Introduction to industrial use of X-Ray

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Short introduction : Non Destructive Testing

- Why NDT ?
  - Inspect, control, investigate without destruction of the part
  - To realise more inspections, tests, etc...
  - To continue using the part
  - To prevent from corrupting the part during destruction (like slicing)

- When ? all phase of a product life
  - R&D
  - Design
  - Manufacturing process
  - Quality control (100%, statistical control...)
  - Customer return

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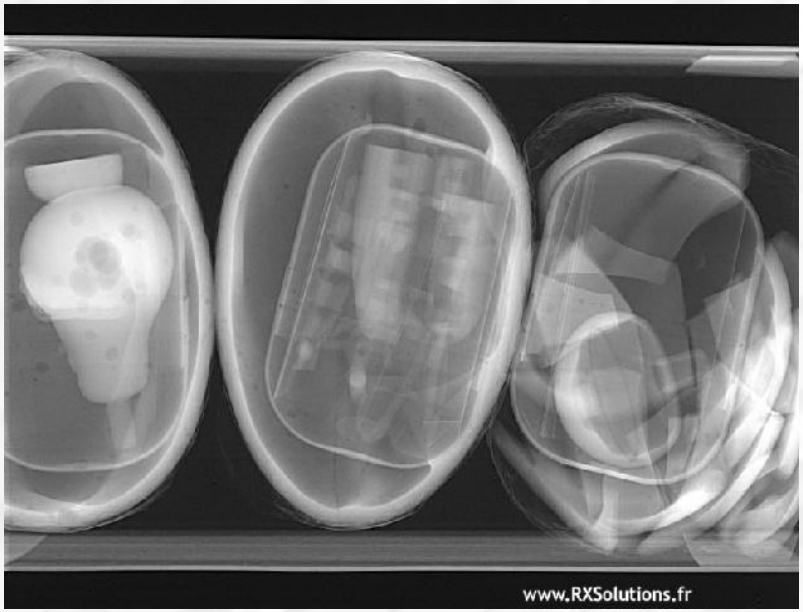
X-ray NDT

- Why ?
  - Look through
  - See inside matter
  - Real time inspection



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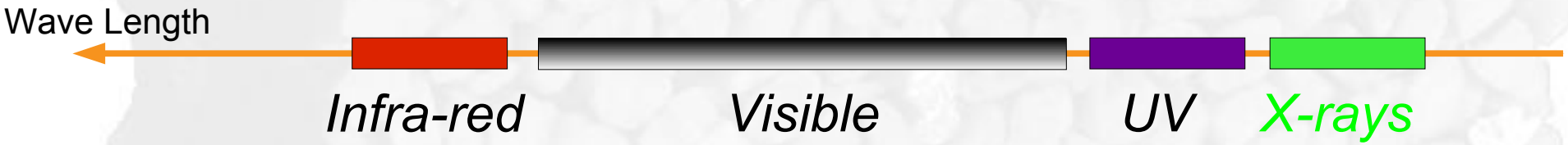
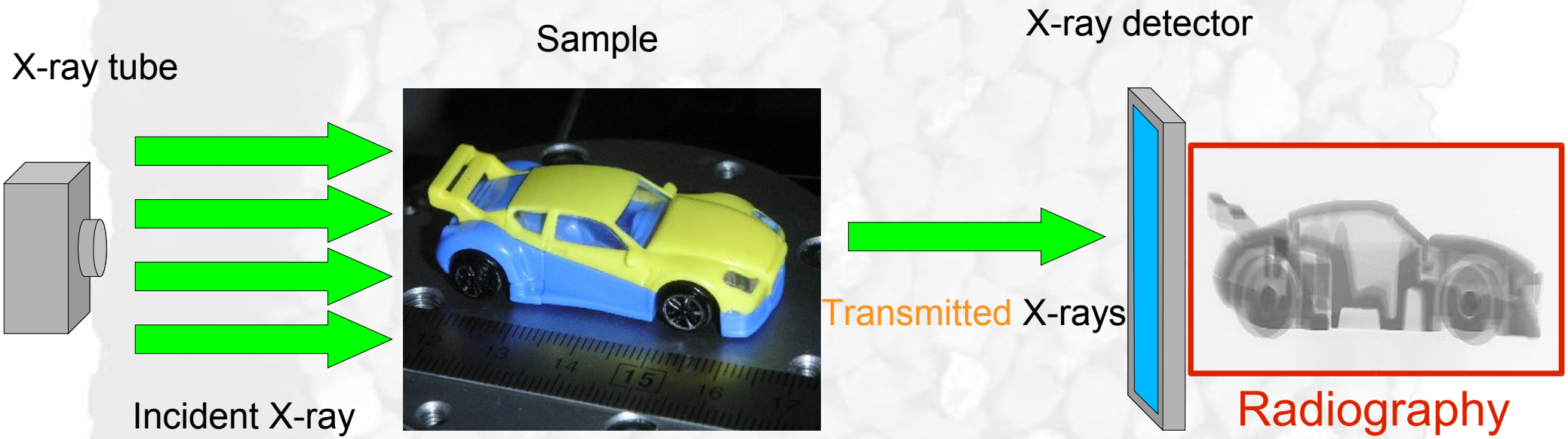
Principles of X-ray imaging

- What are X-rays ?
  - An electro-magnetic wave (like light)
  - A penetrating radiation
  - With interactions with matter



  - Radiation energy : electron-Volt (eV)
  - Energy range for our interest : from 20 keV to a few hundreds keV

Principles of X-ray imaging
Transmission imaging



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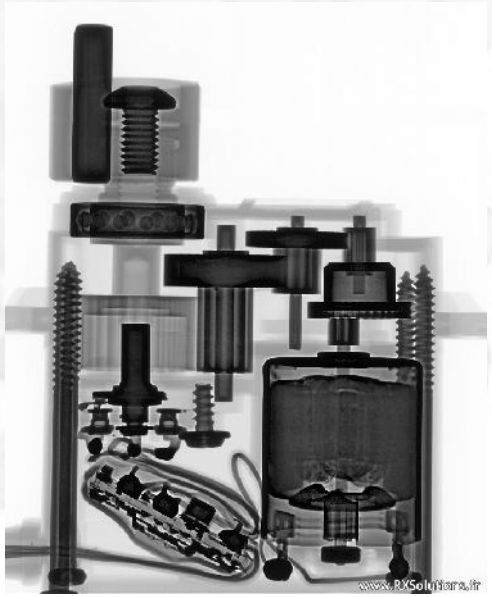
First industrial solution : Radiography

- Harmless for the sample : used also for food ! The sample does not turn radioactive
- Harmful for human beings : need for protection (lead cabinets) or special care
- Radiography = Image of the X-rays photons that went through the sample

One of the very first radiographs, taken by Röntgen (1895)

