IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Subatech

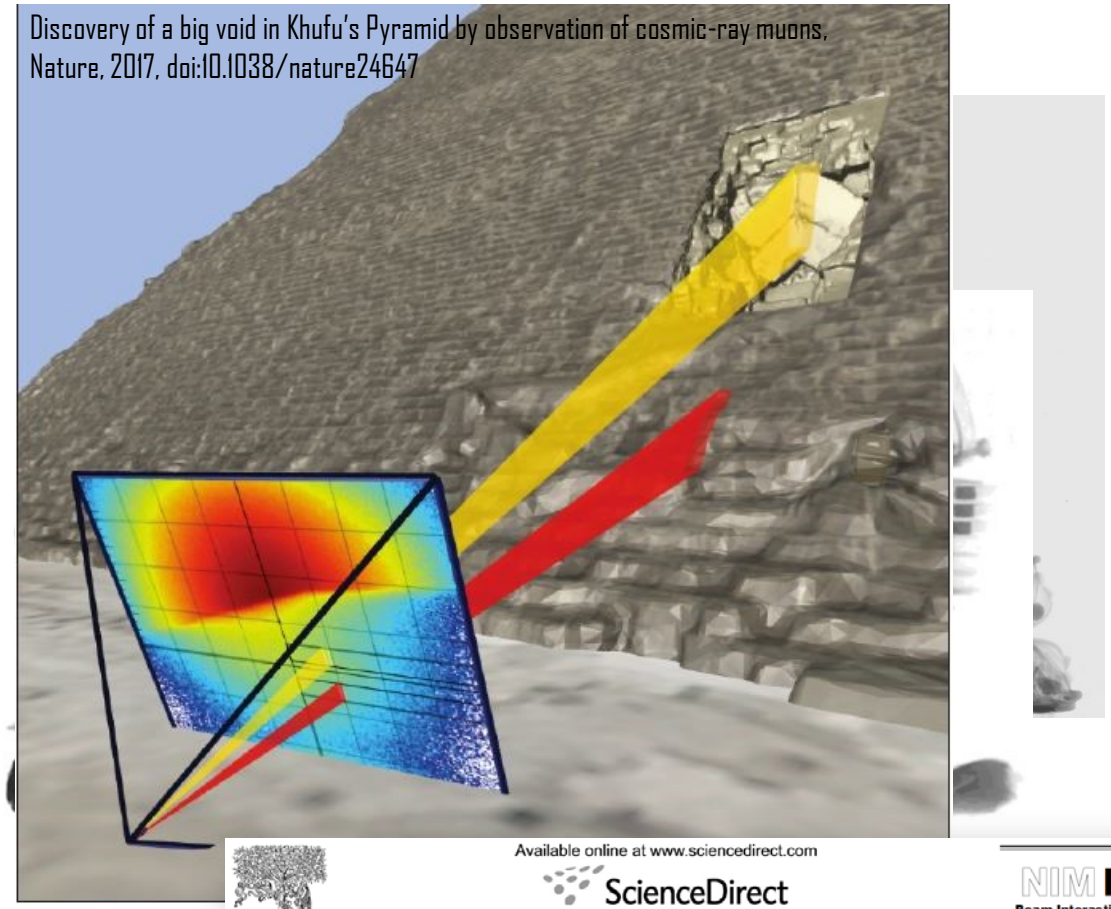
CONTRÔLES NON DESTRUCTIFS ET ANALYSES PAR FAISCEAUX D'IONS

Vincent Métivier | Journée technique PRECEND | 23 nov. 2017

Les sondes « usuelles » en CND

- + **Ondes mécaniques**
  - × Acoustique, ultrasons,...
- + **Flux thermiques**
- + **Électromagnétiques**
  - × Courants
  - × Radar
  - × THz
  - × Optique (IR, visible)
  - × RX
  - × Gamma
- + **Neutrons***
- + **Particules**
  - × Électrons
  - × Positrons
  - × Muons cosmiques
- + **Ions**

RAYONNEMENTS IONISANTS



Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 263 (2007) 317–319
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

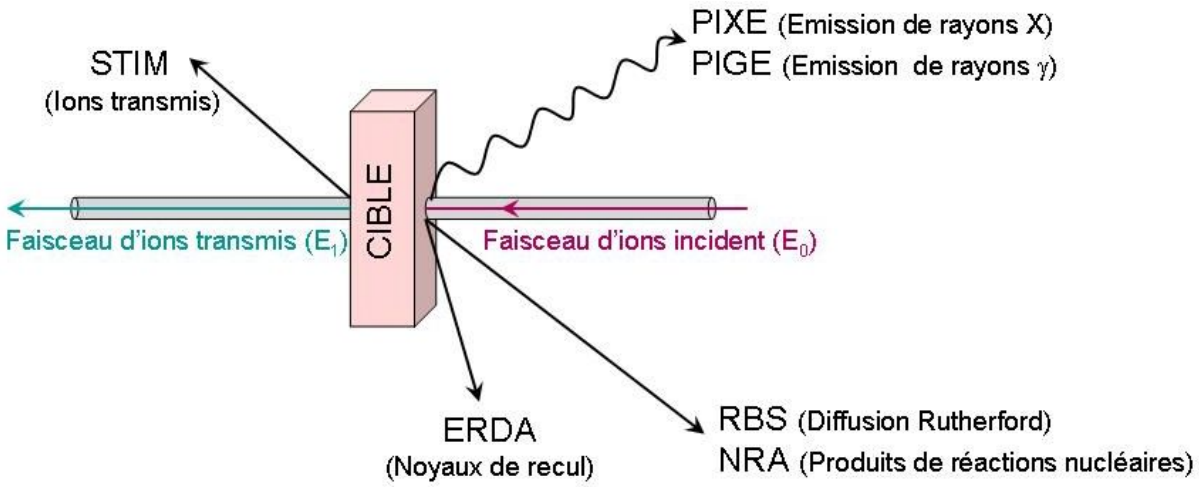
Muon radiography of large industrial structures

