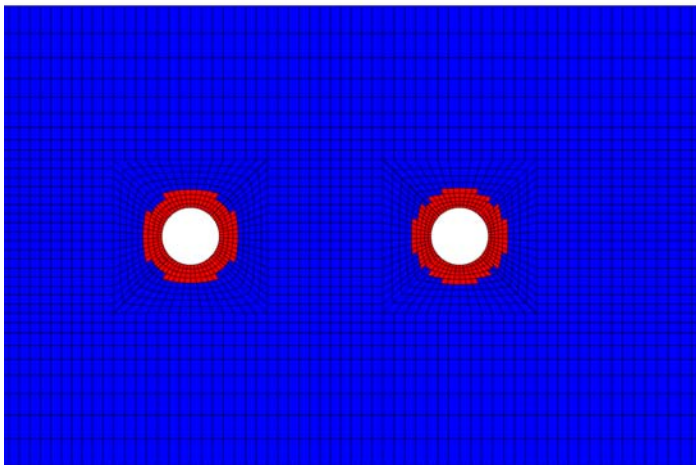
User-defined, time dependent, post-processing meshes and variables



Arbitrary Lagrangian Eulerian method (ALE)

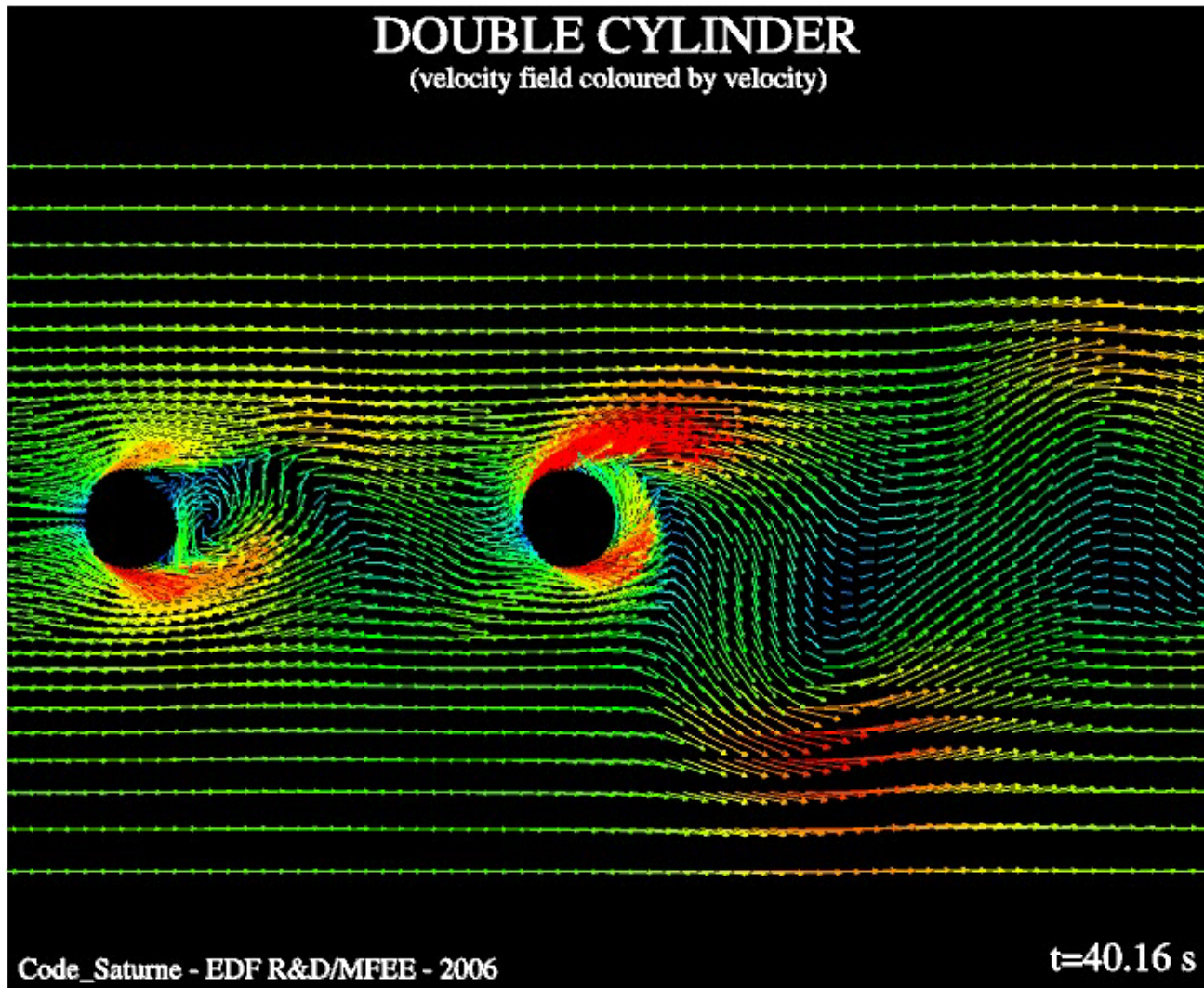
Deformable meshes

- mesh deformation estimated from boundary conditions
- possibility for the user to specify the movement of any node
- internal coupling with user-defined moving structures (frictional spring law)
- external coupling with the structure mechanics tool *Code_Aster*



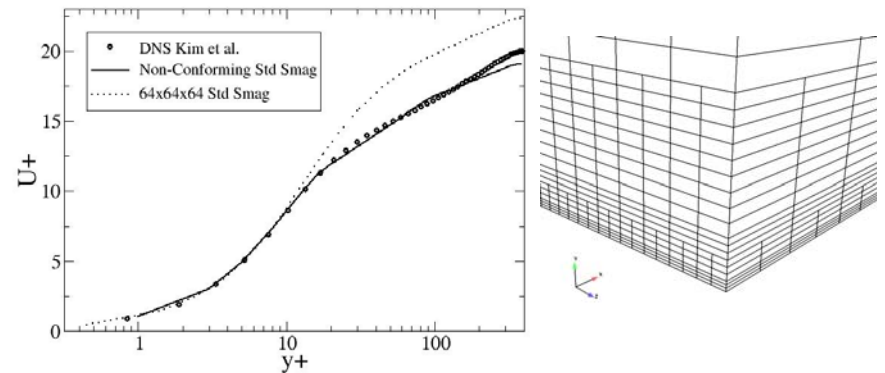
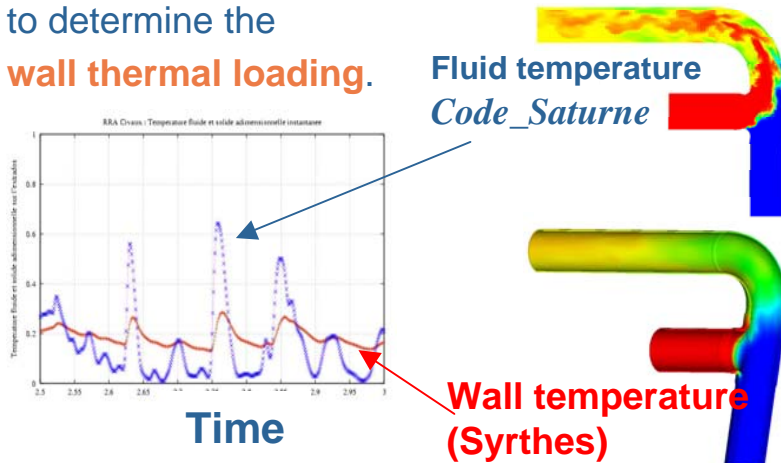
Channel flow with two moving cylinders defined as independent structure with internal coupling (mesh viscosity = 1 (blue) or 10^{10} (red))

Double cylinder flow with ALE internal coupling

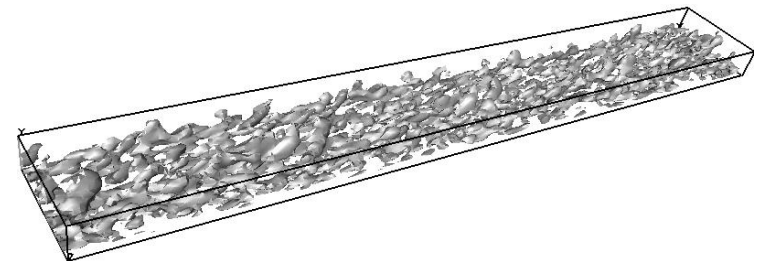


Large Eddy Simulation (unsteady turbulence modelling)

Application example: thermal fatigue
Contrary to classical RANS approaches,
Large Eddy Simulation
allows to represent the
large structures of the flow, and,
by **thermal coupling** with the structure,
to determine the
wall thermal loading.



Wall refinement with hanging nodes



Synthetic turbulence method at inlet

Dynamic model (with filter requiring no homogeneous direction)

Wall treatment: refinement with hanging nodes or wall functions

Synthetic turbulence (for inlet and coupling with RANS)

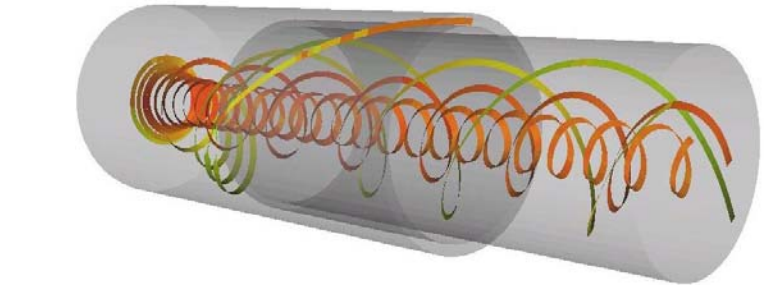
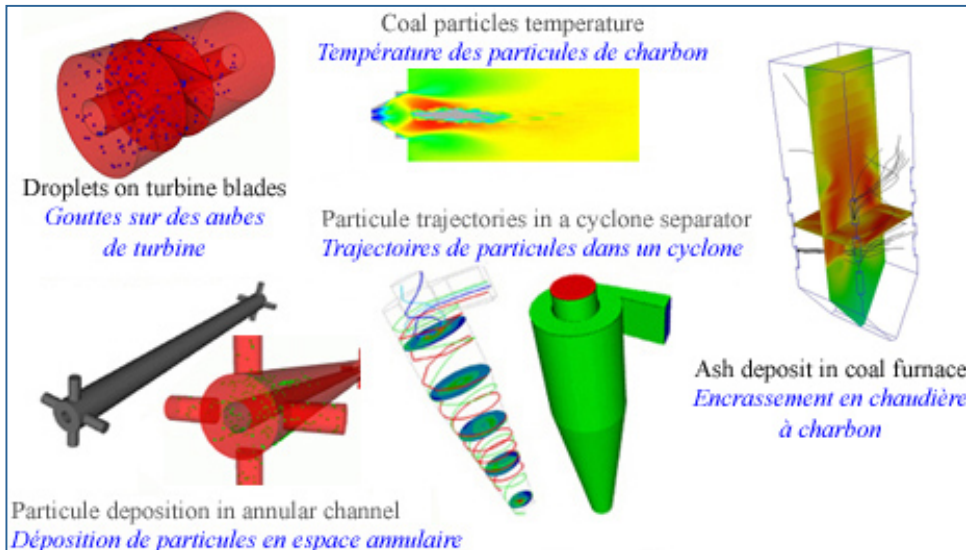
Lagrangian modelling for multi-phase flows

Generally used to obtain refined statistics on a dispersed phase

Stochastic modelling with 2-way coupling (momentum, heat, mass)

Some applications:

- particle trajectories in cyclone separators
- resident times and combustion in polydispersed pulverised coal furnaces
- impact phenomena (turbine blades)
- deposit, slagging and fouling (PWR heat exchangers, coal furnaces...)



Ashes
 $D_{50} = 40\mu\text{m}$

Pollutant prediction in Gas Turbine

Rio-Bravo 495 MW Turbine

constructor data

measurements

CFD complements or replaces data that turn out to be difficult to obtain

Pollutant prediction
(Nox)



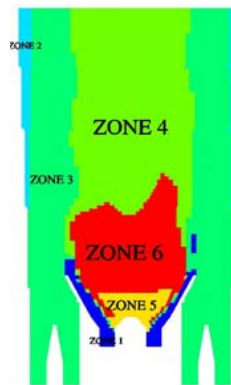
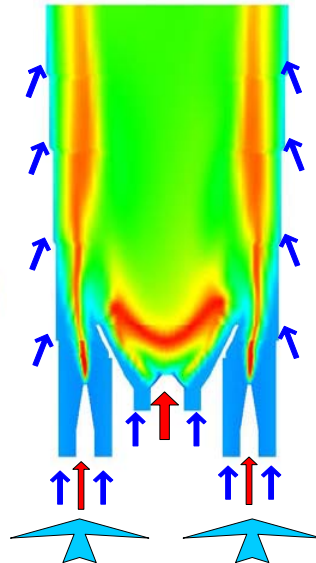
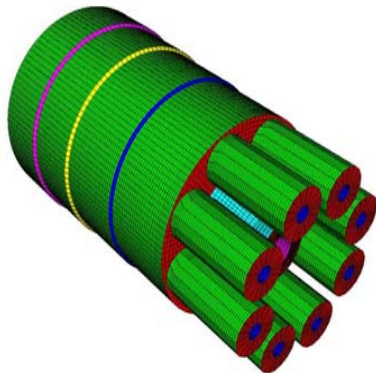
3D computation

Film cooling, swirled inlet

EBU combustion model

Refined chemical analysis

In zones defined from T and f

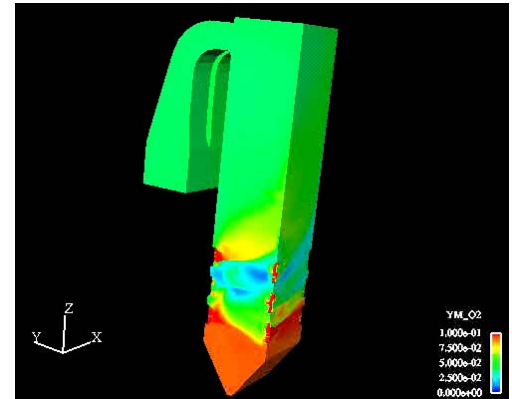
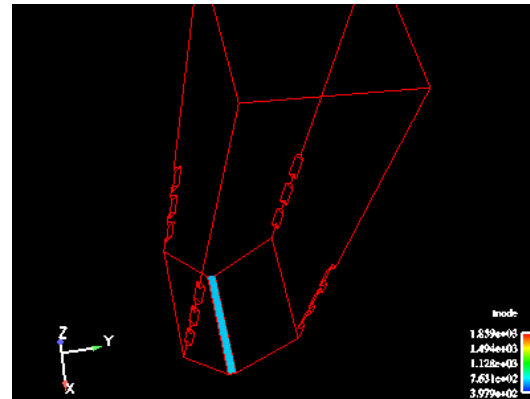
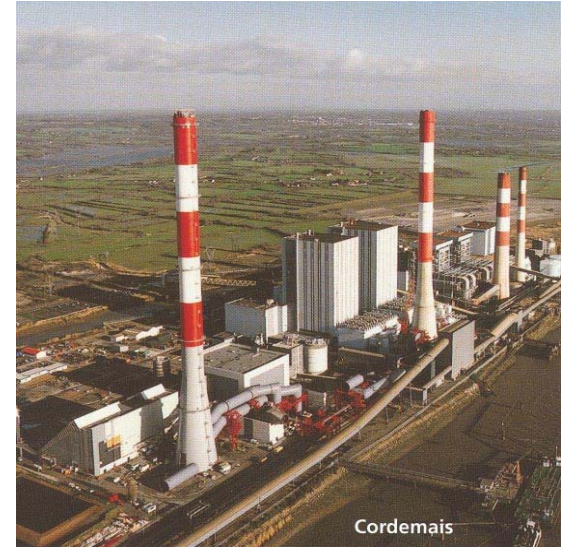
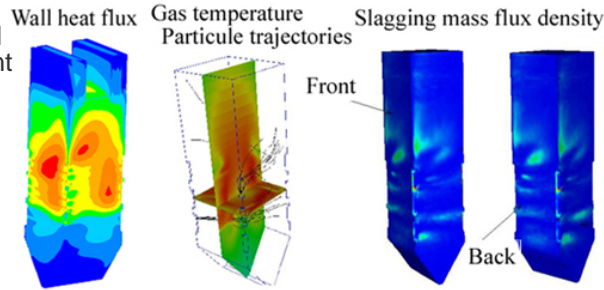
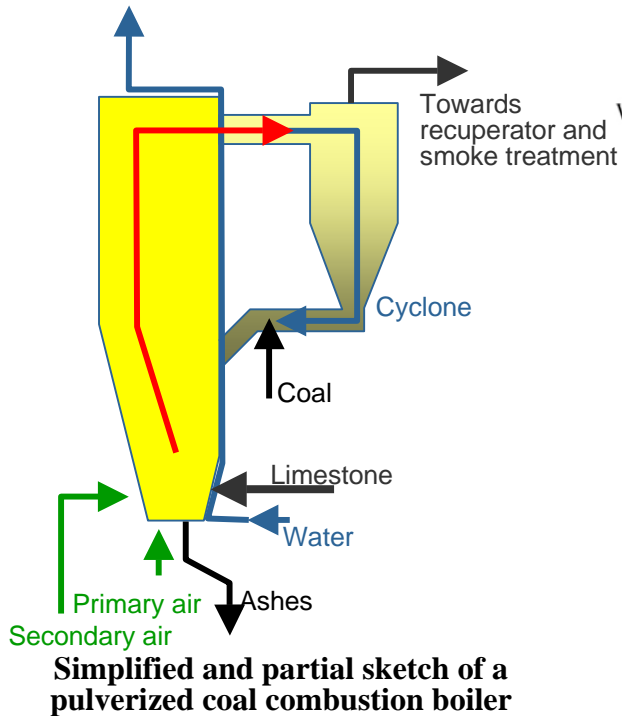


Pulverised coal combustion

Nox, slagging and fouling, flame stability, temperature peaks

3D modelling + refined chemical analysis

⇒ optimization of maintenance and performance



Glass furnace

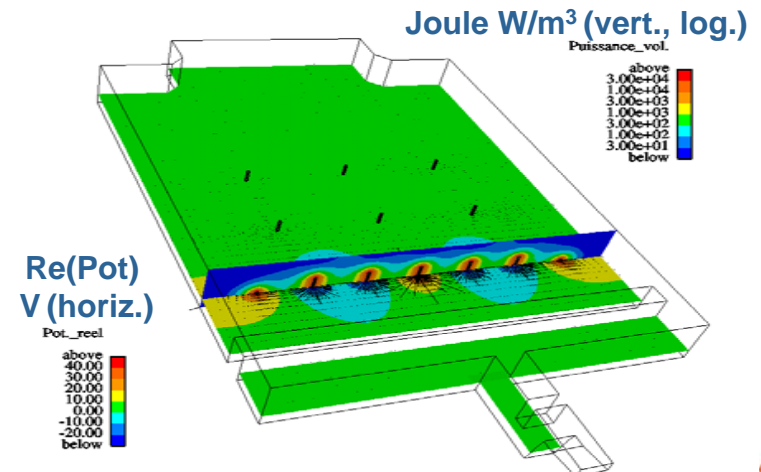
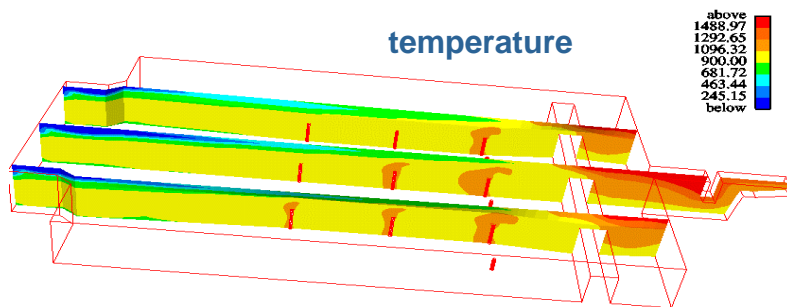
Joule effect

Use of constant complex potential to account for tri-phase alternating current

Offset effect accounted for

Strongly variable physical properties, especially viscosity

Specific pressure-velocity coupling to support large time steps



Electric arcs applications

Applications

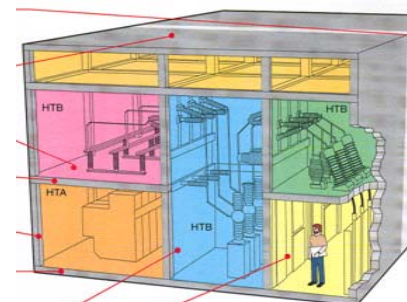
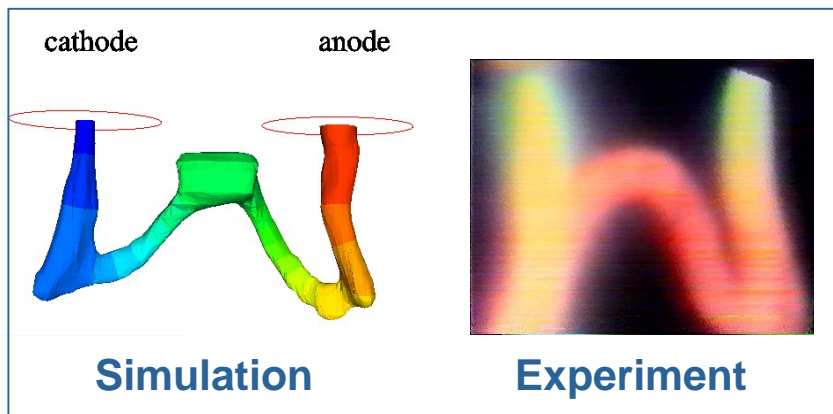
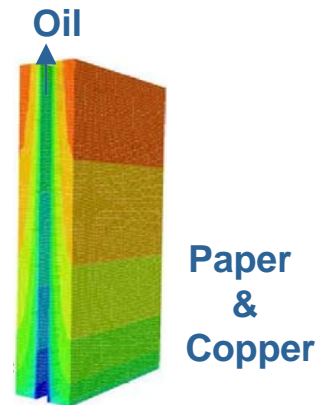
- Temperature peak in electric transformers
- Combustion/Vitrification of radioactive waste (medium activity, long life)
- Arc default effect in closed posts

