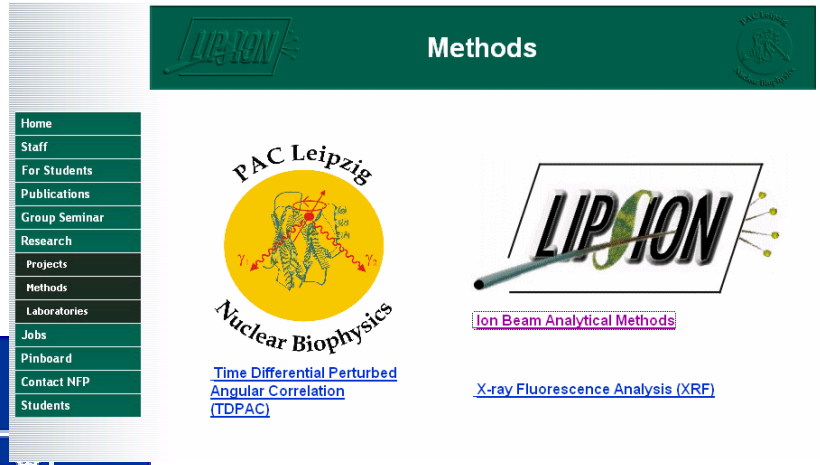
Applications for PIXE and other Ion Beam Analysis (IBA)

PIXE-PAN Summer Science Program
University of Notre Dame
June, 2007

Larry Lamm, Research Professor

Many, many facilities worldwide



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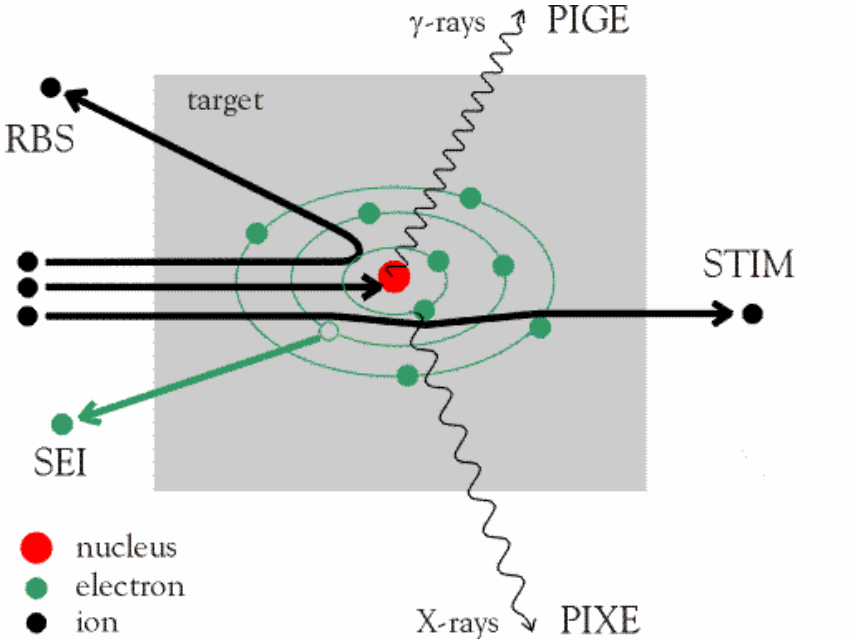
Some IBA Techniques

- Several IBA techniques are illustrated here, including RBS, PIGE, PIXE, STIM, and SEI.



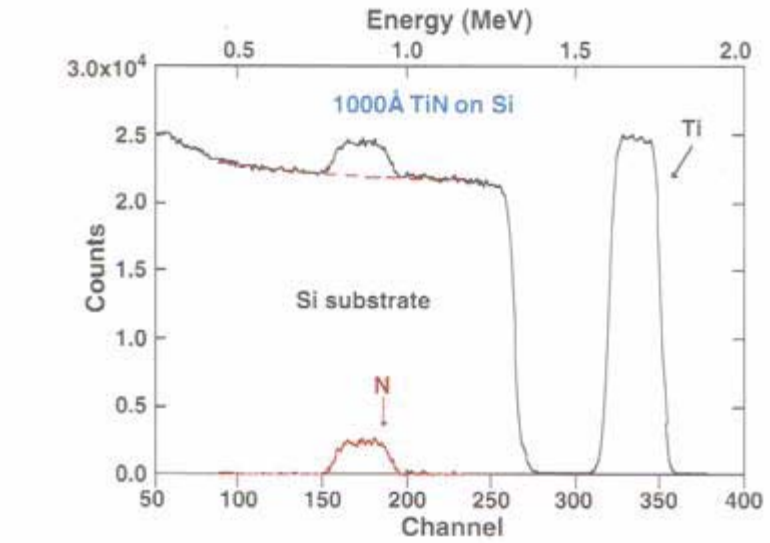
http://www.uni-leipzig.de/%7Enfp/Research/Methods/Ion_Beam_Analysis/body_ion_beam_analysis.html

PIGE
Proton Induced Gamma-Ray Emission

- Protons interact with nuclei in the target, with nuclear reactions taking place that emit high energy X-Rays from the nuclei (known as Gamma-Rays)
- Used in the determination of the elemental content, comparable to PIXE, often done in parallel with PIXE measurements, but only useful for light nuclei (low Z nuclei)