W.B. Gilboy [a,*], P.M. Jenneson [a], S.J.R. Simons [b], S.J. Stanley [c], D. Rhodes [c]

[a] Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, UK
[b] Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK
[c] British Nuclear Fuels plc, Research and Technology, Sellafield, Seascale CA20 1PG, UK

Les analyses par faisceaux d'ions

+ Sonde électromagnétique (très ionisante)
+ Sonde nucléaire



analyse multiélémentaire

non destructive, à l'air

de l'ordre de la ppm (µg/g)

dans solides, poudres, liquides

matériaux « épais » (µm → cm)

informations supplémentaires

densité

épaisseur

profil de concentration en profondeur

multicouches

Quelques applications

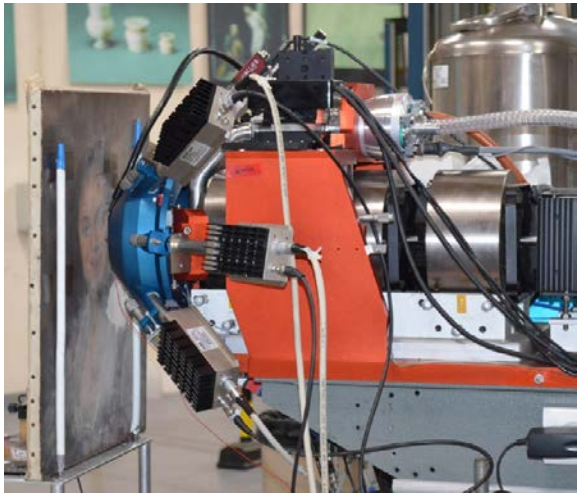
+ Art et archéologie

+ Géologie

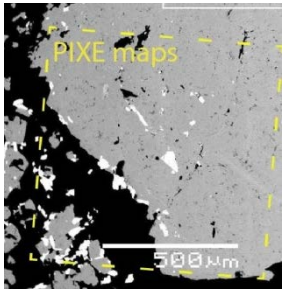
+ Bio

+ Environnement

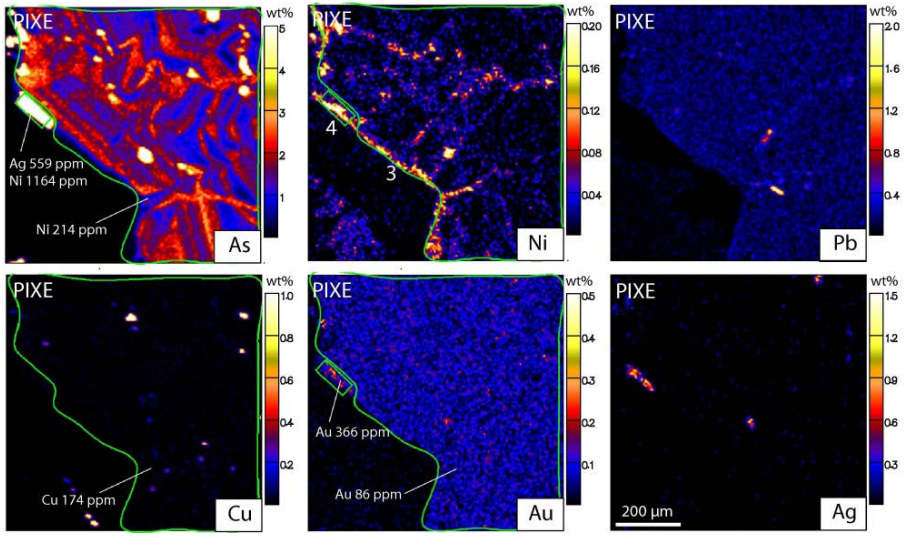
+ ...



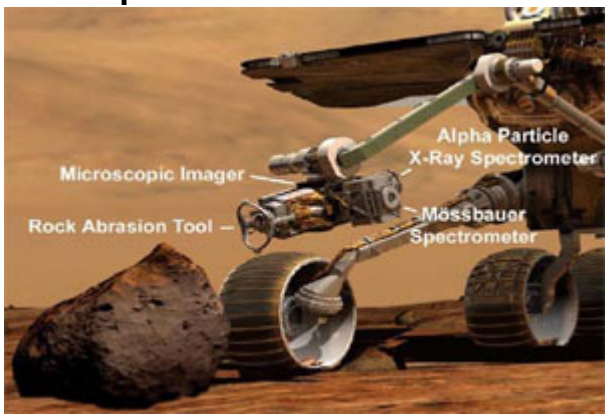
AGLAE – C2RMF - Musée du Louvre



Imagerie PIXE



Mars Exploration Rover



Quelques installations (en France)

