7th workshop
“Combined analysis examples using X-Ray Scattering”

• Dr. Henry PILLIERE
  (Artenay, France)
Summary

Presentation of ThermoFisher X-ray part (very quick)
Interaction X-ray and matter (no maths)
Instrumental function
XRD setup: some instruments and the information they give
- Laboratory systems
- Industrial (on-line)

Some real XRD examples:
- Dust analysis
- Phase transition at (not very) high temperature
- Thin layer: diffraction, reflectometry, stress
- Micro-diffraction
- SAXS
Global Scale
- 50,000 employees in 50 countries
- $17 billion in annual revenues
- Unparalleled commercial reach

Unmatched Depth
- Leading innovative technologies
- Applications expertise
- Lab productivity partner

Premier Brands
- Thermo Scientific
- Invitrogen
- Applied Biosystems
- Unity Lab Services
Resources
All technical and human resources are situated in our headquarter in France :

- Research & Development, technical assistance
- Informatics tools development & assistance
- Mechanical parts design & metrology
- X-Ray diffraction systems assembling
- Installation & After Sales Services for instrumentation
- Components and electronic cards design & integration

Key figures
Creation : 1974 of INEL SAS
Staff 2015 : 20 employees 80% technically qualified (PhD, Engineers and technicians)
Staff seniority average: 10 years

Thermo Fisher Scientific – XRD research
Z.A. C.D. 405
45410 ARTENAY, France
T +33 (0)2 3880 4545
F +33 (0)2 3880 0814
XRD-XRF product portfolio: strong, complementary technologies

EDXRF
ARL QUANT’X
Top performance EDXRF

WDXRF
ARL PERFORM’X
High performance XRF

Integrated XRF and XRD
ARL OPTIM’X – 50W/200W Amazing WDXRF
ARL 9900 Series
Integrated XRF-XRD

Powder XRD
ARL X’TRA

More on www.thermoscientific.com/xray
Skills and expertise in Artenay

**Instrumentation**
Inel designs, manufactures and provides analytical instrumentation:
- X-Ray diffraction instrumentation
- X-Ray radiography instrumentation (CND)
- Extreme Ultraviolet sources instrumentation

**Engineering**
Your needs are specific or evolved and your equipment doesn’t fit your needs anymore? Our mission:
- Project consultant & management
- Feasibility studies
- New equipment design & installation

**Scientific Studies & Projects**
INEL participates in the European and local scale to various projects of R&D to develop Technology.
- European ENVIROMONITOR project coordination: real time automated instrument development using XRD for on-site quantitative analysis on breathable spray particles, including nanoparticles
- Scientific state projects, Thesis financing
- Works coordination & supervision
- Patents creation & operation
- SolXpert project, granted by Région Centre (Fr)
- SOLSA project H2020 raw material
... and radiation always interact with matter ...
Wave-matter interaction

**X-rays Production**: classically by excitation of external electronic level with electron beam

**Bragg's law**: 
\[ d = \frac{\lambda}{2 \sin \theta} \]

- Reflection
- Absorption
- Diffusion
- Diffraction
- Fluorescence
Interaction wave-matter

For a given source (sun), and a sample (Alpes)

- refraction
- diffusion
- reflexion
- absorption

... and eye detector

Instrumentations using radiation for material analysis need to be optimized:
- source characteristics
- detection characteristics
- sample environment
- mechanical design

Who can see the error?
Interaction wave-matter

The energy of photons used for optical spectroscopic measurements of various quanta

<table>
<thead>
<tr>
<th>Frequency</th>
<th>1 GHz</th>
<th>1 THz</th>
<th>1 PHz</th>
<th>1 EHz</th>
<th>1 ZHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>1 m</td>
<td>1 mm</td>
<td>1 µm</td>
<td>1 nm</td>
<td>1 pm</td>
</tr>
<tr>
<td>Photon Energy</td>
<td>1 µeV</td>
<td>1 meV</td>
<td>1 eV</td>
<td>1 keV</td>
<td>1 MeV</td>
</tr>
</tbody>
</table>

