



JP DUCREUX Presentation

# Computational Electromagnetics For Power Engineering



# Summary

## 1. Software

## 2. Focus on NDE

Power Plants

Steam Generator

Tubes

Specific issues with ECT modelling

## 3. Conclusions



N°1

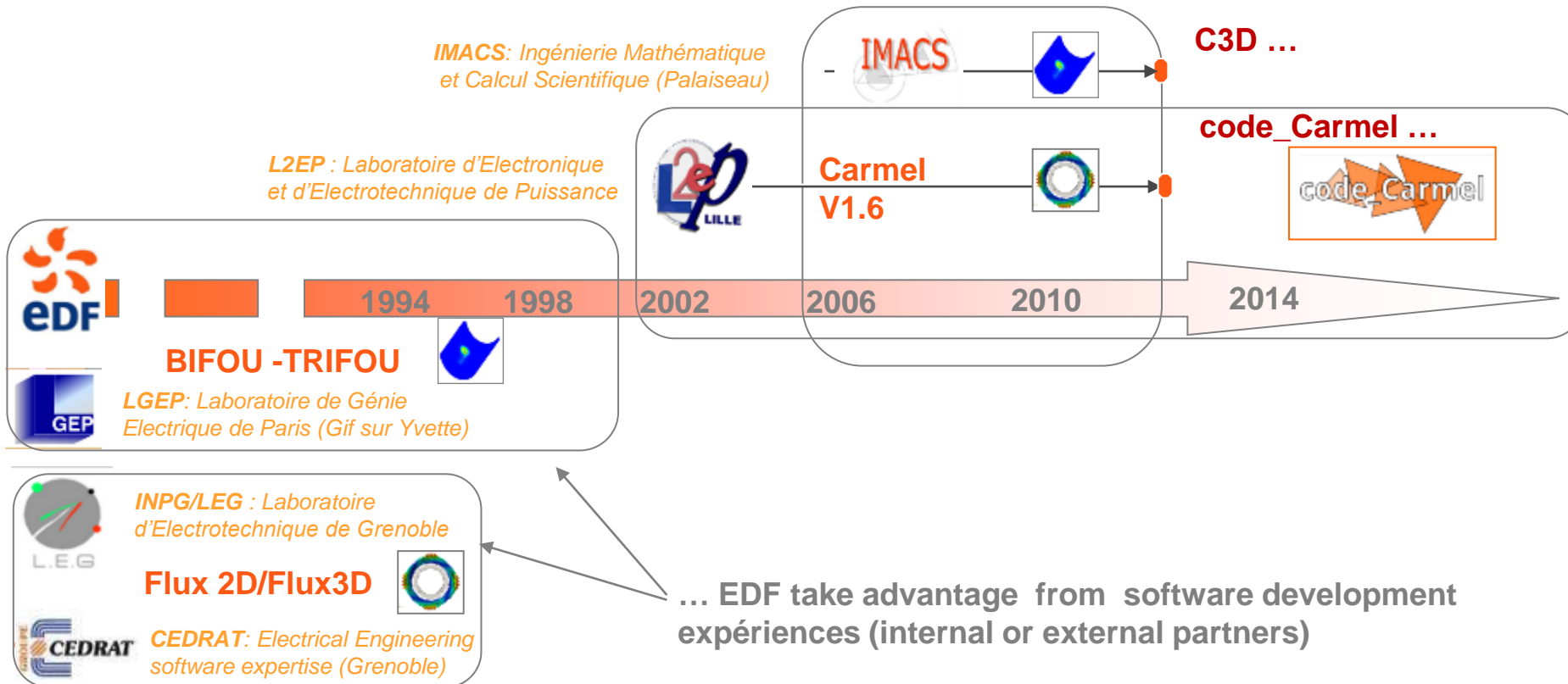
# Computational Electromagnetics

Software Development

# 1. Context and origins



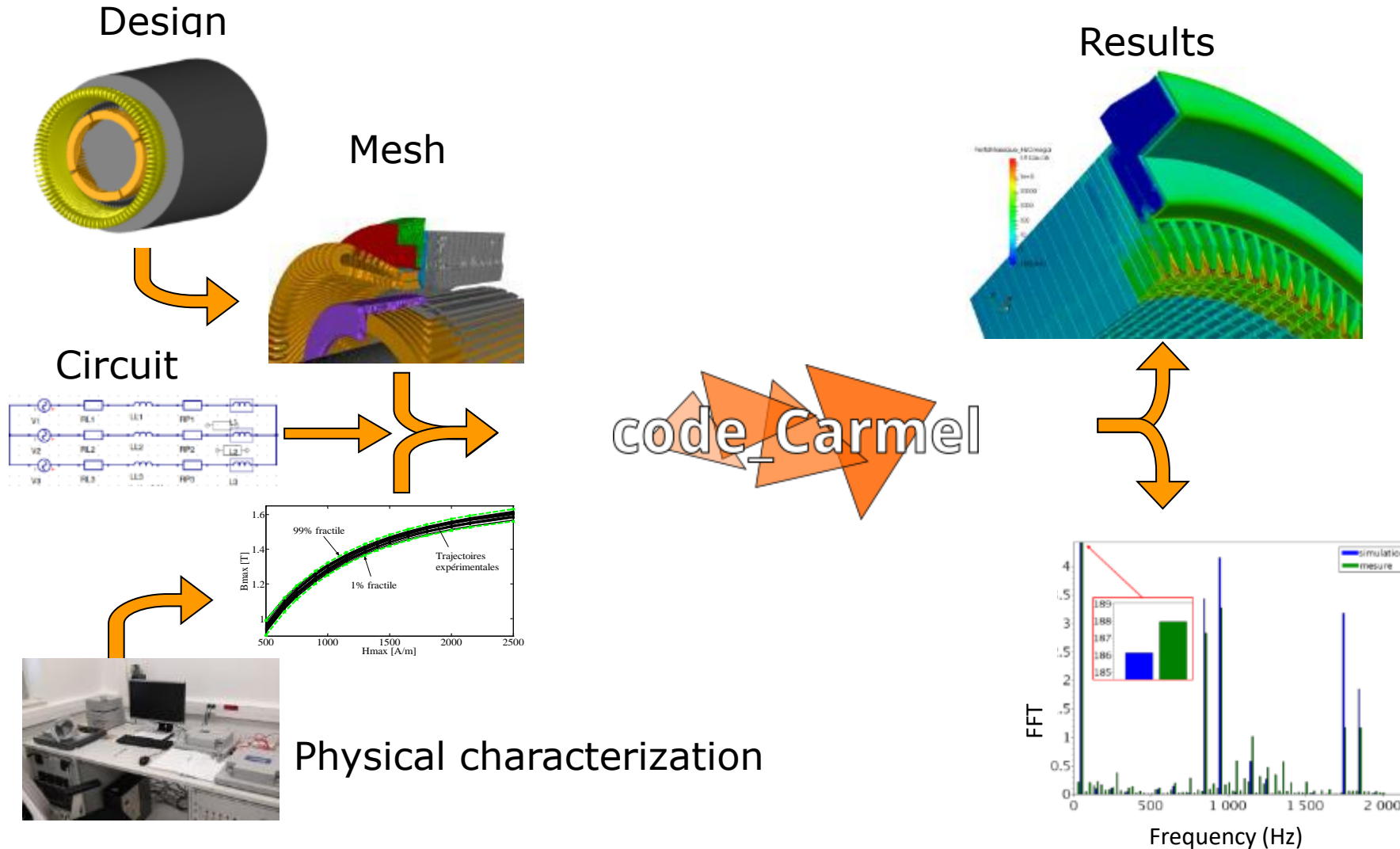
Our software code\_Carmel and C3D-CND result from partnerships...