Foreign bodies detection in chicken wings



Radiography of a motor

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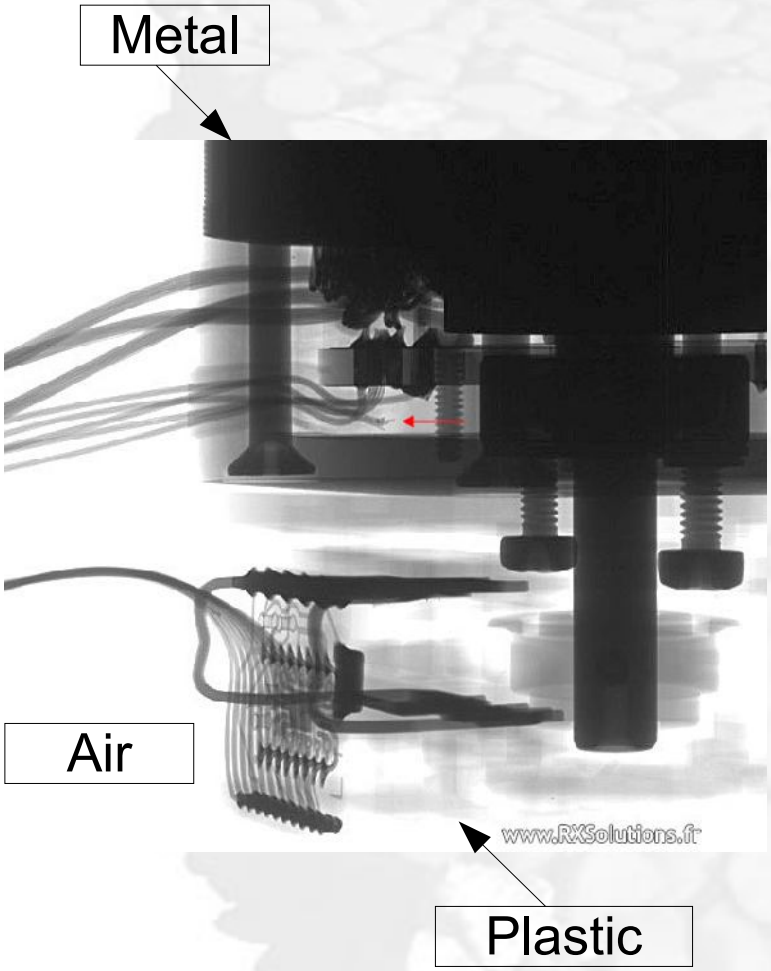
What is to be observed ?



- The interaction between X-rays and matter depends on :
  - X-ray photons energy,
  - Atomic number of the atoms,
  - Density of the matter.
- X-ray photon easily go through the matter if :
  - Their energy is high,
  - Material os made of light atoms
  - Material has low density

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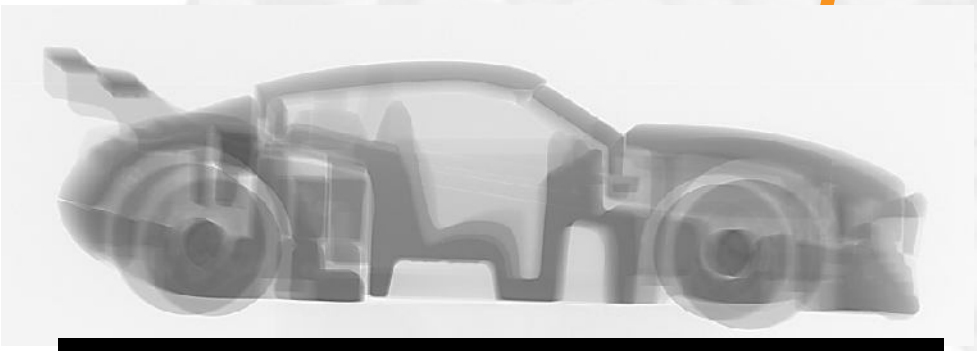
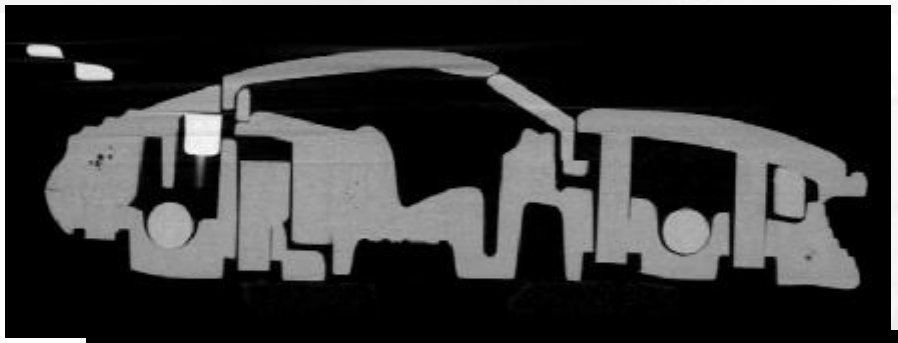
Second industrial solution : Computer Tomography





- Limitations of radiography : impossible to determine depth position of the elements, difficulties to interpret complex structure, components hidden by dense parts...
- Solution : Computer Tomogrphy : virtual slicing of the part
  - similar to medical CT Scan

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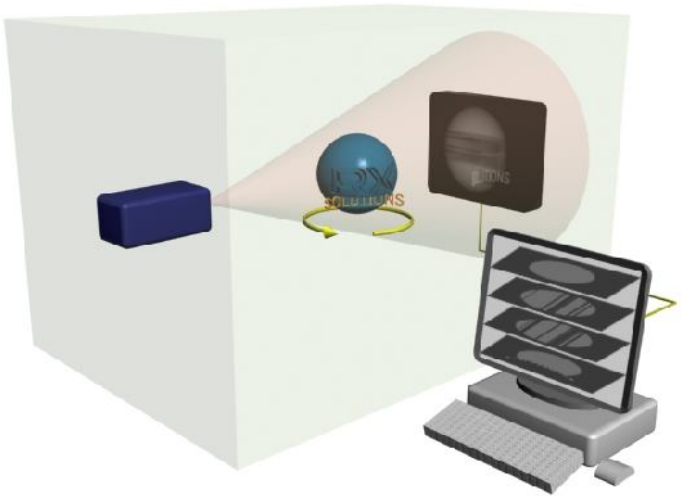
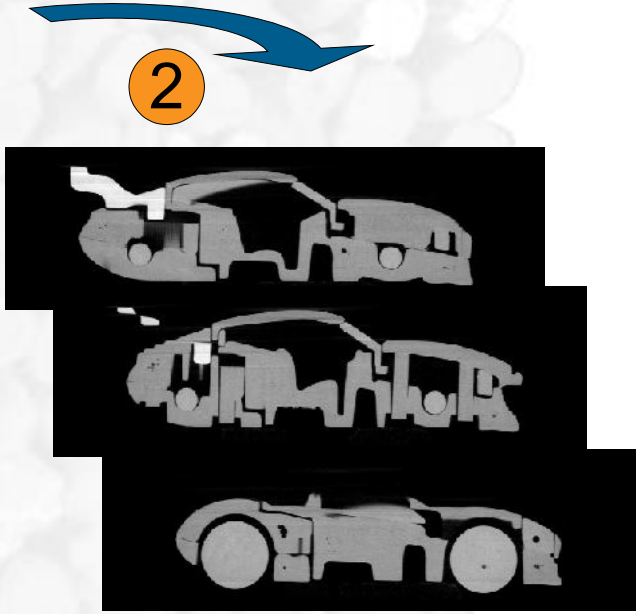
Computer Tomography

Rotation of the Sample



Acquisition of a large number of radiographs at different angular positions

Tomographic reconstruction



- Acquisition : several hundreds of radiographs acquired around the sample (preferably, the sample is rotated instead of the imaging system, contrary to medical imaging)

- Then : Tomographic reconstruction of the part in 3 dimensions as a stack of thin slices through the part (computerized calculation)

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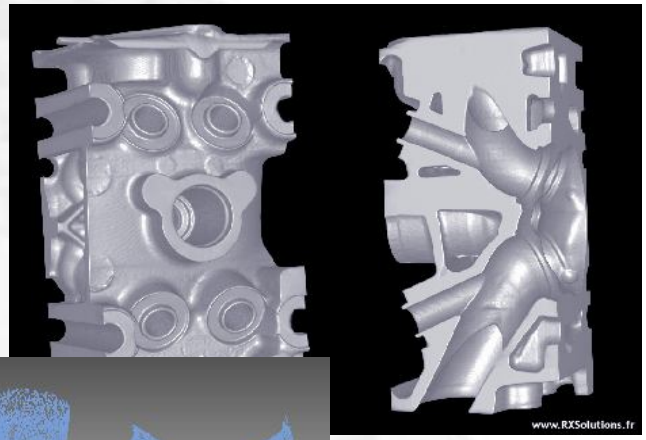
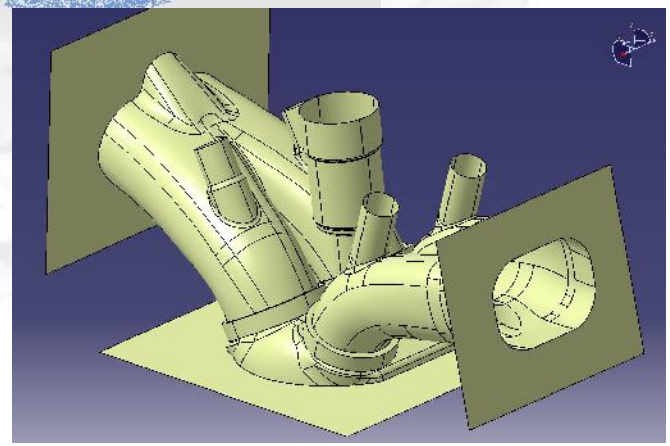
Design