- Microwave
- Far-IR Infrared Near-IR
- UV
- hard X-rays
- γ-rays
- Visible
- soft X-rays

<table>
<thead>
<tr>
<th>Spectroscopic methods</th>
<th>NMR</th>
<th>ESR</th>
<th>FT-IR</th>
<th>IRAS</th>
<th>Absorption</th>
<th>Reflection PL</th>
<th>XAFS</th>
<th>XPS</th>
<th>PAC</th>
<th>MB</th>
<th>PAS</th>
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</table>

<table>
<thead>
<tr>
<th>Quanta studied</th>
<th>Nuclear spin</th>
<th>Electronic spin</th>
<th>Rotation phonon</th>
<th>Valence electron</th>
<th>Core electron</th>
</tr>
</thead>
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</table>

EHz : exahertz \((10^{18})\) - ZHz : zettahertz \((10^{21})\) - YHz : yottahertz \((10^{24})\)
Instrument is designed for the need we are looking for!
Instrument using a wave for probing matter is defined by several functions:

Most instruments using radiation corresponds to this scheme:
XRD – XRF- FTIR- Raman-UV ...
Building an instrument: definition

\(D_x\): Diffraction plane

\(F\): focus of the source

\(M\): Optical position (monochromator, mirror), involving a primary beam deviation

\(G\): Goniometer center where is localized the sample

\(S\): Sample position

\(D\): Diffraction device

\(\text{Dir } X\): Direction of the primary beam

\(\text{Dir } Y\): Direction perpendicular to the diffraction plane (axial direction)

\(\text{Dir } Z\): Direction perpendicular to the sample surface (equatorial direction)
Building an instrument: definition

**Goniometer**
Sample orientation is defined by 3 Eulerian angles:

- “Ω” angle is the incident angle on the sample surface
- “ϕ” angle is the rotation belongs the normal axis to the sample surface
- “χ” angle allows to tilt sample belongs the axis intercept of the diffraction plane and sample surface

Remark:
- “2θ” angle belongs to the detection part
A dictionary to describe the system: CIF

Defining and listing parameters make description easier!

http://www.iucr.org/__data/iucr/cifdic_html/1/cif_core.dic/index.html
A light emission characterized by:
- a spectral range
- a solid angle
- intensity
- dimension and shape of the source

Optimizing the characteristics of a source allows to focus on a given interaction.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>fluorescence</th>
<th>imaging</th>
<th>diffraction</th>
<th>reflection</th>
<th>diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>large</td>
<td>large</td>
<td>Monochromatic (excepted Laue)</td>
<td>monochromatic</td>
<td>monochromatic</td>
</tr>
<tr>
<td>Solid angle</td>
<td>Few degrees</td>
<td>Large (60°)</td>
<td>Small to parallel or focusing</td>
<td>Very small</td>
<td>Very small or focusing</td>
</tr>
<tr>
<td>Source size</td>
<td>Small or large</td>
<td>Small for resolution improvement</td>
<td>small</td>
<td>small</td>
<td>small</td>
</tr>
<tr>
<td>Source shape</td>
<td>point/linear</td>
<td>point</td>
<td>Point or linear</td>
<td>linear</td>
<td>Point or linear</td>
</tr>
</tbody>
</table>

This is achieved by using appropriate optics (1D, 2D, monochromator, mirror, collimator, slits ...)

Molybdenum spectrum vs the applied voltage

Proprietary & Confidential
Function source; shaping the beam!

An optic is characterized by:
- mosaicity → spectral range
- a capture angle → beam size
- divergence → resolution

“Monochromaticity”
A dictionary to describe the source

Deeper in the CIF!
Ones doing programming will see « object oriented programming »
Effect of optic: comparison between high resolution and high flux

Graphite monochromator

Ge111 monochromator

Blue

Green

ACQTIME 300
VOLTAGE 35
CURRENT 35
WAVELENGTH 1.54056000
COMMENT1 inc=10 SFspin

ACQTIME 27815
VOLTAGE 35
CURRENT 35
WAVELENGTH 1.54056000
COMMENT1 inc=8 spin

ACQTIME 1800
VOLTAGE 35
CURRENT 35
WAVELENGTH 1.54056000

ACQTIME 18000
VOLTAGE 35
CURRENT 35
WAVELENGTH 1.54056000
Effect of wavelength

Mixture of minerals

Cukα

Cokα
Effect of optic

With graphite, $k_a/k_a$ doublet is considered as a single peak.