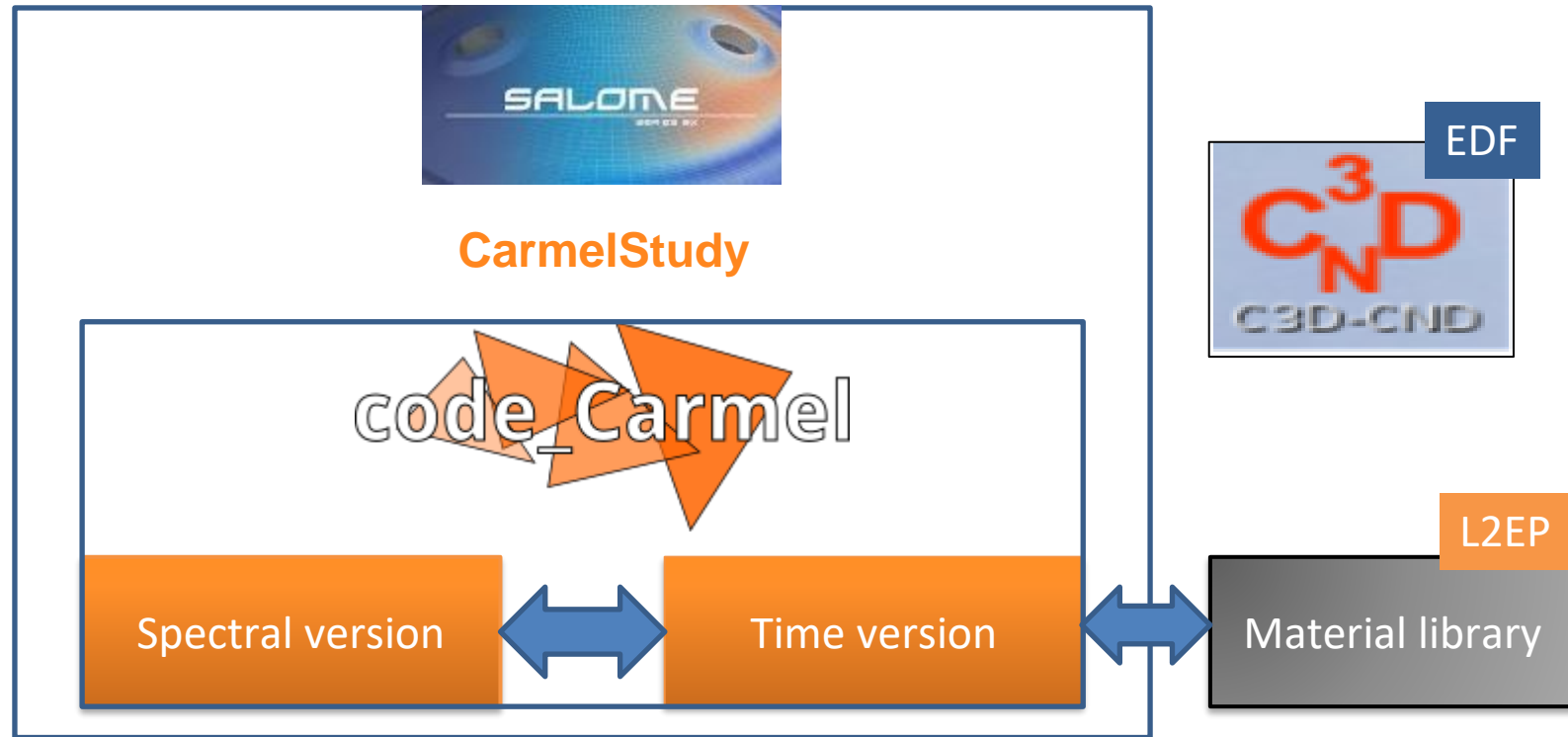
# Code\_Carmel

Code Avancé de Recherche en Modélisation Electromagnétique

Computation of 3D problems with Maxwell equations without radiation

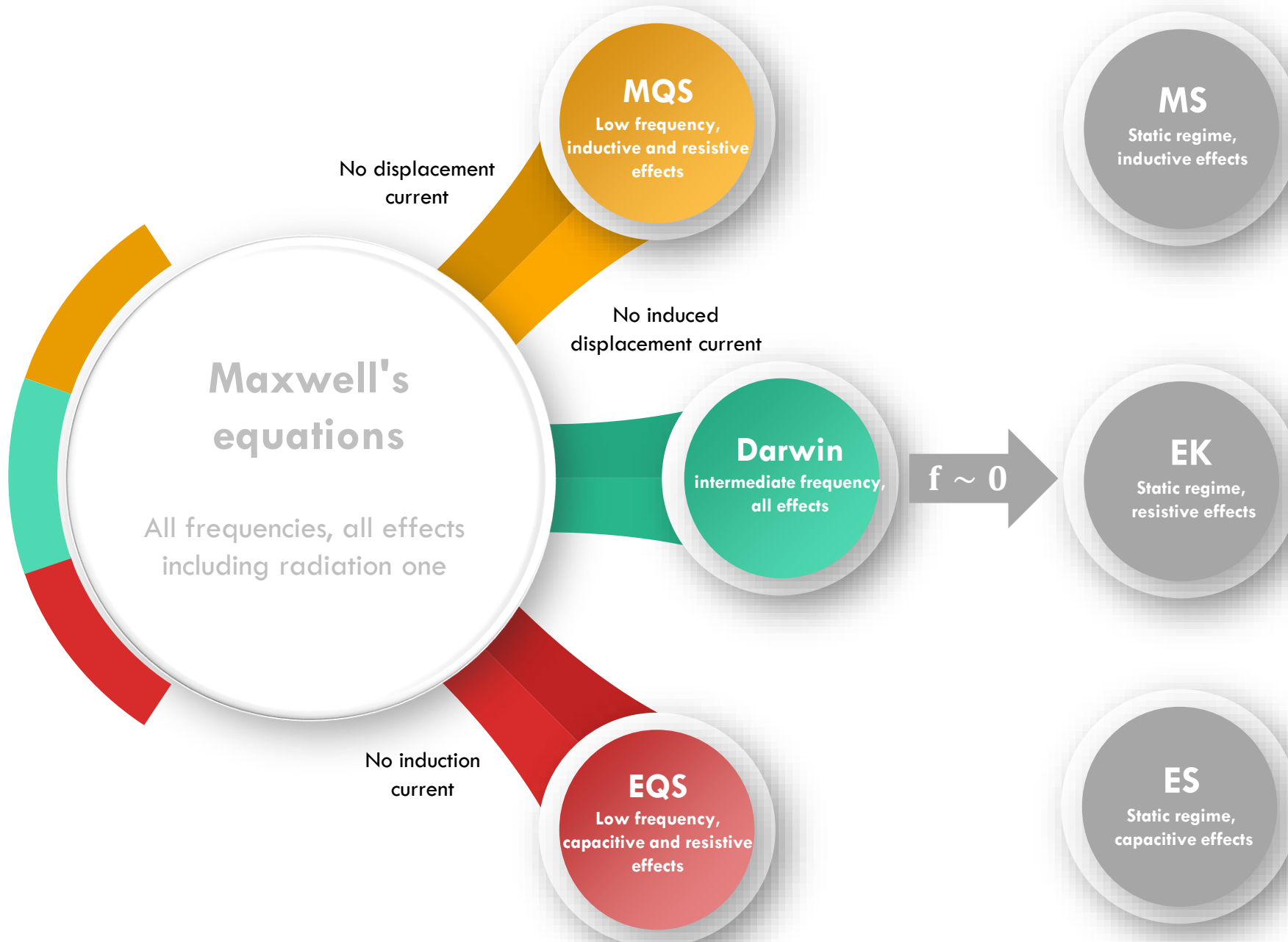


# Code\_Carmel



- Research software : temporal, spectral
- Engineering software : C3D-CND

# Models



# 1. Specificities

## Main Characteristics

- Electrical and magnetical formulation (no waves)
- Non linear physical properties
- Movement
- Global quantities imposition
- External circuits
- Iron losses
- Error estimation
- Adaptative mesh
- Reduced order model
- Uncertainties
- Artificial intelligence ...

## Particular Characteristics

- Compatibility with EDF R&D software
- HPC
- Quality assurance
  - User Documentation
  - Software Documentation
  - Theoretical Documentation
  - Use cases - Validation
  - Bugtracker
  - Web site



N°2

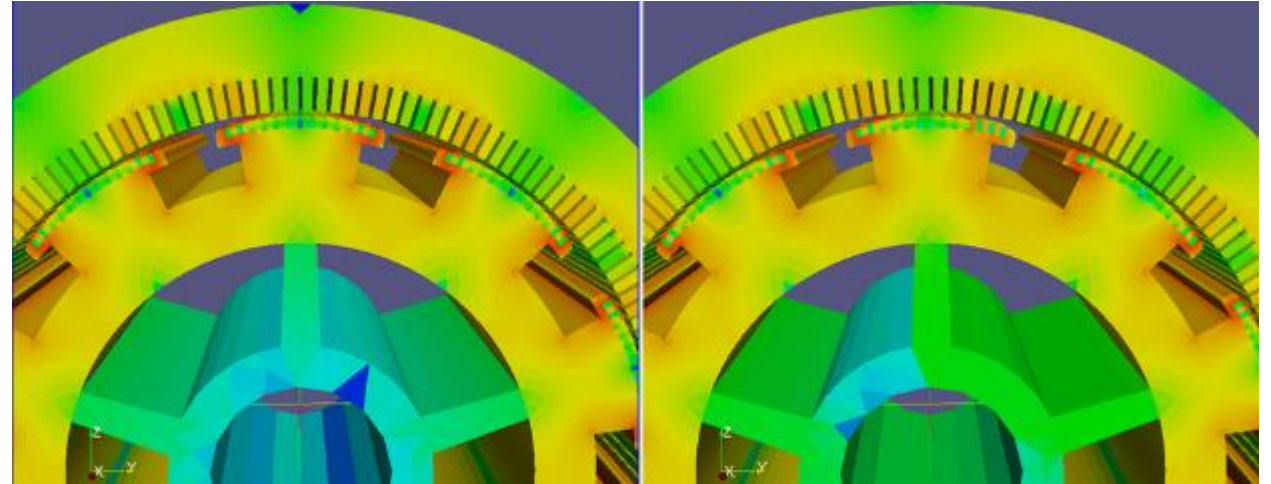
# Computational Electromagnetics

Some applications

## 1. Pole Drop test

- Salient pole generators
- Variable current in the inductor circuit
- Measurement of pole voltages
- Check the integrity of rotor winding
- What about damper cage ?