- Reverse engineering : Building of the CAD model from a prototype
  - From a Computer Tomography : **Surfaces are extracted** from the reconstructed volume at the interface between air and matter and a cloud of points is defined on them.
  - **Reconstruction of the CAD Surfaces** from the point cloud given by CT

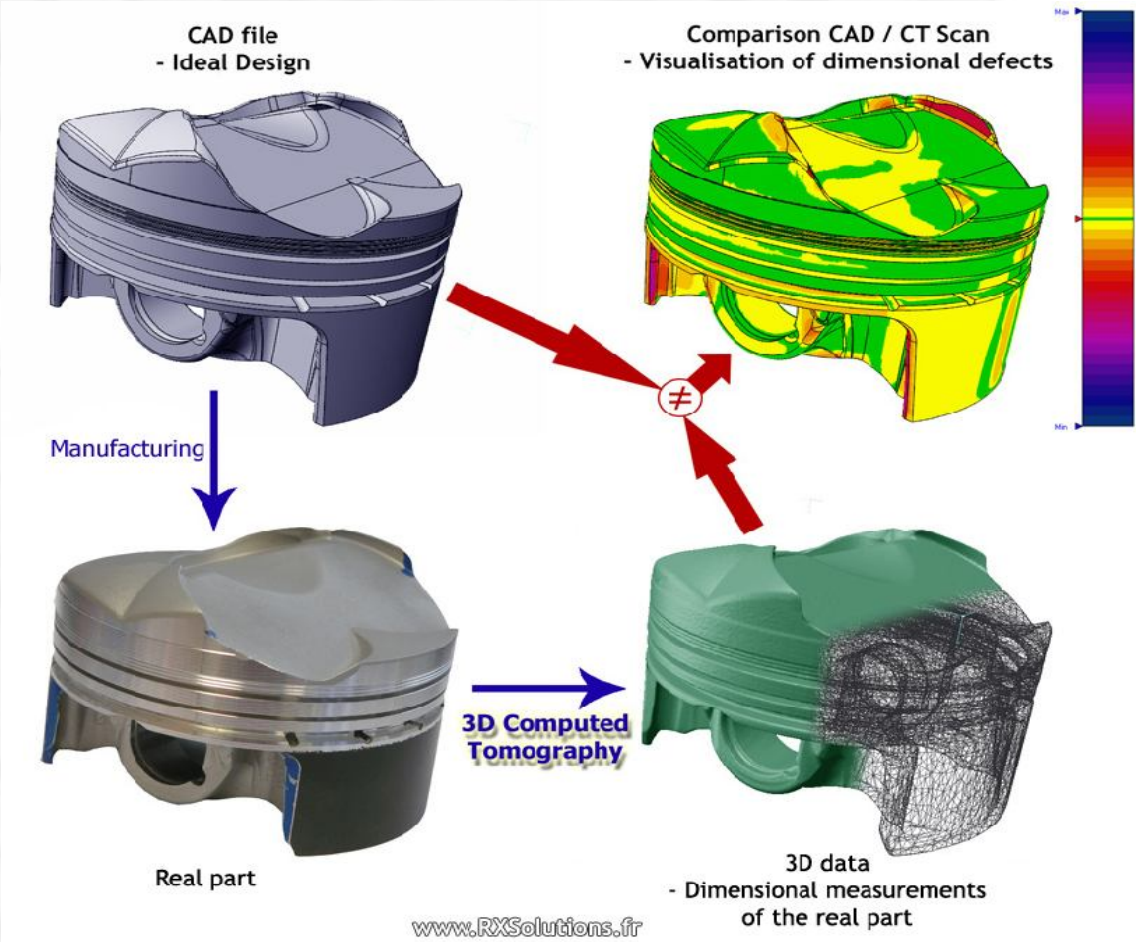
  - Pros : Extraction of the point cloud Completely independant of the complexity of the part
  - Cons : Requires a homogeneous part
  - Used a lot in industrial espionage...





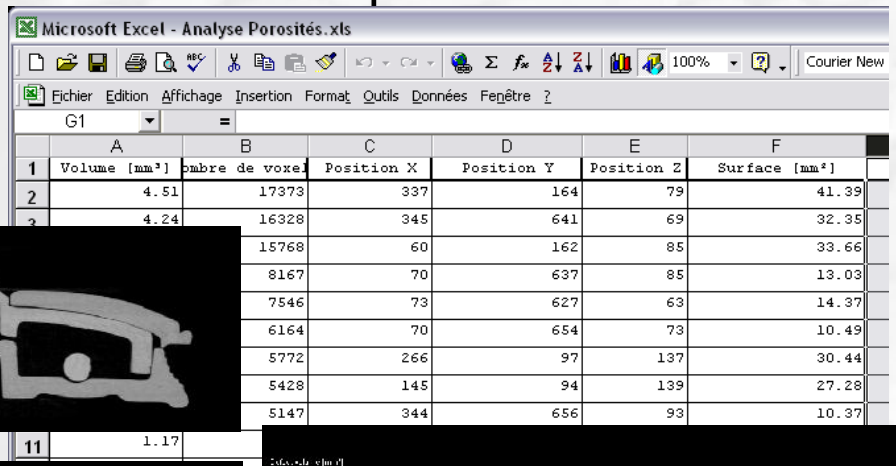
Manufacturing process

- CAD/Real comparison
  - Digitization of the part by computation of the point cloud (similar to reverse engineering)
  - Distance measurement between CAD volume and digitized part



Manufacturing process

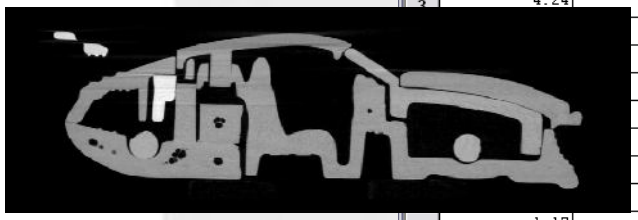
- Gauging the manufacturing process : Analysis, comparison, control of manufactured parts obtained with different parameters in the manufacturing process (molds, matter, temperature, tools...)
  - **Porosity detection** and quantification

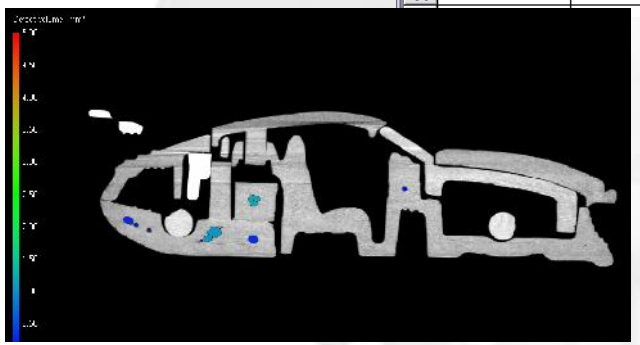

Microsoft Excel - Analyse Porosités.xls

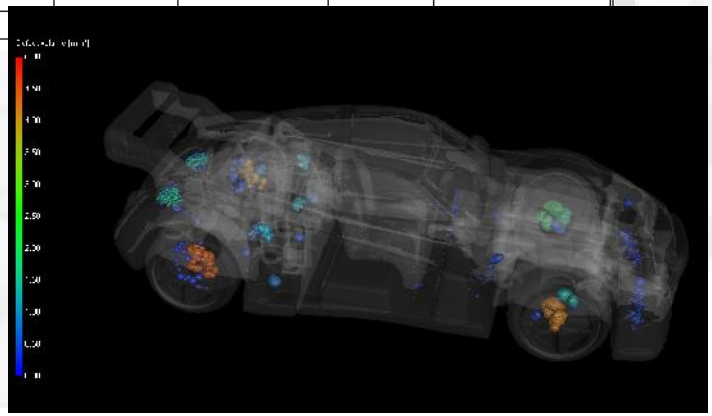
Fichier Edition Affichage Insertion Format Outils Données Fenêtre ?