Phenomena

- Joule effect and Laplace forces
- Radiative heat transfer

Difficulties

- Strong source terms: 28 MJ on tube 1,7 m long and 10 cm diameter
- Unsteady phenomena: 2 arcs 20kA, 1300 V during 500 ms
- Variable physical properties: temperature from 300 to 30000 K



Effect of arc default



Specific physics under development

Heavy fuel oil combustion

- available in version 1.3.1
- out of validation scope

Ionic mobility

- PhD thesis
- more work to be done

Fire driven flows

- more precise 3D approach with respect to zonal codes
- developments scheduled for 2008

Thermal fluide-structure interaction

Conjugate heat transfer, radiative transfer

Coupling with thermal code **Syrthes**

Storage

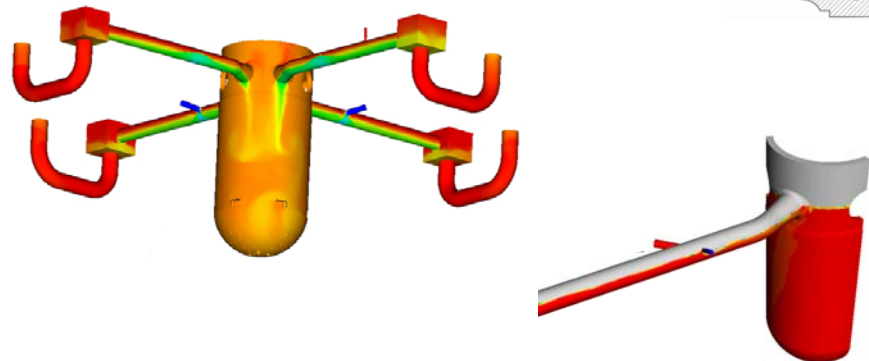
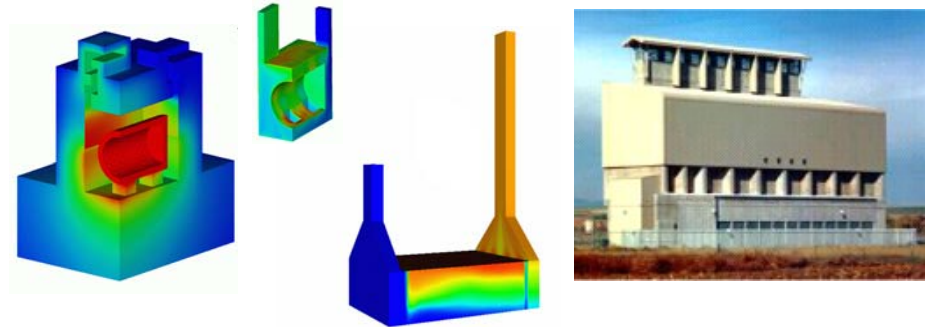
- design expertise

Valve numerical qualification

- thermal shock experiments

PWR vessel life time (LOCA)

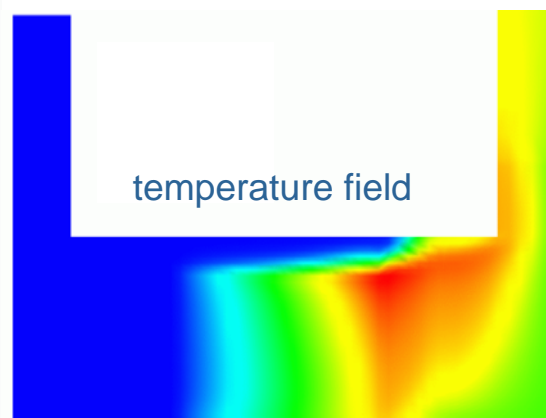
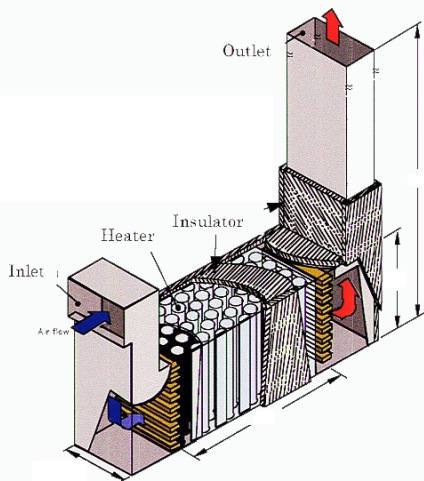
- refined and local thermal-hydraulic coupled approach



Matisse engineering module

Numerical tool for the design of nuclear waste storage facilities

- Integrated *Code_Saturne* module aimed at engineering needs
- No user subroutine needed
- Parametric mesh creation controlled by GUI (generic shape) with Simail tool
- Homogeneous approach for the calculation of the flow



Interface utilisateur de Code_Saturne

Echier Outils Options Aide

Nom de l'étude : CRIEPI3D
Nom du cas : CAS1
Nom du fichier XML : cas1.xml

Géométrie de l'entrepôt

4	Epaisseur des registres/cloisons amont et aval	0.147	m
5	Epaisseur des cheminées	0.4	m
6	Jeu amont entre cheminée/registre	0.25	m
7	Nombre d'éléments entre cheminée/registre amont	4	
8	Jeu entre registre amont/conteneurs	0.35	m
9	Nombre d'éléments entre registre amont/conteneurs	5	
10	Jeu entre conteneurs/registre aval	0.35	m
11	Nombre d'éléments entre conteneurs/registre aval	5	
12	Jeu aval entre registre/cheminée	0.25	m
13	Nombre d'éléments entre registre aval/cheminée	4	
14	Hauteur du convergent	1.8	m
15	Rapport du convergent	1.0	m
16	Hauteur de la cheminée d'alimentation	2.785	m
17	Hauteur de la cheminée d'évacuation	10.0	m
18	Hauteur au bord du toit	15.0	m
19	Hauteur du faite du toit	20.0	m
20	Nombre de couches d'éléments du ciel d'entrepôt	20	
21	Pas transversal du réseau de conteneurs	0.15	m
22	Nombre de pas d'espace transversal	4	
23	Nombre d'éléments par pas transversal	2	
24	Facteur de réduction transversal du module/réel	1.0	
25	Pas longitudinal du réseau de conteneurs	0.13	m
26	Nombre de pas d'espace longitudinal	11	
27	Nombre d'éléments par pas longitudinal	2	
28	Epaisseur d'une couche d'éléments (zone stockage)	0.0452	m
29	Nombre de couches d'éléments dans la zone stockage	28	
30	Diamètre des conteneurs	0.1	m

Cooling towers engineering module

Plumes

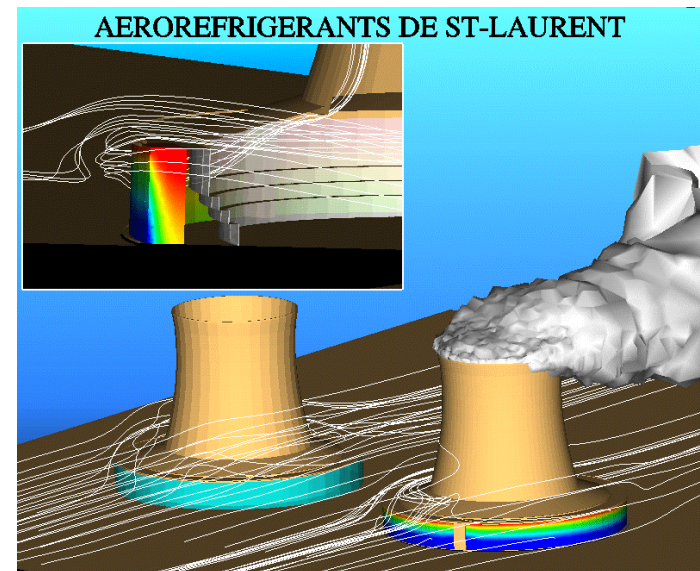
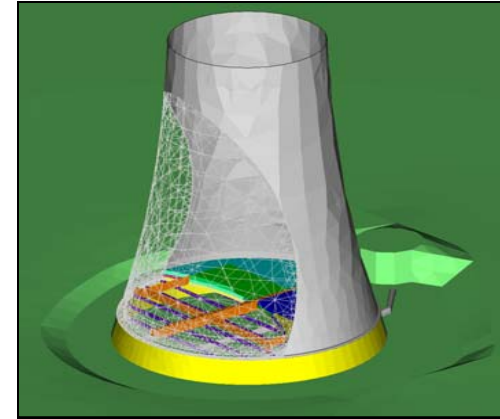
- natural convection

Fans and packing

- turbulence, head losses, forced convection

Rain-zones and frost

- 2-phase flows with heat and mass transfer



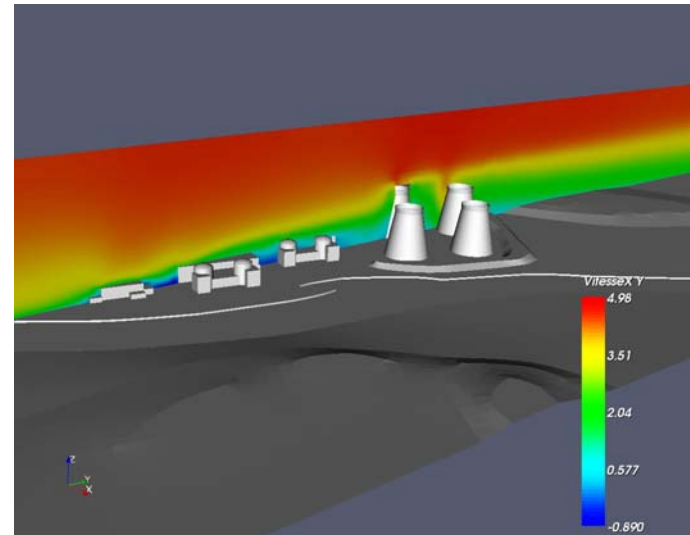
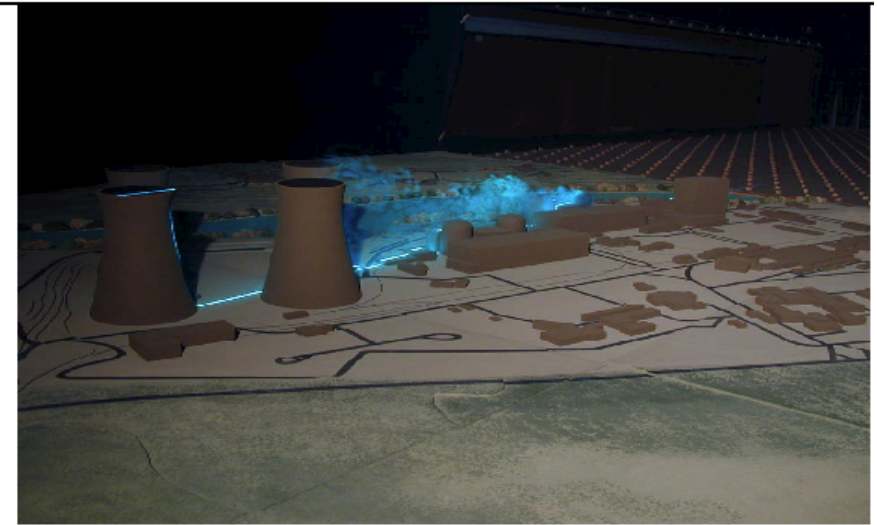
*Mercur*_Saturne for atmospheric flows

Specific models

- boundary conditions
- atmospheric boundary layer
- hydrostatic pressure
- radiative source terms
- micro-physics and chemistry of pollutants

External derived version

- based on *Code_Saturne*
- currently being transferred in the standard version of *Code_Saturne*



Coupling of *Code_Saturne* with itself (under development)

Objective: coupling of several overlapping computational domains

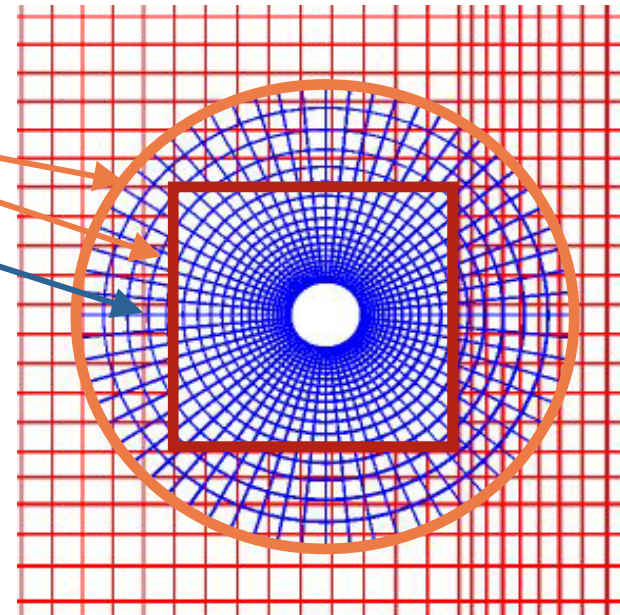
- **RANS/LES coupling** for turbulence → averaged RANS method in most part of the domain and unsteady LES zoom in specific areas
- **Fluid/structure interaction** with large displacement (unreachable to ALE)

Two kinds of communications needed

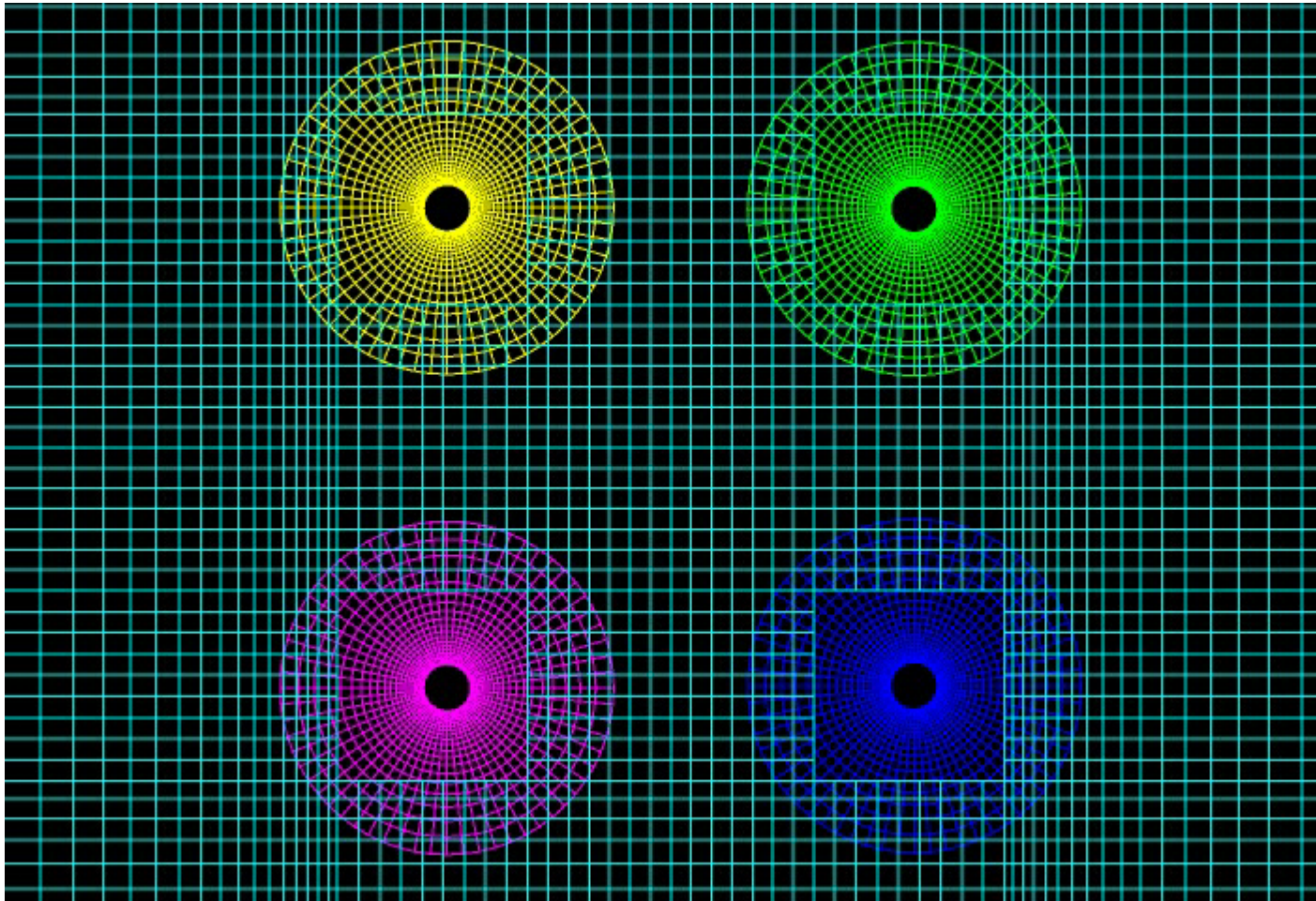
- Data exchange at the boundaries
- Volumic forcing on the intersecting domains

Main issues to be tackled

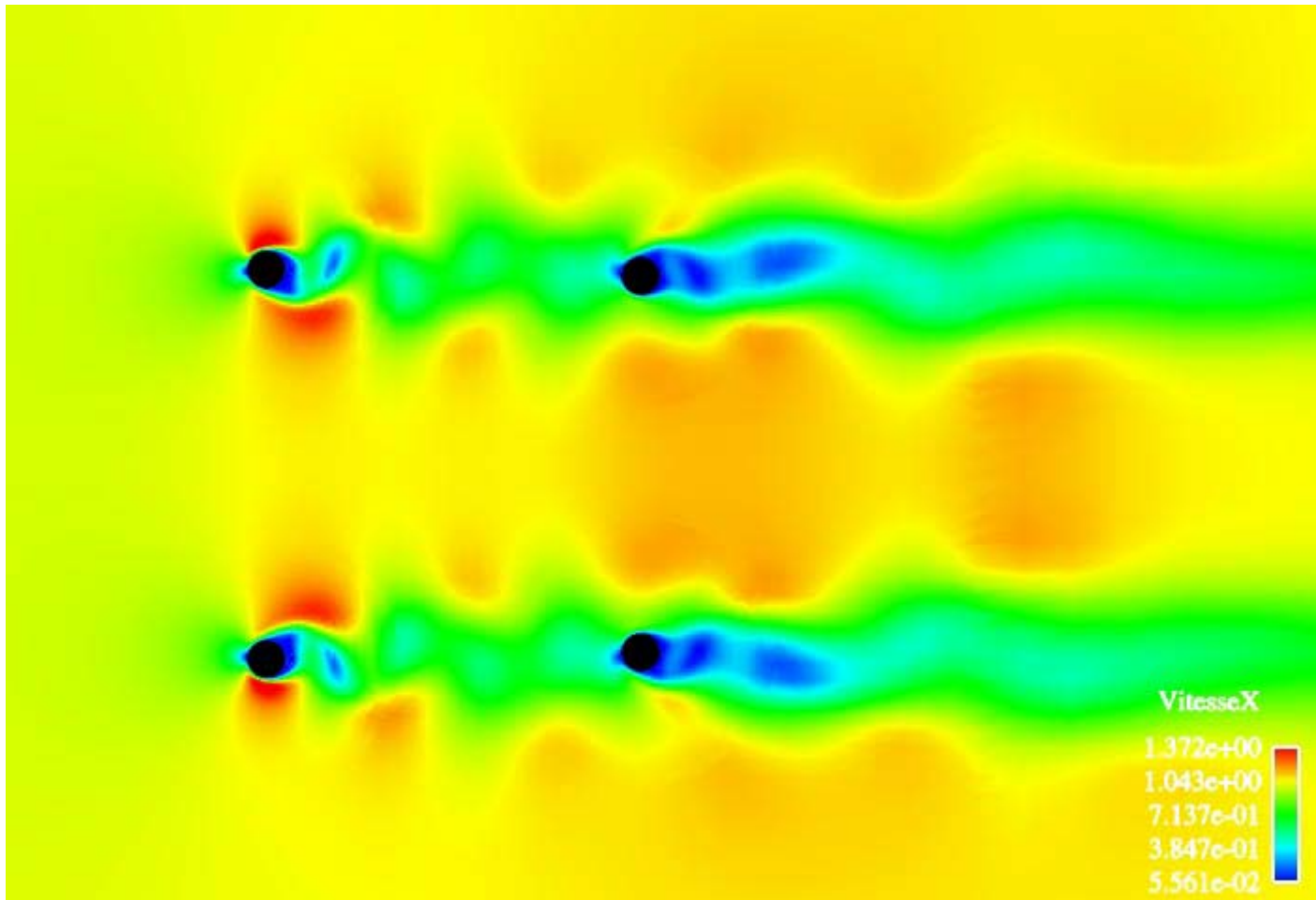
- Conservativity at the interfaces
- Volume/volume intersection for volumic source terms
- Physical coupling when different physical models in each domain