Flux density computation from code\_Carmel



Healthy machine

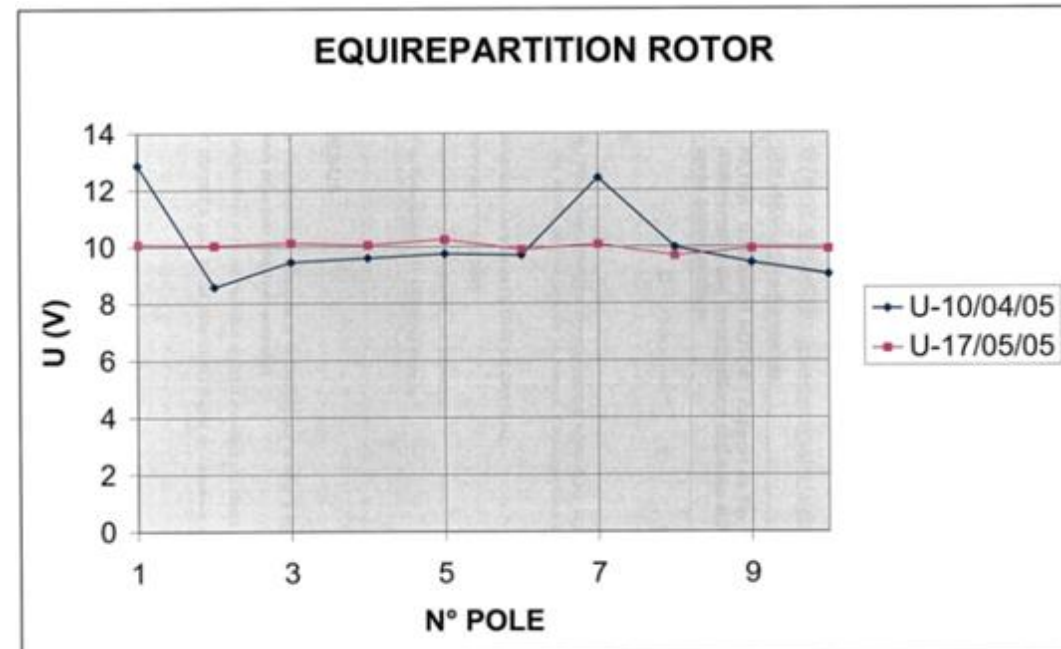
Machine with defects

Voltage per pole

- Red curve = healthy machine
- Blue curve = defects on poles 7 and 1

This test can also indicate problems on damper cage

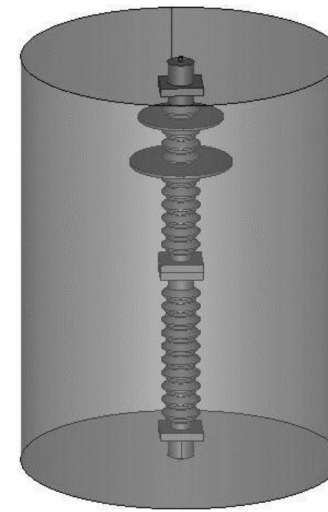
Replacement of experimentation



## 2. Electrical network component modelling

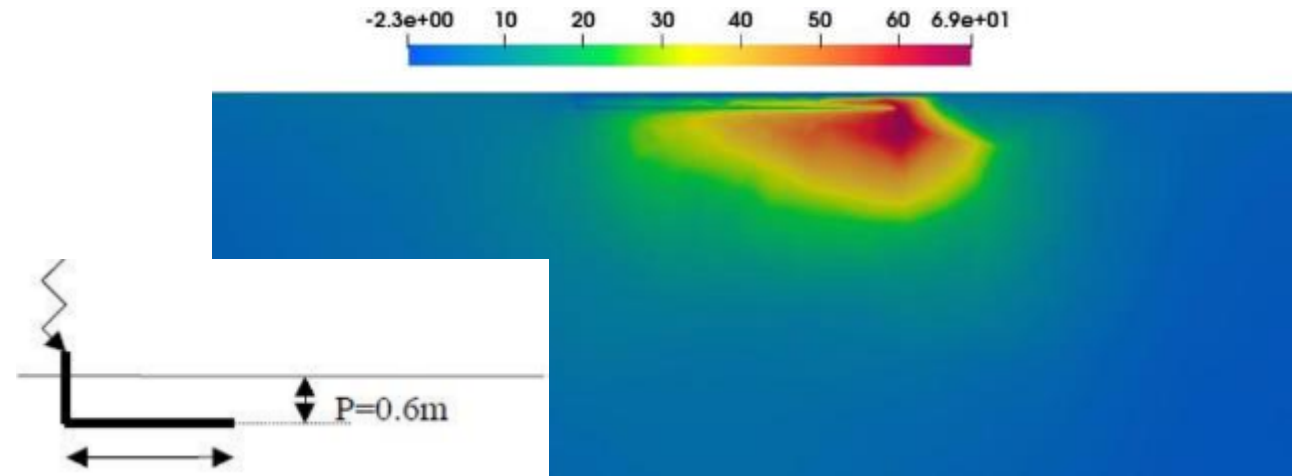
### Surge arrester

- Nonlinearity of dielectric physical properties



### Ground connections

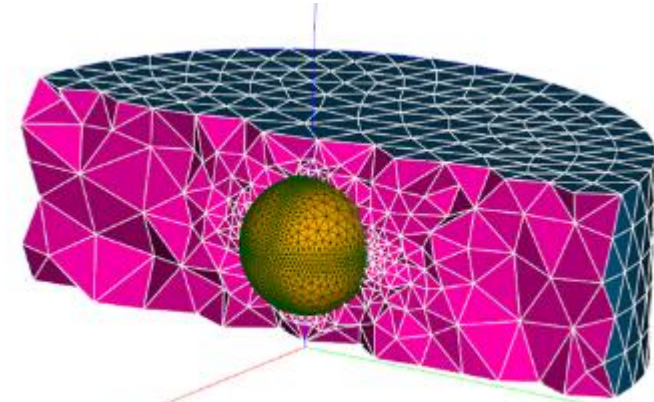
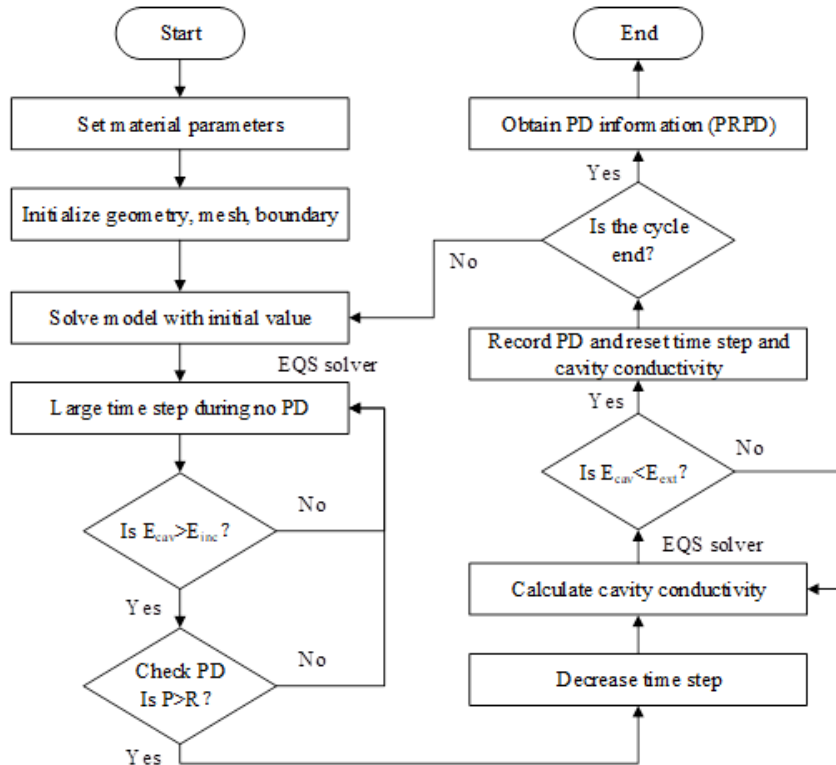
- Modelling simultaneously resistivity, permittivity and permeability



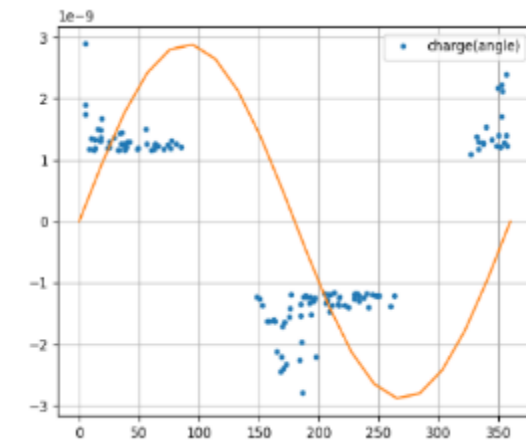
### 3. Partial discharges

Partial discharge (PD) is a discharge event that does not bridge the electrodes of an electrical insulation system under high voltage stress. Although PD does not cause direct breakdown, it is a sign of degradation and indicates the presence of a defect within the insulation system.