G1 =

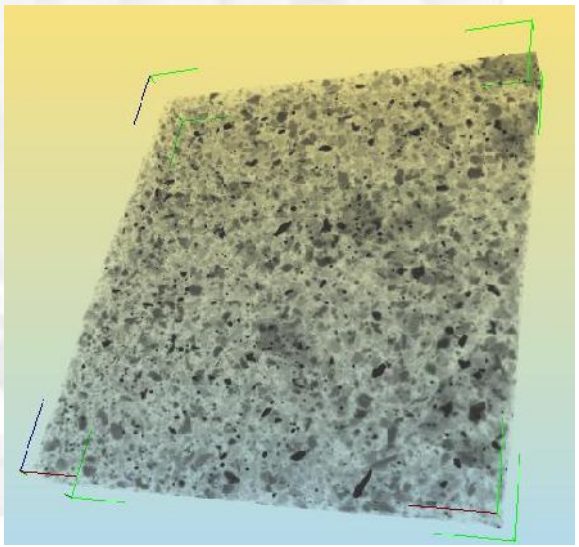
	A	B	C	D	E	F
1	Volume [mm³]	Nombre de voxel	Position X	Position Y	Position Z	Surface [mm²]
2	4.51	17373	337	164	79	41.39
3	4.24	16328	345	641	69	32.35
4	4.11	15768	60	162	85	33.66
5	2.12	8167	70	637	85	13.03
6	1.96	7546	73	627	63	14.37
7	1.60	6164	70	654	73	10.49
8	1.50	5772	266	97	137	30.44
9	1.41	5428	145	94	139	27.28
10	1.34	5147	344	656	93	10.37
11	1.17					







- **Fibres** orientation,**particles** in composites



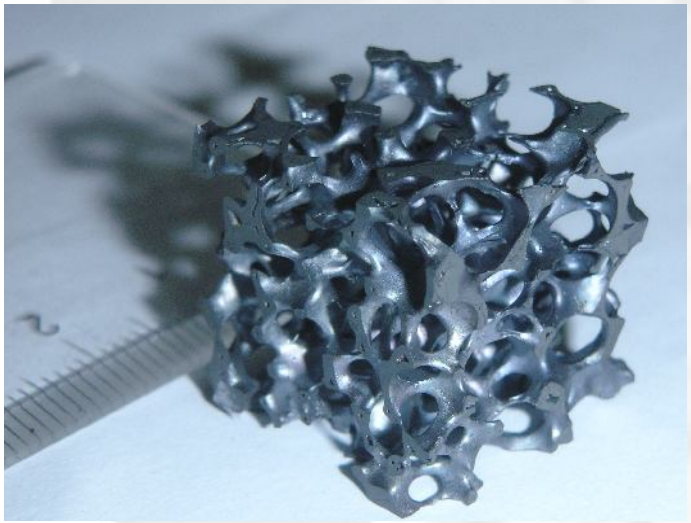
Reinforcement in composite material

X-ray NDT throughout the product life

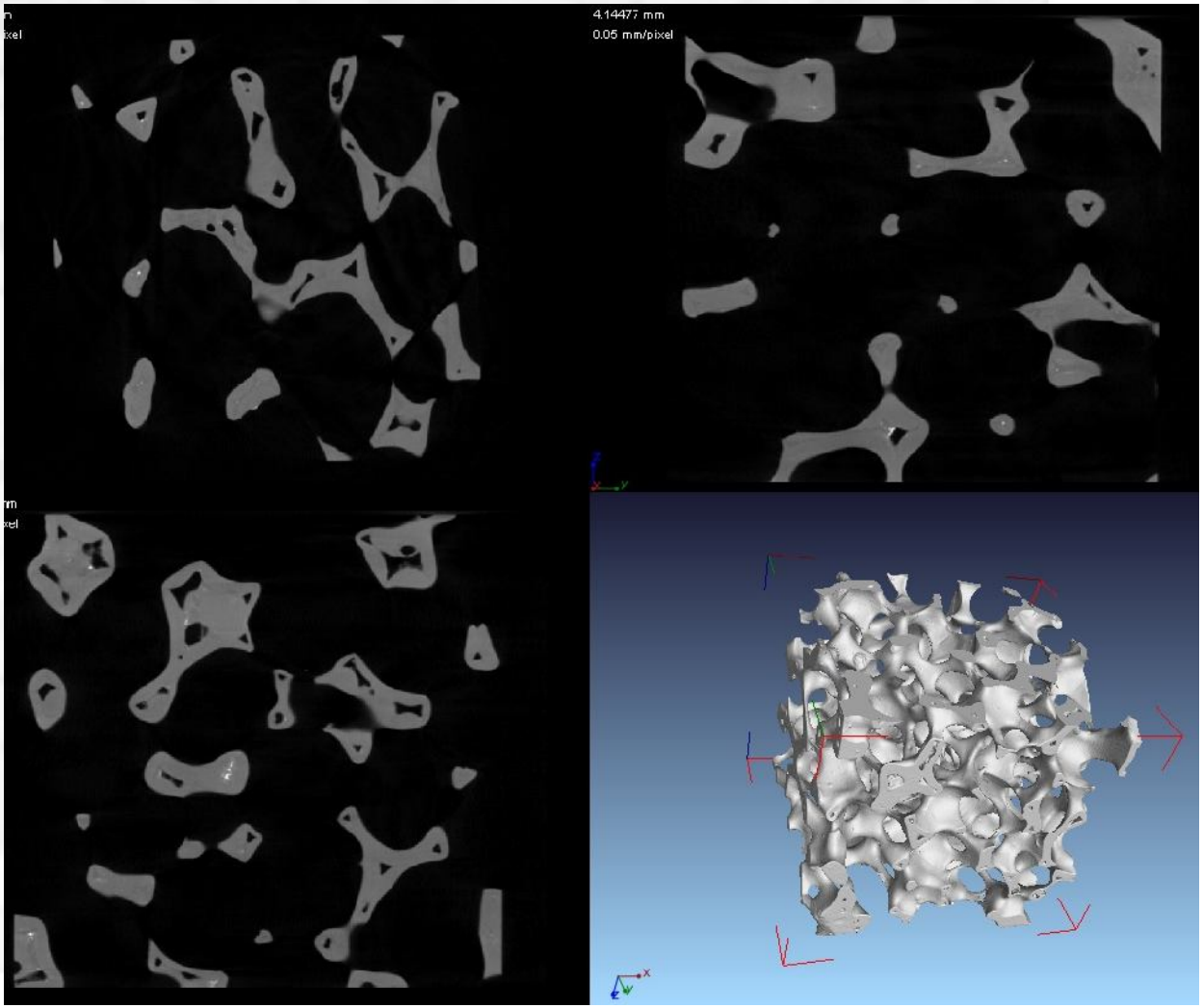
Manufacturing process

Extraction of characteristic numerical parameters :

- used to elaborate or run numerical simulations (Finite Element Models...)
- used to characterise samples and build statistical studies (experimental design...)