Nist SRM 1976 (Alumina)

**Flux ratio**
- Ge(111): 1
- Graphite: 5
- parab. Mirror: 15
- Elliptical mirror: 20
Function detection

A detector is characterized by:
- spacial resolution
- dynamic range
- energy resolution
- dimension

Optimizing the characteristics of a detector allows to improve the measurement

<table>
<thead>
<tr>
<th></th>
<th>fluorescence</th>
<th>imaging</th>
<th>diffraction</th>
<th>reflection</th>
<th>diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacial resolution</td>
<td>none</td>
<td>good</td>
<td>good</td>
<td>none</td>
<td>medium</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>3</td>
<td>4-5</td>
<td>3-5</td>
<td>6-8</td>
<td>3-4</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>~200eV</td>
<td>None</td>
<td>None or 1KeV</td>
<td>None or 1KeV</td>
<td>None or 1KeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Filtering possible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dimension</td>
<td>0D</td>
<td>2D (1D)</td>
<td>0D, 1D, (2D)</td>
<td>0D(1D)</td>
<td>1D-2D</td>
</tr>
</tbody>
</table>

[Diagram of X-Ray Fluorescence of Lead from $^{203}$Cd]

[Graph showing energy distribution]
**Function detection**

**0D Detection:**
Acquisition is done stepwise
2θ and statistics are time dependent

**1D Detection:**
Acquisition is done in snapshots
Statistics is time dependent

**2D Detection:**
Acquisition is done in snapshots
Statistics is time dependent
Texture information but point beam required
A unique detection mode

Curved detectors principle
The EQUINOX diffractometers use the curved detectors principle, namely real time acquisition across a wide acquisition range.
- No motorization required: neither on sample nor on detector incidence
- Asymmetric acquisition mode: for a fix $\theta$ sample incidence you can see all diffraction peaks on $2\theta$ on the detector

3 detector types

<table>
<thead>
<tr>
<th>Detection angular range</th>
<th>Curvature (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS 590</td>
<td>90° $\theta$</td>
</tr>
<tr>
<td>CPS 120</td>
<td>120° $\theta$</td>
</tr>
<tr>
<td>CPS 180</td>
<td>180° $\theta$</td>
</tr>
</tbody>
</table>

The detector choice depends on the requirements of the measure to be made:
- The more the detector is far from the sample, the better the resolution will be
- The more the detector is near the sample, the faster the acquisition will be
Function matter

Gas → Liquid → Solid

States of matter

whatever the state, XRD allows to evidence and measure structural parameters in matter
Informations obtained by XRD

What is the composition? and how much?
what is the cristallite size and morphology?
Is there any constrains inside cristallite? Or in the overall sample?
Is there an organisation at the cristallite scale? And can we quantify a distribution? Pole figures, Structure, organization of electronic density levels:
What is the structural modification of my sample vs physical parameters (P, T...)?
Structural anisotropy:

Phase identification
Phases quantification
Particles size, micro strains
Stress analysis
Preferred orientation (powder) or texture (bulk)
ODF
cell parameters, valence, atomic occupation, ...
dilatation, phase transition
stress, texture, thin film characterization ...

\[ \lambda = 2d_{hkl} \sin(\theta_{hkl}) \]

Overall analysis of peaks shape, position and intensity and background function
Function sample holder

Paracetamol

Better resolution in transmission
Function sample holder

Na-gluten

Better resolution in transmission

Transmission

Reflexion

2θ
Understanding how to get the result

- appropriate instrumental configuration
- appropriate sample conditioning
- appropriate calibrations / corrections

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Type of solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>monochromatic</td>
<td>Single crystal</td>
</tr>
<tr>
<td></td>
<td>polycrystalline</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>polychromatic</td>
<td>Powder XRD</td>
</tr>
<tr>
<td></td>
<td>Laue Method</td>
</tr>
<tr>
<td></td>
<td>ED-XRD</td>
</tr>
</tbody>
</table>
Instrumental function for XRD