RBS – Rutherford Backscattering Spectrometry

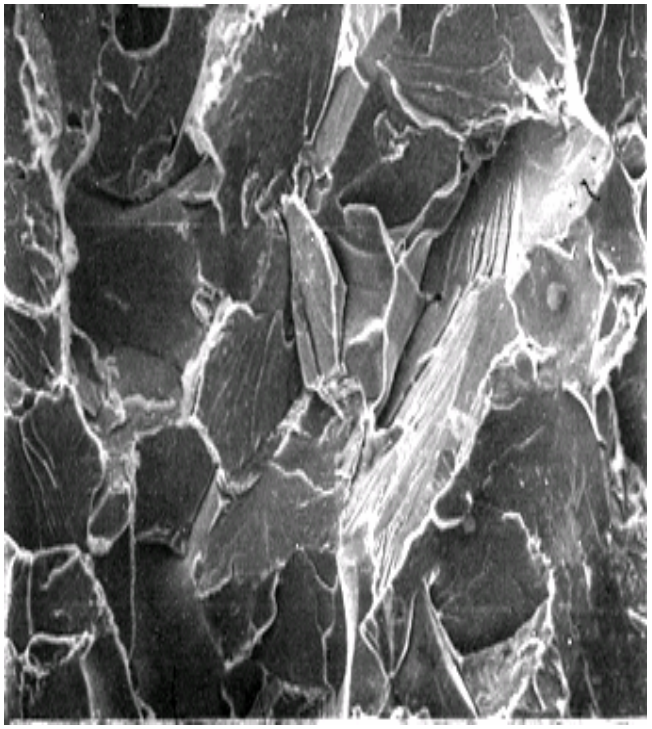
- Uses MeV He ions to bombard the sample (in vacuum), with backscattered He ions detected.
- Yields depth profiles and information on lattice structures.



http://www.mastest.com/rbs.htm#

SEI – Secondary Electron Imaging

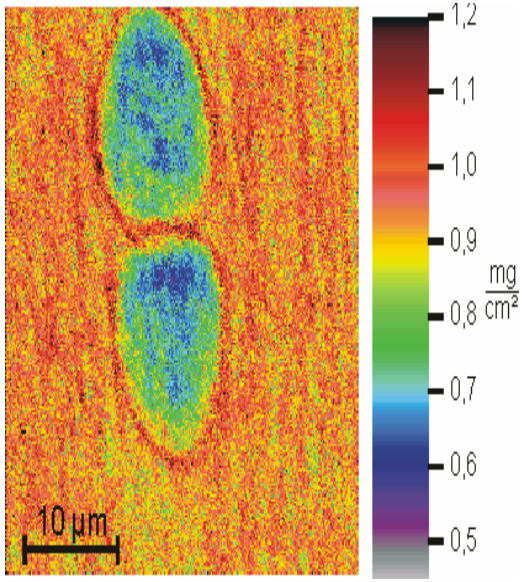
- A technique to examine the surface of the sample, using low energy electrons ejected from outer orbits, typically detecting these electrons using a scanning electron microscope or similar detector.



http://mse.iastate.edu/microscopy/secondary.html

STIM – Scanning Transmission Ion Microscopy

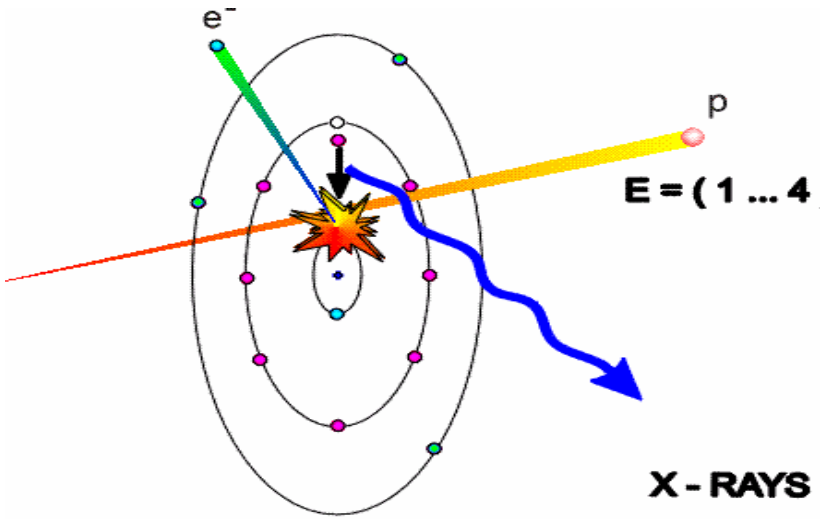
- Here the ion beam is tuned to VERY low intensity, and that portion which penetrates the sample is detected. The energy lost in transit is used to determine the local density of the sample.



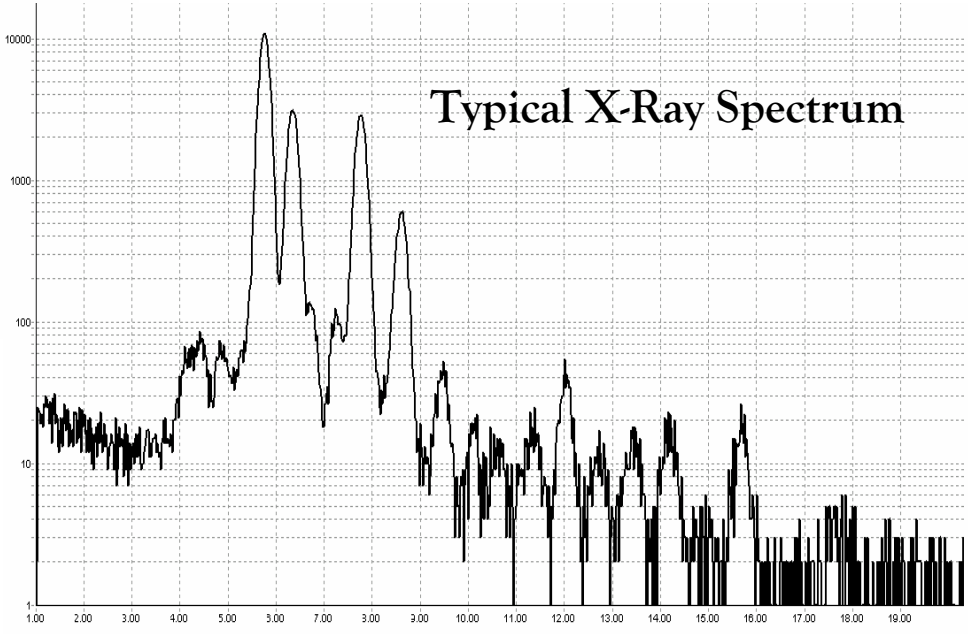
Cartilage cells (*chondrocytes*) with surrounding matrix from a pig's knee joint.