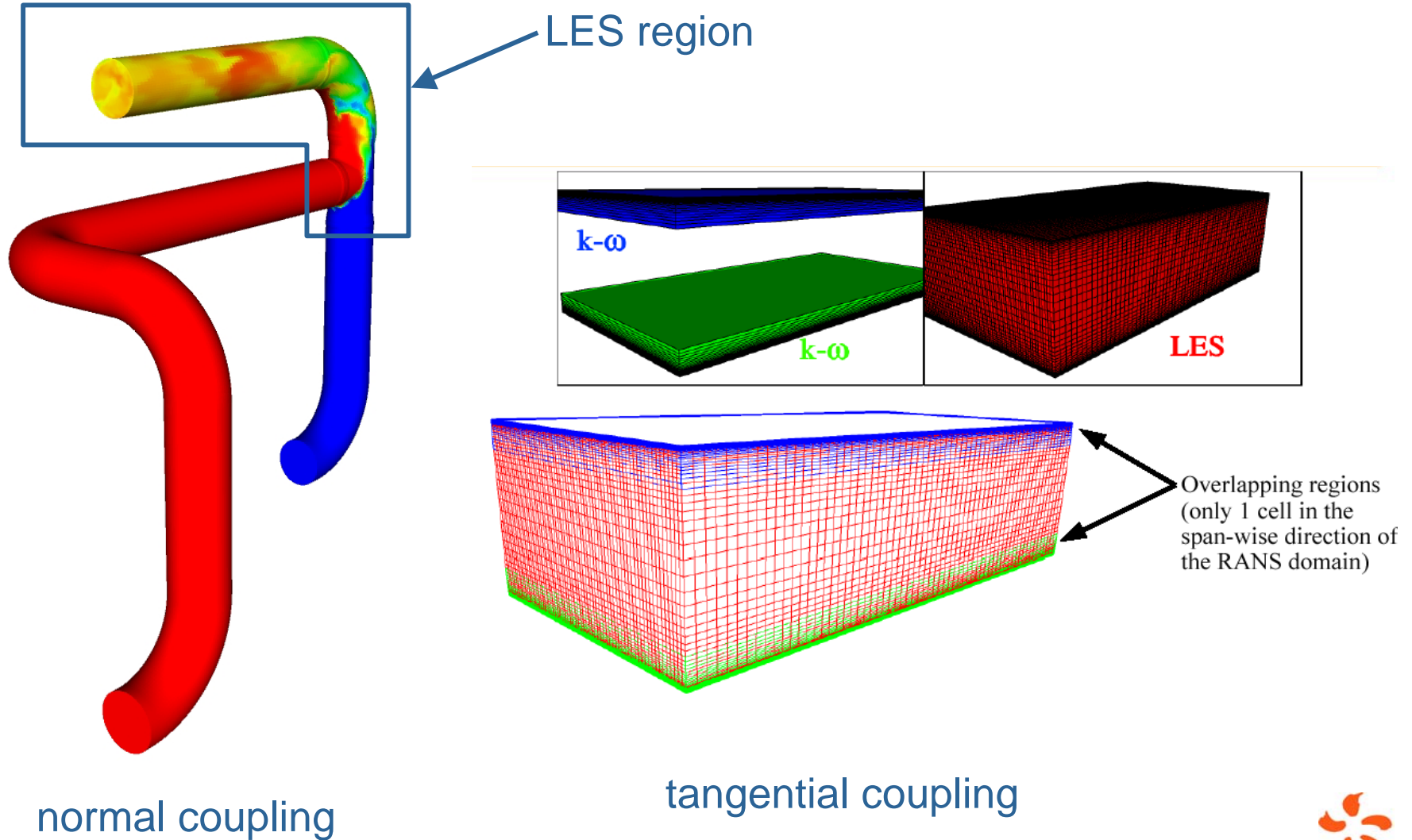
Chimera method: FSI for tube bundle configuration



Chimera method: FSI for tube bundle configuration



RANS/LES coupling



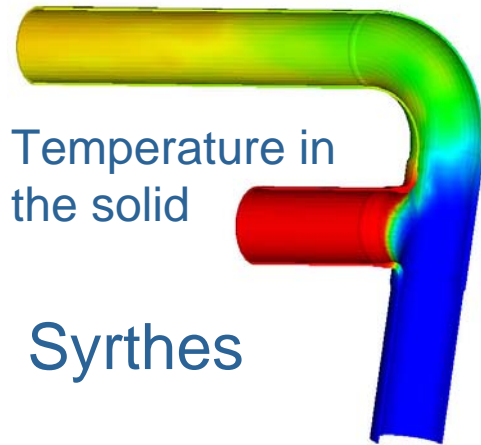
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Examples of industrial applications of *Code_Saturne*

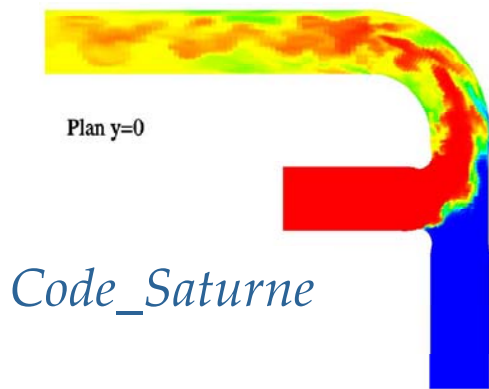
Thermal fatigue in mixing zones

Modelling

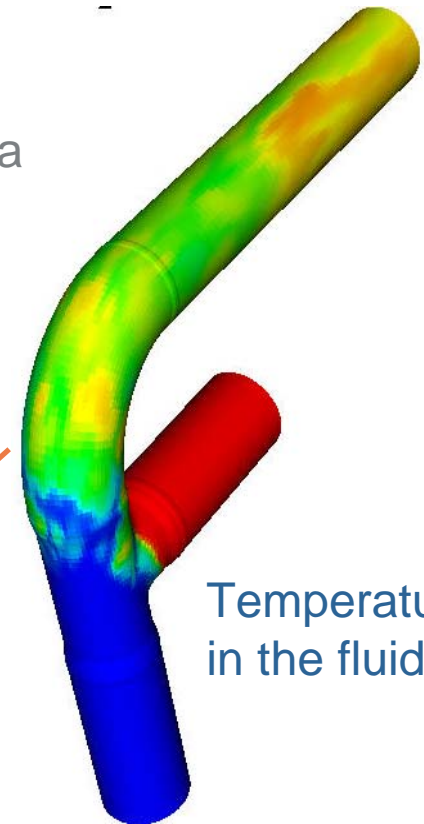
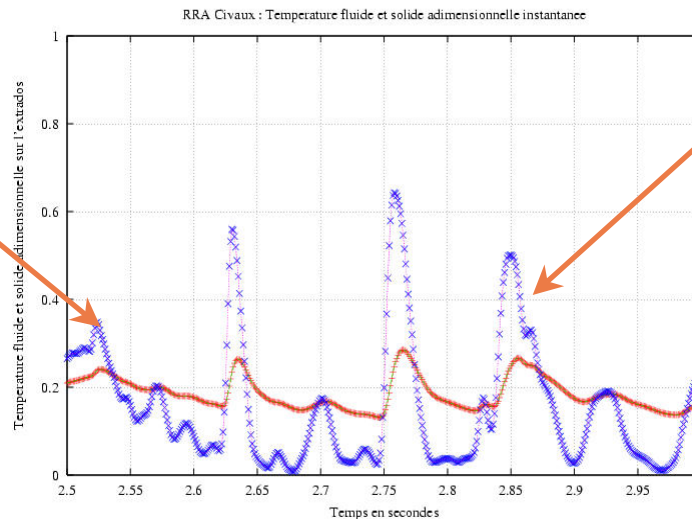
- LES unsteady turbulent modelling in the fluid
- coupling with Syrthes for solid temperature
- thermal fields used as input data for structure mechanics calculations



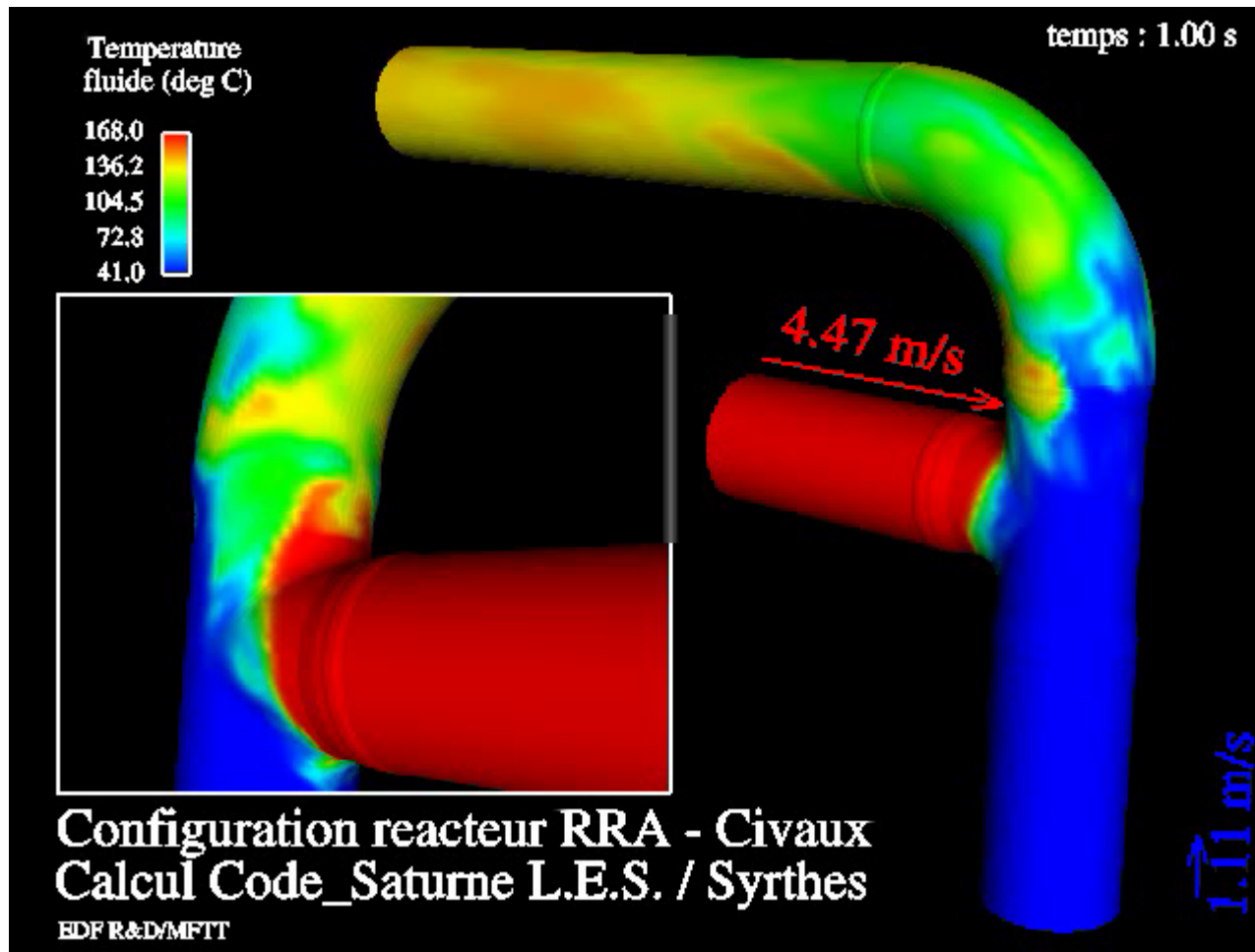
Syrthes



Code_Saturne

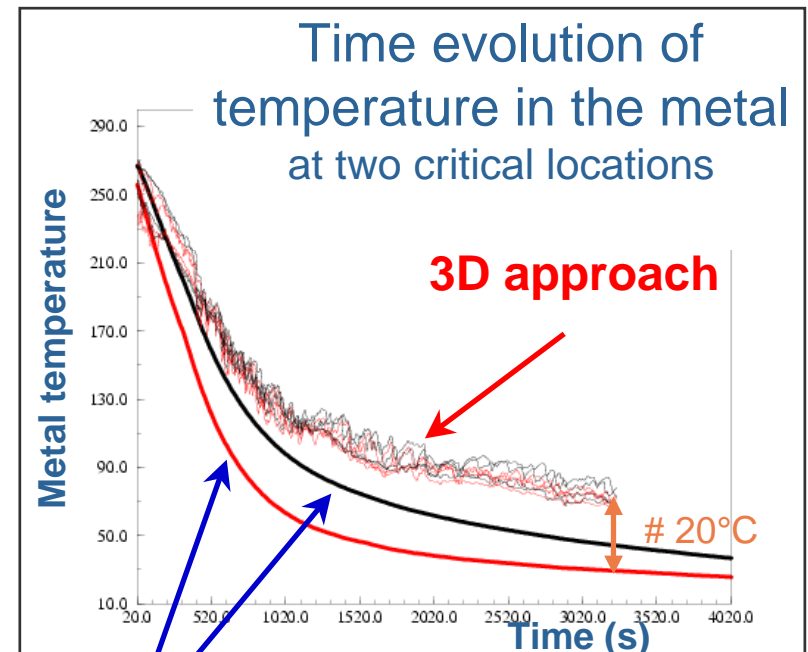
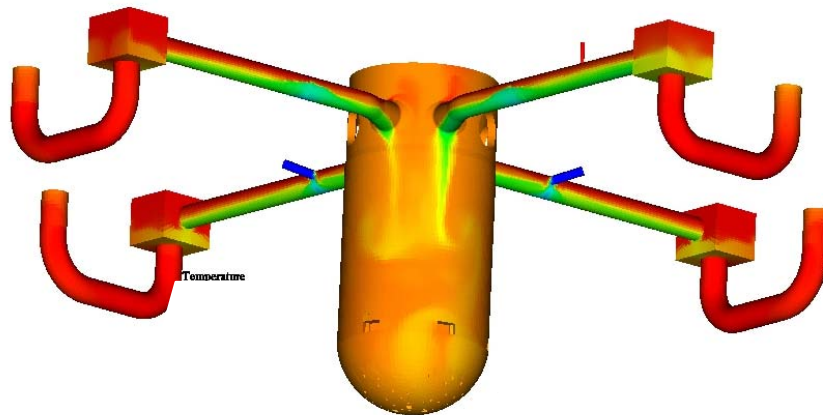


Thermal fatigue in mixing zones



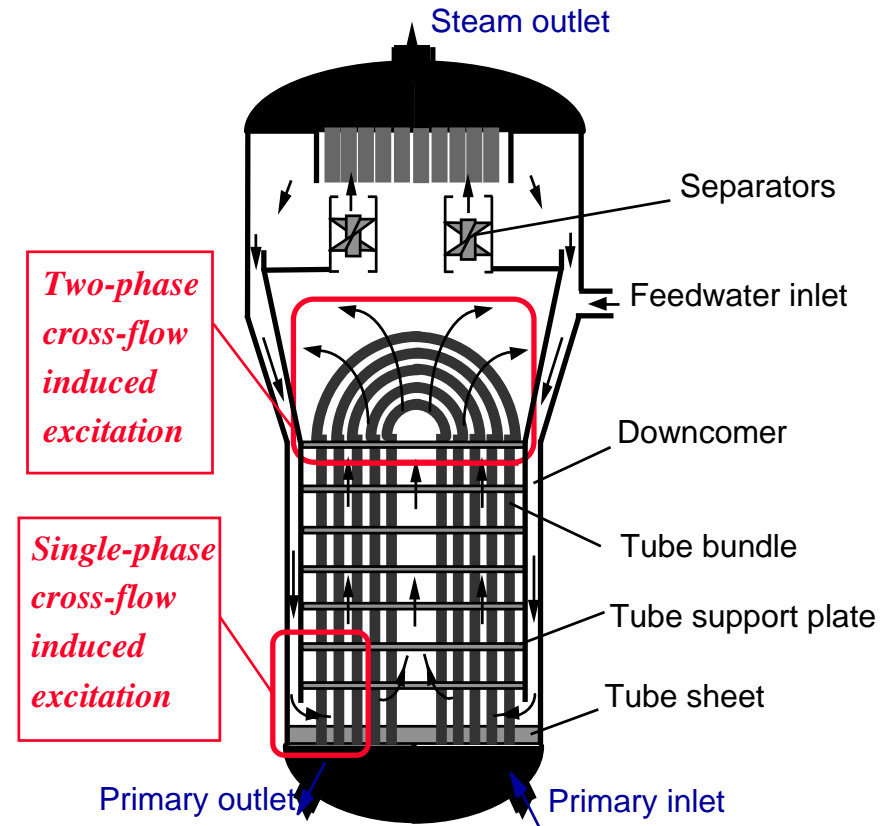
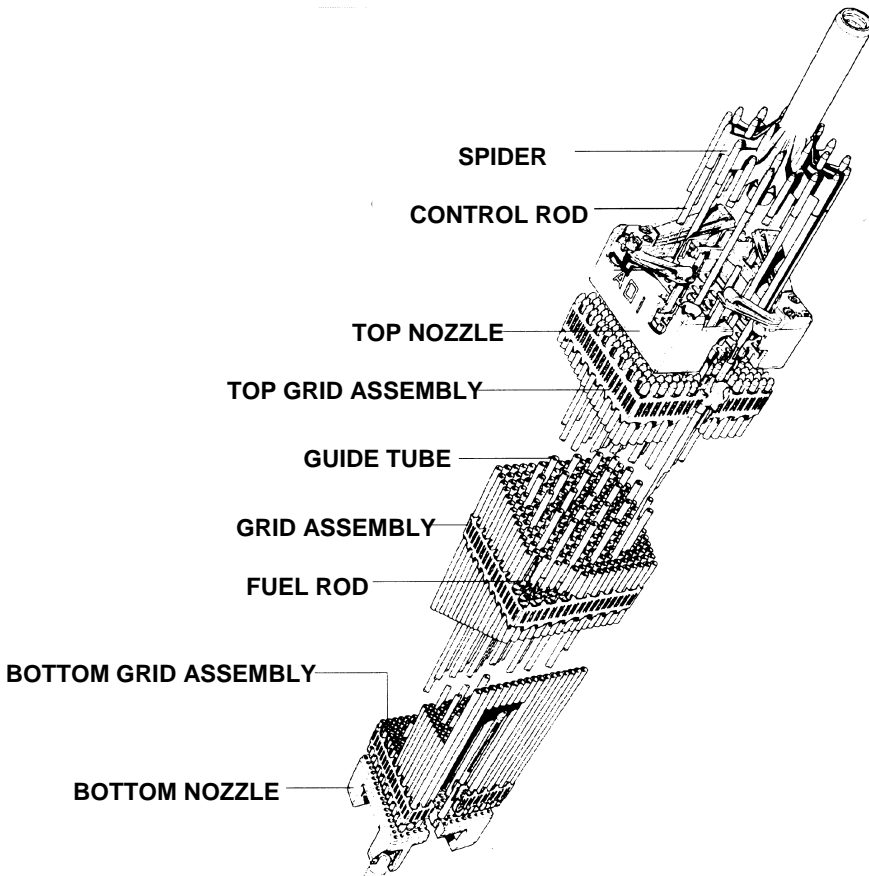
Thermal shock on PWR vessel under LOCA

Better prediction of thermal shock in cas of loss of coolant accident using 3D simulation instead of 1D experimental correlations



1D approach

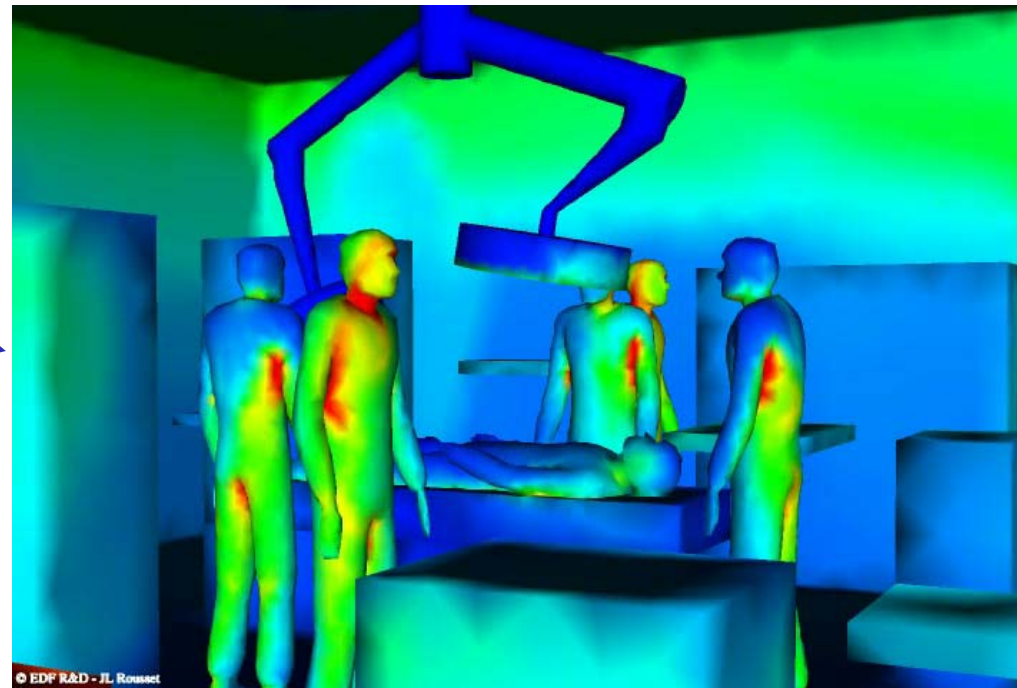
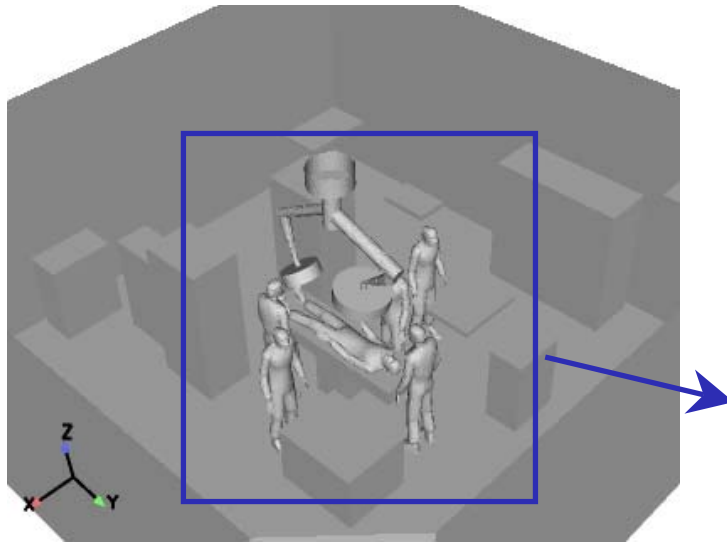
Fluid/structure interaction