Some rules:

- Instrumental function is governed by all components of the XRD instrument:
  - source characteristics
  - optics and collimation
  - detection device
  - sample environment

- XRD components should be compatible to each other
  - Example: 1D optic is not recommended with a 2D detector (equatorial aberration)

- The good knowledge of the instrumental function allows to estimate as well the quality of the result
  - Example: absorption correction or LP correction are not the same in Bragg Brentano or in Debye Scherrer

- The instrument must be adapted to the requested measurement
  - Example: performing transmission measurement with Bragg-Brentano XRD is not appropriate

- Instrumental conditions must be correctly chosen (reproducibility of results)
  - Example: choose of the appropriate wavelength vs sample

- Use of appropriate standards
  - Example: in reflection, eccentricity is influenced by transparency. Using standard with same absorption can correct this
A dictionary to describe the system: CIF
Existing Instruments

And

applications
EQUINOX 100, stand alone benchtop XRD

A stand alone benchtop X-ray diffractometer
Designed for crystalline phases analysis (qualitative, quantitative, structural...) on powder or bulks. It is an ideal instrument for academic and QA/QC laboratories that need a small and easy to use equipment.

- Real time detection across 110°/2θ (CPS180)
- Simplified goniometric deck with no motorization
- No external water cooling
- Works on standard power supply (110V-20A/230V-16A)
- Friendly-user instrument driving & data treatment software

Applications: qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation...

lactose

reflection

transmission
EQUINOX 1000, benchtop XRD

A fast and powerful benchtop XRD
with small dimensions, ideal for all your X-ray diffraction applications on powder.
It is a very easy using instrument. No diffractometer alignment is required and the
operating protocol is saved by the software. XRD experiments are available to anyone in a
few moments.

- Real time detection across 110°/2θ (CPS180)
- Monochromatic optics
- 3500 Watts generator
- External water cooling
- Working wavelength : Copper or Cobalt

Applications:
Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation...
Quality control in detergent

On the graph below, are represented diffractograms recorded for each sample. We can clearly evidence an increase of STPP 1 with the index (red arrows).

Acquisition time: 2 min

Quantitative analysis has been performed by using the Rietveld method. Good reproducibility, and good agreement with other techniques (chemistry)
EQUINOX 2000, routine XRD

A routine diffractometer

with the EQUINOX 1000 performances and a bigger sample space, the EQUINOX 2000 enlarges your applications capabilities. You can now realize variable temperature and/or atmosphere measurements.

• Fast results
• Thermodiffraction (phases transitions, unstable compounds)
• Large sample space
• Real time detection across 110°/2θ (CPS180)
• Monochromatic optics
• 3500 Watts generator
• Working wavelength : Copper or Cobalt
• Environmental chambers (option)
• 30 positions auto-sampler (option)

Applications

Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, ...
EQUINOX 3000, powder high resolution XRD

A fast, powerful and multi-purpose XRD
You are now able to realize variable temperature and/or atmosphere measurements, or even add a motorized sample holder to perform thin layer analysis.

• Evolutive depending on your needs
• Real time detection
  • CPS120 across 120°/2θ
  • CPS590 across 90°/2θ (High resolution)
• Monochromatic optics
• 30 positions autosampler (option)
• Environmental chambers (option)

Applications
Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, thin layer analysis, uniaxial stress analysis...

Thermal diffraction: 5sec/pattern
Phase transition at low $2\theta$

Source: Copper
Generator: 3.5 kW
Optique: Parabolic mirror
Incidence: Transmission (1mm capillary)
Sample holder: non spinning furnace type FURCAP
Detector: CPS120
Power: 35 kV – 35 mA
Acquisition time: 3 min
Setting: MPD

Transition at 70°C

**figure 1**: temperature profile: from RT to 70°C step 10°C and every 5°C while cooling down.
**EQUINOX 4000, DRX microdiffraction / cartographie**

**EQUINOX 4000** is designed for all your microdiffraction or mapping applications. The instrument uses X, Y and Z translation stages with strong travel.