+ **Région parisienne**
  - × AGLAE (Louvre)
  - × Orsay/Saclay

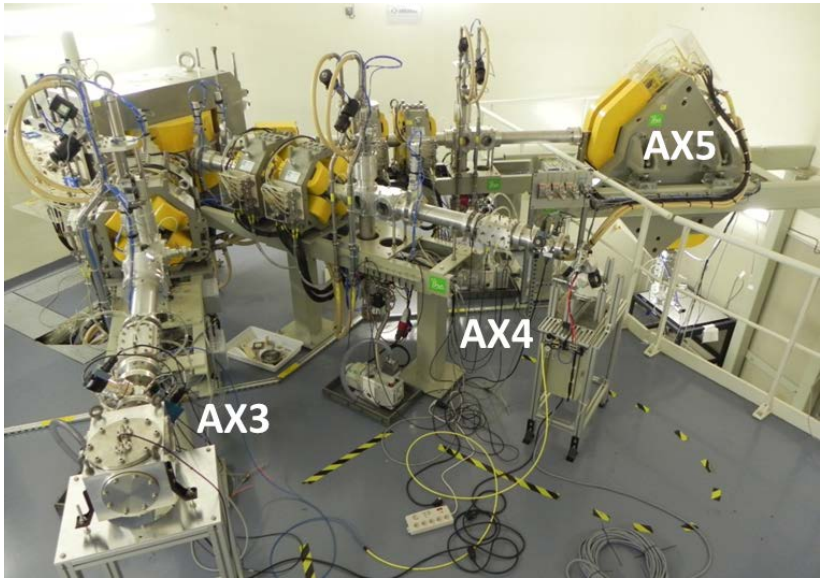
+ **Bordeaux**
  - × AIFIRA

+ **Lyon**
  - × ANAFIRE

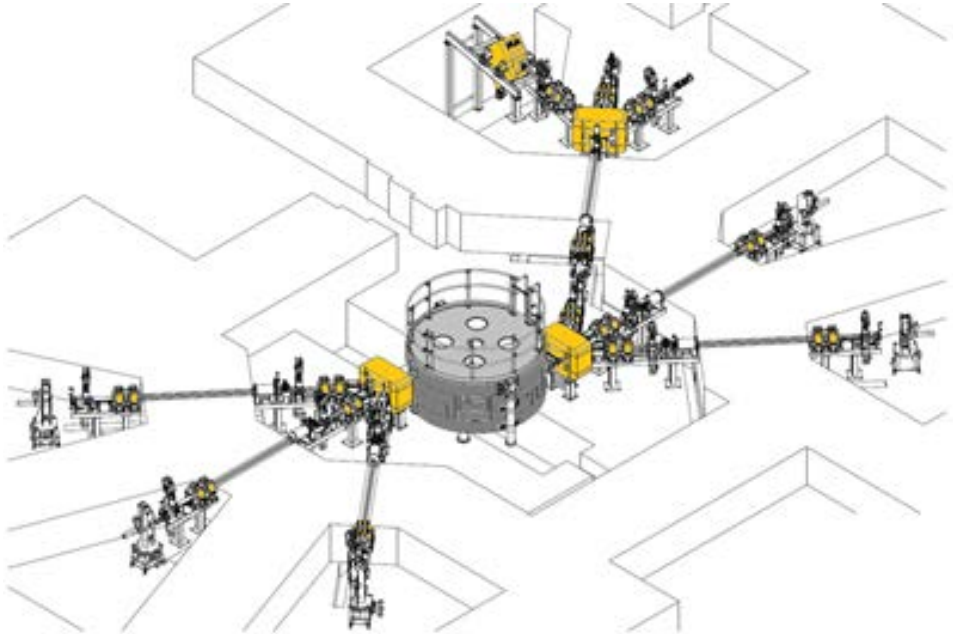
+ **Nantes**
  - × ARRONAX
    - Haute énergie
    - Unique en France

Arronax

Extrated Beam	Accelerated Particle	Energy (MeV)	Intensity (µA)	Dual Beam
Proton	H^-	30 to 70	≤ 350	Yes
	HH^+	17	≤ 50	No
Deuteron	D^-	15-35	≤ 50	Yes
Alpha	He^{2+}	68	≤ 70	No

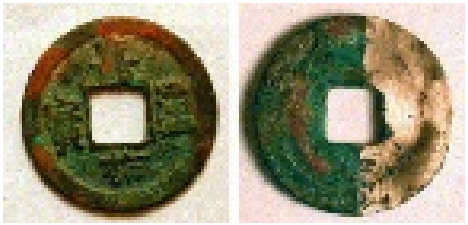


+ Production de radionucléides innovants pour la recherche en médecine nucléaire
+ Recherche sur l'interaction des rayonnements avec la matière inerte et vivante
+ Formation



PIXE à haute énergie

+ Travaux antérieurs (HZBerlin) :



Analyse d'une pièce de monnaie sous une couche de corrosion de 1 mm

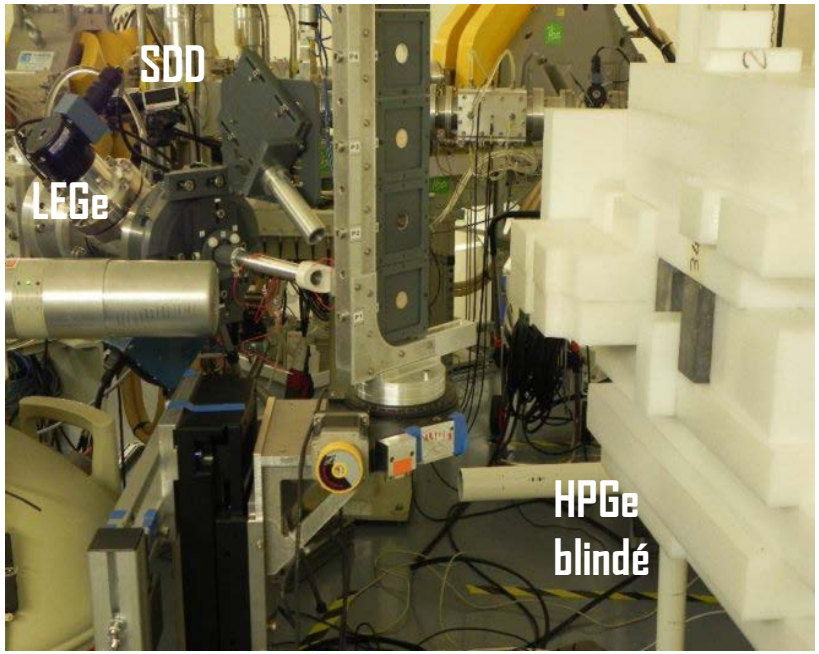
A. Denker et al. Nucl. Instr. & Meth. , 226, 2004