http://www.uni-leipzig.de/%7Enfp/Research/Methods/Ion_Beam_Analysis/STIM/body_stim.html

PIXE
(Proton Induced X-Ray Emission)



from the Division of Nuclear Solid State Physics
at University of Leipzig



X-Ray Energy (keV)

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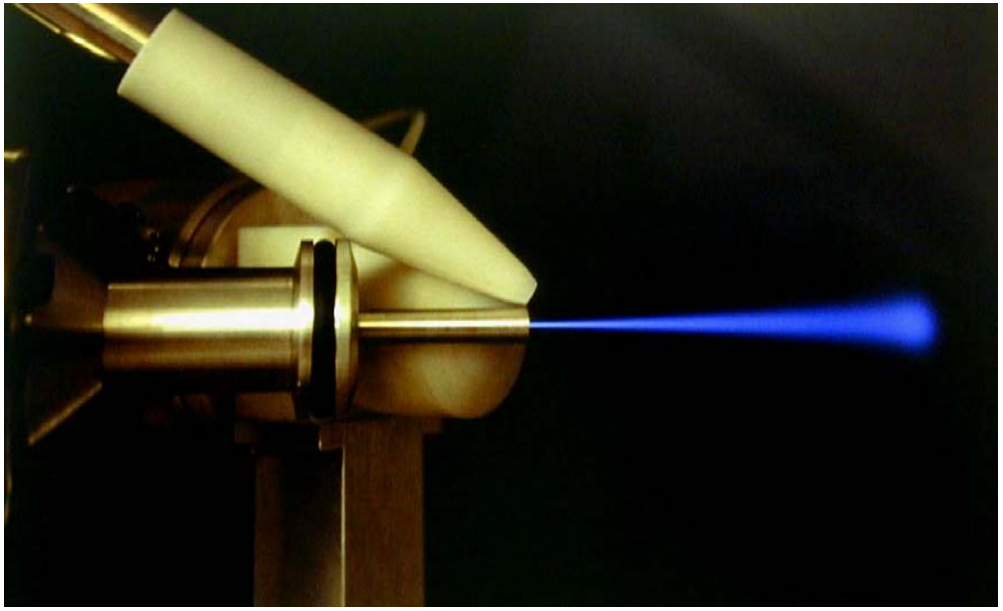
External Beam PIXE

Here is a view of the proton beam emerging into the air in the target room. The blue light is from the interaction of the proton beam with the atoms and molecules in the air.



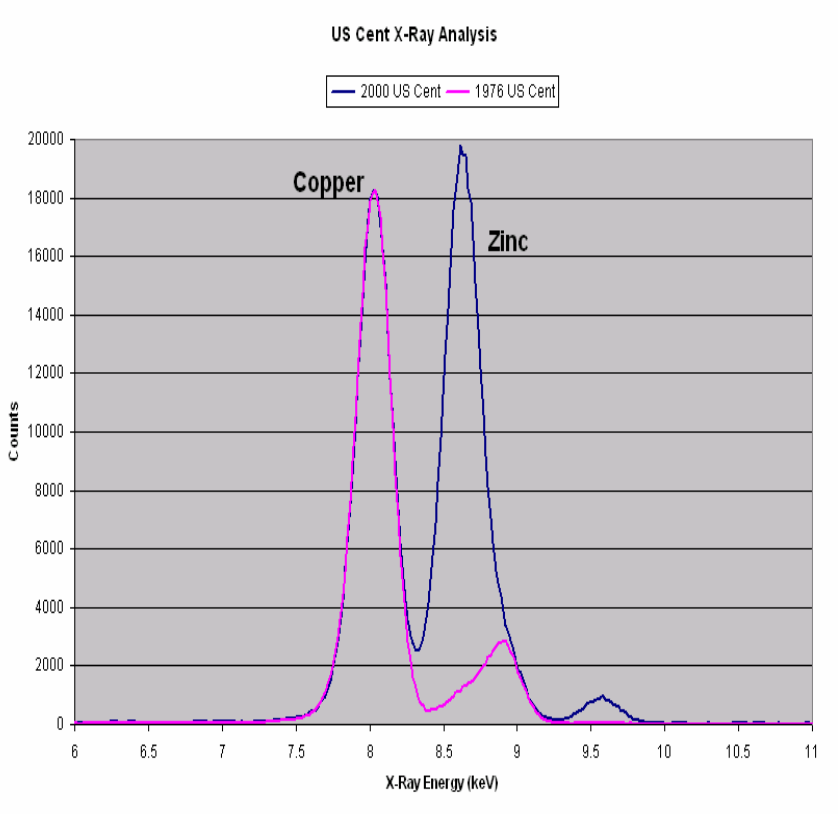
This allows us to examine materials which could not be explored in vacuum, as would be required with some other ion beam analysis techniques.