Vibration wear of fuel assemblies

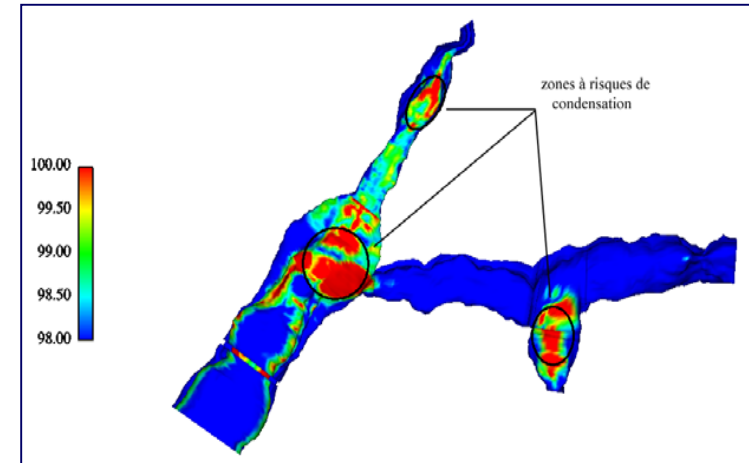
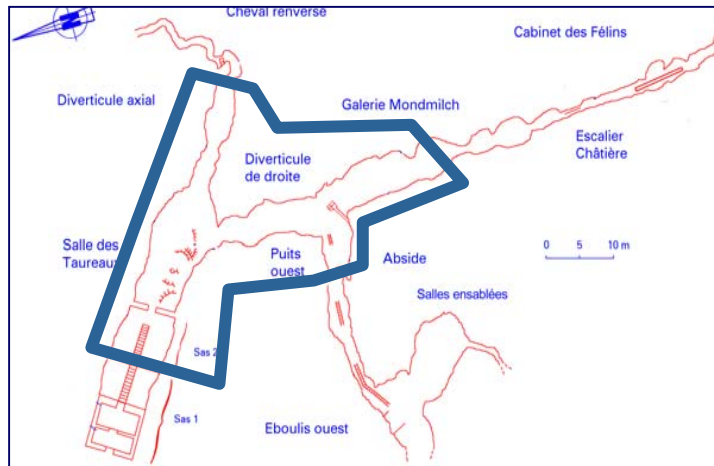
Vibration of tube bundles in Steam Generators

Air quality in operating theaters

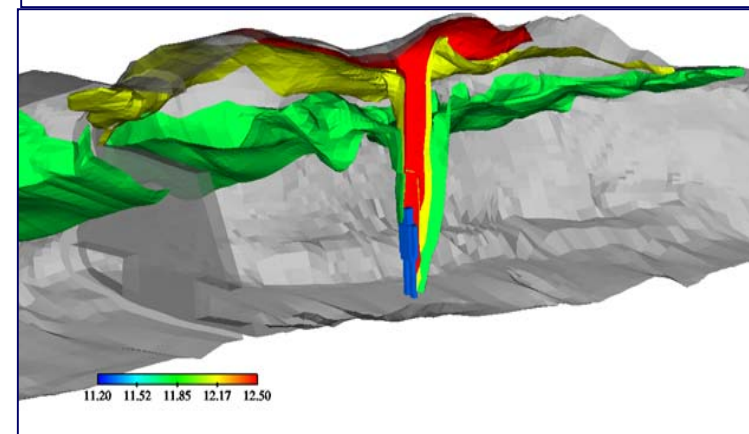


Preservation of the Lascaux cave

Aeraulics, thermal and hydric transfers



Salle des Taureaux Diverticule Axial
Collaboration with French Ministry of Culture



5

Code_Saturne is open source

Users and partners

Open source distribution of beta version 1.3 since march 07

download available from the edf.com website

EDF R&D (70 users)

- › Nuclear thermal-hydraulic applications
- › Combustion (coal furnaces, gaz turbines...)
- › Thermal loading
- › Fluid-structure interaction
- › Valves
- › Acoustic
- › Cooling towers
- › Heat pumps
- › Aeraulics (health and safety, environment...)
- › Atmospheric environment
- › Salome project
- › Electric arc, plasma, ionic transport
- › Glass furnace

EDF DIN SEPTEN

- › EDF Basic Design Department: fossil-fired furnaces and nuclear plants

Outside EDF [France, UK, Poland, China, Algeria]

- › **CEA le Ripault** (arc and plasma)
- › **CEA Saclay, CEA Grenoble**
- › **CEREA** (atmospheric)
- › **CETIM** (algorithm)
- › **CS-SI** (code coupling)
- › **ENSTA, ENPC**(teaching)
- › **ENSIL** (arc and plasma)
- › **IMF Toulouse** (multiphase, FSI)
- › **LCD Poitiers** (combustion)
- › **LEA, LET Poitiers** (turbulence)
- › **LMM Paris 6** (LES, atmospheric)
- › **ONERA** (electric arcs)
- › **TPRI China** (combustion)
- › **TREFLE, U. Bordeaux** (algorithm)
- › **U. Manchester UK** (turbulence)
- › **UST Lille** (FSI)
- › **UST Oran Algeria** (turbulence, LES, FSI)
- › **UT Gliwice Poland** (combustion)
- › **Valeo** (acoustic)

Why go open source?

Ease up the collaboration process

- No contract, collaboration agreement, nor non-disclosure-agreement to sign before giving the sources
- Simplicity for any potential partner to test *Code_Saturne*

Enlarge the user community and the range of applications

- Better national and international recognition of *Code_Saturne*
- Larger feedback and better validation of *Code_Saturne*
- Provide industry with a open software

Enlarge the developer community

- Capitalise in *Code_Saturne* the work and knowledge of partners
- External involvement in the *Code_Saturne* support
- External developers to support the EDF development team
- External developers to provide their own developments on their own applications

Coherent with EDF's open source strategy

- *Code_Aster*, Salome platform, OpenTurns, ...

Code_Saturne open source practical info

Distribution of *Code_Saturne*

- **GPL licence**, auxiliary libraries (BFT and FVM) under LGPL licence
- Download page http://rd.edf.com/code_saturne (temporary page but permanent address)
- Downloadable versions:
 - 1.3.f beta version
 - 1.3.0 used for validation since july 2007
 - 1.3.1 corrected version currently available on web site
 - 1.3.2 fully validated version in january 2008

Contact and support around *Code_Saturne*

- Contact and support address **saturne-support@edf.fr** (no warranty on availability of support)
- Annual User's Club meeting in November/December in Chatou (78)
- To appear in the mailing list → saturne-support@edf.fr
- **Initial training sessions** in march and november (but not for free!)

External development integration

- Any useful external contribution welcome
- For easier licence management, any contribution given for integration will be under EDF's copyright
- Contributors will be clearly mentioned in the author's list
- *Code_Saturne* is a trademark property of EDF



Présentation du module Arc Electrique de Code_Saturne®

*Clarisse Delalandre, EDF R&D, Département MFEE (Mécanique des Fluides Energie Environnement)
6 quai Watier 78400 Chatou*

mardi 8 janvier 2008

Association Arc Electrique : *Présentation du module ARC de Code_Saturne®,*

Clarisse Delalandre, EDF R&D 

Equations de base résolues dans Code_Saturne®

• Continuité
$$\frac{\partial \rho}{\partial t} + \text{div}(\rho \vec{U}) = 0$$

• Quantité de mouvement
$$\frac{\partial \rho \vec{U}}{\partial t} + \text{div} [\rho \vec{U} \cdot \vec{U}] = - \text{grad } p + \text{div } \vec{\tau} + \rho \vec{g} + \boxed{\vec{J} \times \vec{B}}$$

Force de Laplace

• Bilan en énergie
→ Enthalpie
$$\frac{\partial \rho h}{\partial t} + \vec{\nabla} \cdot (\rho h \vec{U}) = \vec{\nabla} \cdot \left(\frac{\lambda}{C_p} \vec{\nabla} h \right) + \boxed{\vec{J} \cdot \vec{E}} + S_{rad}$$

Effet Joule

Terme source radiatif

Equations de base résolues dans Code_Saturne®

Équations de Maxwell

$$\vec{\nabla} \cdot \vec{B} = 0 \quad \rightarrow \quad \vec{B} = \vec{\nabla} \times \vec{A}$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$$

$$\vec{\nabla} \cdot \vec{E} = 0$$

$$\vec{\nabla} \times \vec{E} = 0$$

$$\vec{E} = -\vec{\nabla} Pot$$

$$\vec{J} = \sigma \vec{E}$$

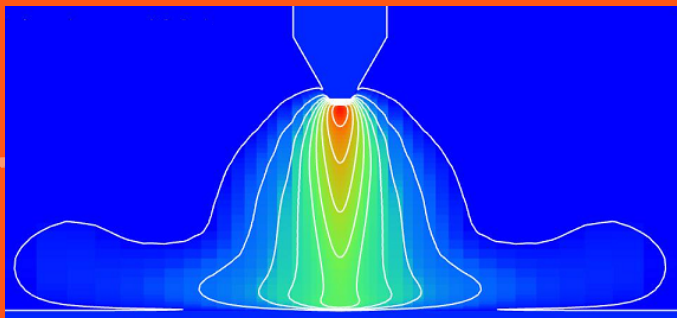
$$\vec{\nabla} \cdot \vec{J} = 0$$

$$\Delta \vec{A} = -\mu_0 \vec{J}$$

$$\vec{\nabla} \cdot (\sigma \vec{\nabla} Pot) = 0$$

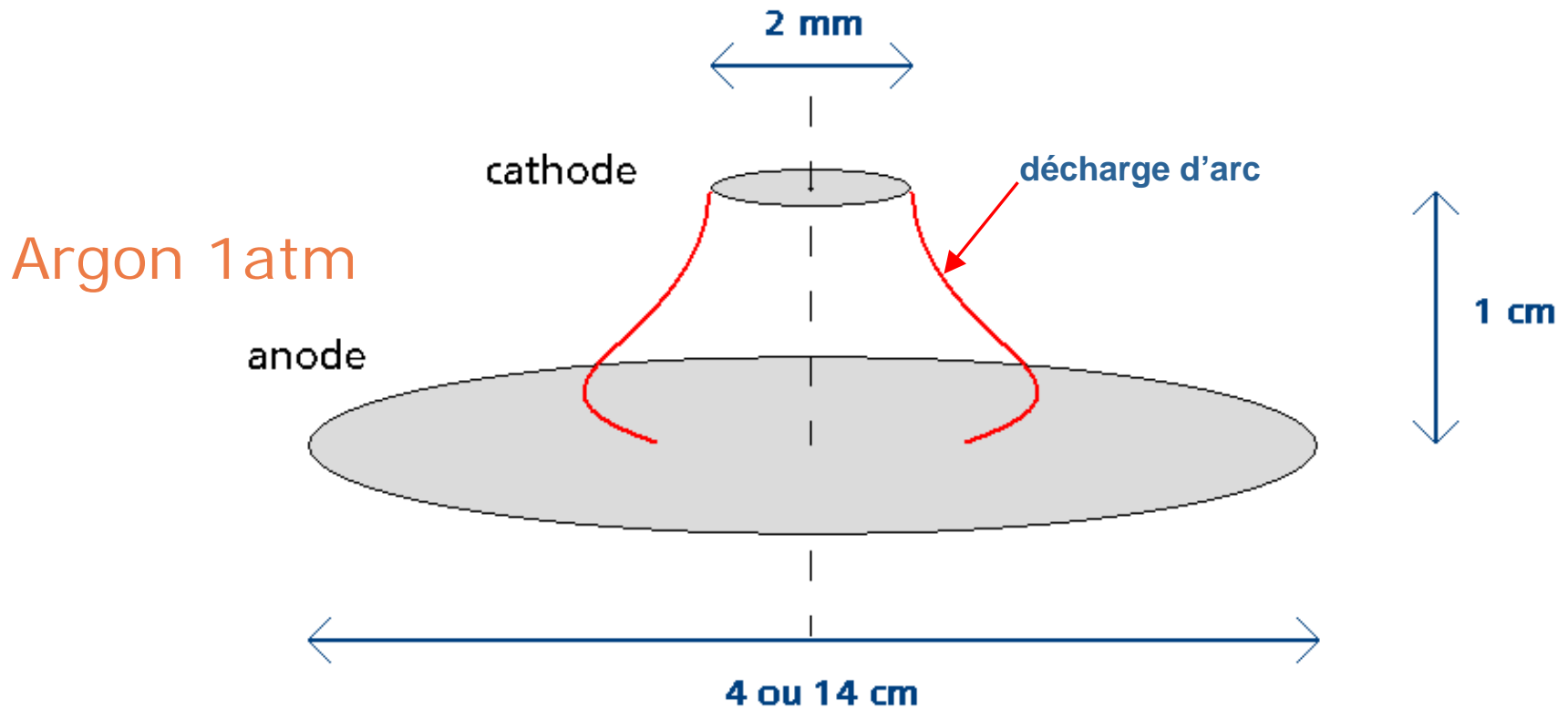
loi d'Ohm généralisée

conservation de la charge



Cas test de validation
Argon 1 atm, 200A, 1cm
(Pfender et al. 1985)

Validation : arc de 200A et de 1cm (1 atm)

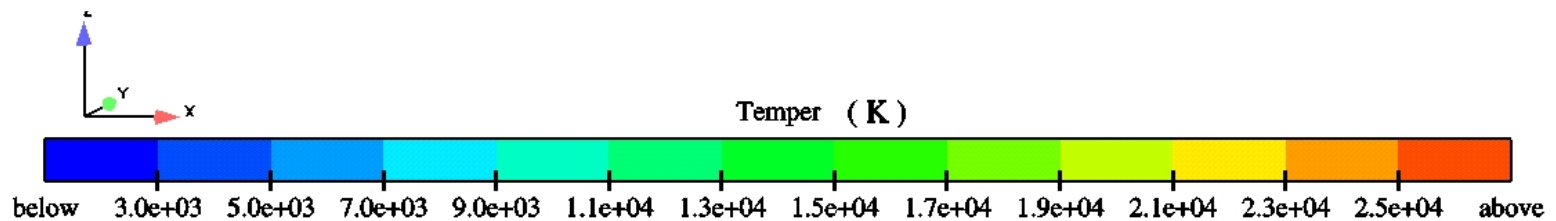
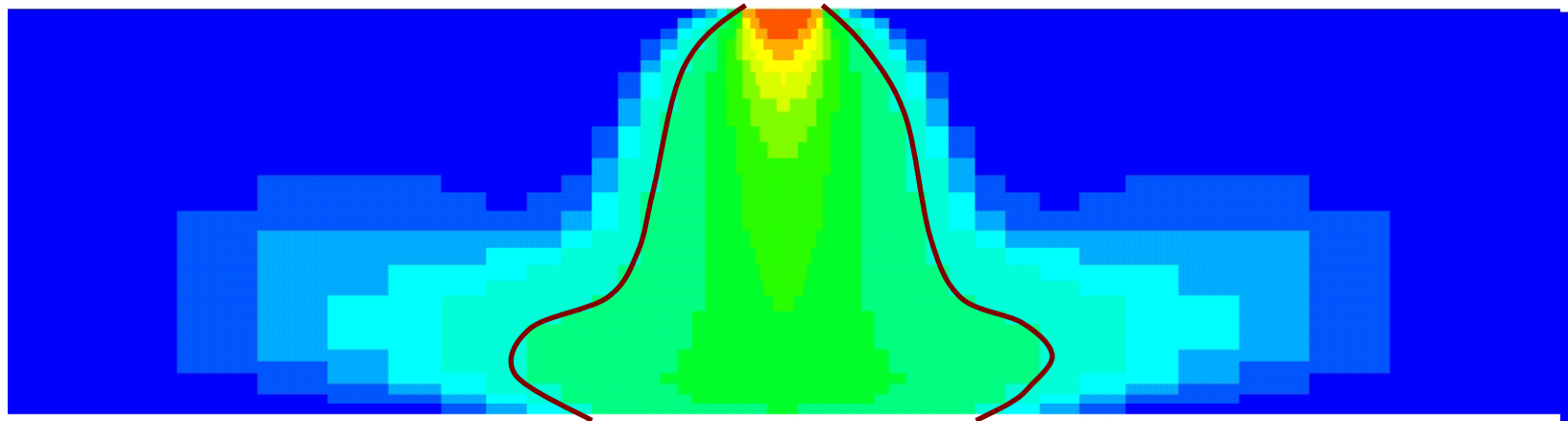


$I = 200$ Ampères

Les températures

Validation : arc de 200A et de 1cm (1 atm)

10 000 iterations
 $t = 10 \text{ ms}$



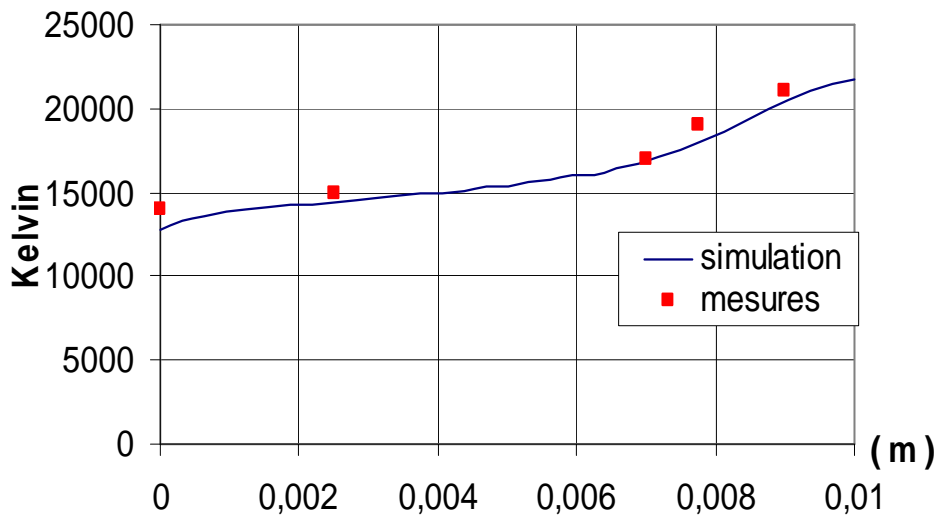
Validation : arc de 200A et de 1cm (1 atm)