Détection en profondeur des éléments onstituants les pigments d'un tableau

« Adoration of the Sheperd »
A. Denker et al.,
Nucl. Instr. & Meth. , 213, 2004

+ À Arronax : p,d,α à 16-70 MeV

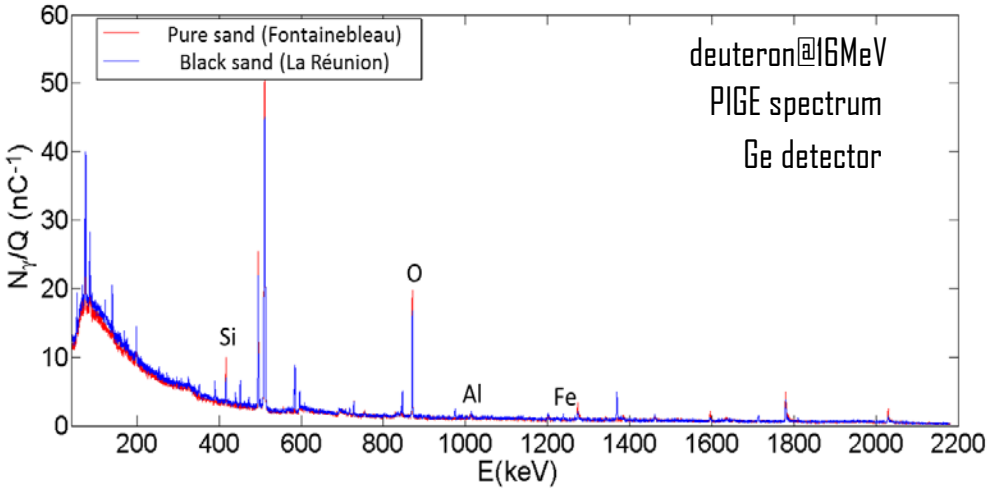
- × **protons** are selected for their **higher range** in matter
- × **Alpha particles** for their **higher sensitivity** (K X-ray production cross section)
- × low energy **deuterons** essentially for **PIGE**

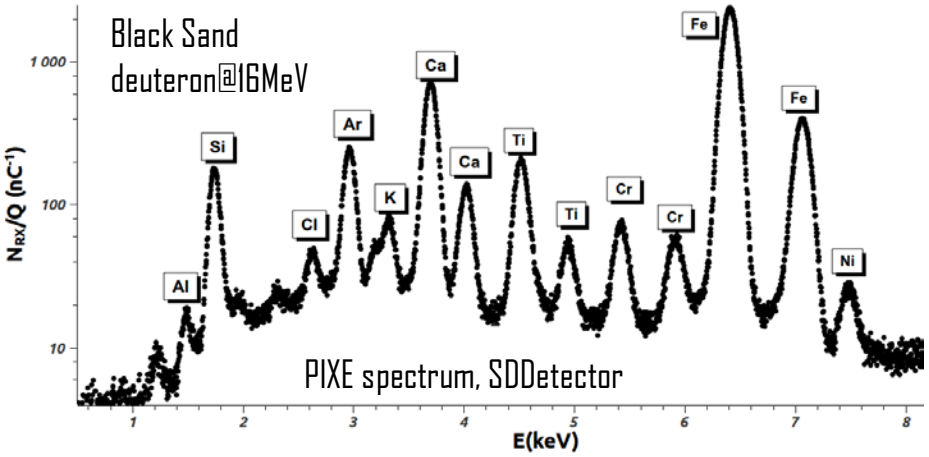


High energy PIXE/PIGE at Arronax

A. Subercaze et al., 7ème Colloque Interdisciplinaire en Instrumentation, 2016

+ Ex: volcanic sand analysis





Pure Sand from Fontainebelau (ref.)