Specific implementation in code\_Carmel



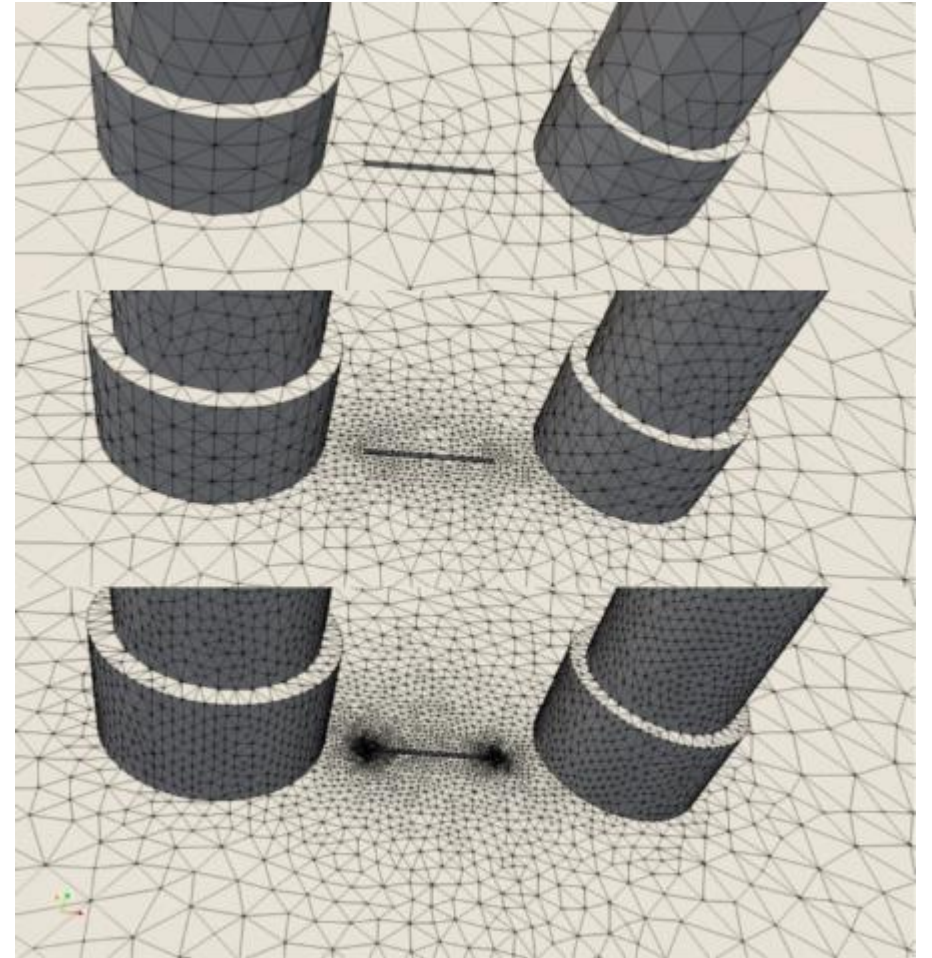
Mesh of the vacuole in the dielectric



Representation of electric charge vs. phase

## 4. Adaptative Meshing

- Dual formulation of code\_Carmel
- No user intervention (precision criteria only)
- Gain in number of elements compared to "expert" work



Computation Quality with local quantities

## 5. Reduced order models

### Objective :

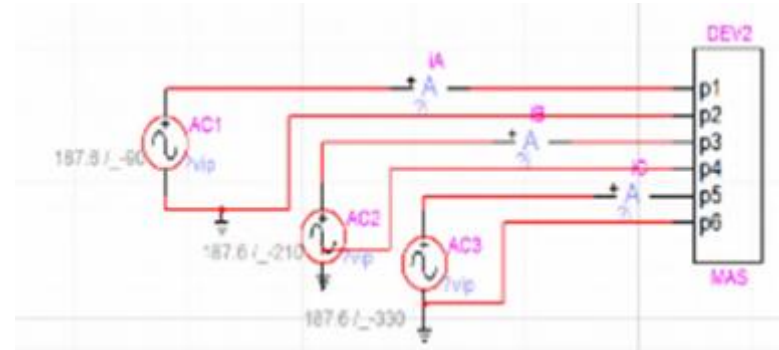
- Analysis of the behaviour of induction motors in English power plants
- Analysis of wind generators

### Issue :

- Modelling the starting of an induction motor with Power Electronics converter
- Too difficult to introduce Power Electronics components in the finite element software
- Mix finite elements and circuit modelling

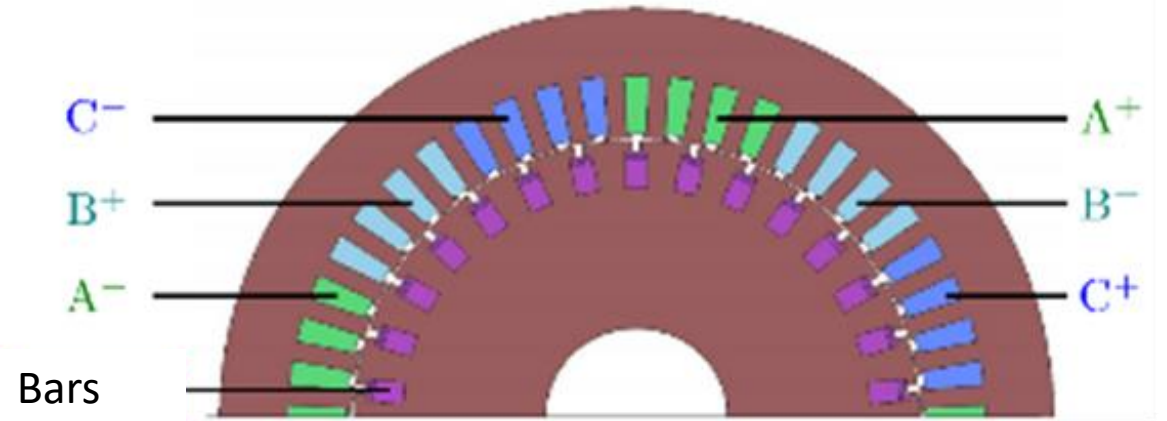
### Solution :

- Reduced order model



Electrical circuit modelling

Induction machine

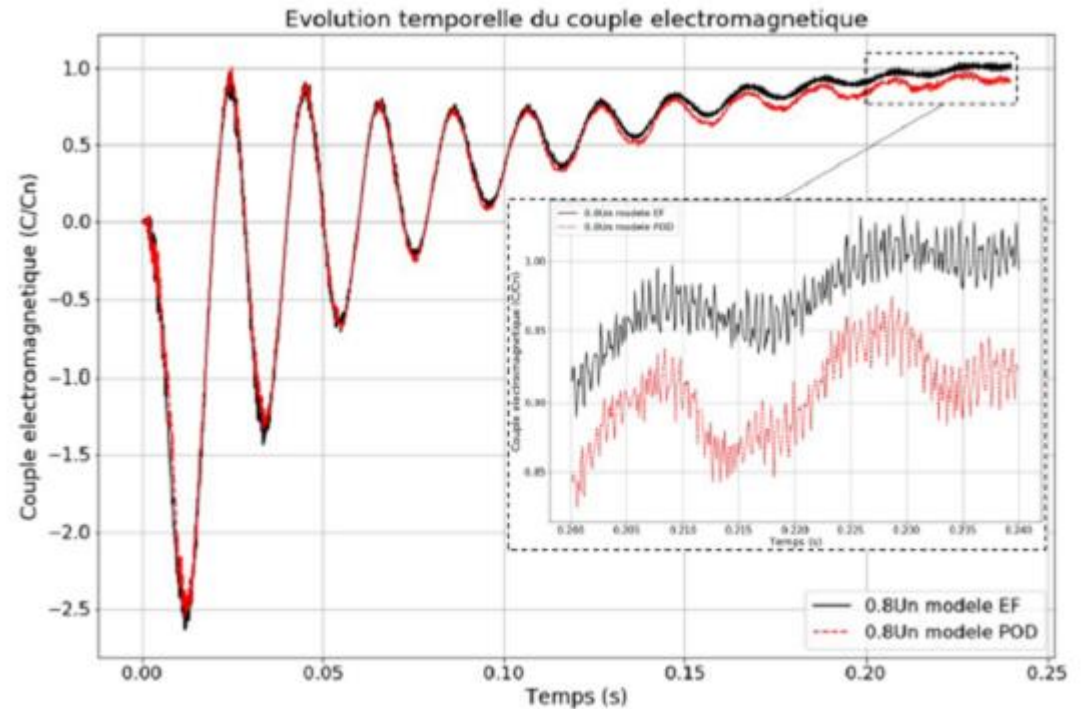
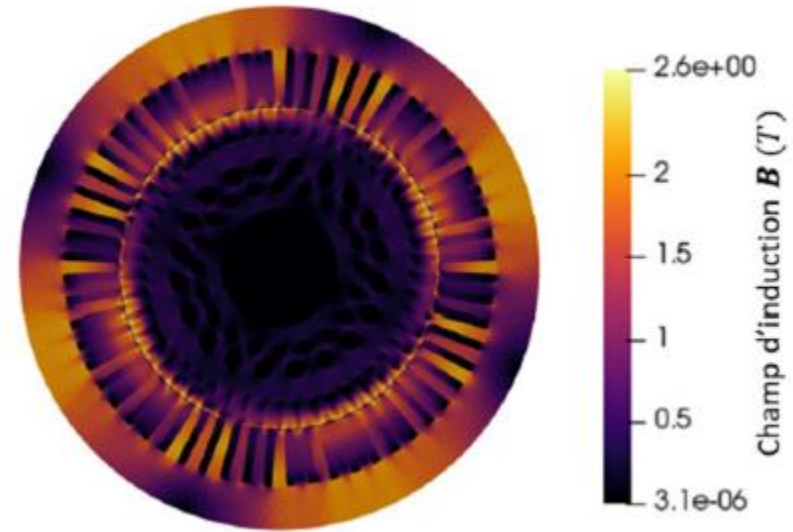