→ condition limite de température à la cathode

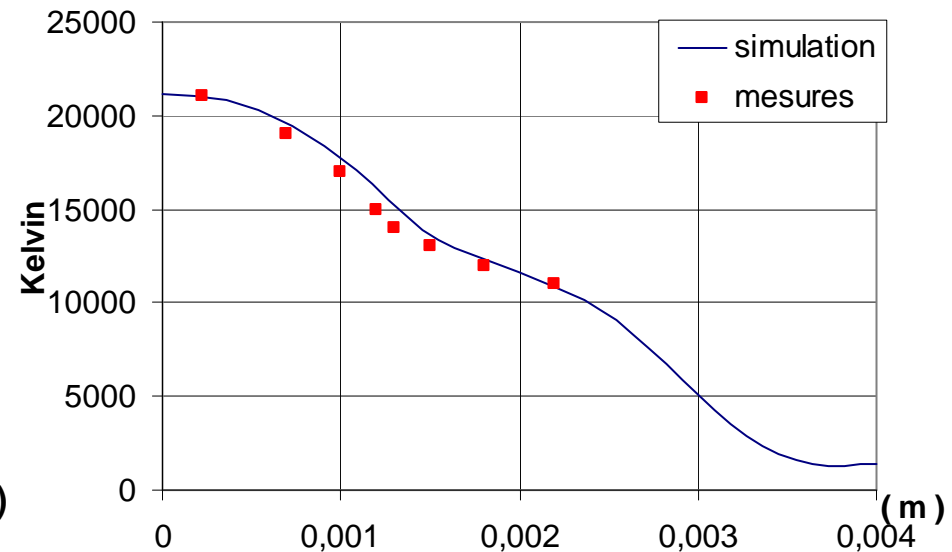
Augmentation de la tâche cathodique

Passage d'un rayon de 1mm ⇨ 1,5 mm

profil axial



profil radial en z= 9,5 mm



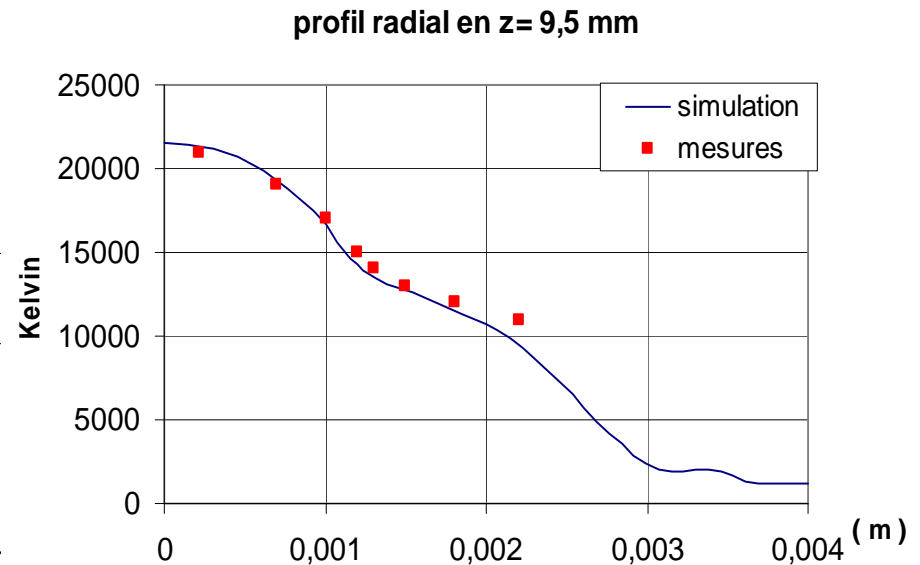
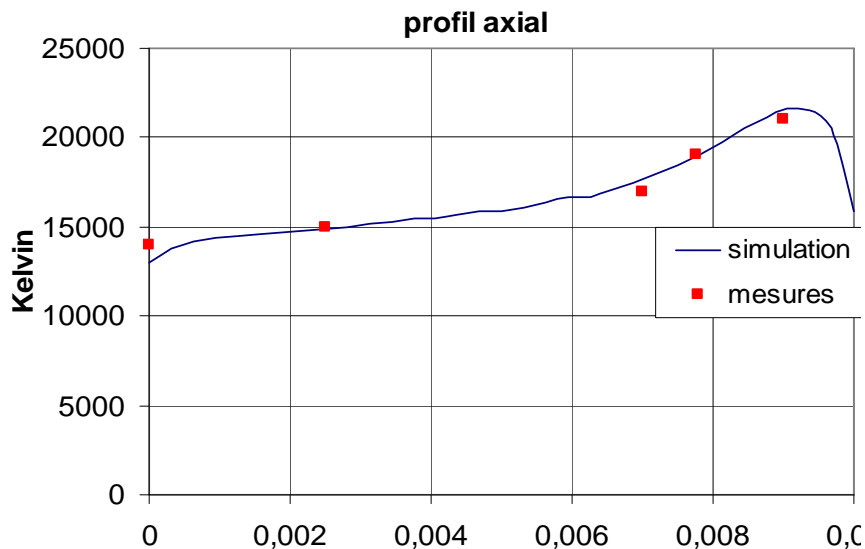
→ bon accord avec les mesures de température

Validation : arc de 200A et de 1cm (1 atm)

→ condition limite de température à la cathode

Ajout d'un flux à la surface de la cathode

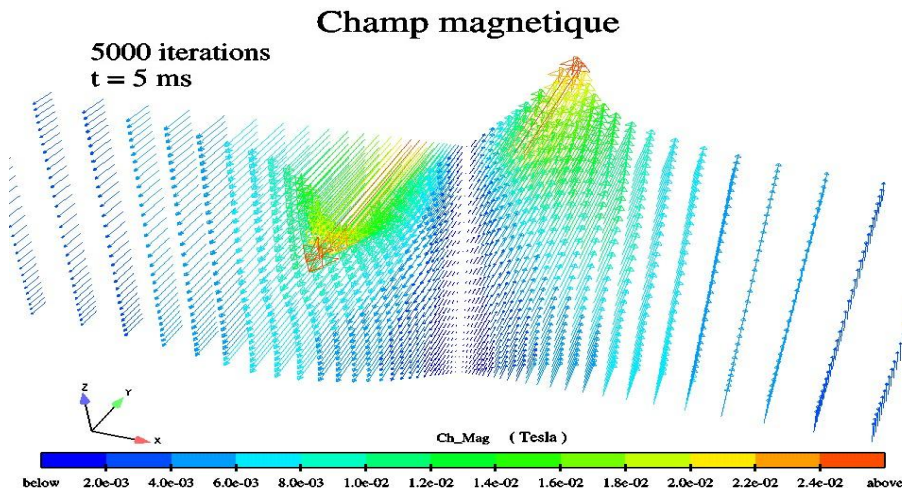
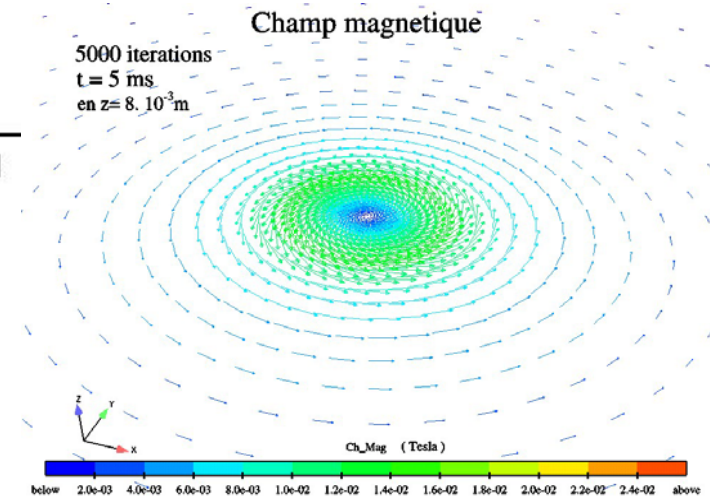
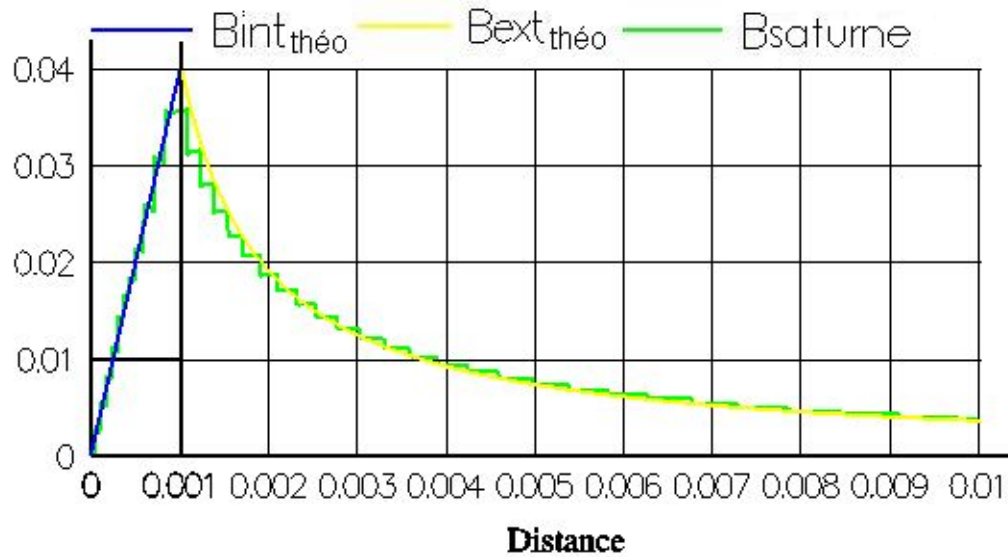
pertes par refroidissement de la cathode ⇒ flux de température de 10^8 W/m².



→ bon accord avec les mesures de température

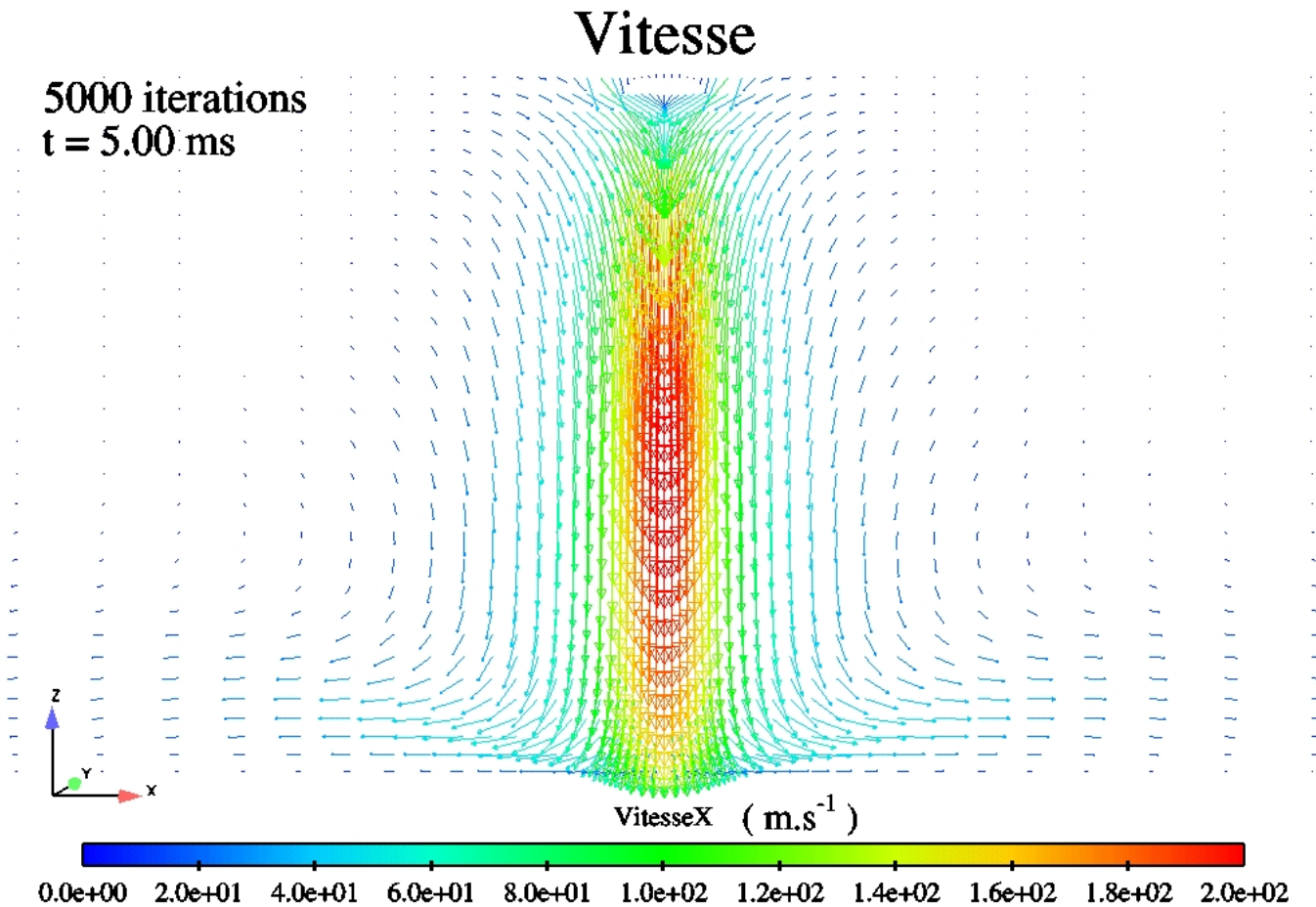
Validation : CL sur A, modèle théorique du fil infini

Tesla



Validation : arc de 200A et de 1cm (1 atm)

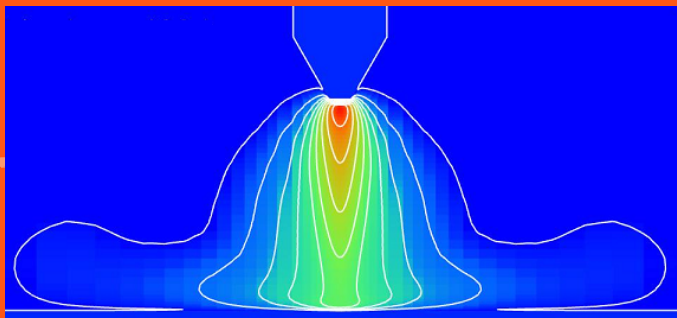
- Vitesse max d'environ 200 m.s⁻¹ au centre



- Etat stationnaire atteint dans la colonne à partir de t= 3 ms

mardi 8 janvier 2008

Association Arc Electrique : Présentation du module ARC de Code_Saturne®.

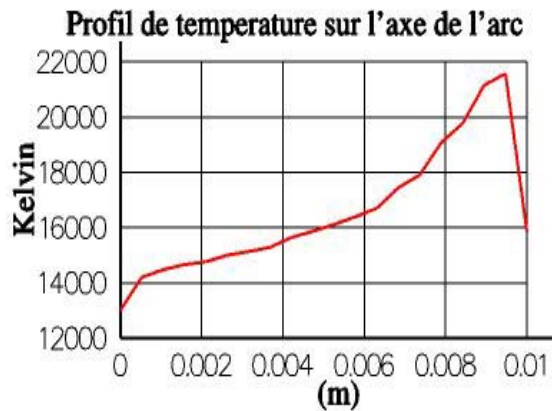


Couplage avec le module de transfert radiatif de *Code_Saturne*[®] :

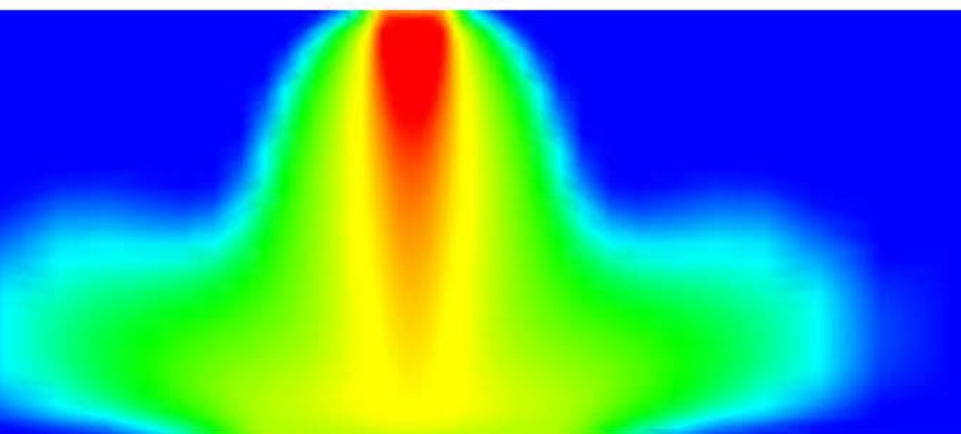
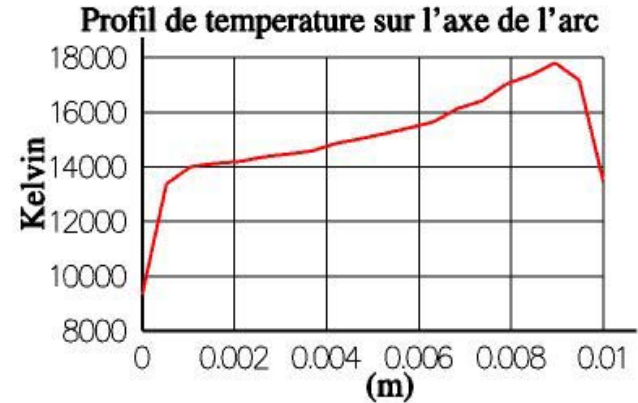
Méthode des Ordonnées Discrètes (gaz gris)

Couplage avec le module de transfert radiatif (ODM)

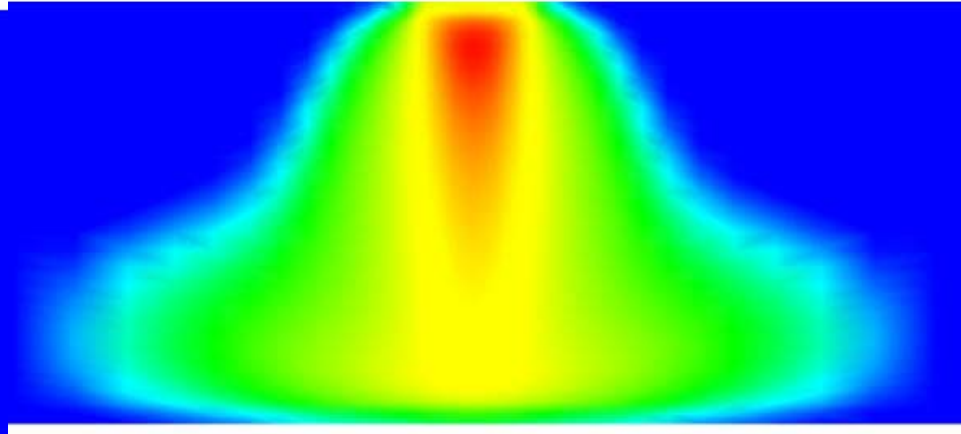
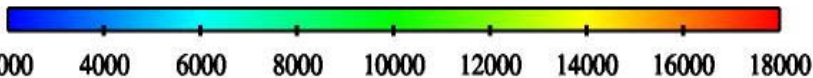
TS : EMISSION NETTE



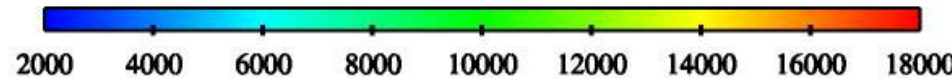
TR : ODM



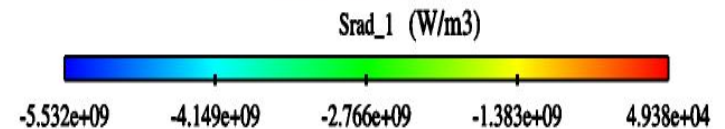
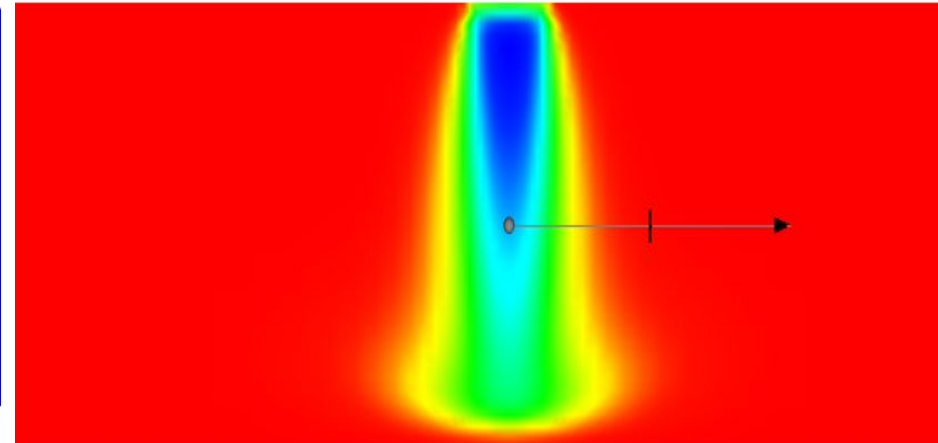
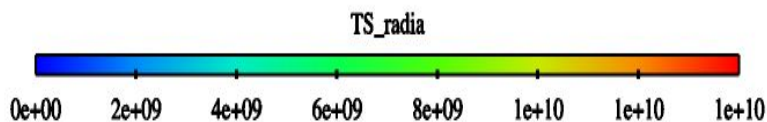
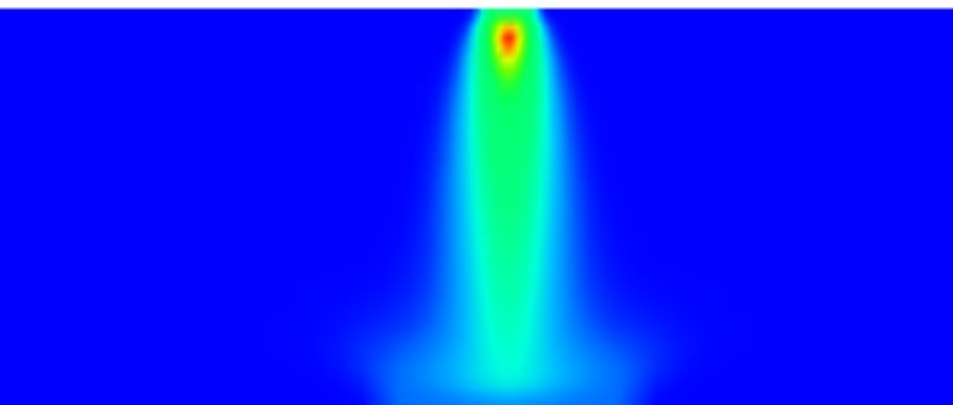
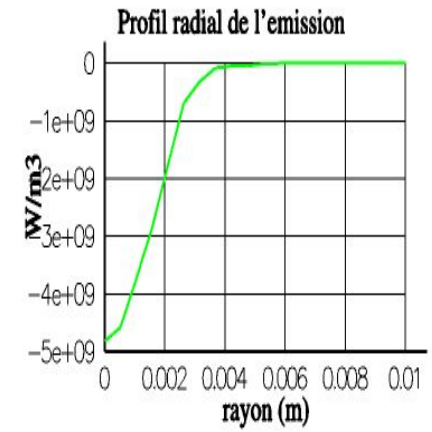
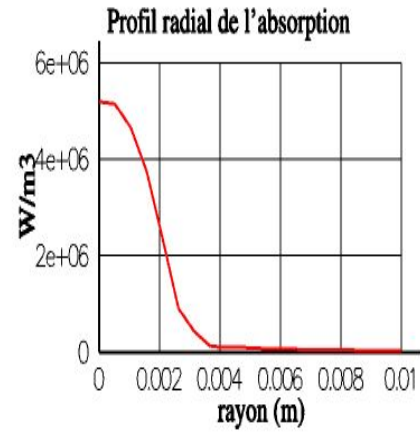
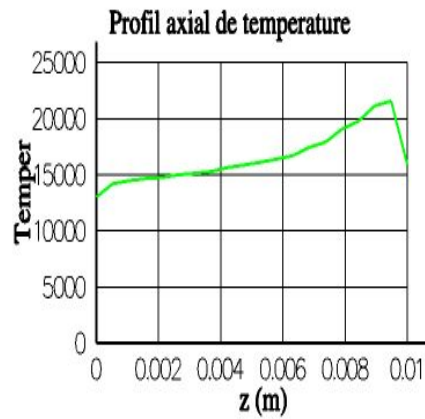
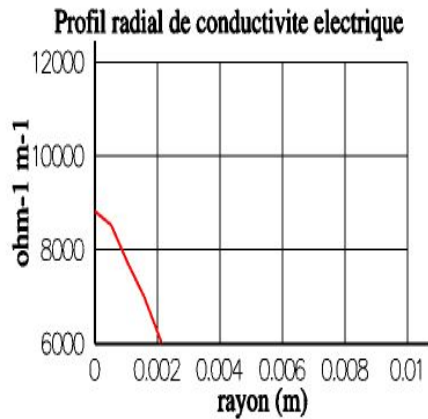
Kelvin