Si-SiC foam sample (above) and CT reconstruction (right)



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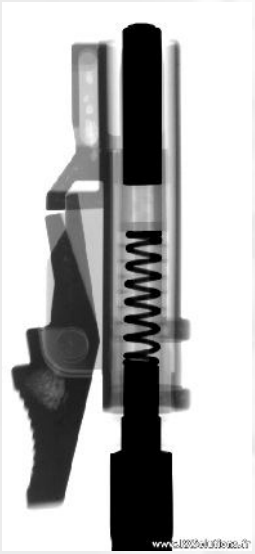
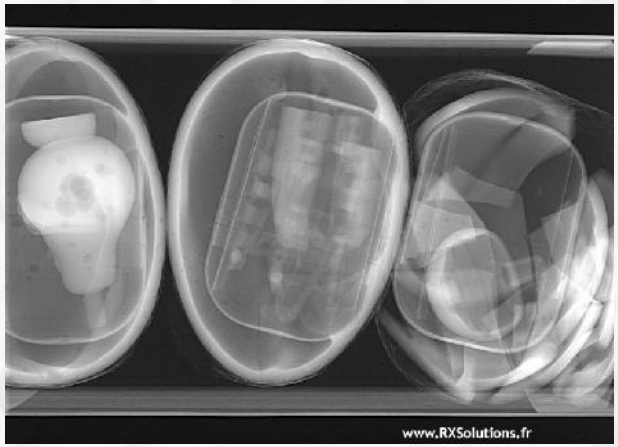
Quality Control

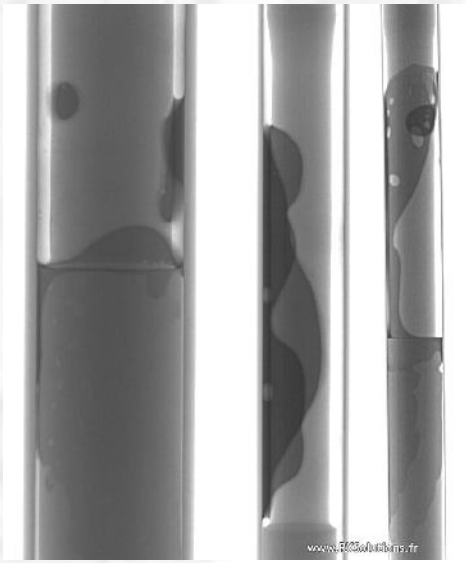
- 100 % online control : generally radiographic control for rapid and automated rather qualitative control (presence of components, position, global aspect...)



Optical fiber connector



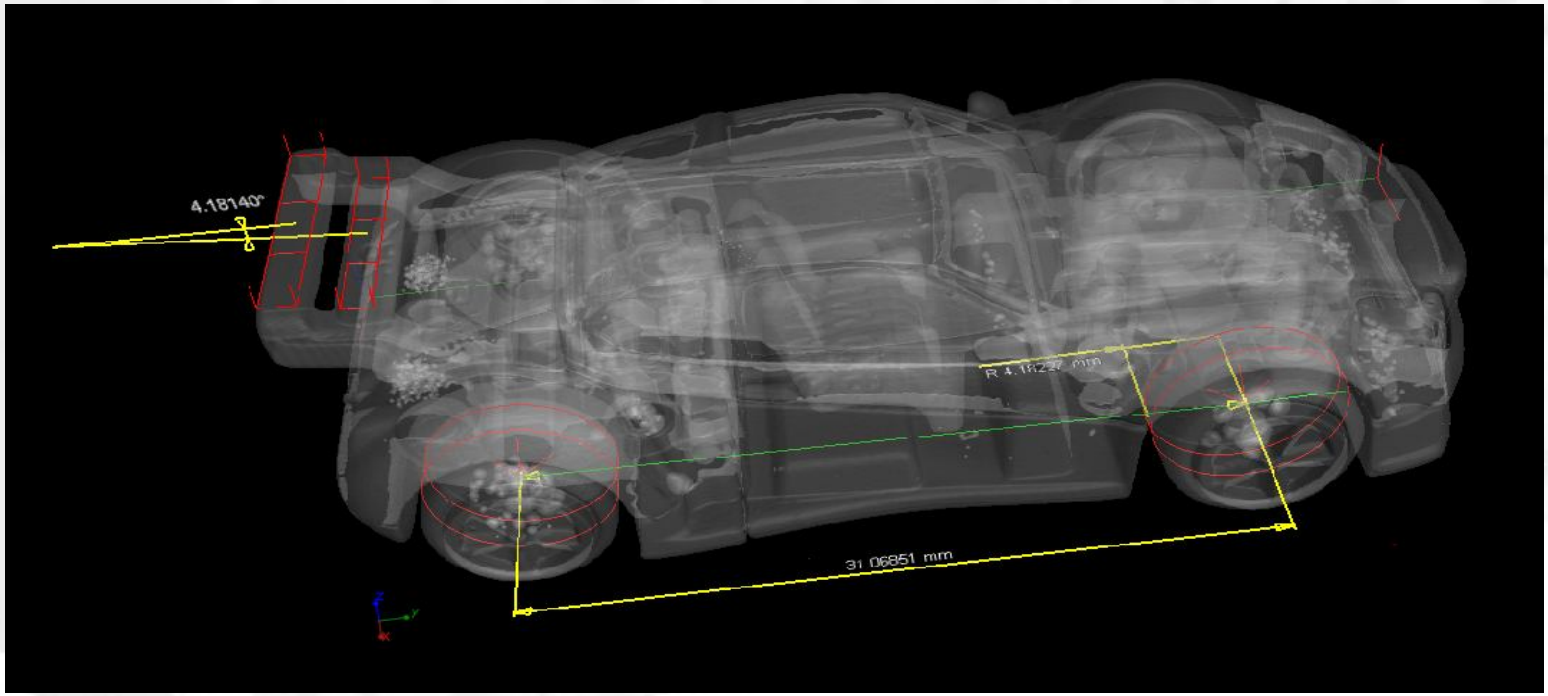
Chocolate eggs



Brazing

Quality Control

- Statistical process control : allows longer, thus deeper analysis, via radiography or even CT, to perform quantitative controls : metrology, porosity analysis, etc.



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Customer returns

- Non destructive testing is essential in case of conflict : both parts need to preserve the defective piece(s) to preserve the evidences.
- Radioscopy and tomography are used to identify the origin of a problem to:
  - correct the production process
  - determine the responsibility of the default

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Most demanding industries

- For quality : industries where reliability is critical
  - Aeronautics
  - Automotive
  - Medical
- Manufacturing process : specially when a very large number of pieces is involved
  - Molding
  - Injection
- X rays are more and more utilized for NDT in all industries thanks to better accessibility and lower prices.

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Components of the systems

- Electrical X-ray Tube :
  - high tension generator
  - Electron tube
  - Target (often Tungsten) emits X-ray photons when hit by high energy electrons (« bremsstrallung » or braking radiation)
  - Given voltage of the generator result in given maximum energy of the emitted photons
  - Given current of the generator result in given quantity of emitted photons (i.e. flux)
  - The power as the product voltage x current is limited
  - The size of the area of photon emission is related to the power

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Components of the systems

- Digital 2D X rays detector (replace old films used for medical radiographs)
  - Indirect detection : a camera is sensitive to visible light, not to X rays. Photons are first converted for X rays to visible light before being detected by a digital camera
  - Direct Detection : X photons are directly detected by sensitive numerical sensor (more recent and more expensive)
  - Full size of the detector determines the maximum size of the observed area
  - Pixel size determines the level of détail detectable on the image (i.e. the resolution)
  - Impossible to have very large detector with very small pixel size : need for a compromise

Components of the systems

- Computer driven precise mechanics
- Leaded cabinet to protect users from X-rays
- Image Acquisition software
- Image processing software

Every component is chosen for each application in order to optimize image quality according to the materials, the object size, cycle times...