## 5 . Reduced order models (cont'd)

- Snapshots
- POD
- Reduced basis

Flux density computation from the reduced order model

Time evolution of the torque (ROM / Finite element)

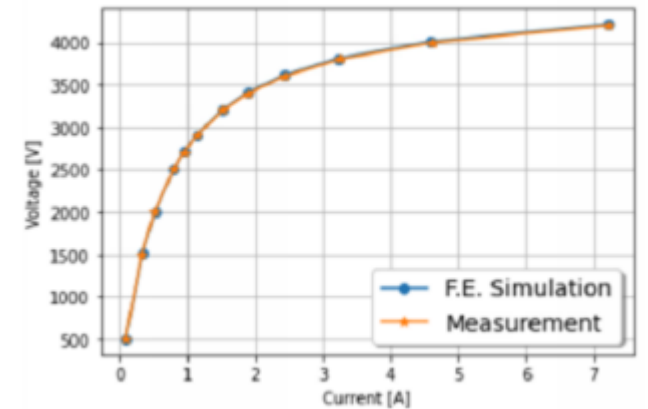
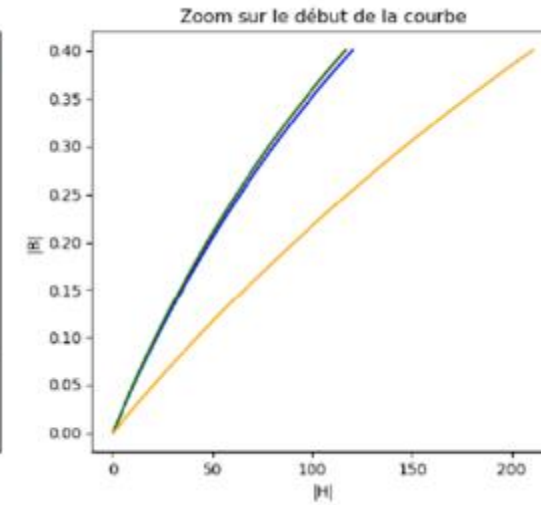
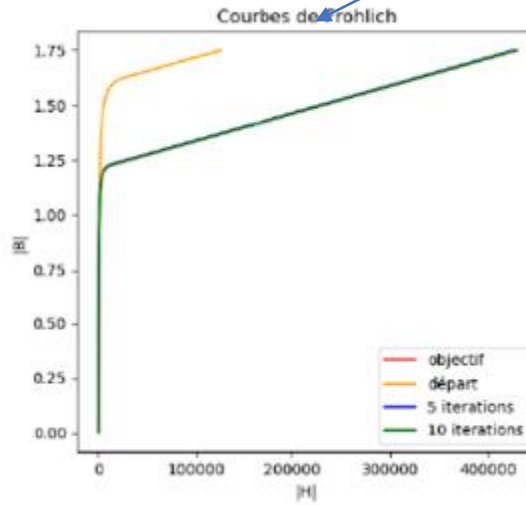
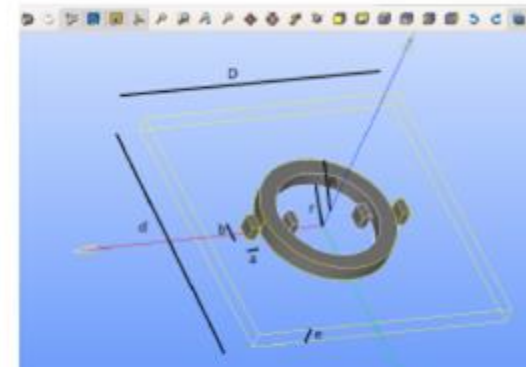


## 6. Parameter identification – B/H curve

In magnetic device, physical characteristics are often nonlinear and not well known. Using electromagnetics computations and measurements, we built a relevant curve.

Figures in the middle, we tried an inverse problem approach

Last figure, we performed a data assimilation approach





## 7. MultiPhysics – Cable ampacity

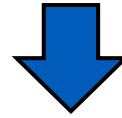
Current in cables is limited by the temperature reached by dielectrics around the conducting part.

Joule losses are computed with code\_Carmel

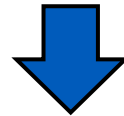
Heat exchange are computed with thermal field software

Natural convection is computed with CFD software

Industrial cable

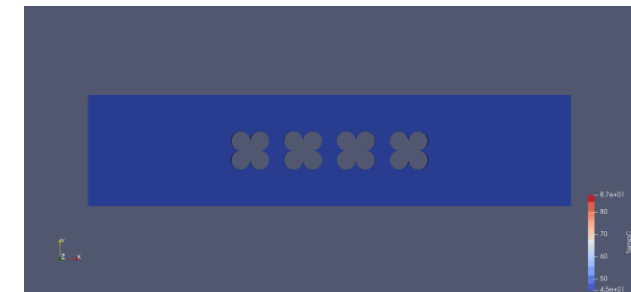
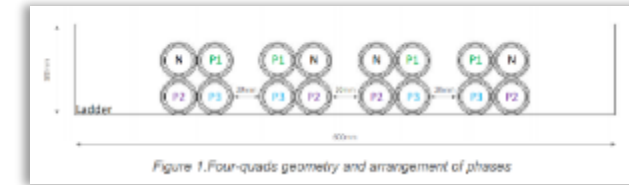


Electromagnetics Computation



Thermal and CFD computation

- Radiation impact
- Losses projection
- Cable ampacity
- Temperature influence on electrical conductivity  $\sigma(T)$