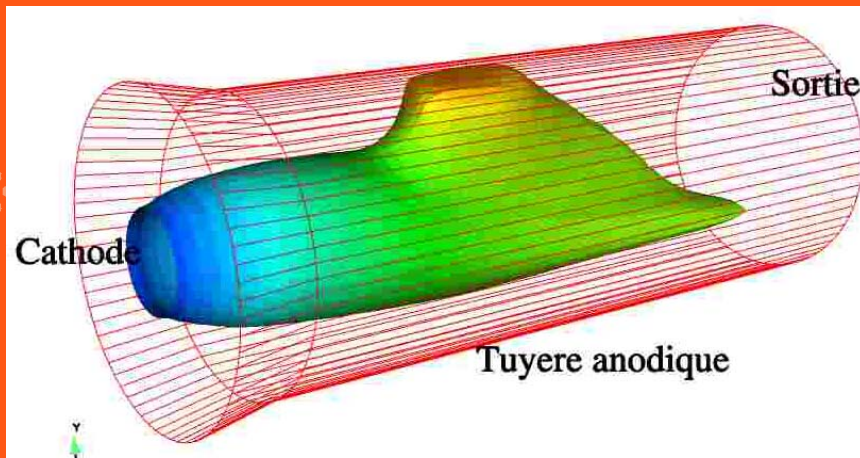
Kelvin



Couplage avec le module de transfert radiatif (ODM)



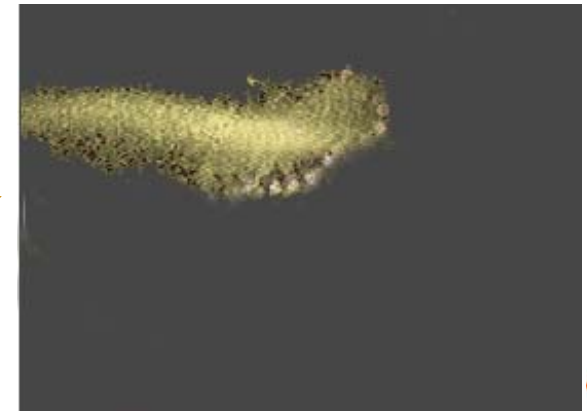
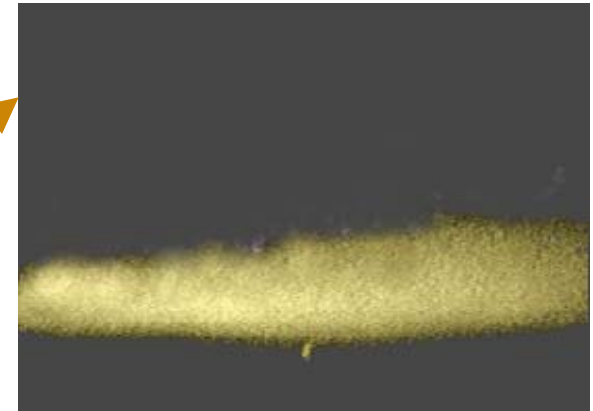
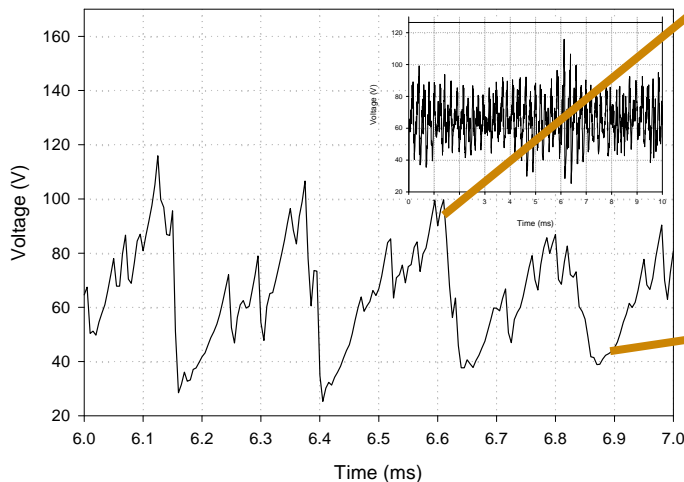
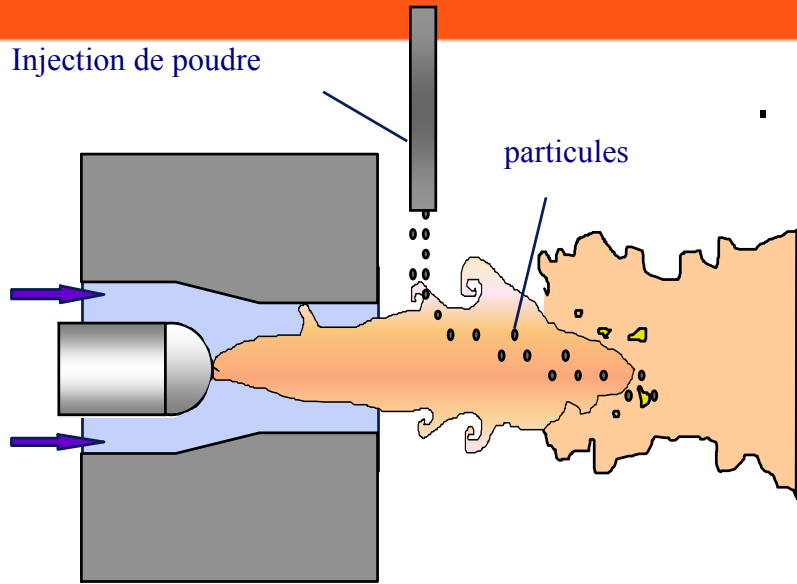
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Autres exemples présents (sommairement)
dans nos routines utilisateurs :

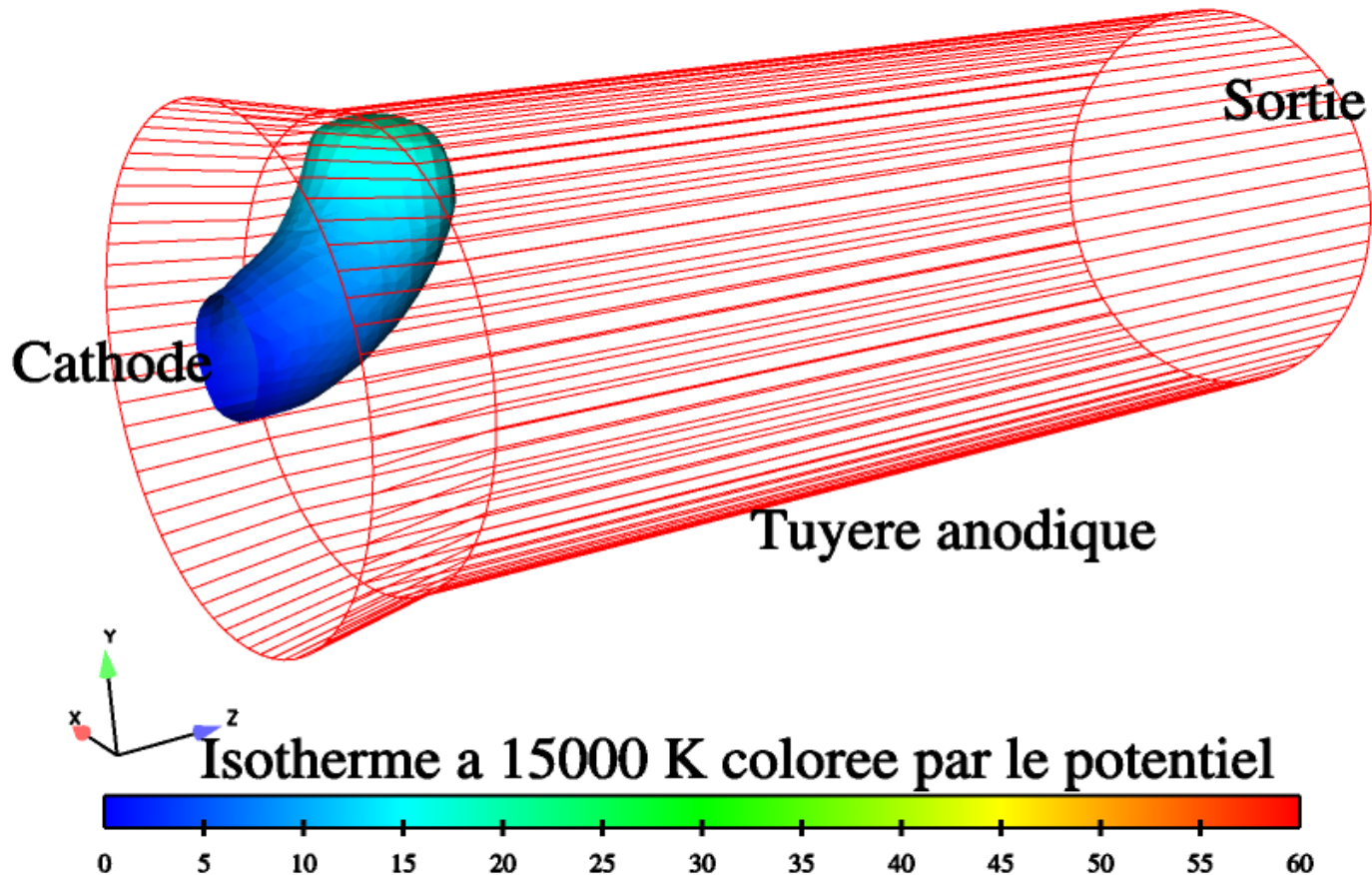
Modèle de reclaquage dans une torche à plasma
tel que mis en place en 2004 par Cyril Baudry (post-doc ENSIL)

Fluctuations de vitesse et température du jet de plasma

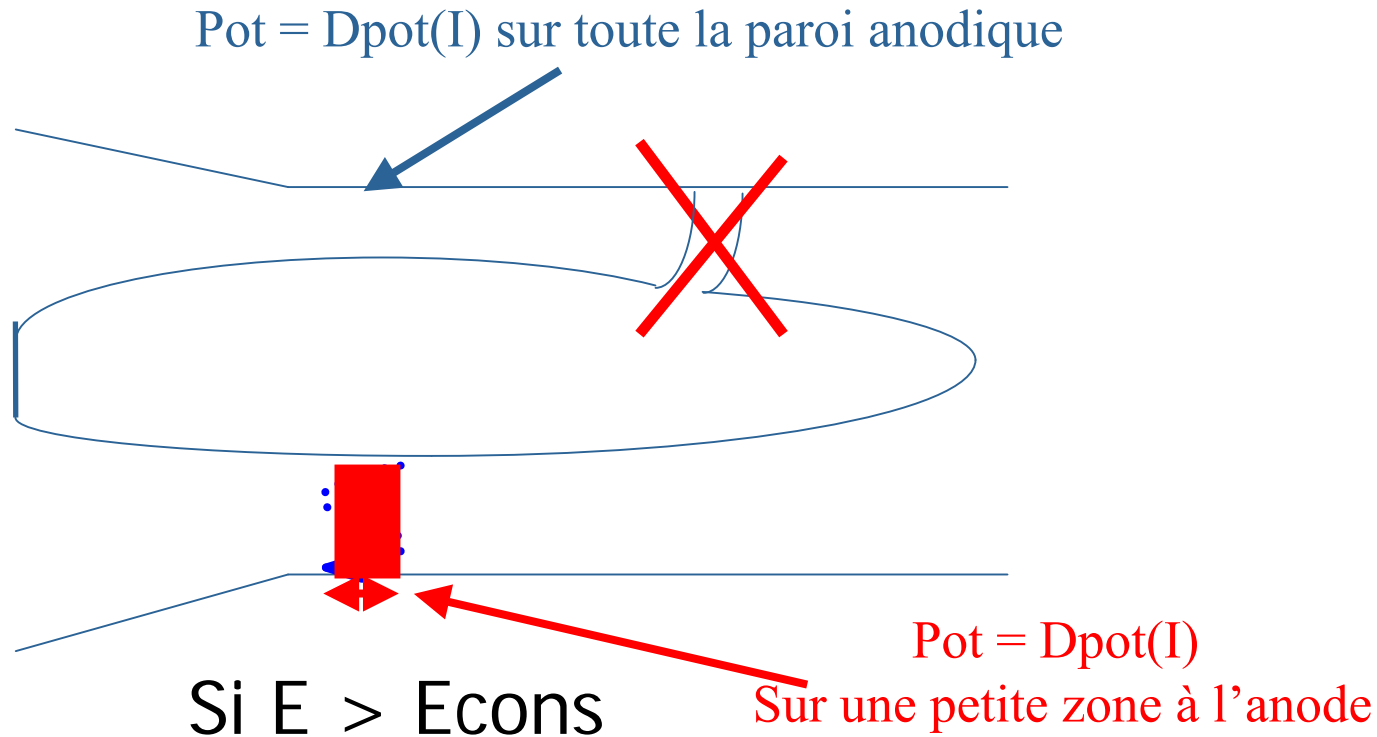


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Simulation d'un arc électrique 3D instationnaire Resultat Code_Saturne



Modélisation du "Restriking"



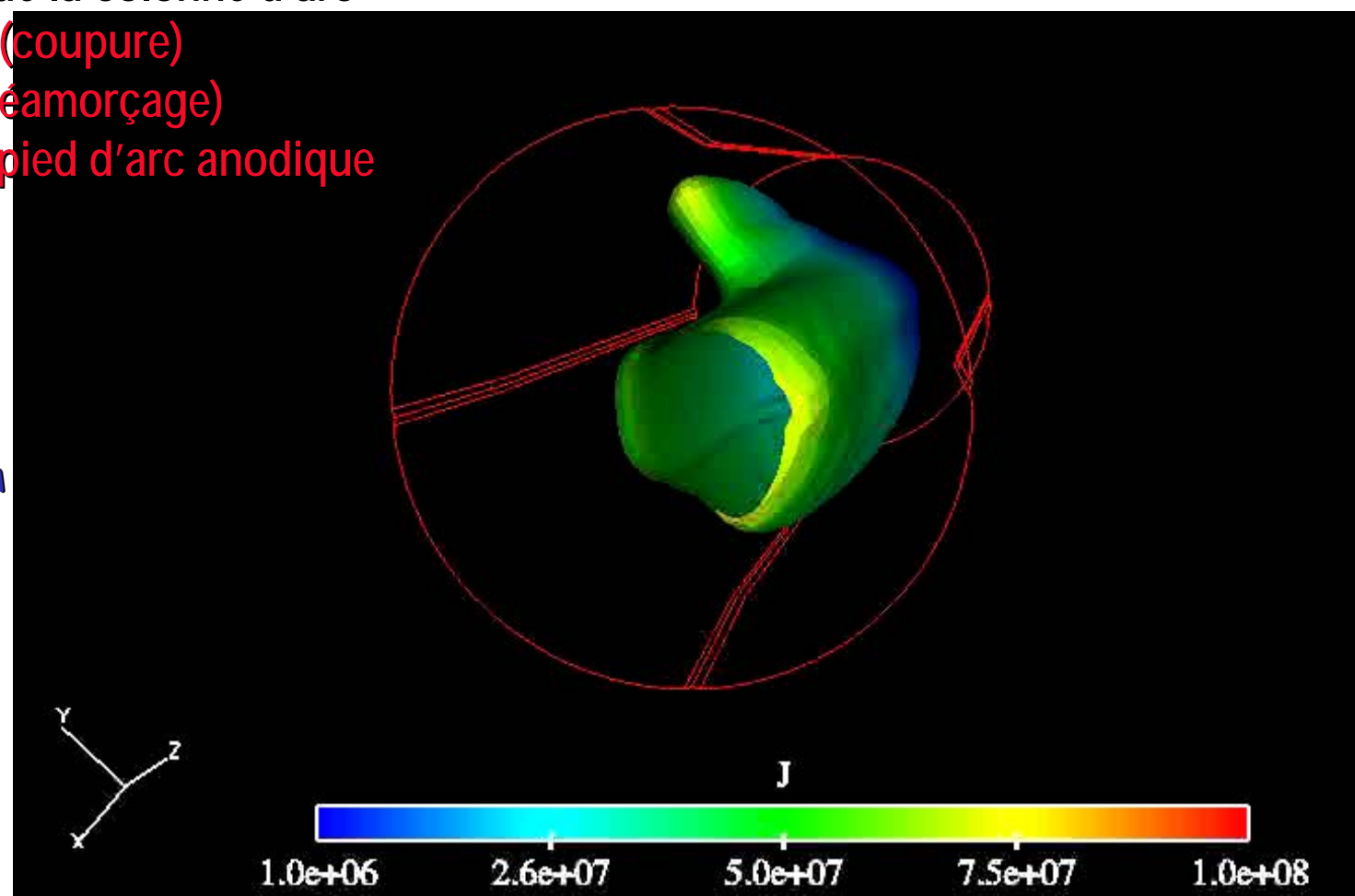
$$160,000 < E_{cons} < 300,000 \text{ V/m}$$

Comportement dynamique de l'arc (torche Ar H2 600 A)

- Expansion de la colonne d'arc
- breakdown (coupure)
- restriking (réamorçage)
- rotation du pied d'arc anodique

$E > 280,000 \text{ V/m}$

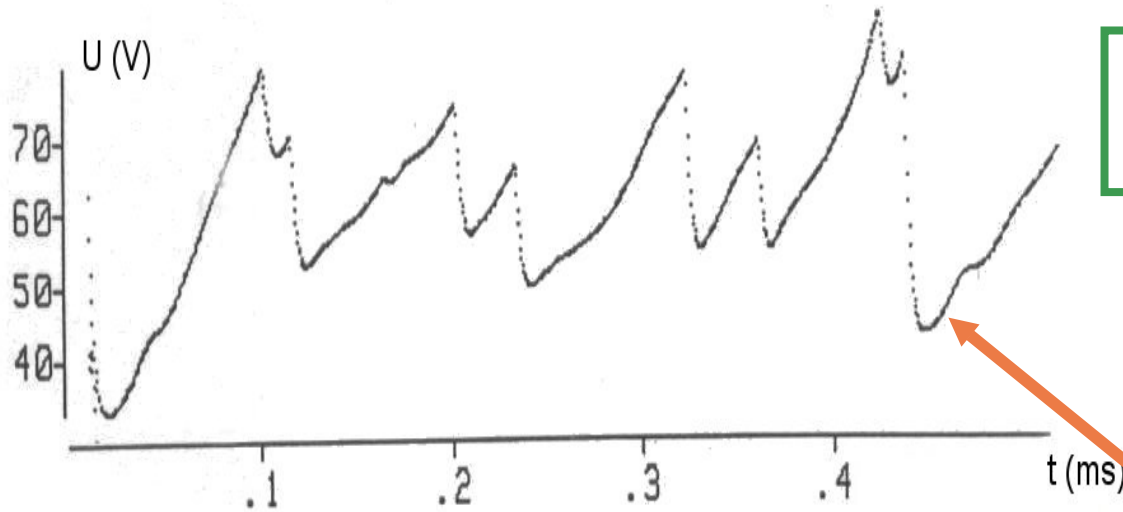
Isotherme 3D
à 16000 Kelvin



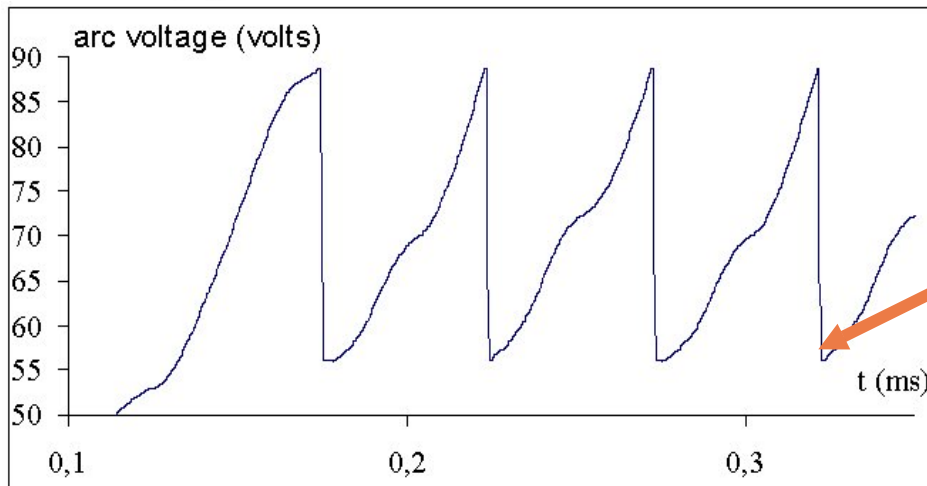
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Arc électrique 3D instationnaire dans une torche

Evolution de la tension d'arc au cours du temps



Résultat Expérimental
(Planche 1987)



Claquage
(Re-striking)

Résultat de Simulation
(Baudry 2003)

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Association Arc Electrique : Présentation du module ARC de Code_Saturne®.