- Real time detector (CPS 120)
- $\theta / 2\theta$ goniometer with large stages X, Y and Z
- Working wavelength: Copper or Cobalt

**Applications**

Microdiffraction, mapping...

---

**Microdiffraction on the edge of an aluminum plate**

**Experimental:**
- Beam size: 20mic, Power: 1200W
- Acquisition: 120sec/pattern
EQUINOX 5000, high resolution XRD

A high resolution diffractometer
for all your powder analysis under variable temperature and/or atmosphere that require a very high resolution.

- \(\theta/\theta\) or \(\theta/2\theta\) 2 circles goniometer
- High resolution detection (CPS 590)
- Environmental chambers (option)

Applications
Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, thin layer analysis, uniaxial stress analysis...

Coating on stainless steel

Thin film analysis
**EQUINOX 6000, 4 circles texture/stress XRD**

**4 circles X-ray diffractometer**
Ideal for all your 4 circles goniometer X-ray diffraction applications.

- Robust and multi-purpose goniometer
- Heavy loads accepted on every movements
- Large sample space
- Real time detection (CPS590)
- 4 circles goniometer (θ, 2θ, χ, φ)
- Collimating monochromatic optics
- 3500 Watts generator
- Variable working wavelength
- Temperature chambers (option)

**Applications**
Texture, stress, thin layer, qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, microdiffraction...

*Texture analysis on stainless steel foil*
Small Angles X-ray Scattering
To better answer its customers needs, Inel designed a flexible SAXS line to make textured samples analysis or small angles scattering.
This technique is used to determine particles structure at nanometric range (size, form, distribution...). Studied materials can be solid, liquid or gas. This non-destructive method is accurate and requires usually only a minimal sample preparation. It can be used as well for research as for QA/QC.

- Evolutive mounting
- Variable sample/detector distance
- Specific supports and chambers available
- 1D or 2D detection with dedicated software

Applications
Colloids, metals, cement, clays, oil, polymer, plastics, proteins, pharmaceutical industry...

PET semi-crystalline (30%)
PET semi-crystalline (30%) deformation 1.4
Laüe back reflection diffractometer

**A fast tool for cristal orientation**

- Easy sample positionning
- Fast acquisition
- Fast orientation determination

Sample holder can be customized according to cristal

*Si220 orientation*
**Inel XRD flexibility**
Combining X-ray diffraction with other techniques:

- One sample and several datas
- Real time analysis
- XRD comes to sample
- XRD for on line industrial control

**Inel portable XRD systems:**

- **EQUIRAM**  Combination of XRD and Raman spectrometer
- **XRD/DRIFT** Combination of XRD and DRIFT spectrometer
- **STRESS/WAXS** Combination of WAXS and stress analysis
- **SWAXS**  SAXS WAXS diffractometer
- **COSMA**  On-line production control XRD
- **PRECIX**  Robotics for XRD residual stress measures
**XRD/DRIFT combination**

**Phase transitions observation**

- Development of a laboratory system, combining XRD and DRIFT, to perform in-situ measurement
- Development of an adapted environmental cell pressure-temperature
- Concept of instrumented system, with an appropriate expert software
- XRD in transmission with Mo radiation
- IR spectrometer in reflection (DRIFT)
- Sample cell with pressure/temperature, and gas mixing.

DRIFT spectra recorded during thermal decomposition of calcium oxalate (50 mg, 5 K min$^{-1}$).

X-ray diffraction patterns recorded during the thermal decomposition of calcium oxalate (50 mg, 5 K min$^{-1}$). Blue traces represent stable crystallographic phases and orange diffraction traces indicate intermediate crystallographic structures.
Some developments

- **1997**: COSMA, on-line XRD control of cement
- **2000**: G3000 4-axis goniometer
- **2006**: PRECIX for in-situ stress measurement
- **2006**: HEXRAY High energy XRD
- **2007**: 9-axis vertical goniometer for Epitaxy
- **2008**: 6-axis horizontal goniometer for Epitaxy
- **2008**: Stress-Waxs combination
- **2010**: XRD-DRIFT combination
- **2011**:
**XRD combining**

**Interest of combining**

- sample is a complicate mixture: XRD+XRF, XRD + Raman

- complementarity to observe phase transition: XRD + IR, XRD + Raman, XRD + DSC

- relationship between mecanical properties and structure: texture + stress

- many other combinations ...