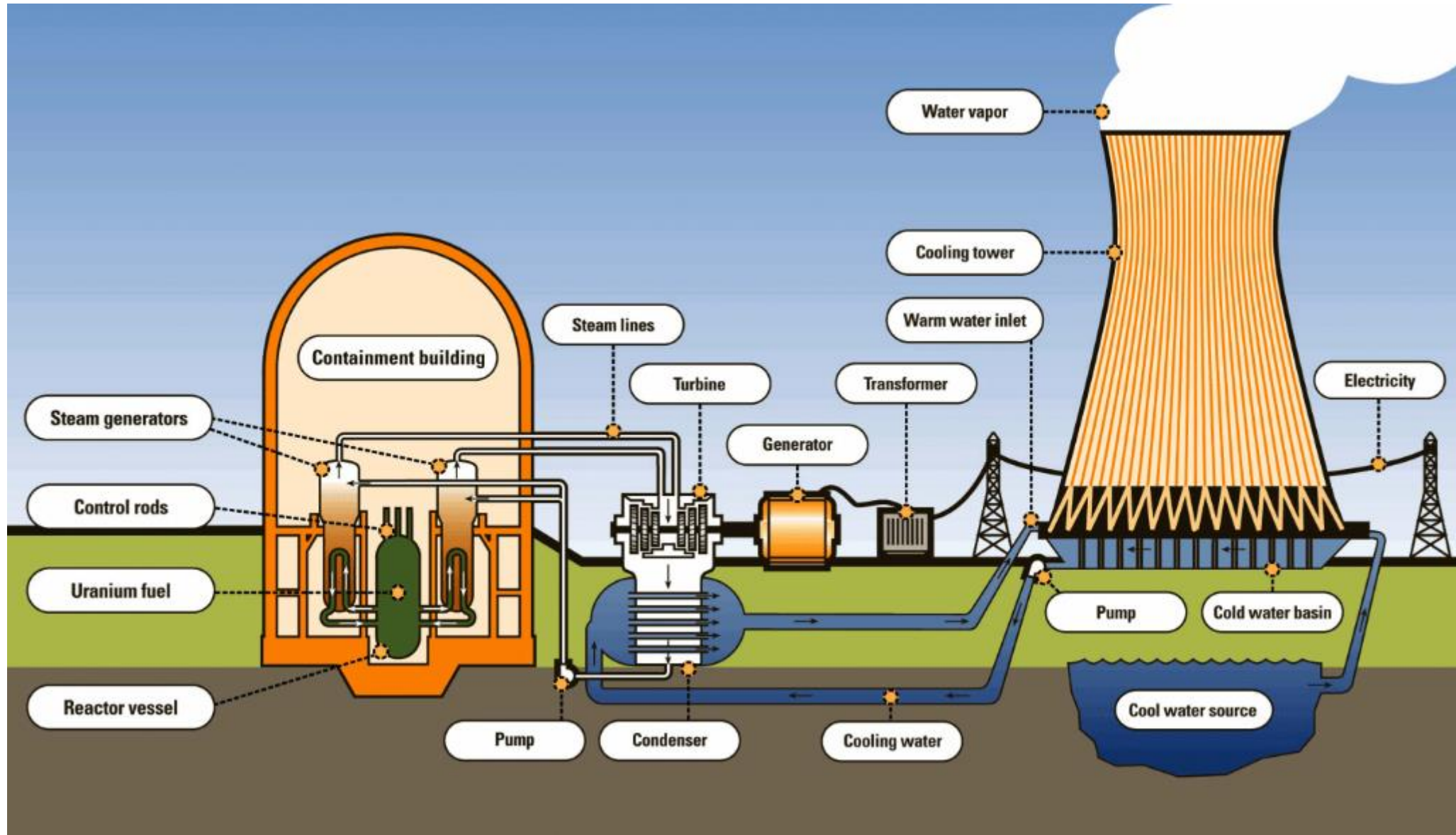


N°3.1

# Focus on NDE - ECT

Power Plant

# 1. Nuclear Power Plant



N°3.2

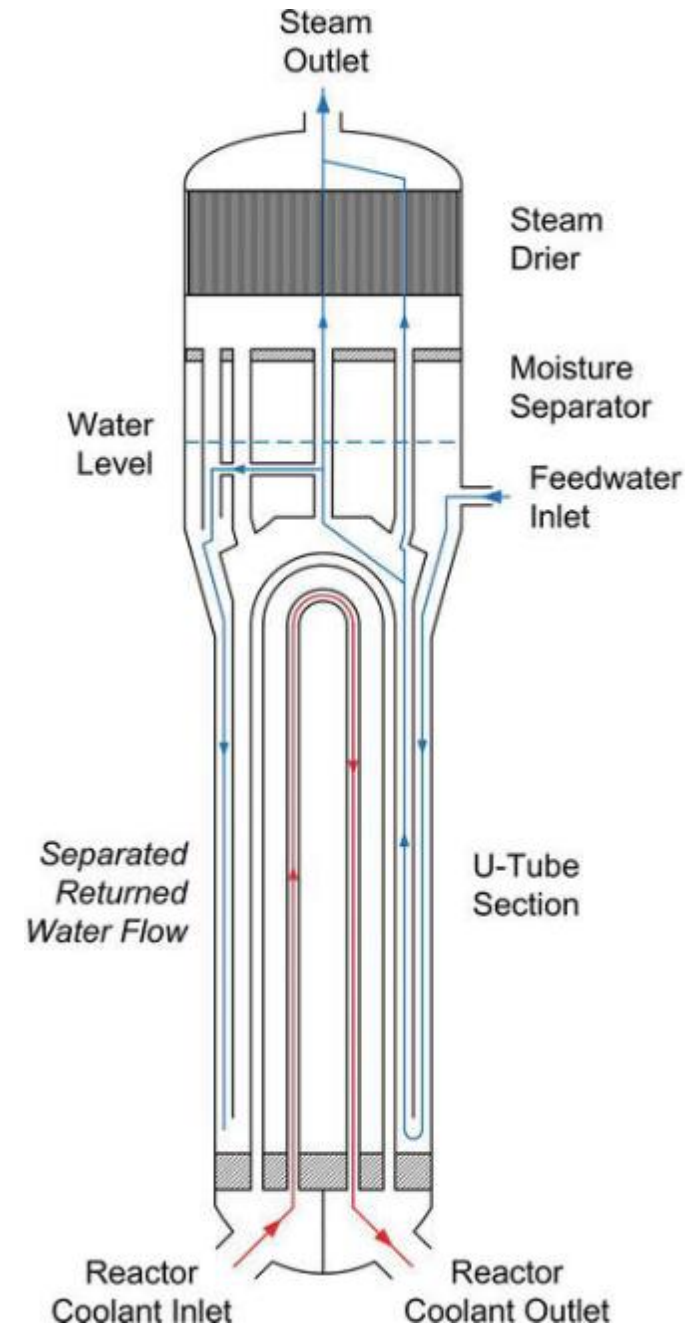
# Focus on NDE-ECT

Steam Generator

# 1. Steam Generator

A steam generator is a device that transfers the heat produced by the nuclear reaction to the water in the secondary circuit, which is transformed into steam and fed to the turbines to produce electricity.

There are different types of steam generator, depending on the design of the nuclear reactor.



N°3.3

# Focus on NDE-ECT

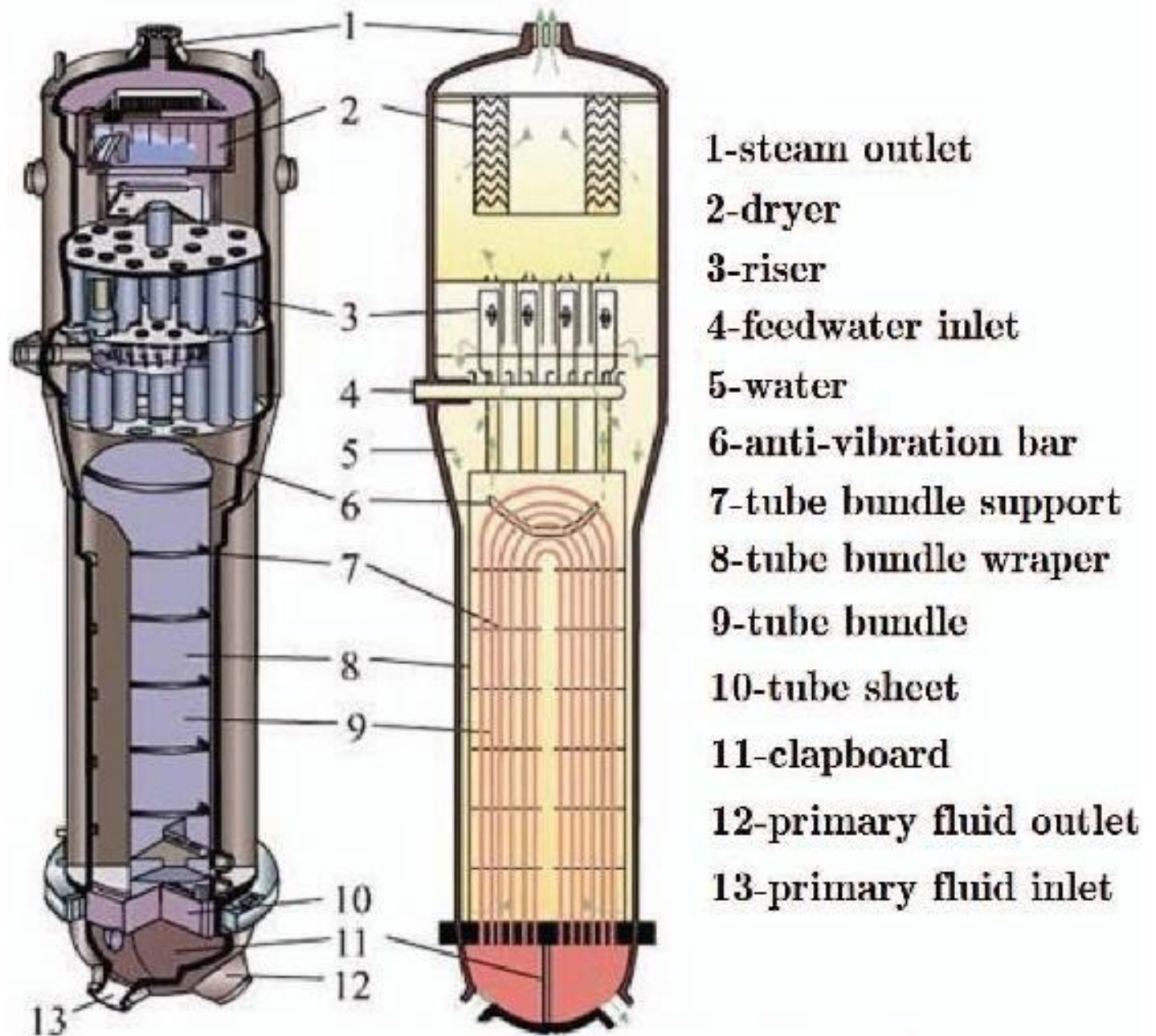
Tubes

## 1. Tubes

Steam generators are an important safety component in nuclear power plants, providing a seal between the primary and secondary circuits.

There are vibrations due to temperature and pressure variations. This can lead to failure.

They are subject to regular checks and maintenance to prevent damage and leaks.