Clarisse Delalandre, EDF R&D





Derniers résultats :
Application au foudroiement d'un aéronef
Thèse de Laurent CHEMARTIN (2005-2008)

Collaboration

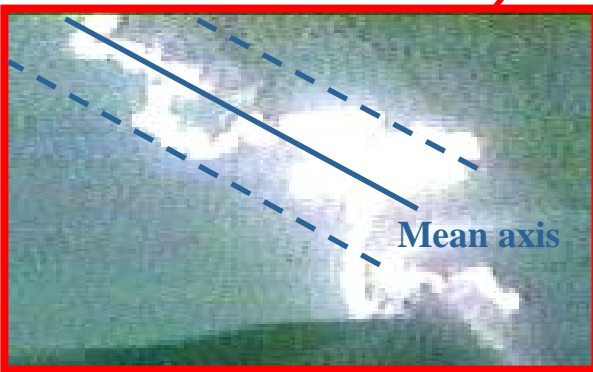
ONERA, EDF, CEAT et CORIA Université de Rouen

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images de foudroiement en vol (AIRBUS)

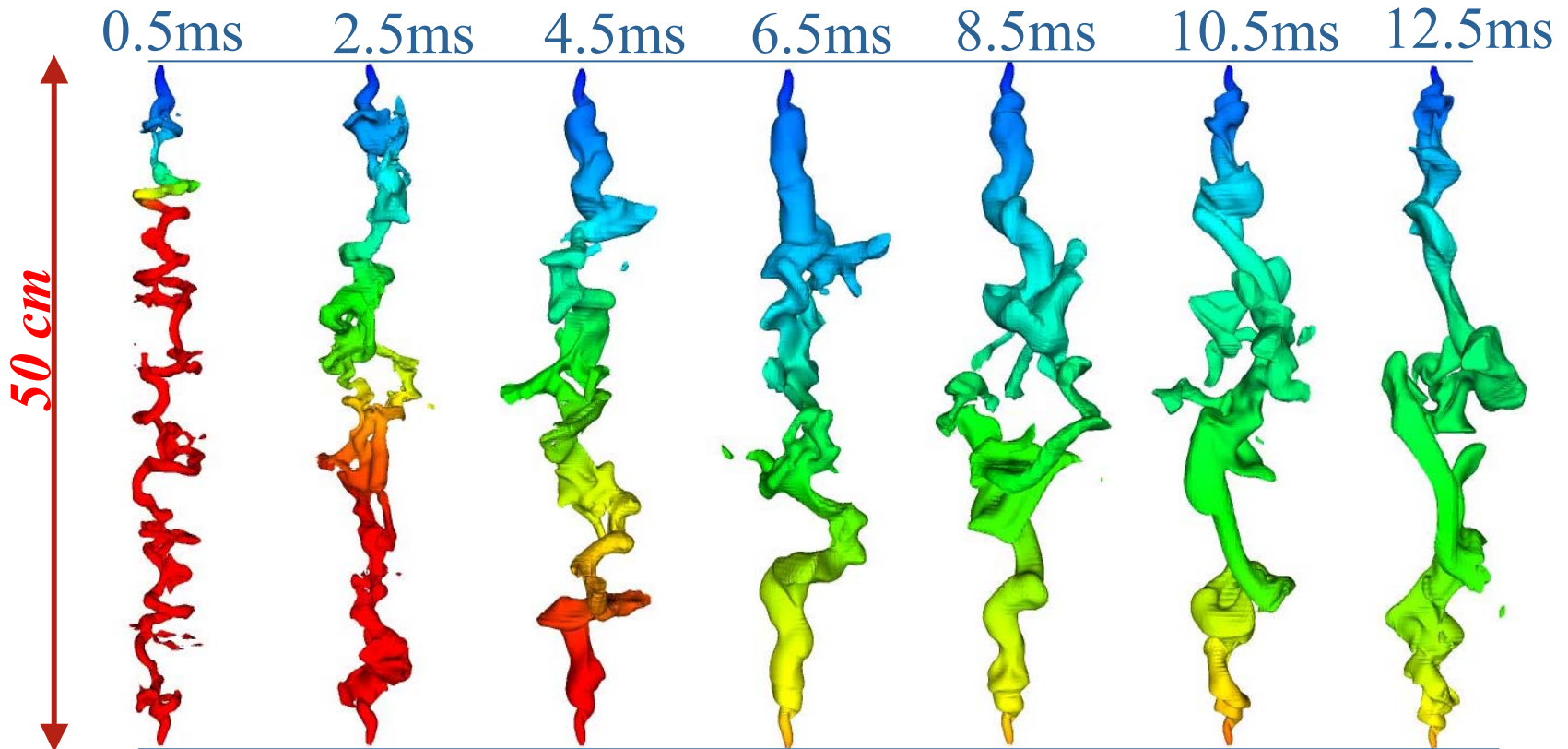


Stochastic motion



Simulation de colonnes d'arcs libres de 800A entre 2 pointes

50cmPoPo.mpg



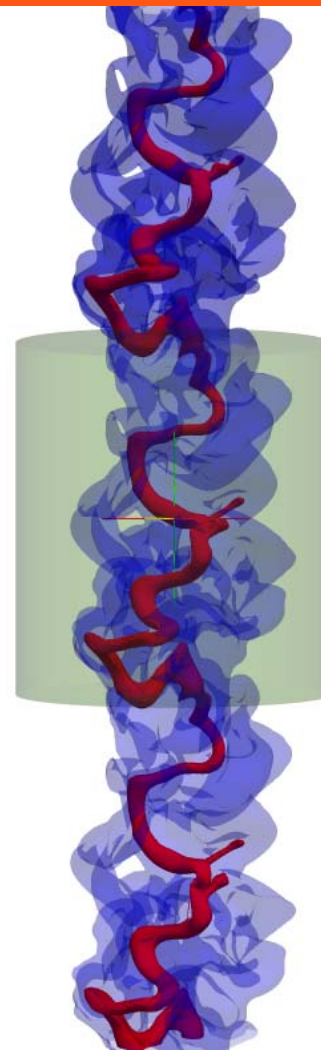
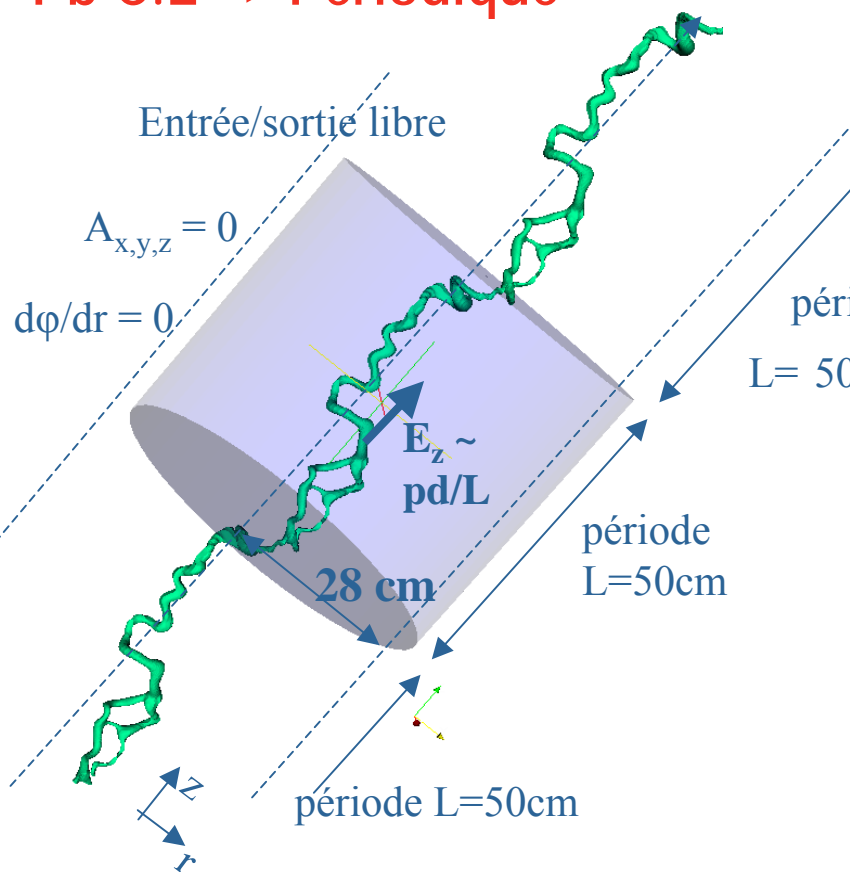
mardi 8 janvier 2008



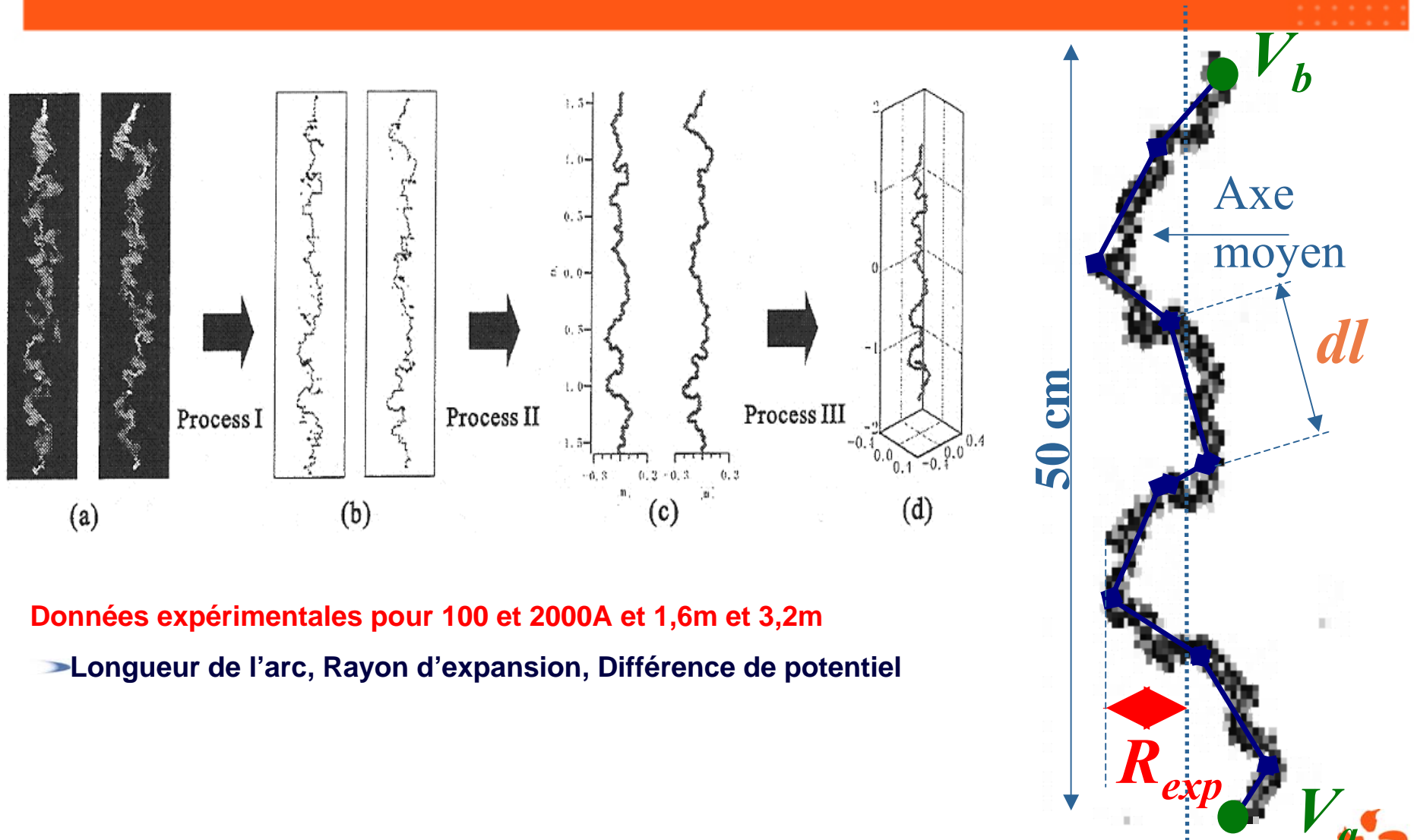
Calcul périodique

Simulation numérique du mouvement stochastique du canal de foudre en configuration périodique

Pb C.L => Périodique



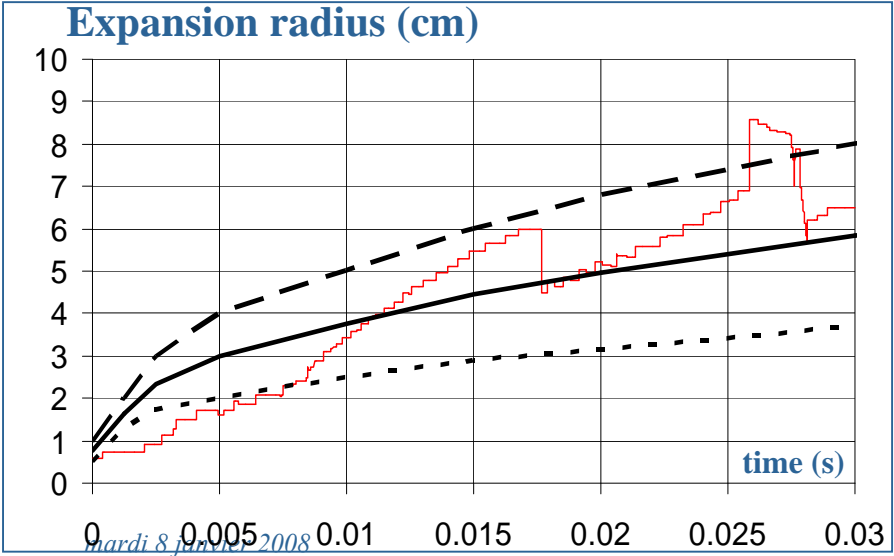
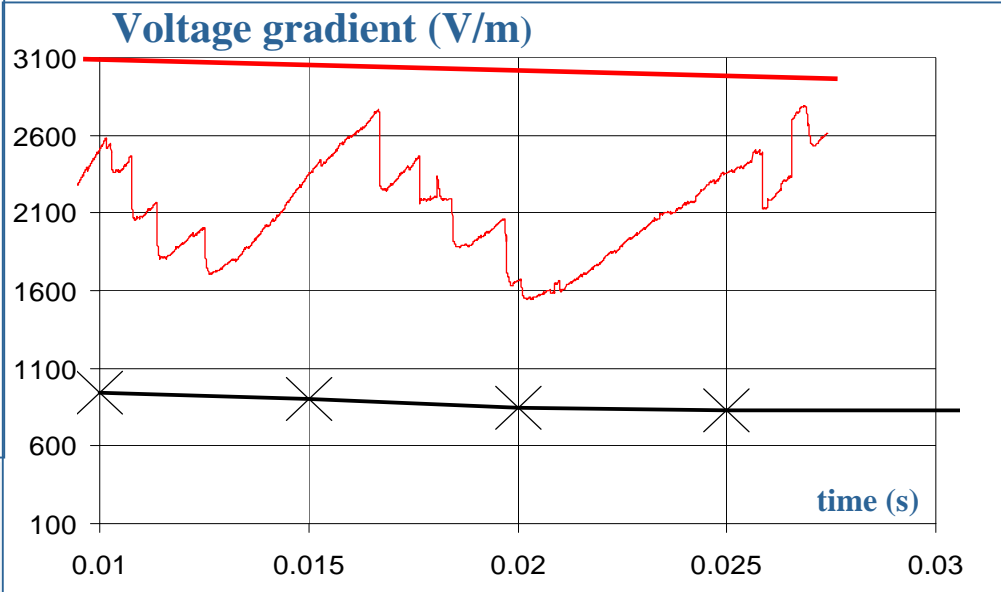
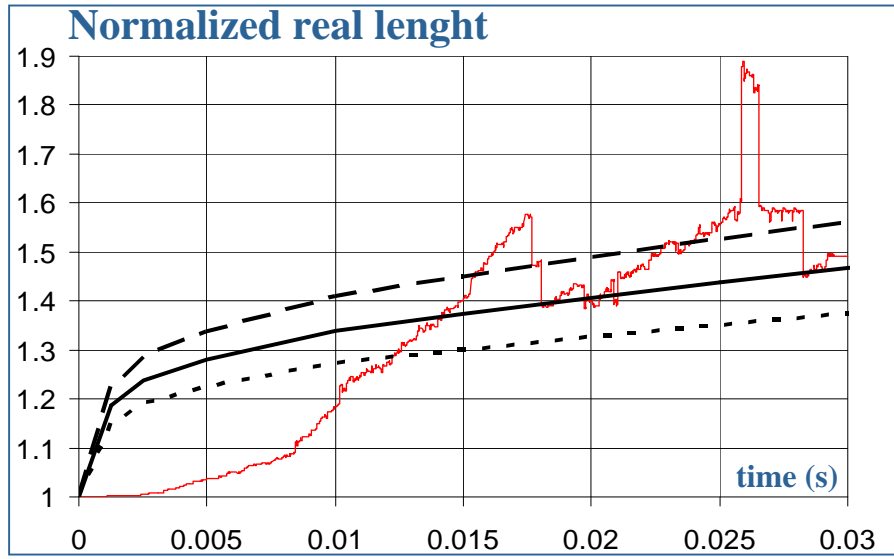
Comparaison avec Tanaka et al. (2000)



Données expérimentales pour 100 et 2000A et 1,6m et 3,2m

➤ Longueur de l'arc, Rayon d'expansion, Différence de potentiel

Comparaison pour un arc de 100A



- - - Maximum values of experiment (Tanaka, 2000)
- Mean values of experiment (Tanaka, 2000)
- Minimum values of experiment (Tanaka, 2000)
- Computation

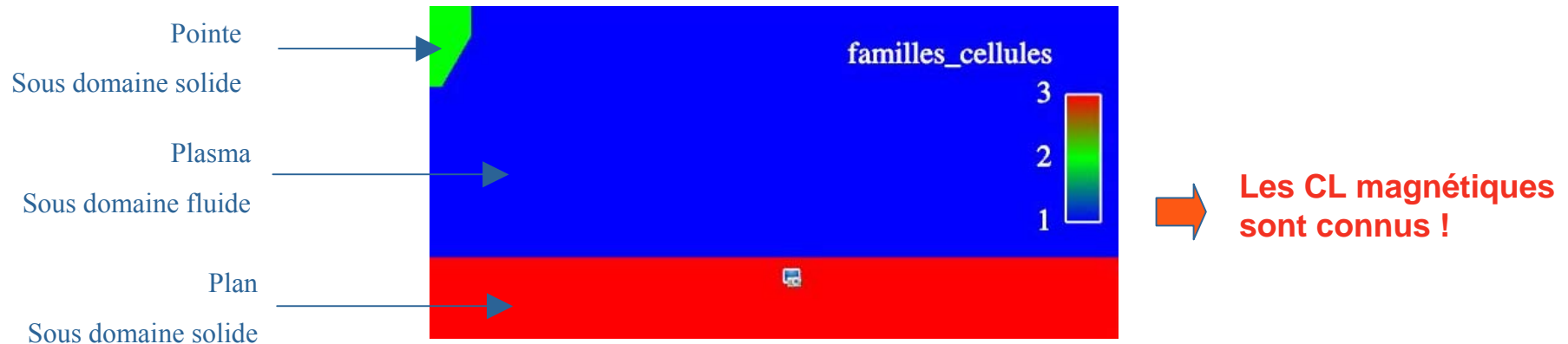


Interaction Arc-Structure

Interaction arc structure

Utilisations de Sous domaines :

avec des propriétés physiques ou des modélisations différentes



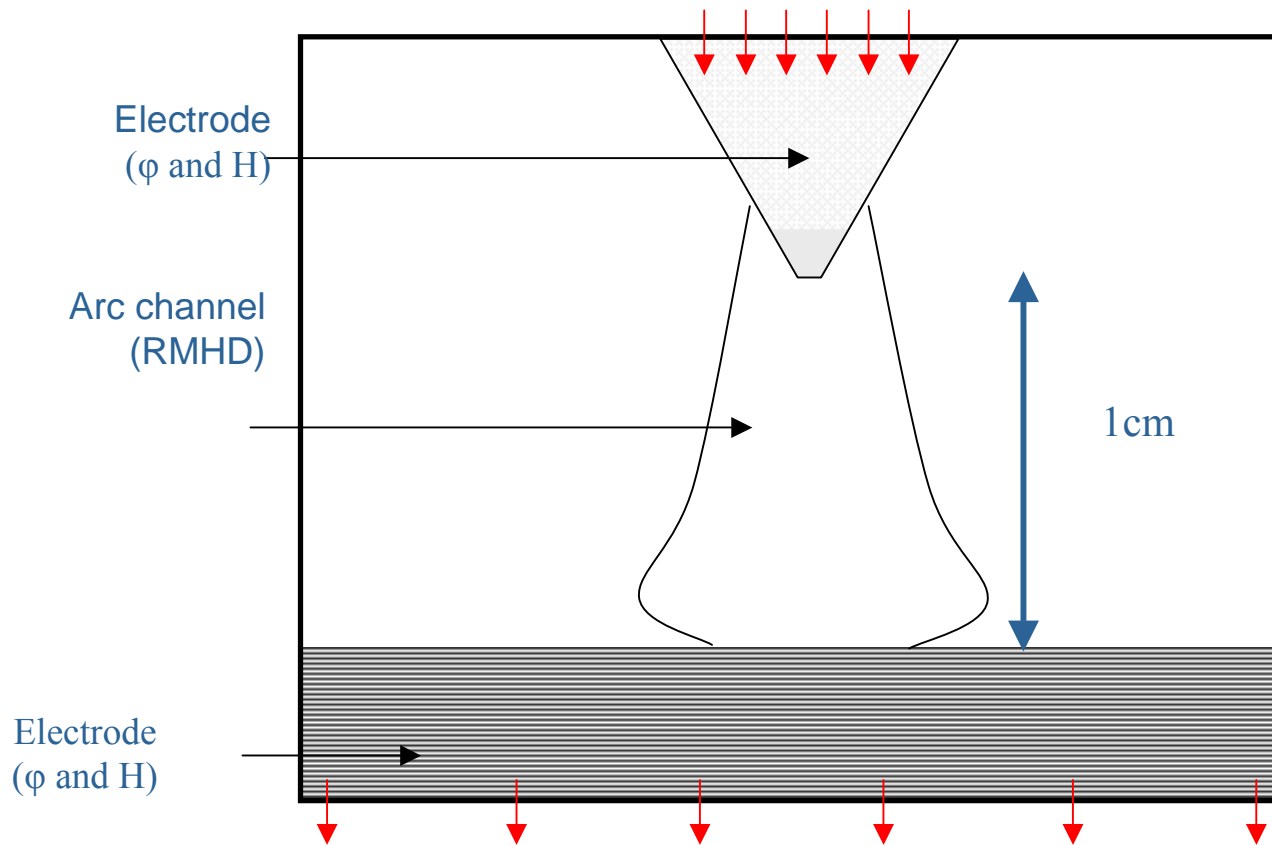
Comment résoudre l'hydrodynamique dans un domaine solide ?