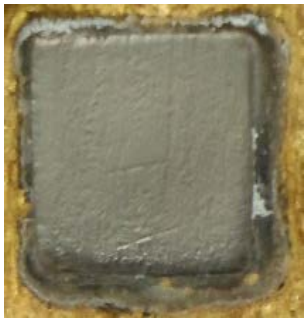
Volcanic Sand from La Réunion

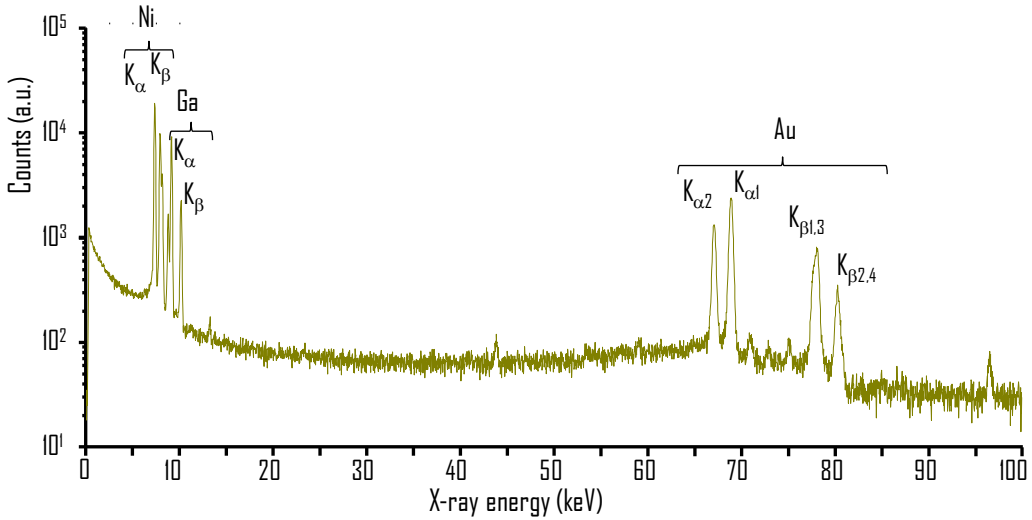
Iterative calculation

	PIXE		PIGE
Élément	$a_k(\%)$	Élément	$a_k(\%)$
O	$45{,}8 \pm 5{,}5$	O	$43 \pm 0{,}9$
Al	$11{,}4 \pm 1{,}4$	-	-
Si	$22{,}3 \pm 2{,}7$	Si	$21 \pm 1{,}3$
Ca	$5{,}75 \pm 0{,}69$	-	-
Ti	$1{,}60 \pm 0{,}2$	-	-
Cr	$0{,}41 \pm 0{,}05$	-	-
Mn	$0{,}29 \pm 0{,}03$	-	-
Fe	$11{,}9 \pm 1{,}4$	-	-
Ni	$0{,}16 \pm 0{,}02$	-	-

Thick sample analysis

+ **Ex: Ni/Ga alloy electrodeposited on gold carrier**
  - × the mass fraction and the density of the Ni/Ga alloy are calculated trough an iterative process based on the K X-ray intensities of Ni and Ga.
  - × the thickness of the alloy is then determined thanks to the attenuation of the K X-ray coming from the gold carrier.





*X-Ray spectrum from irradiation of a Ni/Ga alloy (on gold substrate) target with a **70 MeV proton** beam (LEGe detector at 25 cm).*

+ Mass fraction (wt%):

	HE PIXE	ICP-AES	SEM/EDX
Ni	**34.81 ± 0.7**	34.15 ± 0.4	34.04 ± 0.3
Ga	**65.19 ± 0.8**	65.85 ± 1.6	65.96 ±1.3

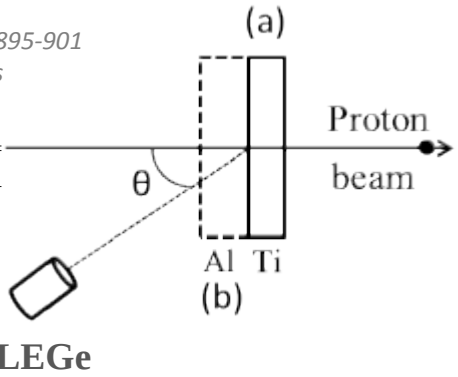
+ thickness: **317 ± 32 µm**

+ density: **6.9 g.cm^{-3}**

Multilayer analysis

C. Koumeir et al., AIP Conf. Proc. 1412, pp. 105-112
D. Ragheb et al., J Radioanal Nucl Chem (2014) 302:895-901
A. Subercaze et al., ECAART12 (2016), NIMB, in press

Target 1		Target 2	
Element	Position	Element	Position
Titanium	1	Aluminium	1
Silver	2	Titanium	2
Gold	3	Aluminium	3
-	-	Silver	4



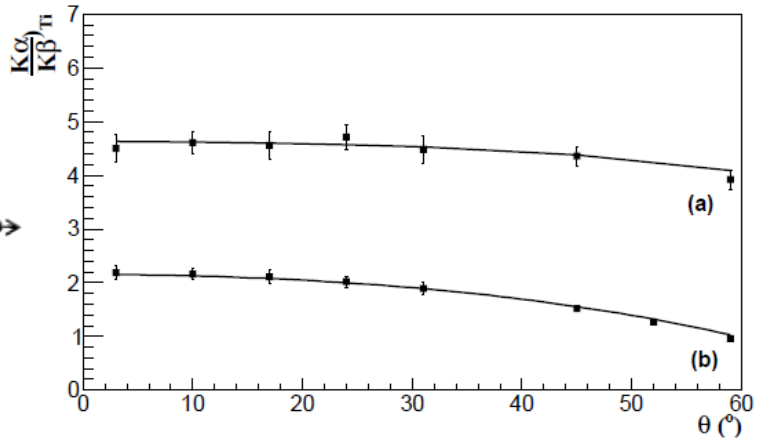
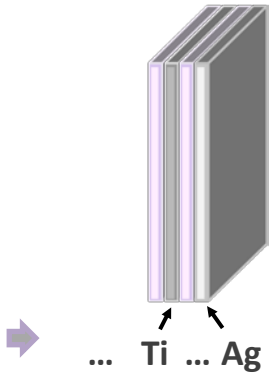
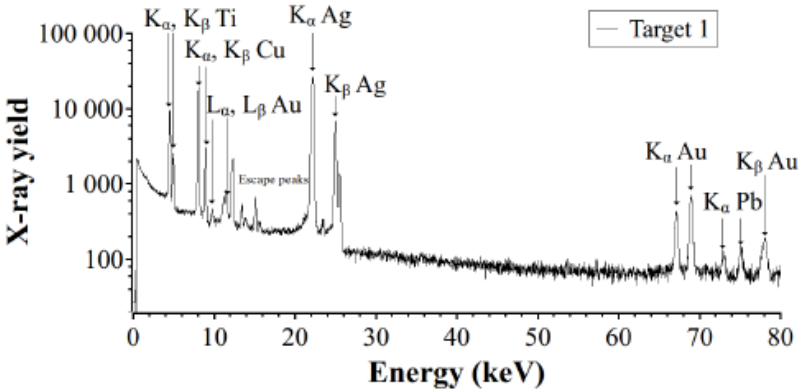


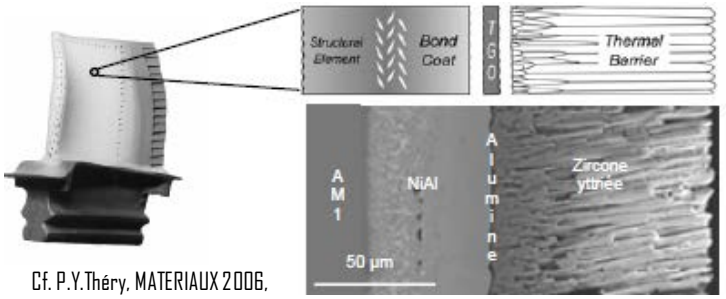
Table 3: Results of the multi-layers analysis using detection angles of 3° and 45°