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X-ray machines examples

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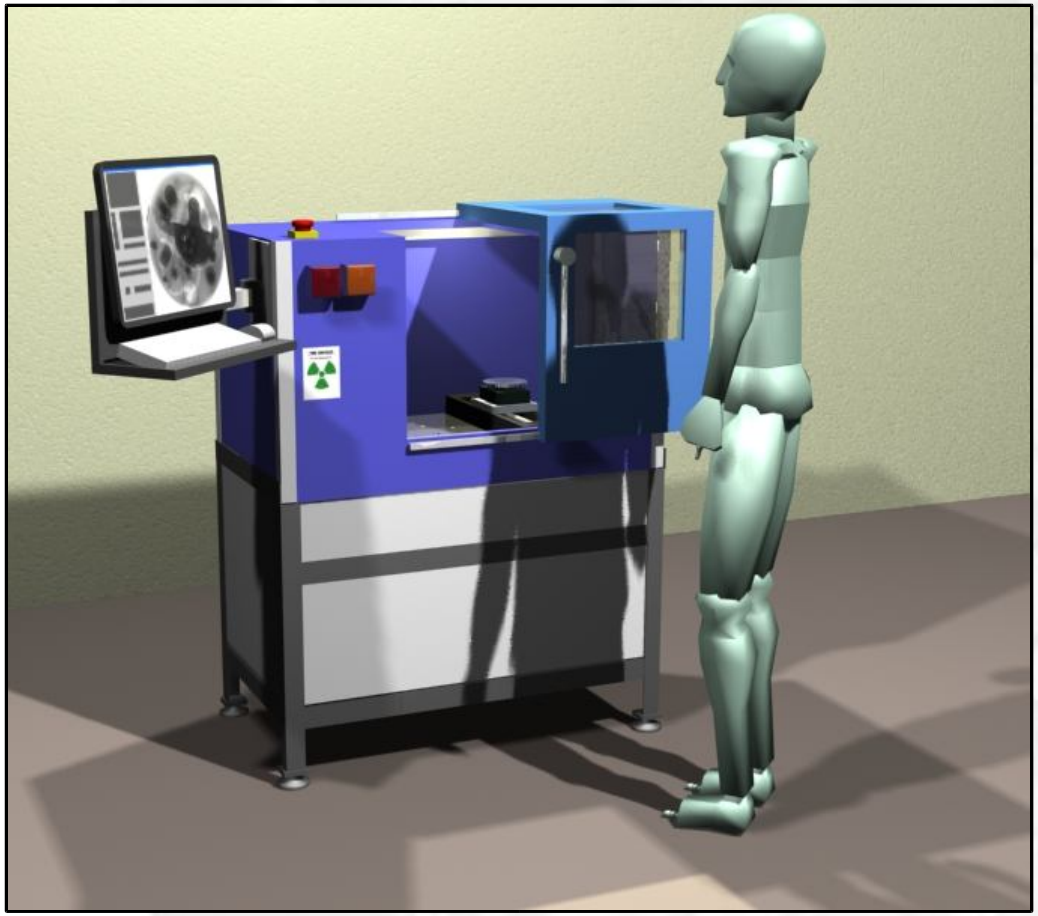
X-ray NDT systems



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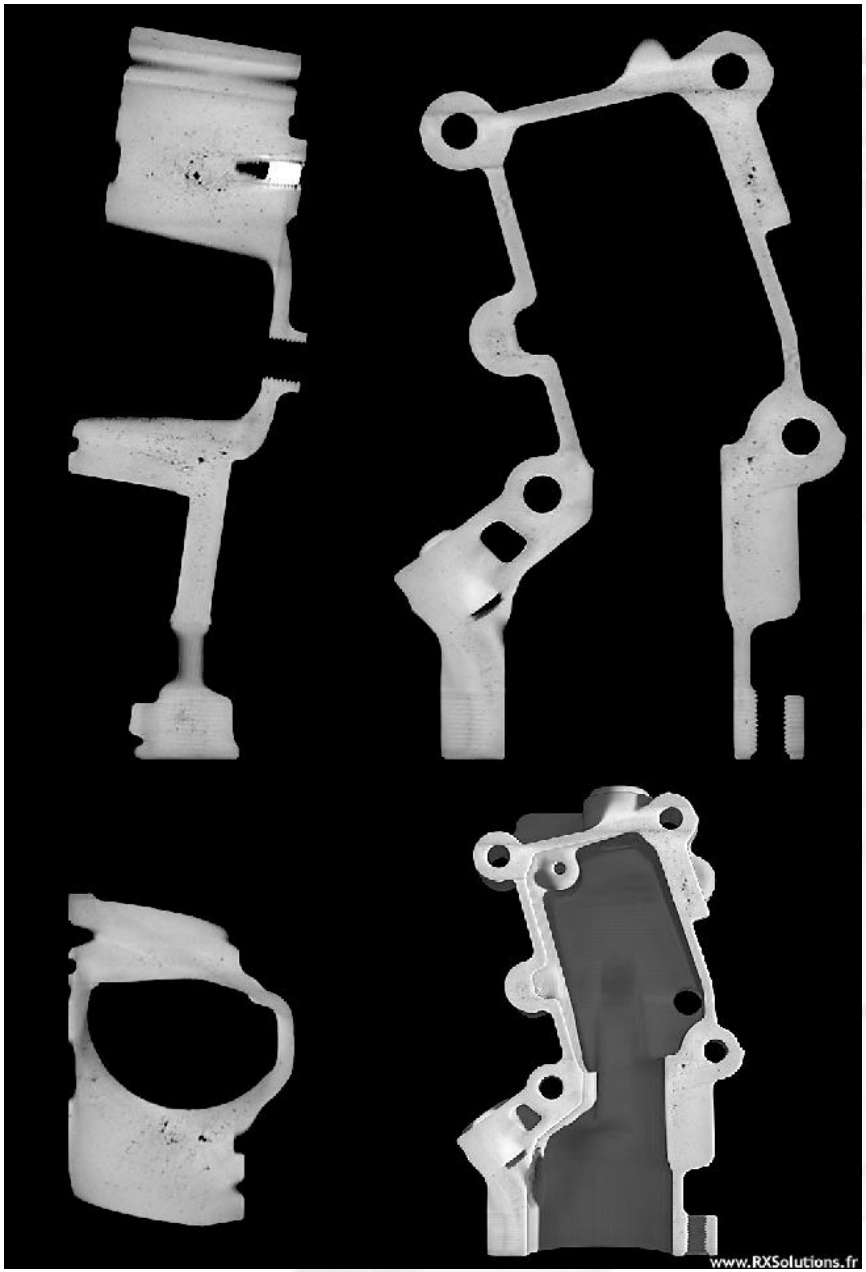

Application samples

Porosities in Aluminium pump

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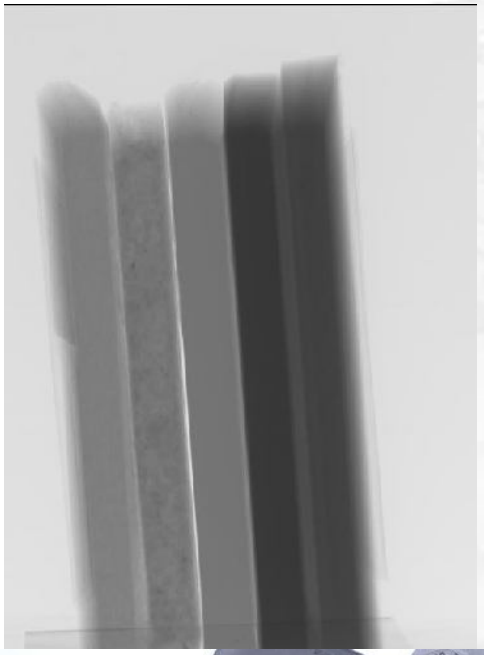
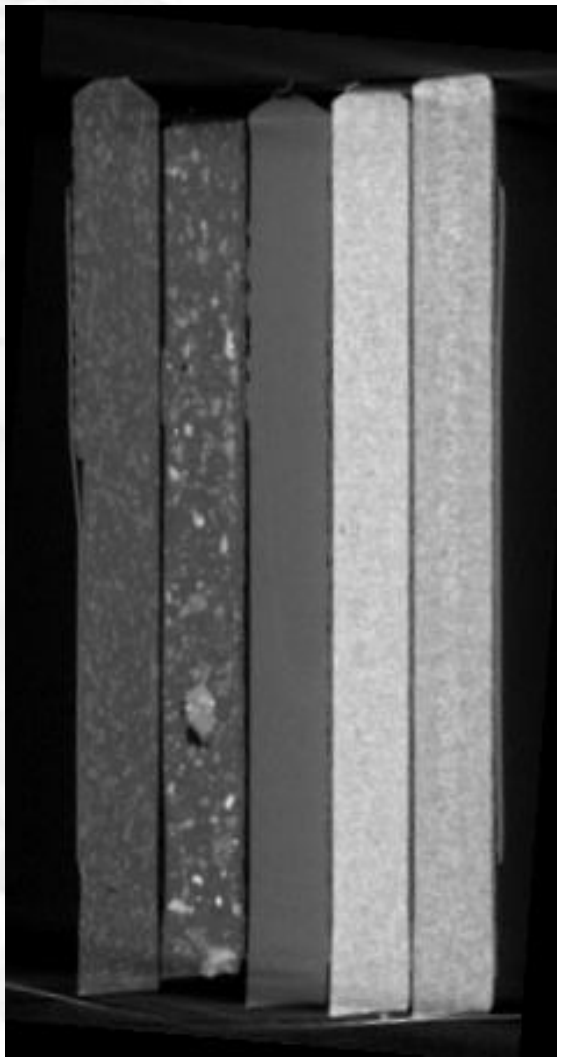
Radiographies