Viscosité infinie

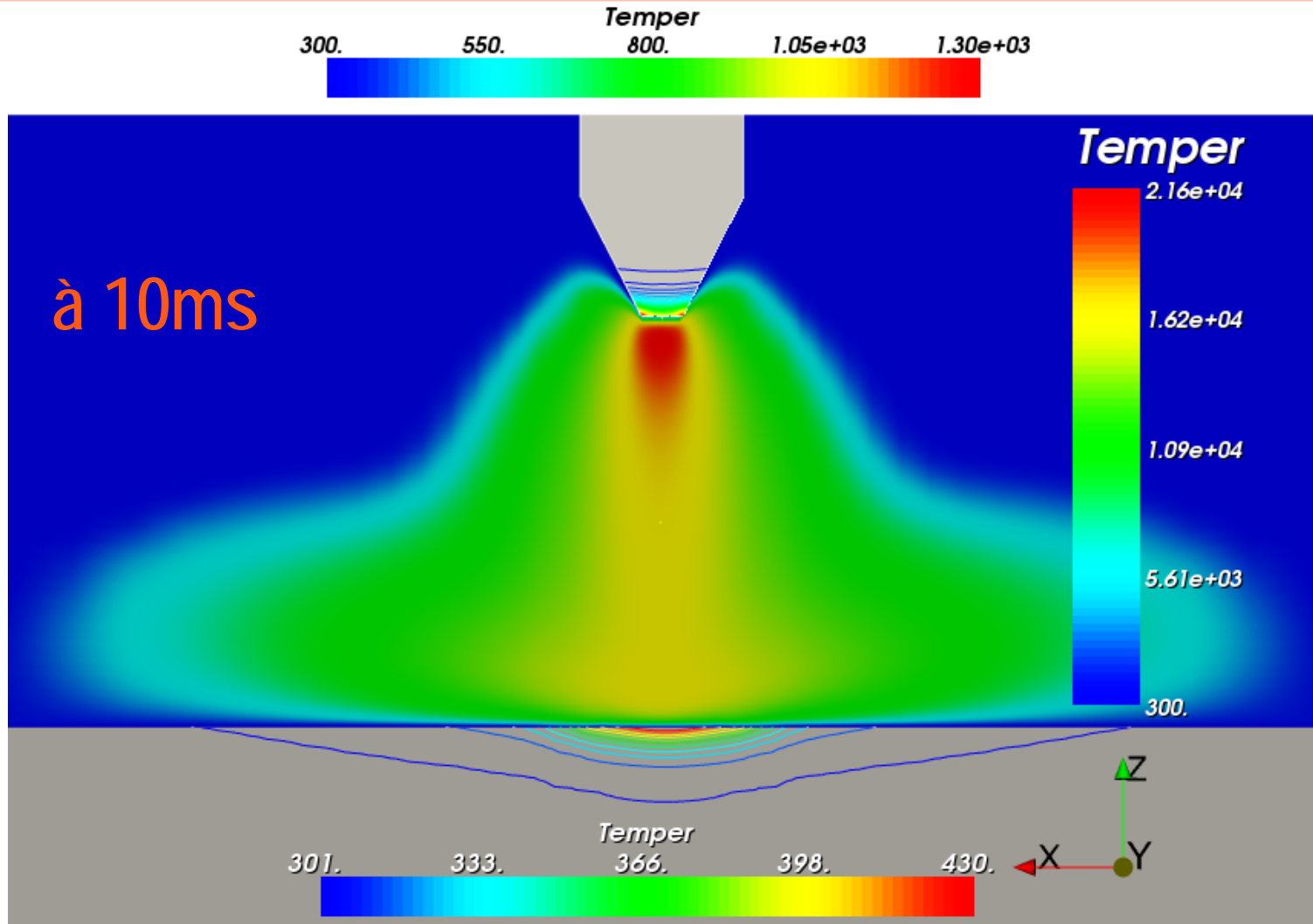
Terme source ajouté dans l'équation de QDM

Impact sur la structure de l'aéronef

Point-plane



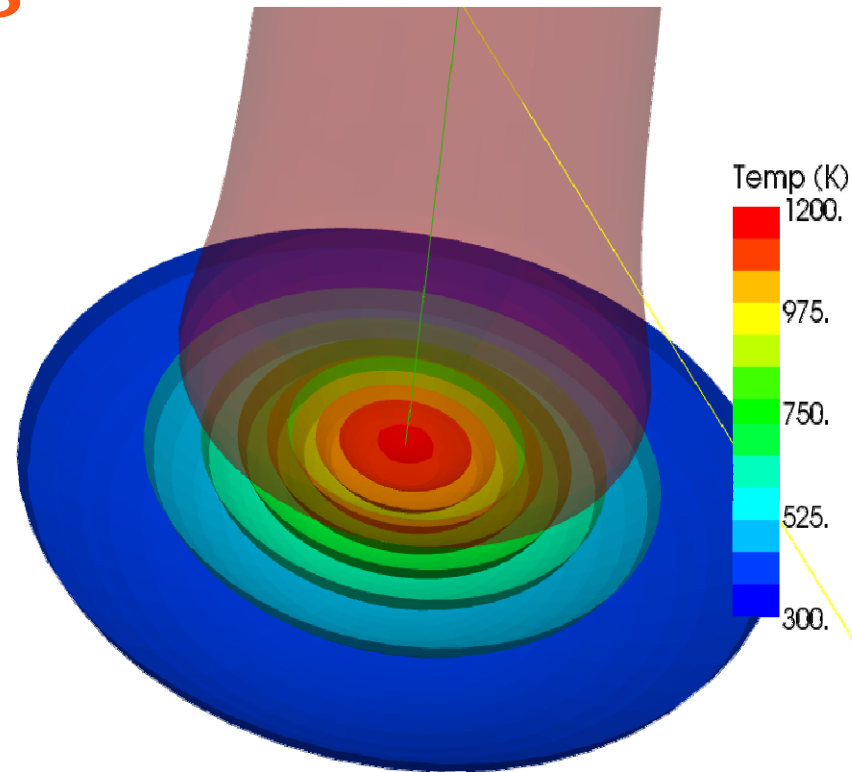
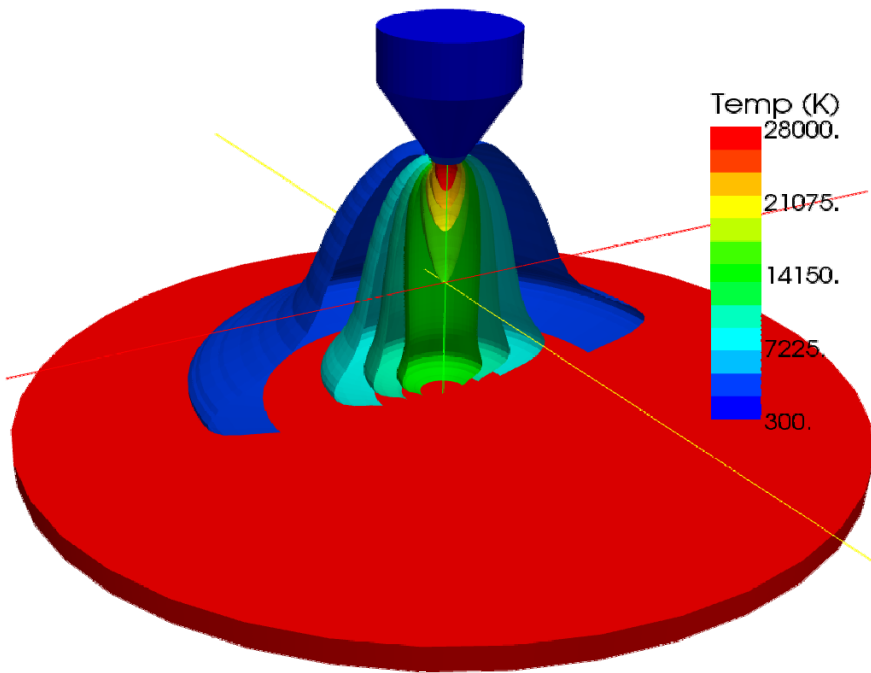
Matériau = Alu, arc = 1cm, I=200A, $T_0=300^\circ\text{K}$, t = 10ms



mardi 8 janvier 2006

Matériau = Alu, arc = 1cm, I=200A, T0=300°K, t = 25 ms

à 25 ms



Surfaces isothermes dans le matériau

$T > T_{\text{fusion}}$ (933K pour l'aluminium), mais $T < T_{\text{ébullition}}$ (2300K)

mardi 8 janvier 2008

Association Arc Electrique : Présentation du module ARC de Code_Saturne®.

Clarisse Delalondre, EDF R&D

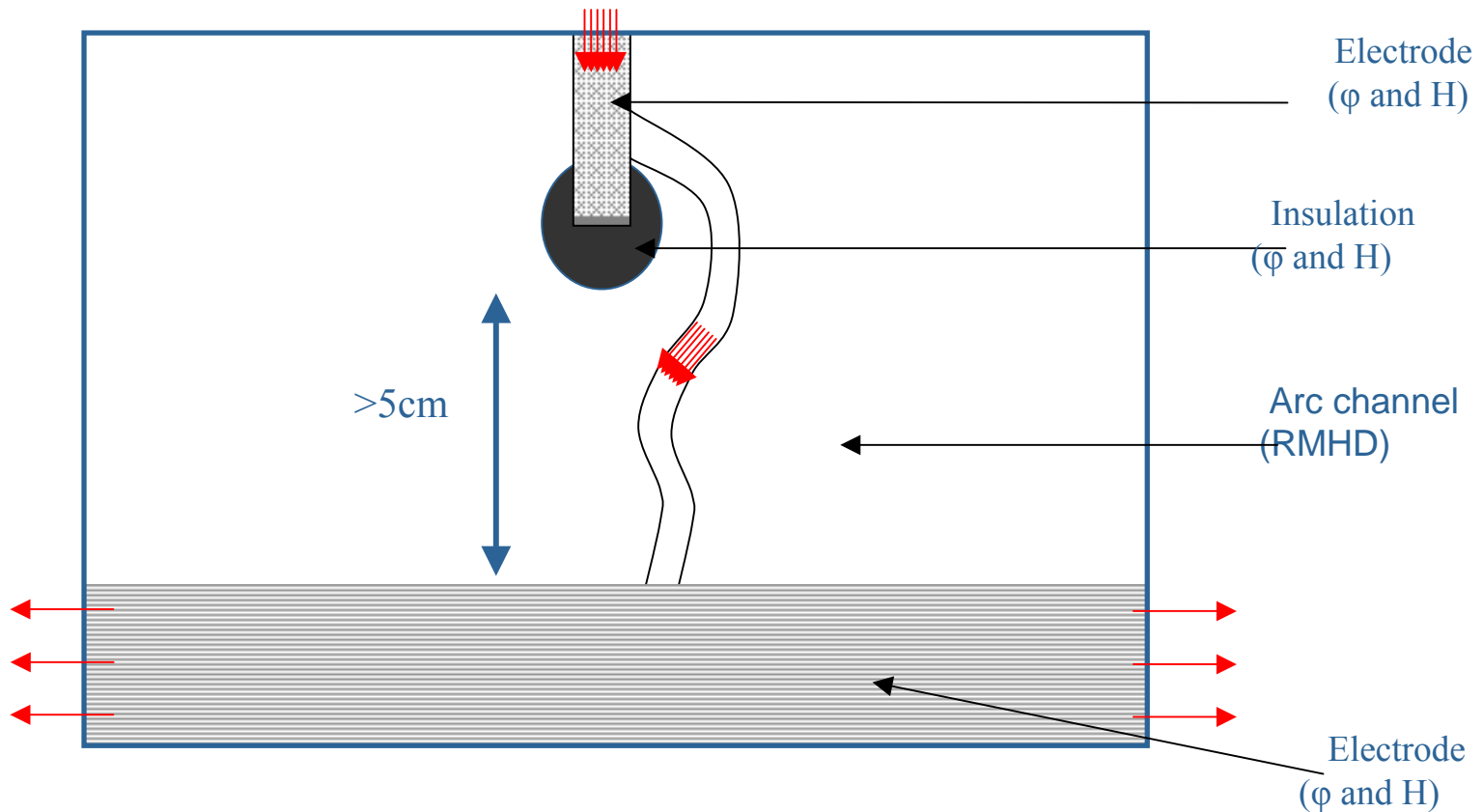




Application au dispositif expérimental du CEAT

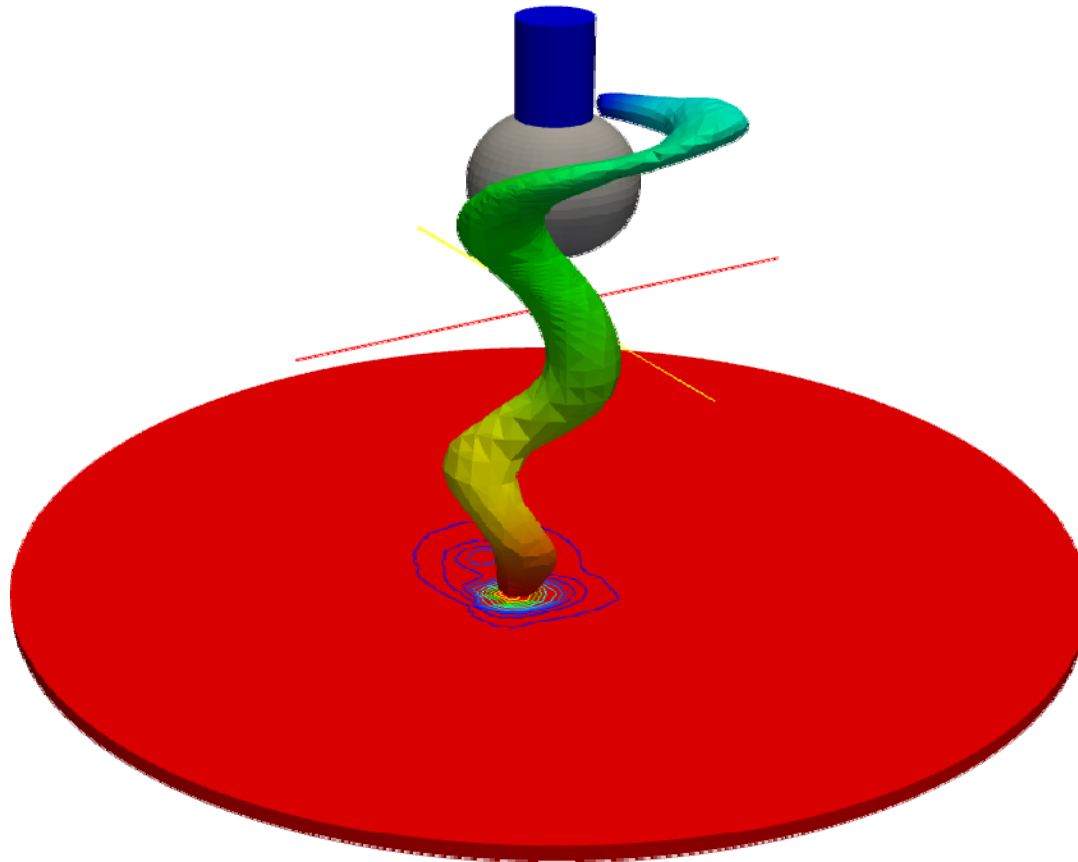
Montage expérimental CEAT avec Déviateur (isolant)

JET DIVERGING ELECTRODE



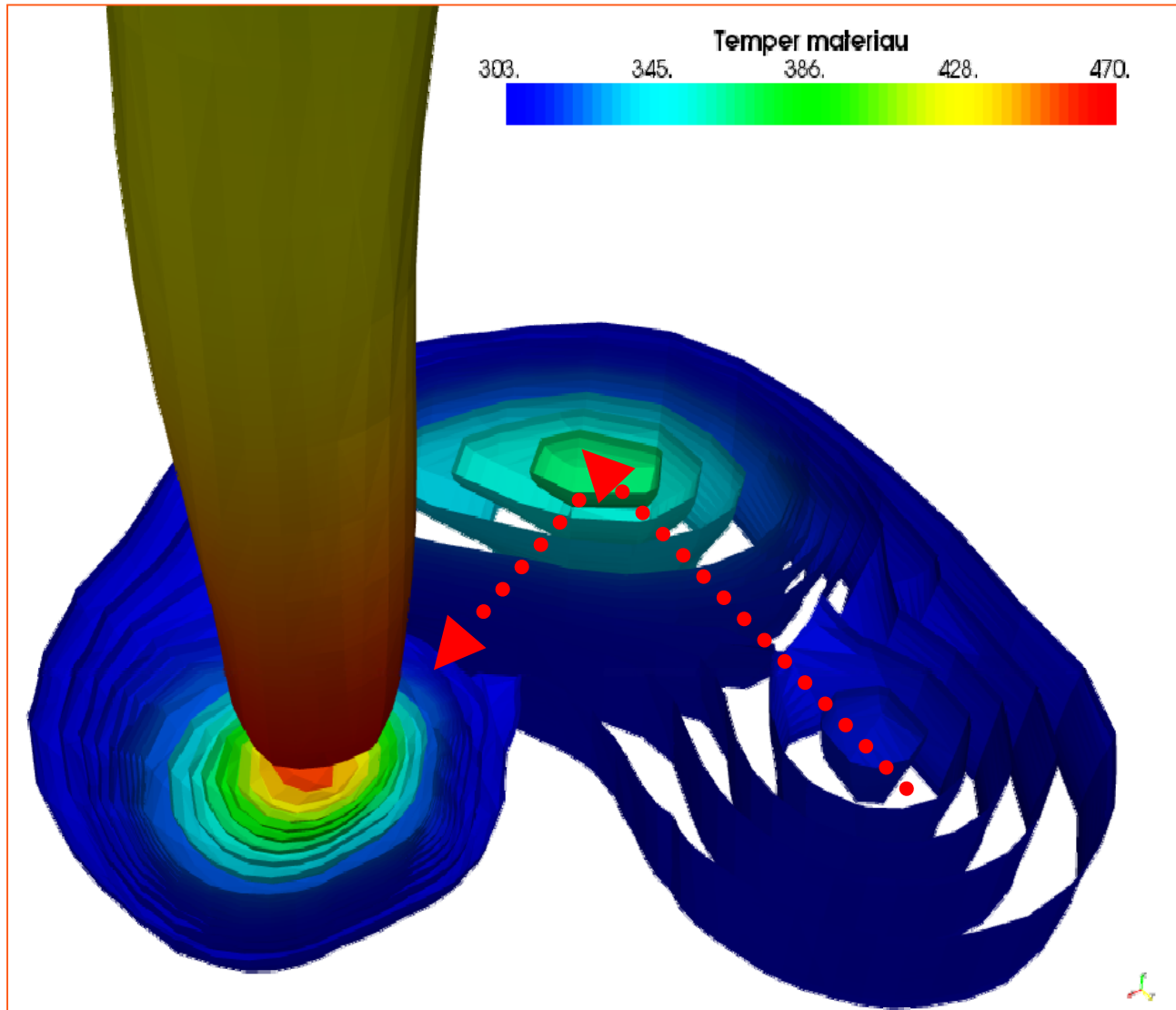
Arc de 200A dans l'air à $t = 10\text{ms}$

Matériau = aluminium et tige (cathode) en fer



Arc de 200A dans l'air à t= 15 ms

Matériau = aluminium et tige (cathode) en fer



mardi 8 janvier 2008

Merci pour votre attention !