Target 1			
Element	$(\Delta\mu \cdot d)'$	Calculated thickness (μm)	Calibrated thickness (μm)
Titanium	92 ± 6	10.40 ± 0.62	10.03 ± 0.02
Silver	860 ± 40	25.82 ± 1.29	24.87 ± 0.04
Gold	12200 ± 600	9.11 ± 0.59	10.74 ± 0.02
Target 2			
Titanium	664 ± 62	9.25 ± 0.93	10.06 ± 0.02
Silver	4168 ± 348	10.33 ± 0.21	10.32 ± 0.02





+ Applications potentielles :



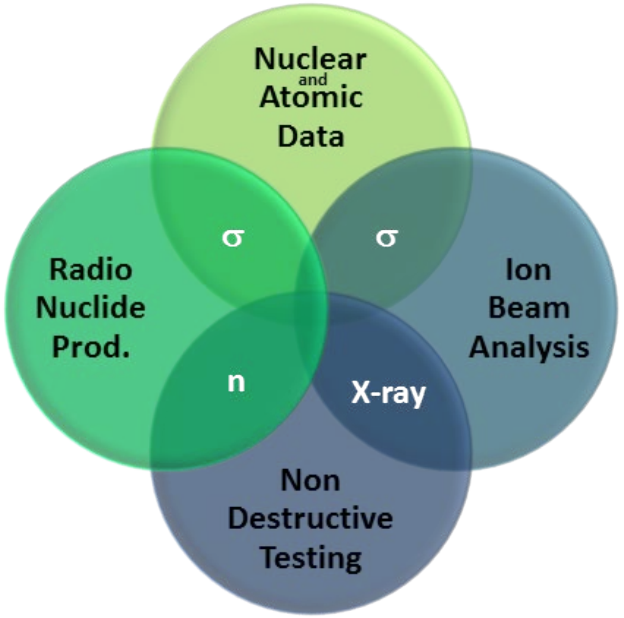
Cf. P.Y.Théry, MATERIAUX 2006,
Etude de l'adhérence des systèmes barrière thermique pour aube de turbine,

PRISMA

Physics of Radiation InteractionS with Matter and Applications

Subatech — IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom — IN2P3 — Université de Nantes

Laboratoire de physique subatomique et des technologies associées



+ **Basic and Applied Research**
+ **In the scope of two main issues with major societal impact:**
  - × Health (cancer, cardiovascular disease, etc.)
  - × Integrity and reliability of structures (transport, energy, etc.)

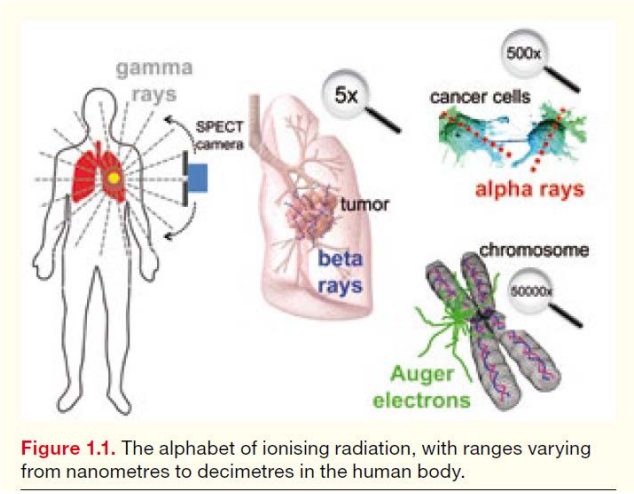
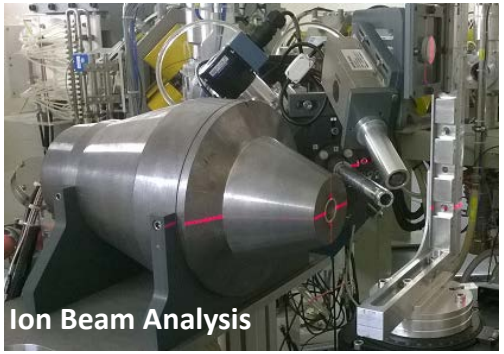


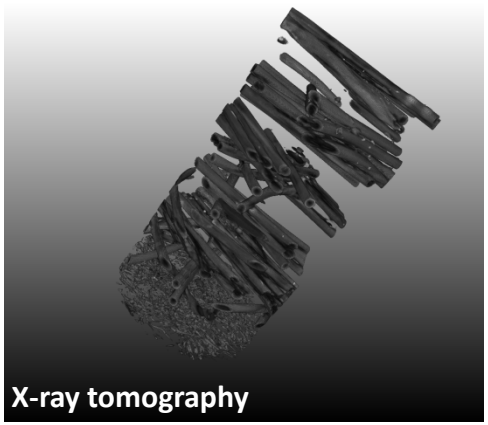
Figure 1.1. The alphabet of ionising radiation, with ranges varying from nanometres to decimetres in the human body.

from Nuclear Physics for Medicine (NuPEEC report, 2014)

PRISMA : Radiation interactions with matter and applications

+ Ion beam analysis
+ New tools for radiobiology
+ Non-destructive testing


Ion Beam Analysis

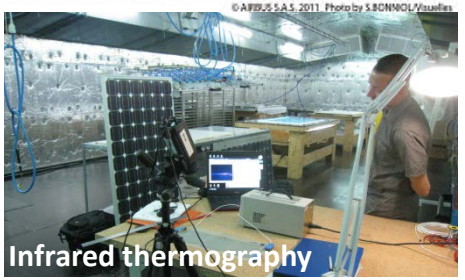

X-ray tomography

+ Safety and high value-added materials :
  × Aeronautics
  × Civil engineering
  × Energy
  × …