From Pier Andrea Mandò, Dipartimento di Fisica and Sezione INFN, Florence, Italy

PIXE Analysis

- Every element has a unique X-Ray "fingerprint", a unique pattern consisting of a combination of K, L, and M X-Rays, due to the variation in atomic structure for each element.
- The challenge is to "unfold" the information about the elemental concentrations from the resulting spectrum.

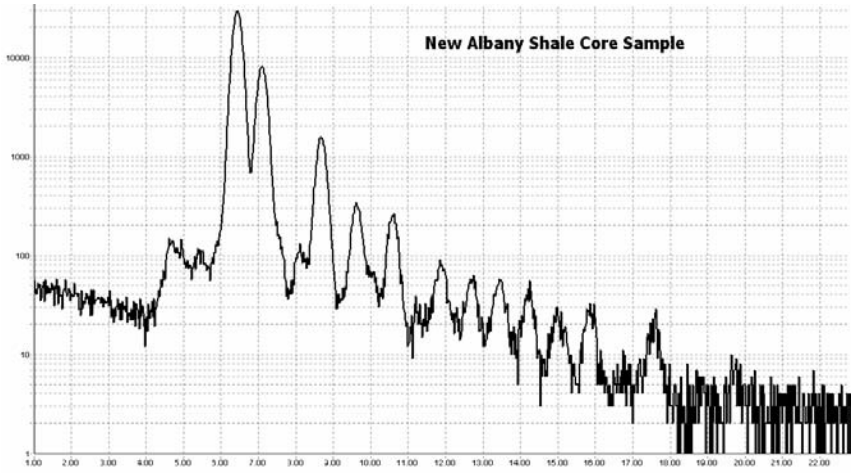
US Cent Analysis



- Composition of the US Cent changed in 1982 from solid bronze (95% Cu, 5% Zn and Sn) to copper plated Zn (95% Zn, 5% Cu plating). With enough energy, the PIXE protons can penetrate the Cu plating to the Zn core.

Often, More Complicated

- This is a sample of the work we are doing to examine core samples.
- We are working to determine the elemental concentrations as a function of depth.
- Many elements to unfold.



Applications of PIXE

Because PIXE is relatively easy to do, and because it can be done in a non-invasive manner, the technique has been and is currently being applied to a wide range of material analysis problems.

It should be noted that PIXE is nearly always used as a tool to analyze materials, and generally not as a tool to explore for new physics.

PIXE Applications

Multielemental Analysis of Genetically Modified Food using ANAA and PIXE Techniques

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Received on 12 August, 2005

This paper describes the application of two techniques, ANAA and PIXE, used in the analyses of some available commercial food containing regular and genetically modified ingredients, as well as soybens cultivated with regular and genetically modified seeds (GMS). The aim of this work is determine their elemental composition to perform a comparative analysis. The elemental composition results of both types of food, obtained by the two techniques, were in agreement for all elements. Our results show the same elemental composition for all food samples but the quantitative analysis between soybeans seeds (regular and GM) suggested that the product made with GMS have higher concentration values, mainly for Cl, P and Zn, while for industrialized food, made with genetically modified products, a low concentration values were measured for most of the elements.

Some PIXE applications

Earthworm transport of heavy metals from sewage sludge: a micro-PIXE application in soil science

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Available online 16 October 2002.

Abstract

Micro-PIXE was used to analyze earthworm fecal material and the linings of earthworm channels in the soil below a land area on which sewage sludge had been applied. Metals present in the sludge were identified both in fecal pellets and in the linings of the channels, at concentration markedly higher than in the soil matrix. PIXE elemental data in raster format were spatially analyzed during image analysis demonstrating in a quantitative manner the spatial correlations among elements transported by the earthworms.

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
Volume 77, Issues 1-4, 1 May 1993, Pages 509-516

PIXE Applications

ELSEVIER

Nuclear Instruments and Methods in Physics Research B 109/110 (1996) 218–226

NIM B
Beam Interactions with Materials & Atoms

Elemental analysis by PIXE and other IBA techniques and their application to source fingerprinting of atmospheric fine particle pollution

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ANSTO, PMB1, Menai, NSW 2234, Australia

Abstract

The PIXE technique in conjunction with PIGME, PESA and RBS has been used to routinely measure over 20 different elements present in fine particle atmospheric samples. PIXE provided data for selected elements from Al to U while the other techniques provided information on elements lighter than Al such as H, C, N, O, F and Na. Detection limits for the ion beam techniques on Teflon filter papers were typically between 0.02 and 0.2 $\mu g/cm^2$ for a few minutes of accelerator running time. The multi-elemental capability of PIXE enabled us to use these 20 or so different elemental measurements to define fingerprints for various fine particle sources. These fingerprints included anthropogenic sources such as motor vehicles, industry and coal combustion as well as natural sources such as seaspray and soil.

PIXE Applications

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Nuclear Instruments and Methods in Physics Research B 150 (1999) 484–490

NIM B
Beam Interactions with Materials & Atoms

Geogas prospecting – an ideal industrial application of PIXE

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[b] *Department of Nuclear Physics, LTH, Lund University, P.O. Box 118, S-221 00 Lund, Sweden*

Abstract

In geogas prospecting the extremely small concentrations of trace elements, in an upward gas stream, are measured with high sensitivity using the PIXE technique. The measured elemental composition in the geogas across geological formations reveals much about the bedrock composition and the possible presence of concealed mineralizations and ore bodies. The possible origin and transportation of the geogas matter through the bedrock are discussed. The sampling procedure, the data analysis and the normalisation procedures are described. Finally, the possibility to extract three-dimensional information from a two-dimensional measurement is demonstrated as an example from a field experiment.