**Advantages**

- 1 sample for several measurements, but 1 result

- eliminating non possibilities (XRF prefiltering before search match)

- ...
Since 2010, wedlock between PSD detector and X-ray minisource

**XRD « escapes » from laboratories**
Combining X-ray minisource and CPS detector:

- Low consumption XRD
- Robust instrument
- No external water cooling
- Works on standard power supply

**Inel portable XRD systems:**
- **EQUINOX 100**: Stand alone benchtop XRD
- **Enviromonitor**: Aerosol quantification expert system
- **XSOLO**: Nomadic Stress System
- **Equinox Trail**: Rackable XRD
- **SOLXPERT**: Portable XRD/XRF system for in field applications
Granted projects to develop ideas

**Nanoair Project:** (FP7 222333). Design of a prototype, composed by a combination WAXS/SAXS XRD device. Birth of FPSM software (deviation of MAUD), for automatic phases identification and quantification by using the Rietveld method and the COD database.

**Results:**
- Partial feasibility
- New automatic software for data treatment

2009-2011

**Enviromonitor project:** (FP7 SME-2011-3 CP grant agreement N° 286570) for the realization and miniaturization of a mobile system for aerosol sampling and analysis.

**Results:**
- Feasibility in certain conditions
- Performance in miniaturization
- Target market not clearly visible

2012-2014

**Secondary results:**
Optimization of a low power bench top XRD

**Equinox 100:** Bench top XRD

Too big!
Granted projects to develop ideas

**XRD integration in mobile lab**
Mobile lab start to be developed, in order to improve the reactivity in the decision.

- Compact instrumental part
- 19” electronic part

**SolXpert, innovation to serve field expertise**
Combining XRD-XRF for in-field measurements
Total power : 200 W

**Applications**
Environment, geology, police, industry...
Goal of software,

Driving instruments

And

Assistance in methodology
Software in the future

Development of instrument control software

UNIVERS: from 2013, transition to more universal software:
- data storage (configuration, sample description, raw data and refined data in a unique SQL database)
- sub-programs drive components (servers)
- Master communicates with servers in TCPIP
UNIVERS: from 2013, transition to more universal software:
- data storage (configuration, sample description, raw data and refined data in a unique SQL database)
- sub-programs drive components (servers)
- Master communicates with servers in TCP/IP
Innovative software for search-match

Not yet launched.

The FPSM (Full Pattern Search-Match method)

Developed inside the Nanosiq project for the portable instrument

Pro:
- No user intervention, automatic analysis
- No peaks identification required (works with nano materials/particles
- Full Rietveld quantitative analysis provided
- Works for neutron and electron diffraction

Cons:
- Only phases with known crystal structure are ready to be used (unknown structures require a list of peaks and calibrated intensities, PONKS)
- Available databases are still uncompleted
- If no elemental composition provided \( \rightarrow \) requires > 20 minutes on 12 cores computer
- Good ranking algorithm required for very small phase amount

A demo version has been setup online at:
http://nanosiq ling.unins.it/PSFPM

search and quantification is limited by the time required (or better server response time) so it should be used restricting the composition as much as possible to speed up computation. A limited number of concurrent connections are supported also. INEL SAS can be required for the full version.

See also the demo at the Software Fair at 3pm on Tuesday afternoon.
Innovative software for Rietveld refinement

Free software

Originalities:
- combined refinement with XRD method (powder, texture, stress, grazing …)
- combined refinement with other techniques (XRF)
New concepts for the future

- Light instruments
- Expert system because of measurement/modeling combination
- Low power
- Applications designs
- Technics combination
- Unique software for expertise: MAUD
Thank you for your attention

This presentation has been made using only open source software, so if it didn’t work as expected that’s normal...