Roadway inspection


Toward composite planes

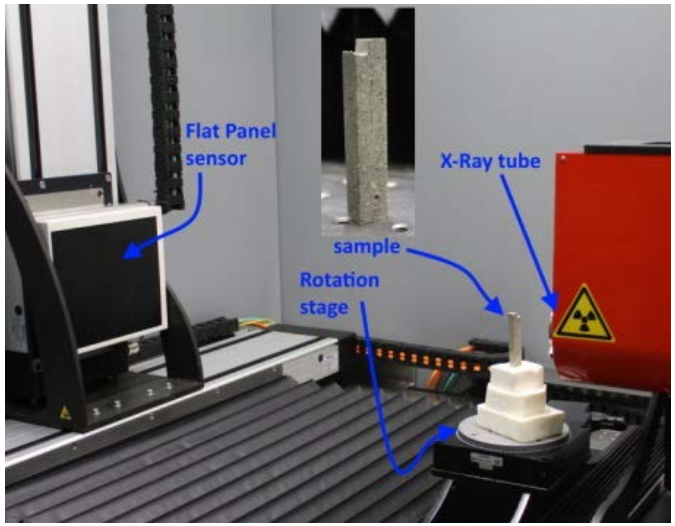

Laser ultrasonics

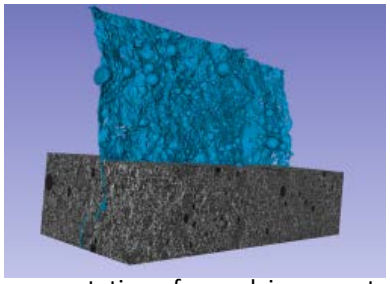

Infrared thermography


Concrete NDT

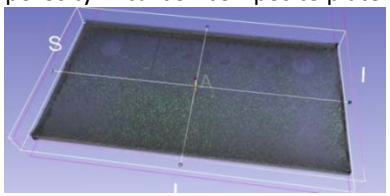
PRISMA : X-ray tomography

+ **X-ray microtomograph**
  - × spatial resolution down to 4µm
  - × Large object up to ~1m²

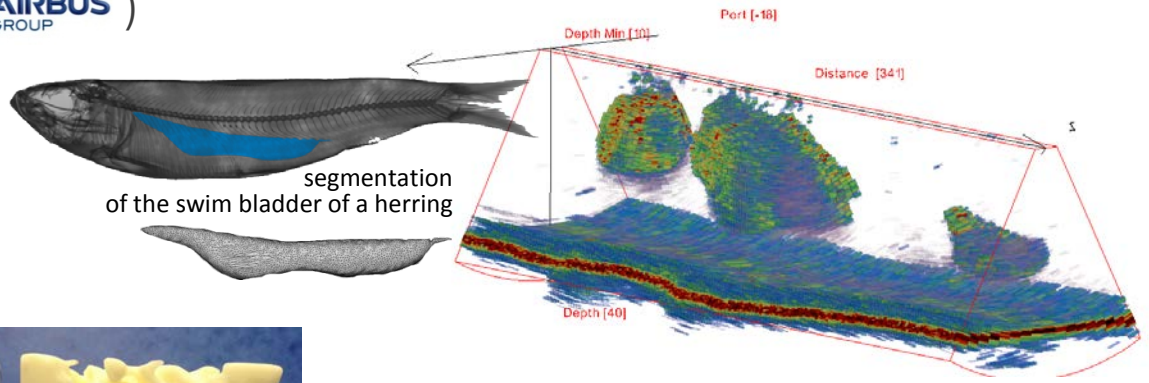




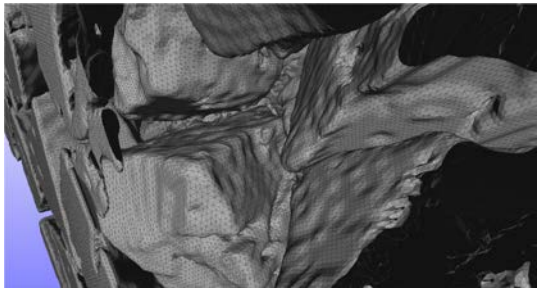
segmentation of a crack in concrete porosity in carbon composite plate



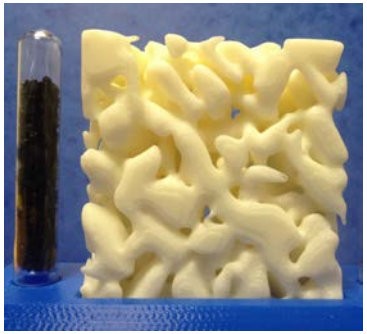
+ **Example of projects**
  - × cracks in concrete (IFSTTAR)
  - × porosity in composite materials (AIRBUS GROUP)
  - × TOMOFISH (Ifremer)
  - × Microstructures (DGA)