N°3.3

## Focus on NDE-ECT

Specific issues with NDT-ECT modelling



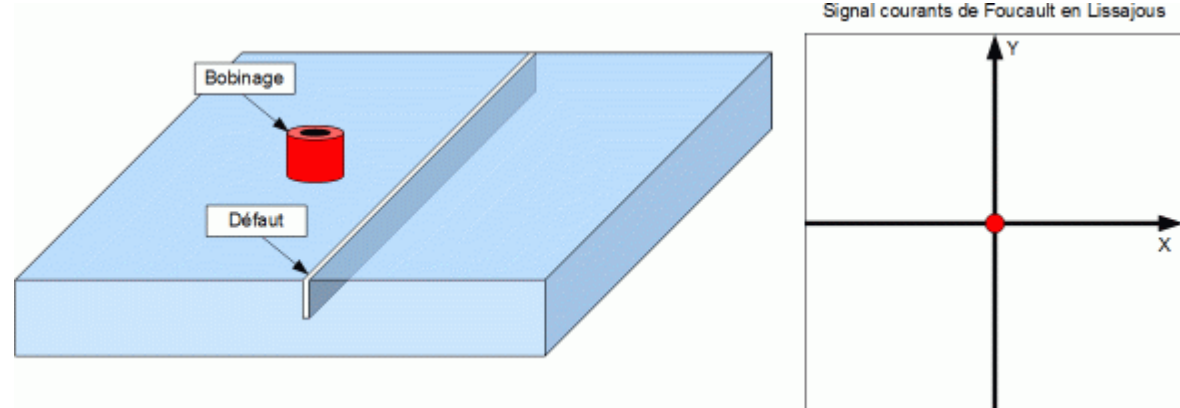
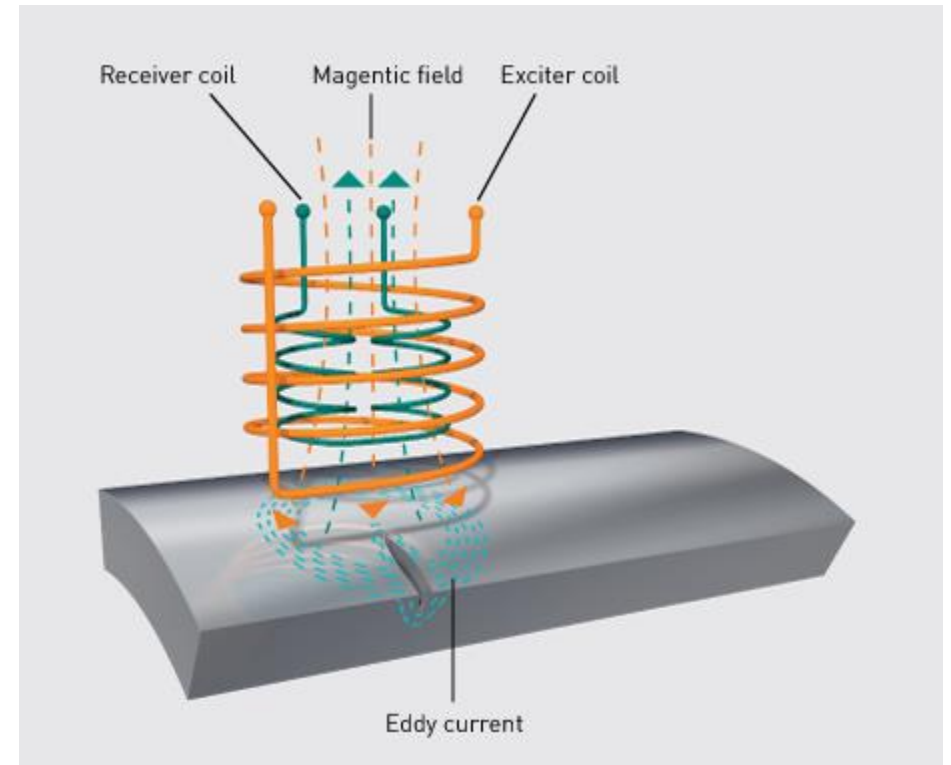
# 1. Principles

From the exciter coil, we have a magnetic varying field.

It induces eddy currents in the tube.

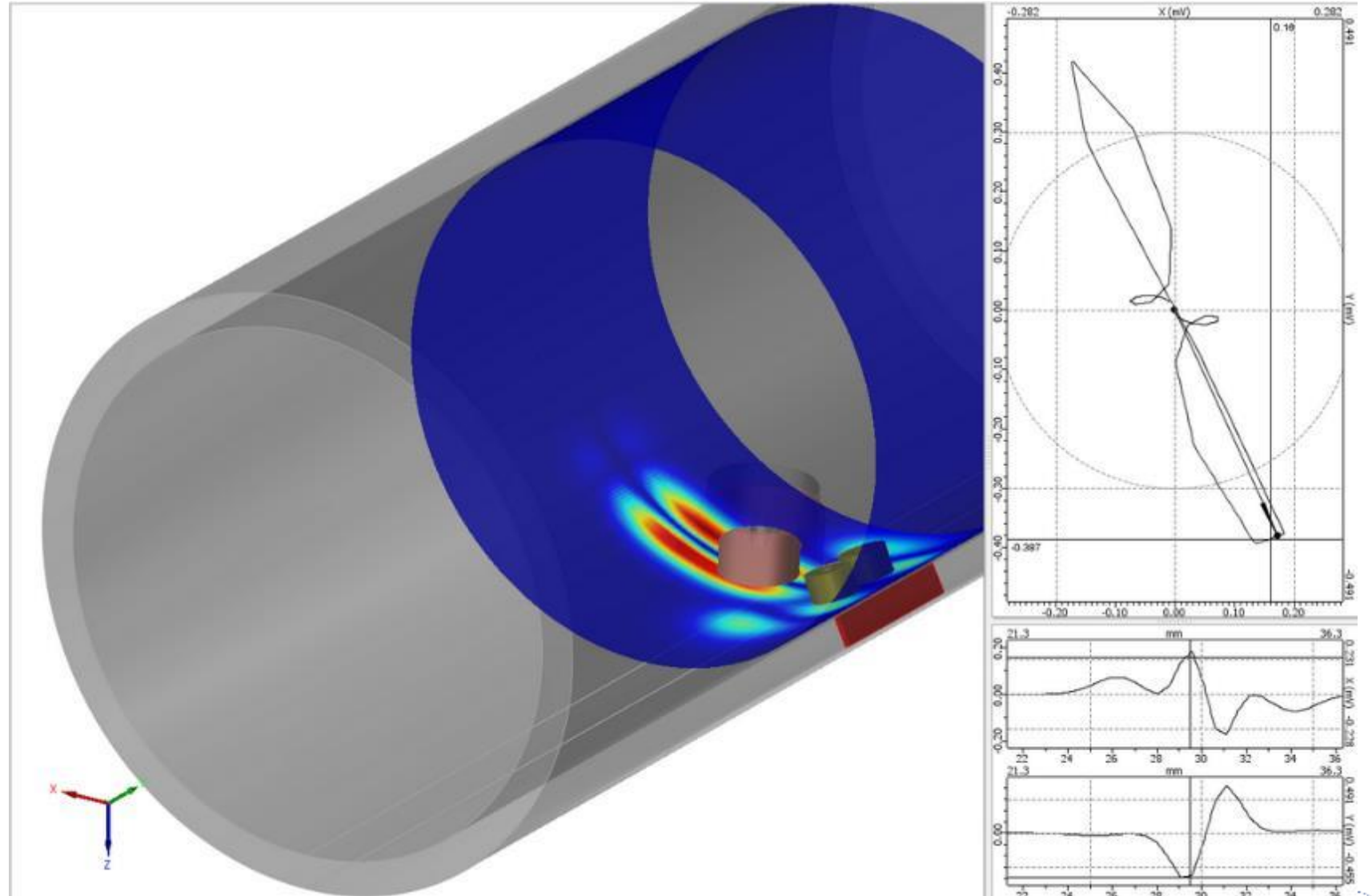
The resulting magnetic field is caught by the receiver coil. The obtained voltage (or flux) can be divided in a real and imaginary part. The representation is a Lissajous curve.

The eddy currents are modified by a flaw and so the Lissajous curve.



## 1. Expecting Results

- Computation of magnetic field for each position of the probe
- Computation of voltage or flux in the receiver coil(s)
- Movement of the probe