PACS: 2970; 9165; 9365; 9385
Keywords: Geogas; Geogas prospecting; PIXE; Mineral prospecting

PIXE Applications

Application of PIXE and RBS methods in the analysis of thin films of high-T_C superconductors

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Joint Institute for Nuclear Research, Dubna, Russian Federation
Institute of Physics, SAS, Bratislava, Czechoslovakia

Available online 17 October 2002.

Abstract

The possibilities of the PIXE method in combination with the RBS method in the analysis of the high-$_c$ superconducting thin films are discussed. The results obtained applying ^{4}He ions with energies up to 3.1 MeV in the bombardment of Y---Ba---Cu---O layers on selected substrata are presented. The heavy element concentrations are determined by the PIXE method using the yields of K_α for Cu as well as Y and L_α for Ba. The quantitative analysis based on fundamental parameters as well as external standards have been applied. The content of heavy elements can be determined with an accuracy of about 2–3 rel.%. The oxygen content was determined using 3.045 MeV resonance in ^{16}O(^{4}He, ^{4}He)^{16}O elastic scattering with an accuracy of even 1 rel.%. The RBS method was used to determine the layer thickness as well as the chemical composition. Finally, the comparison with ICP-AES, XRF and AAS methods is given.

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
Volume 75, Issues 1-4, 3 April 1993, Pages 392-396

PIXE Applications

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Nuclear Instruments and Methods in Physics Research B 109/110 (1996) 658–661

NIM B
Beam Interactions with Materials & Atoms

Application of the external PIXE analysis to ancient Egyptian objects

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Abstract

Mural paintings with ~$20 \times 25\ cm^2$ in size excavated in Egypt were analyzed by the external PIXE technique. Colored layers were stacked with white, yellow, red and black pigments in sequence, which were composed of $Mg_3Ca(CO_3)_4$ (white), $\alpha FeO \cdot OH$ and As_2S_3 (yellow), αFe_2O_3 (red) and soot (black), respectively. A single particle of As_2S_3 was also found from the yellow colored part, which glinted in the sun. A thin paraffin layer did not disturb the PIXE analysis, which was a part of reinforcement materials for ancient remains and was flowed out from a back side to a surface region.

PIXE Applications

Archaeometry **45**, 2 (2003) 333–339. Printed in Great Britain

THE IMPROVED LNS PIXE-ALPHA PORTABLE SYSTEM: ARCHAEOMETRIC APPLICATIONS*

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The possibilities presented by the improved portable PIXE system are discussed. Examples are given of applications in the cultural heritage field, and in particular in the characterization of pigments and silver patina on ancient Roman coins. The limitations of the system are also discussed.

KEYWORDS: PIXE, PORTABLE SYSTEM, PIGMENTS, SILVERED COINS

PIXE Applications

The improved LNS PIXE-alpha portable system 335

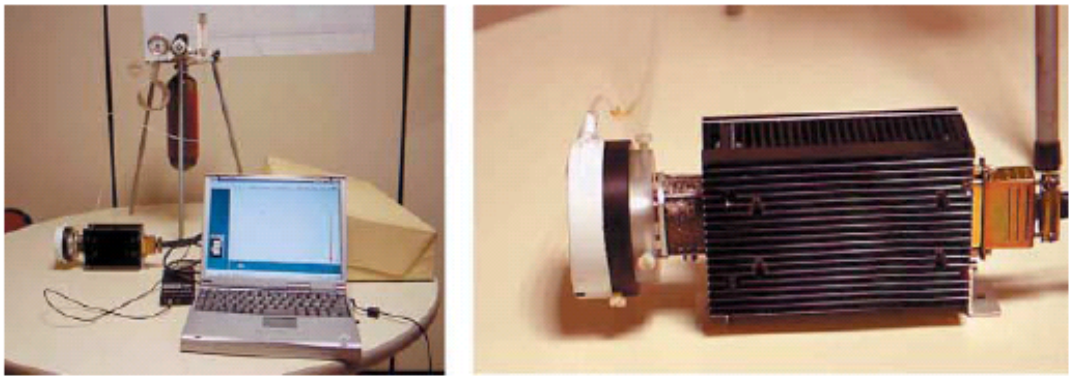
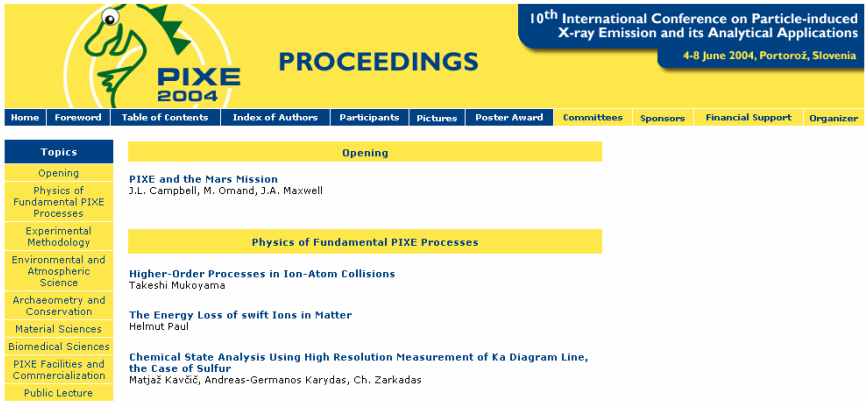


Figure 1 *The new version of the PIXE-alpha system. The photograph on the right shows the alpha source coupled to the Si-drift detector.*

- This is portable PIXE system, suitable for field work with archeological sites. Allows for field analysis, as a sort of "triage" to determine which samples might require more in-depth analysis.