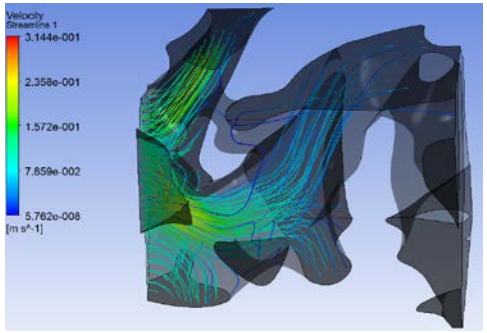


segmentation of the swim bladder of a herring



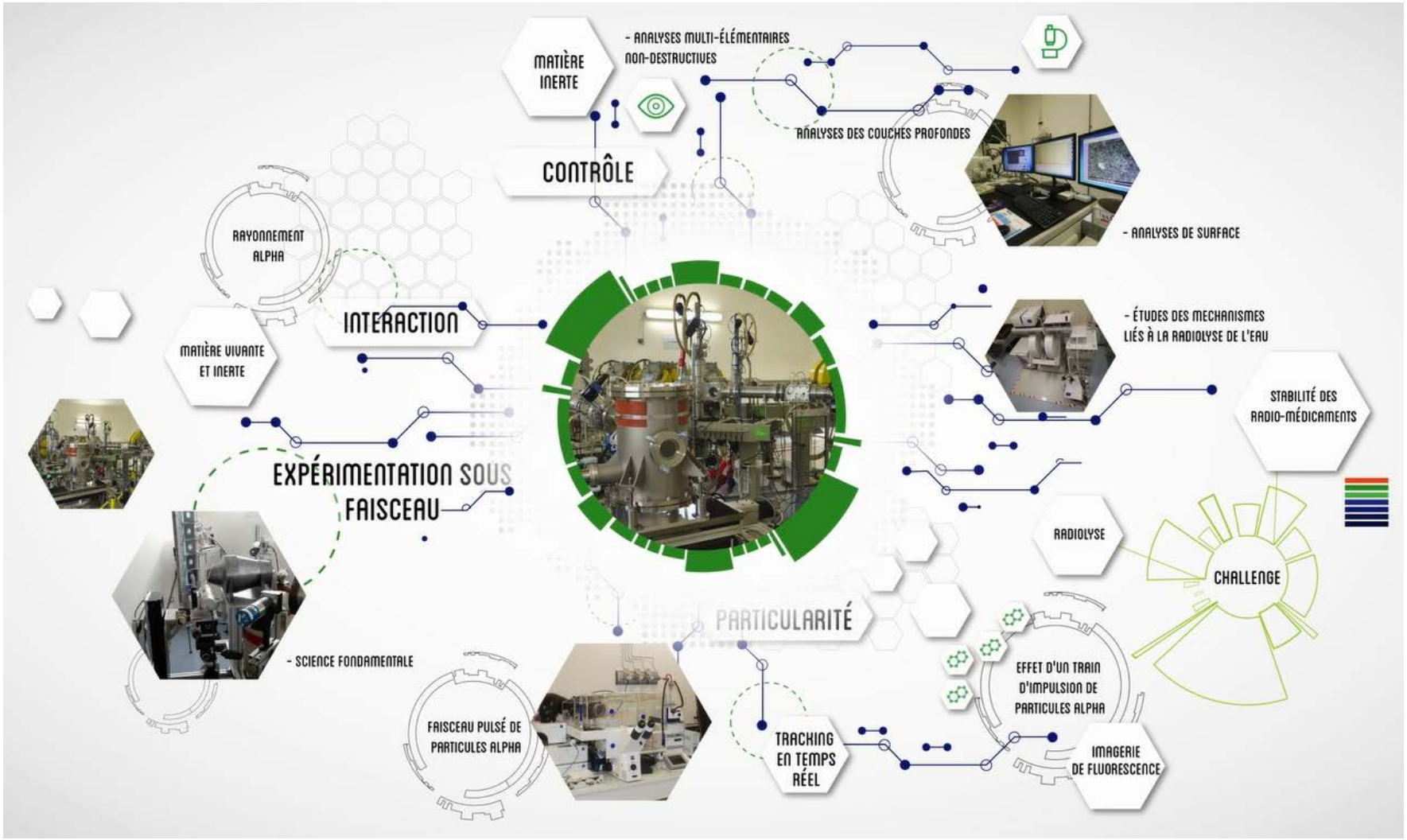
Granular activated carbon filter imaging, digital and real upscaled 3D mock-up





Plateforme ArronaxPlus

+ http://www.cyclotron-nantes.fr/



PRISMA

Physics of Radiation InteractionS with Matter and Applications

Subatech — IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom — CNRS IN2P3 Les deux infinis — UNIVERSITÉ DE NANTES

Laboratoire de physique subatomique et des technologies associées

+ Nuclear physics for medicine

+ Non-destructive testing

+ Associated research centers and platforms

ARRONAX — Technocampus EMC² Innovation et technologies composites — Mi2b — Arronax Plus — IRT Jules Verne — iron labex — precend Compétences CND en réseau

+ Main collaborations

× CRCNA, GEM, LAUM, IFSTTAR, CEREMA, IFREMER,...

× MEDICIS (CERN), INR TROISK, INFN Ferrara, ...

× AIRBUS, EADS IW, AAA, LEMER PAX, KEOSYS,...

× In discussion: LPC Caen, IPHC/Cyrce, IPN Lyon, SPIRAL 2, ...

× Contacts: A. Denker (HZB, Berlin), E. Fritsch (IMN Jean Rouxel), A. Koning (NRG Petten/IAEA), F. Mathis(U. Liège), C2RMF/AGLAE (Louvre Museum), AIEA, NUPECC,...

STAFF (June, 2017)

+ Permanent

- Xavier de la BERNARDIE (IR IMT)
- Arnaud GUERTIN (CR CNRS)
- Férid HADDAD (Pr UN, HDR)
- Elisabeth LYS (MA IMT)
- Vincent METIVIER (Pr IMT, HDR)
- Ahmed RAHMANI (MC UN)
- Noël SERVAGENT (MA IMT)
- Thomas SOUNALET (CR CNRS)

+ Associated

- Charbel KOUMEIR (IR GIP ARRONAX)

+ PhD Students

- Alexandre SUBERCAZE, IMT (2017)
- Maddalena MAIETTA, ITN Promed (2018)
- Roberto FORMENTO, ITN Promed (2019)
- Etienne NIGRON, CNRS/PdL (2019)