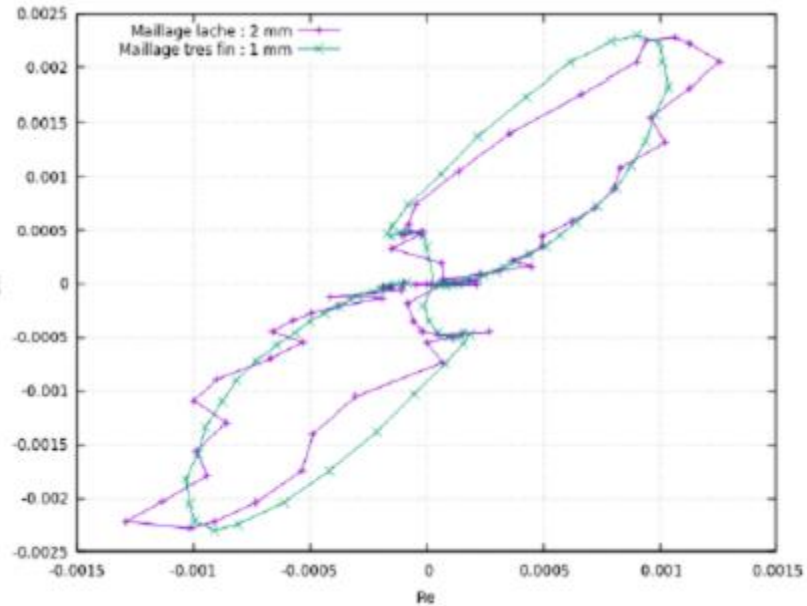
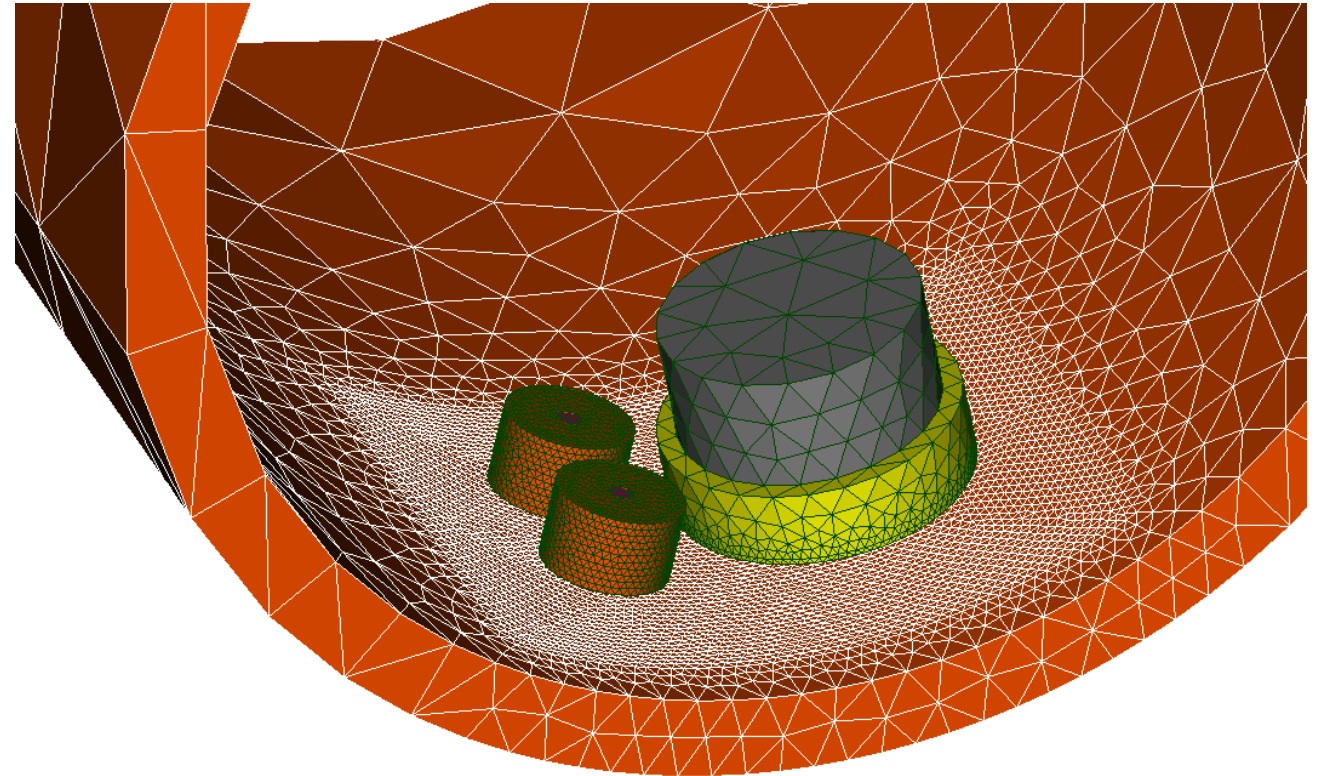


# 1. Finite element modeling

The flaw requires a fine mesh

The probe and especially the coils have a fine mesh.

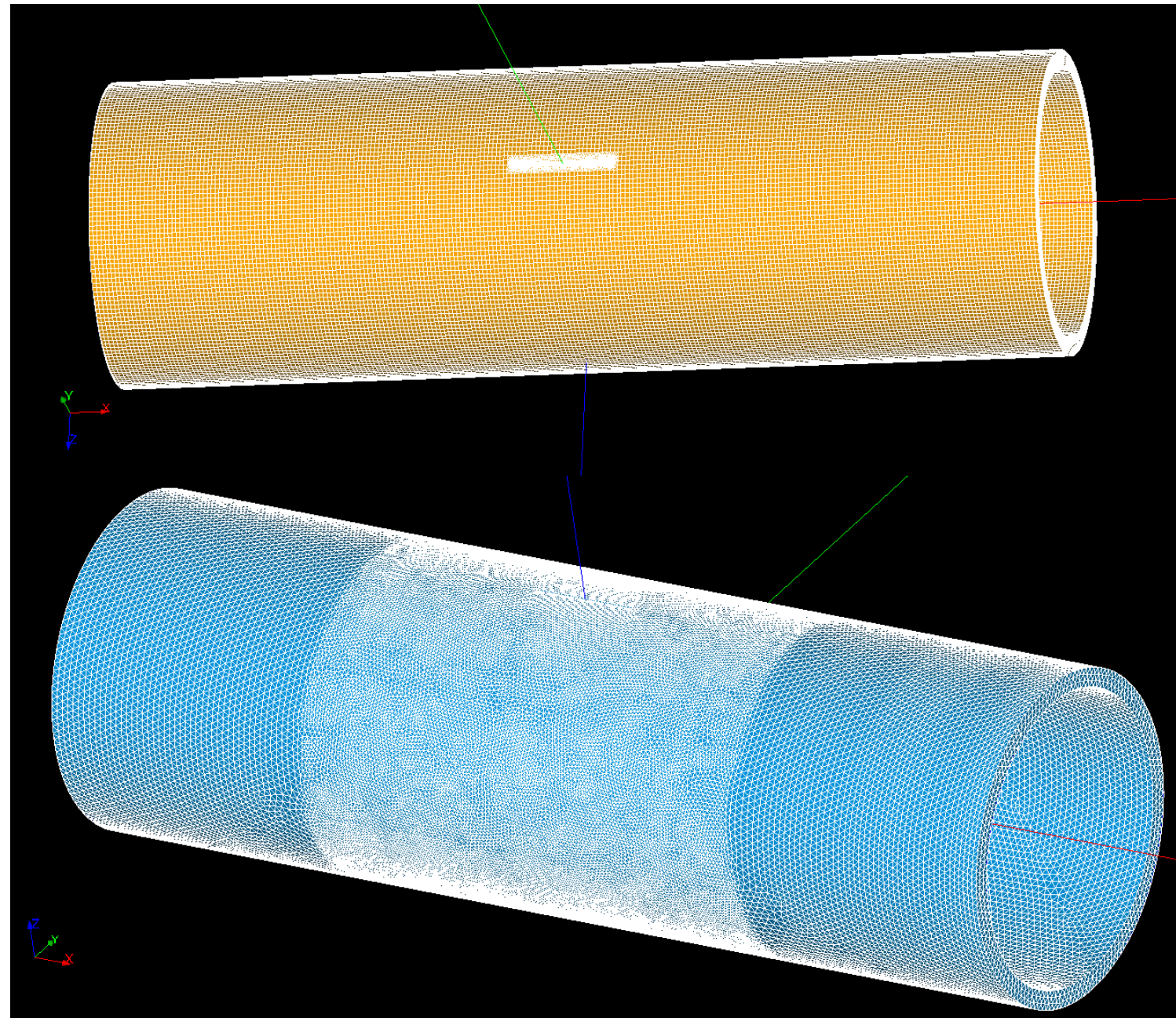
The mesh influence is important for result quality and time computation.



## 2. Finite element modeling

The flaw meshing is a critical task. For straight defects a regular mesh is used. It simplifies the movement representation.

For complex defects, it will be no longer possible. A very fine mesh is required. The moving part (probe) and the fixed part (tube) are meshed separately. For each position only the remaining part (air) is remeshed.



N°4

# Conclusions

HHO modelling

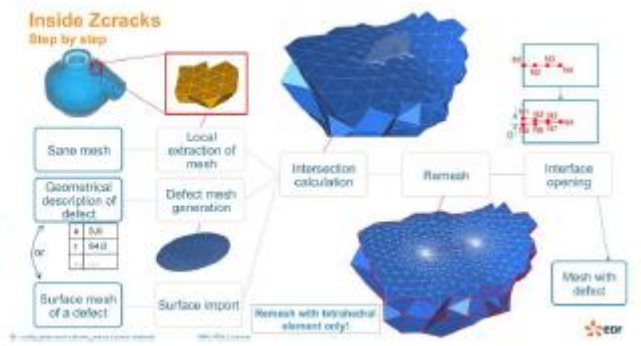
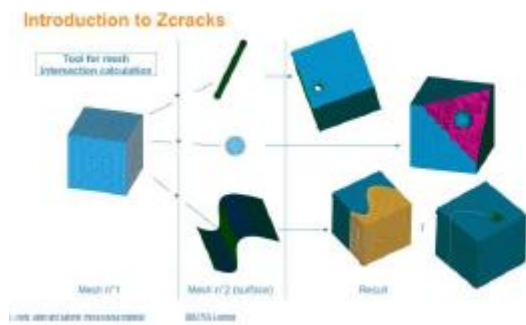
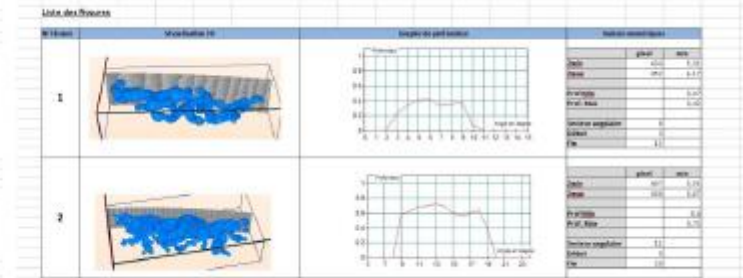
# 1. Conclusion and extension to complex flaws

A complex flaw requires a specific modeling and meshing.

A solution is the Zcracks software to include the flaw mesh in in the tube mesh.



HHO solution





Thank you