Very Active Field of Study



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The Joint Institute for Nuclear Astrophysics
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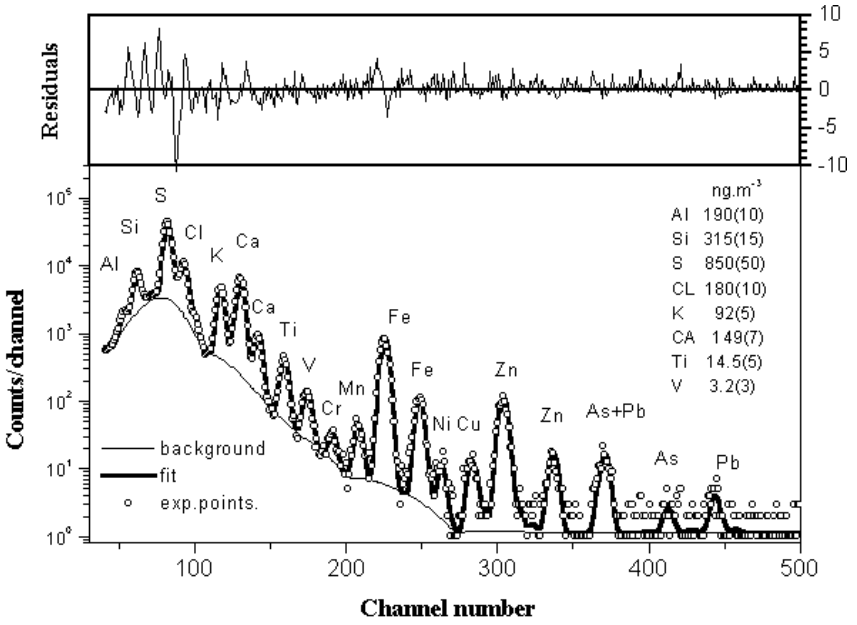
Trace Element Analysis

PIXE is used (often provided as a commercial service) to perform trace element analysis of the environment to study pollution. PIXE can measure the presence of minute quantities, a key advantage to this technique.



http://omega.ujf.cas.cz/CFANR/pixe.html

PIXE for Envionmental Research

"**Applications:** The PIXE technique can be applied to a wide variety of sample materials. At ANSTO, PIXE is often used for quantitative analysis in geology, archaeology, biology, materials science and environmental pollution. To find more about specific applications in various areas follow these links: Air Pollution, Archaeometry and Materials Science, or for more general information go to Projects, Capabilities, or Publications. "

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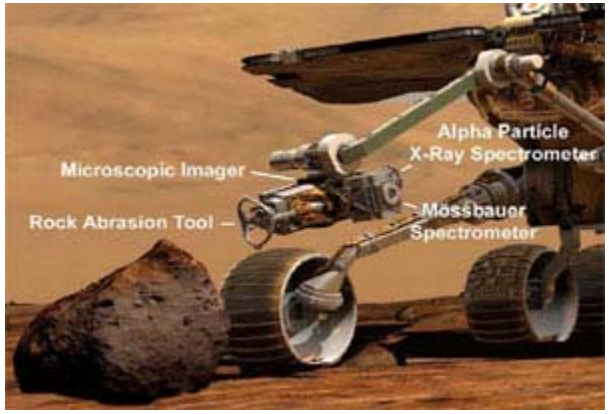
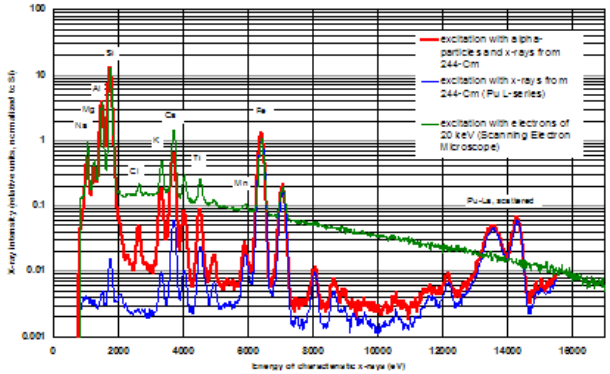
ansto
Australian Nuclear Science and Technology Organisation

Sulfide Mineral Analysis

Evaluation of ore bodies and subsequent exploitation to recover silver, gold, platinum-group, and other elements, demand knowledge of the distribution of minor and trace elements in the various sulfide mineral species of the ore. The need to analyze well-characterized individual grains demands an in-situ microprobe technique. Analysis of co-existing minerals e.g. silicates may also be necessary in arriving at a complete understanding of elemental distribution.