Samples : composite material

Tomographic slice



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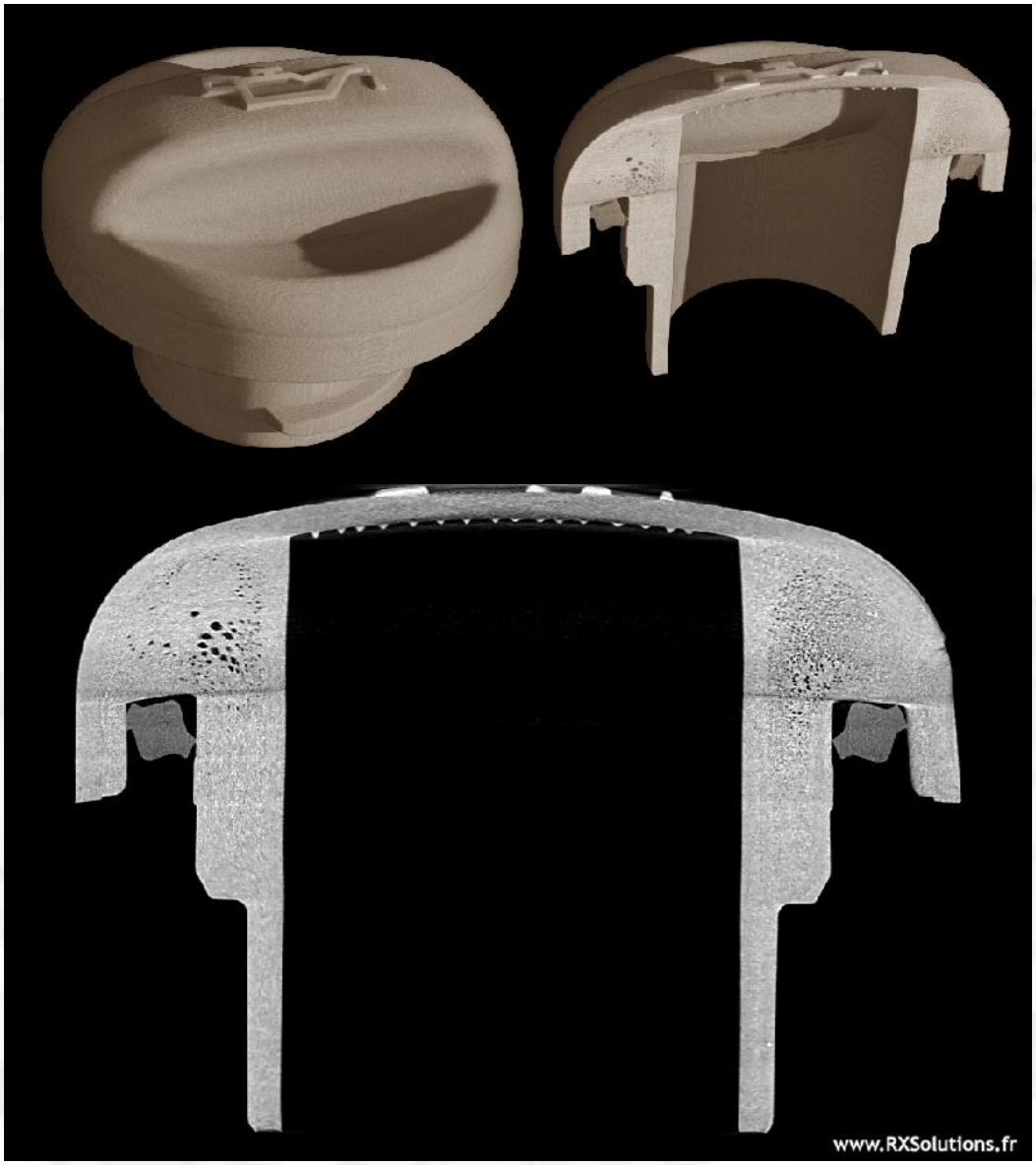

Porosities in plastic oil shutter

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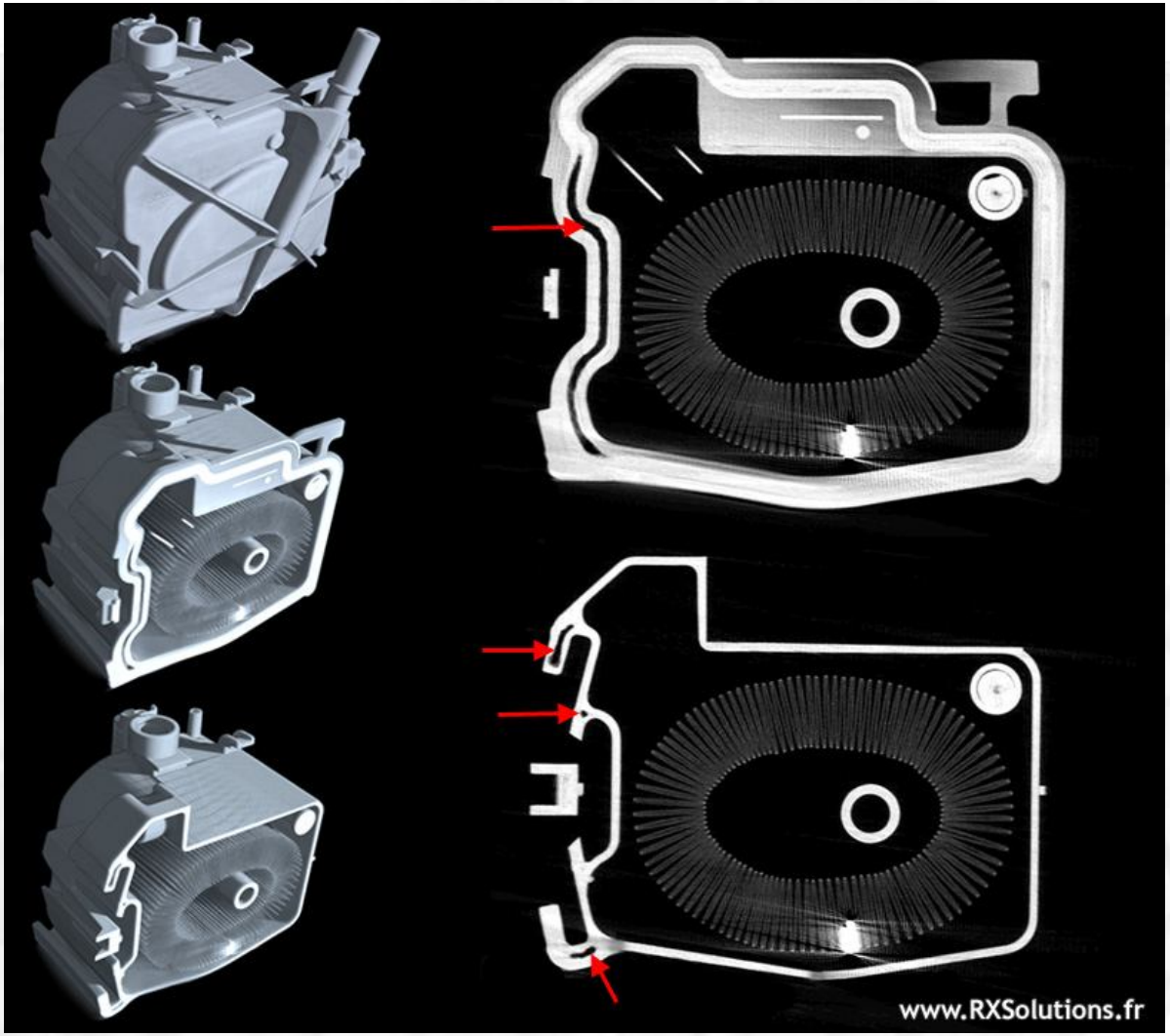