Martian PIXE





MARS APXS SIMULATIONS

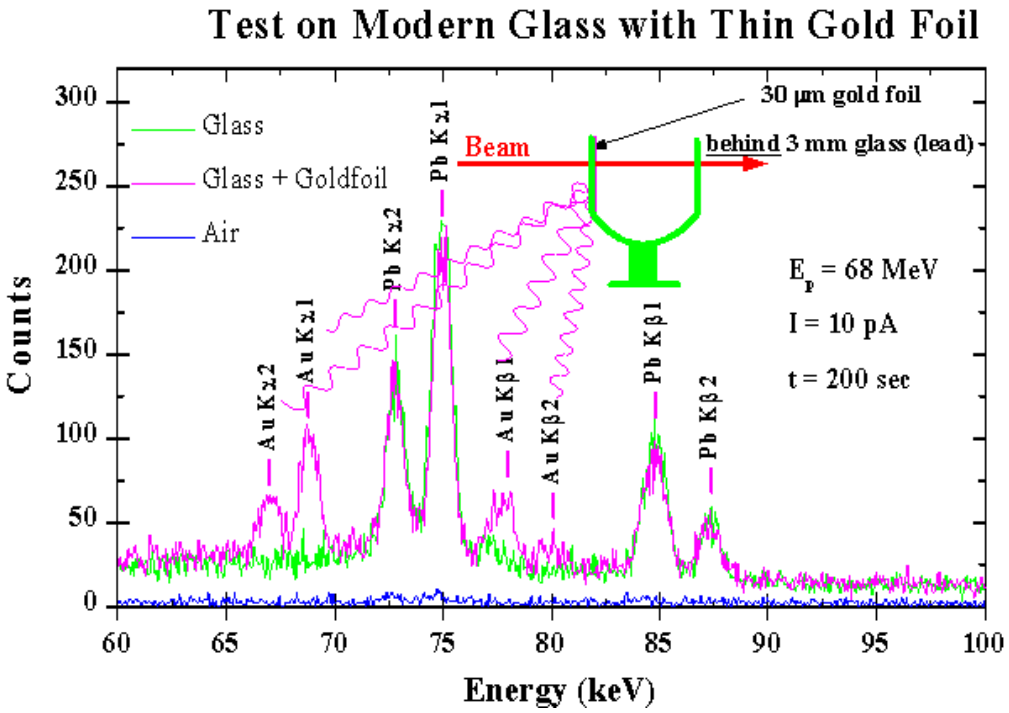
Guelph PIXE Group

Each of the Mars Exploration Rovers which attracted worldwide attention for their exploits in 2004/5 carries an Alpha-particle X-Ray Spectrometer (APXS). GUPIX subroutines are being used to analyze the data.

http://pixe.physics.uoguelph.ca/home/

Material Studies with PIXE

Some facilities use very high energy beams to allow them to probe materials to greater depths. Care must be taken with such measurements to prevent damage to the sample and to protect against beam induced radiation.



http://www.hmi.de/isl/ana/pixe-2_en.html

Artwork Analysis

PIXE can be used to examine sculptures, looking at the pigments in paint. We have already examined some Meso-American figurines and used PIXE to help understand the nature of the paints used to decorate the figurines.

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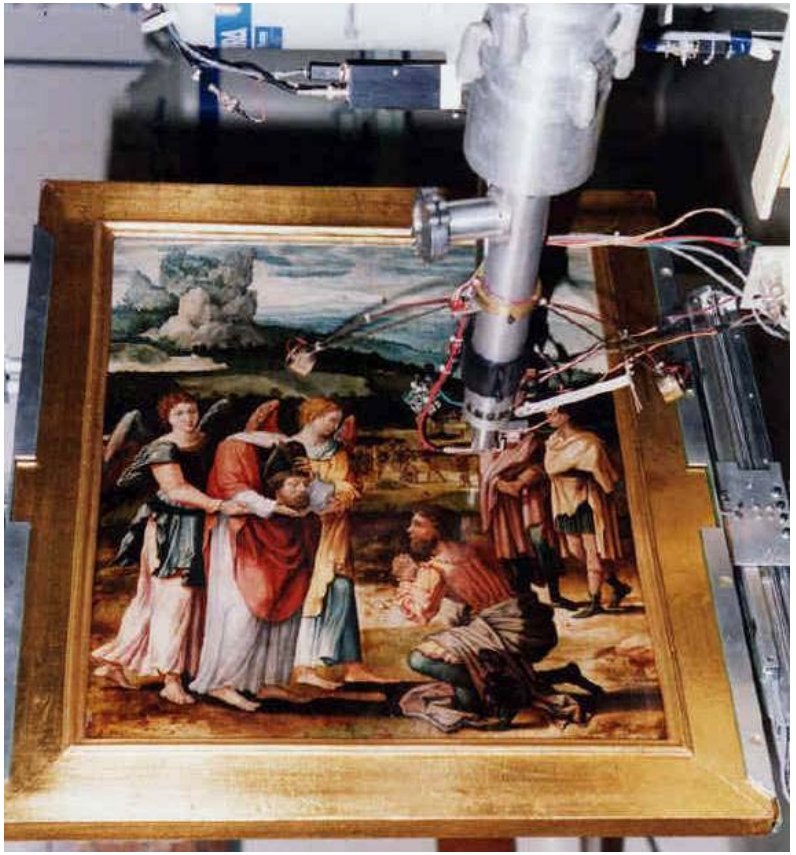
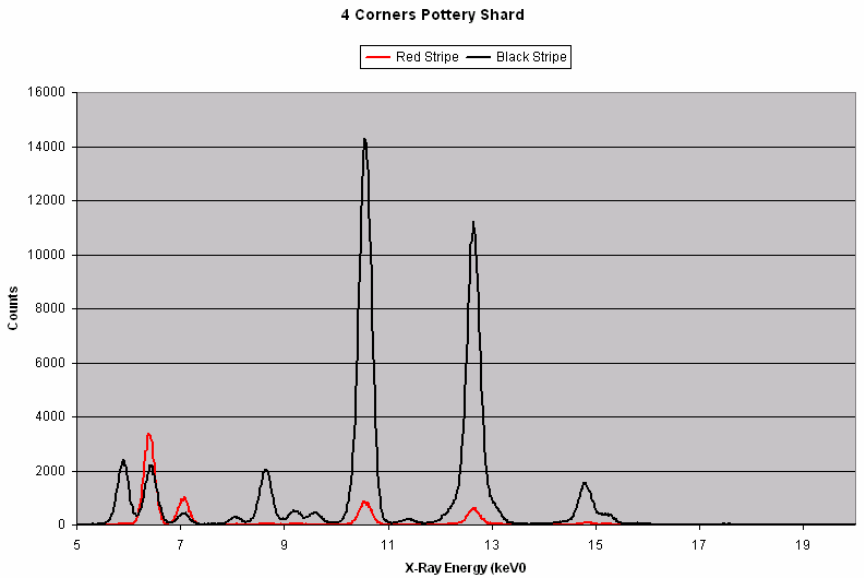
Artwork Analysis

PIXE is often used to examine artwork. Provenance can often be established by examining the pigments used in the paints. Forgeries can easily be distinguished by the modern components in the pigments.



Pigment Analysis

Pottery shard courtesy of Ms. Mary DeWitt



- Here are our results on a pottery shard from the 4 Corners region of the U.S. Note the clear differences between the black pigment and the red pigment.

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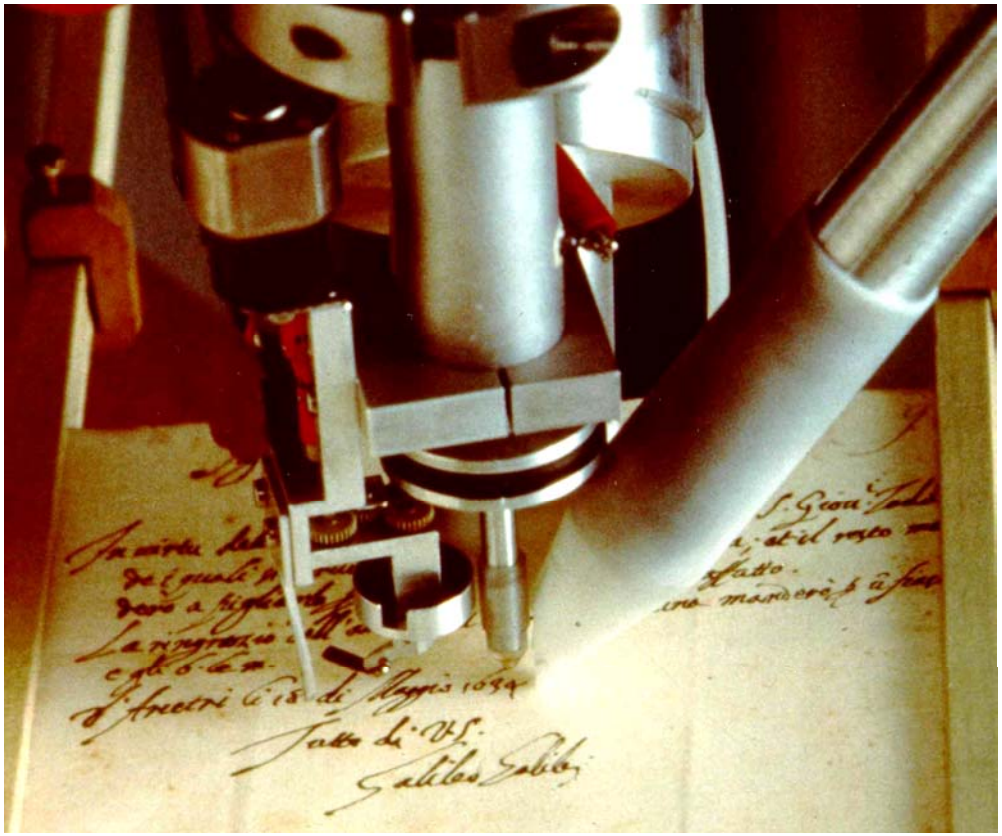
Historic Document Analysis

PIXE analysis of the inks used in Galileo's documents can be used to establish a chronology of historic events.



From Pier Andrea Mandò, Dipartimento di Fisica and Sezione INFN, Florence, Italy

Dürer Silver Pen PIXE Studies

Fig. 1.A. Dürer, *A young and an old woman of Bergen-op-Zoom,* Chantilly, inv. 891v°.

Fig. 2.A. Dürer, *Sitting bishop and portrait of a man with a fur cap*, Berlin, KdZ 34r°.

- Sketches attributed to Albrecht Dürer, made using the silver pen technique, were analyzed using PIXE to establish provenance.

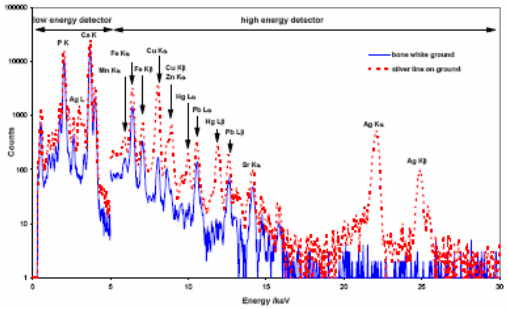


Fig. 4. 3 MeV PIXE spectra of a silver point stroke and of the preparation layer drawing on "*A young and an old woman of Bergen-op-Zoom*" (Chantilly, musée Condé, inv. 891r°).

More Applications?

Applications for PIXE as a tool to analyze materials are probably only limited by our imaginations.

We hope to develop PIXE here as a teaching tool, and perhaps, to provide some limited materials analysis services to outside entities.

But, we would also like to build interdisciplinary research efforts, with archaeology, anthropology, geo-sciences, etc...

Dinosaur Samples to study

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Anthropological Samples to Study