Filter (automotive)

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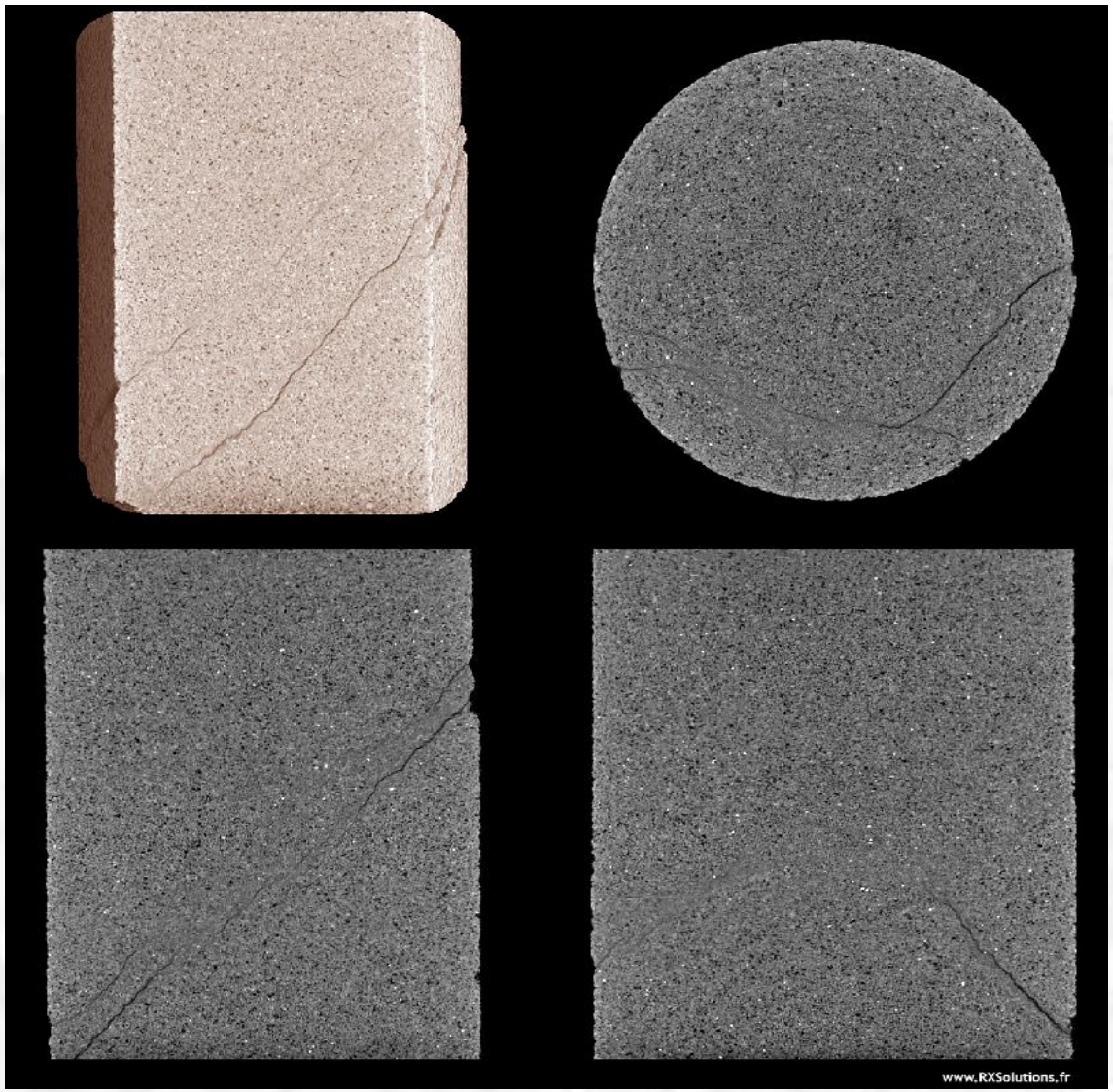

Geomaterial sample after compression

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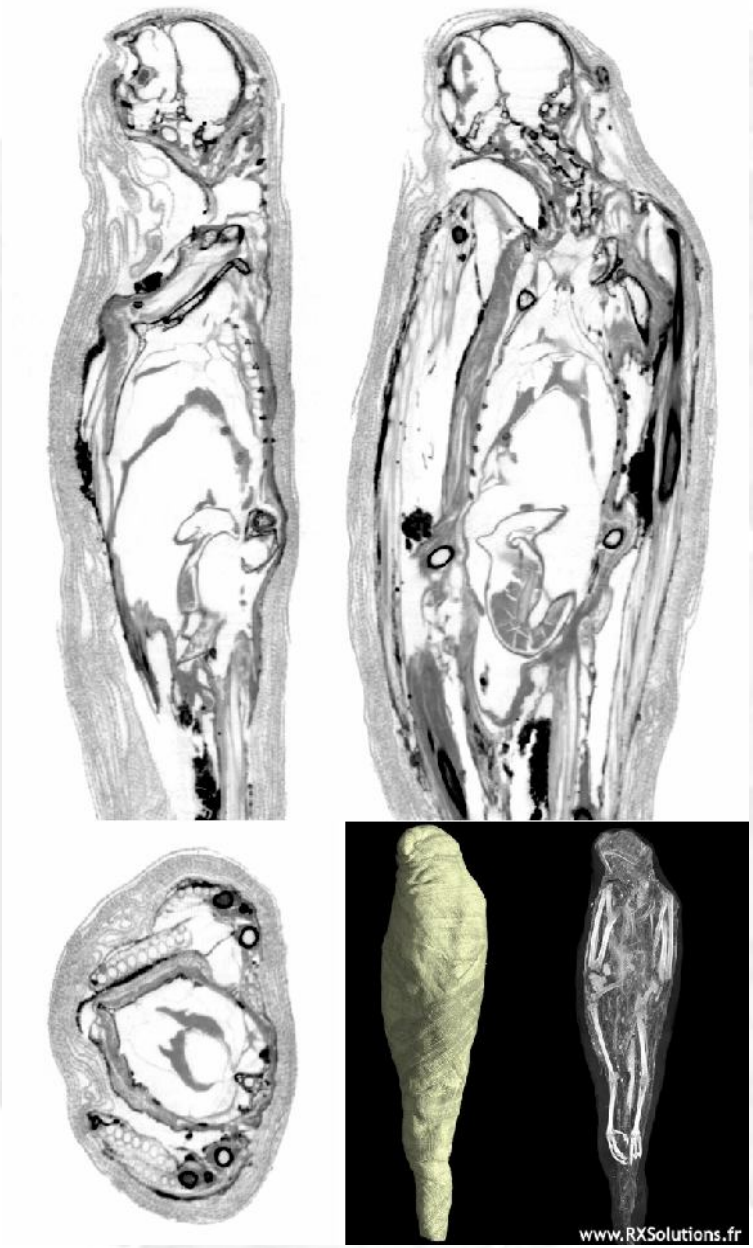

Falcon mummy (Egypt)

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