16th International Conference
on
Particle Induced X-ray Emission

Unravelling secrets from atoms to planets

PIXE2019 - Programme and Abstracts

24-29 March 2019 - Cultural and Congress Centre of Caldas da Rainha – Portugal

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16th International Conference on Particle Induced X-ray Emission
24 - 29 March 2019, Culture and Congress Centre, Caldas da Rainha, Portugal

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Welcome

Welcome to PIXE2019, the 16th International Conference on Particle Induced X-ray Emission.

Initiated on the 1970's decade, the PIXE conference presents itself as a conference series that lasted so far more than 40 years.

Originally focused on the techniques development as well as in its analytical applications, the conference, by the end of the century, started to face problems that resulted from the techniques wide spread applications. In the late 1990's, applications works started to be presented at fields conferences and the PIXE conference saw a decline.

In 2010, the conference was renovated, gained a new focus on developments, either on fundamentals, hardware, software or applications, and a lemma for each conference.

In PIXE2019 the lemma is "Unravelling secrets from atoms to planets", and as we will surely see along this week, PIXE is presently in fact doing that and aiming to further developments at both ends of size scales.

The old dream of Sir J. J. Thomson of using positive ions particles to dig the secrets of intermediate electron levels in atoms, is becoming a reality by the use of X-ray Microcalorimeters, while at the other end, deploying PIXE systems in Mars or using them to study old trade routes, allows to help to understand the history of the solar system, but also our own history as social and cultural human beings.

PIXE2019 may come to be the last of a conference series, or not. This will also be under discussion during this week, but whatever the result will be, one thing is certain, the PIXE technique is presently quite alive and growing in applications and in its contributions to the growth of human society and culture. And the conference either as an independent conference or as an important component of a major one, will surely prevail and provide the PIXE community a place to discuss their work at the high level that we have become used to.

Enjoy the conference.

Miguel A. Reis

Committees

International Advisory Committee

- M. A. Reis (Chair) - Portugal
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- A. Denker - Germany
- J. F. Dias - Brazil
- S. Fazinić - Croatia
- W. Kada - Japan
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- Luís C. Alves - IST - ULisboa
- Raúl Bernardino - ESTM - IPLeiria
- Alexandra Carvalho - IEQUALTECS
- M. Luísa Carvalho - FCT - UNL
- P. Cristina Chaves - IST - ULisboa
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Organizers, Exhibitors and Sponsors

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International Atomic Energy Agency
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U LISBOA
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DE LISBOA

Ad Fisicateca

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VACUUM & CRYOGENICS

40 ANOS
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FACULDADE DE
CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Torres Vedras
Câmara Municipal

IEQUALTECS

RAYSPEC
X - RAY SPECTROSCOPY

POLITÉCNICO DE LEIRIA
ESCOLA SUPERIOR
DE TURISMO E TECNOLOGIA DO MAR

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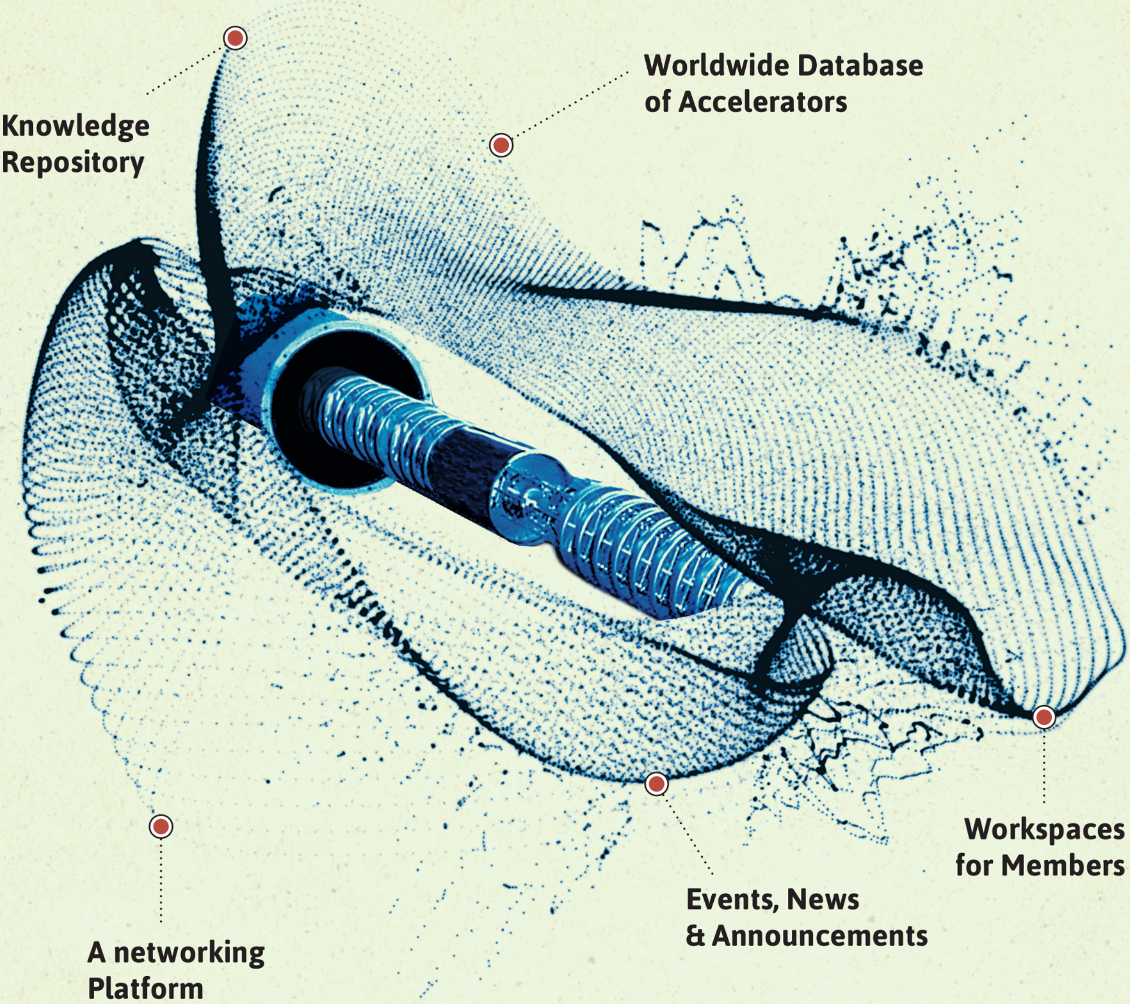

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A networking Platform

nucleus.iaea.org/sites/accelerators

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Improves collaboration opportunities
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Promotes knowledge transfer within the Accelerator Community

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

For further information on the Portal, facility updates
and enquiries please contact: **Accelerators.Contact-Point@iaea.org**

FAÇA UMA PAUSA À ROTINA E REGRESSE COMO NOVO

TAKE A BREAK TO THE ROUTINE AND COME BACK AS NEW

Num ambiente de conforto, qualidade e elegância, desfrute de uma magnífica refeição no restaurante Lisbonense, onde encontra uma carta variada de pratos de peixe, carne e marisco e uma criteriosa seleção de vinhos.

In an atmosphere of comfort, quality and elegance, enjoy a magnificent meal in Lisbonense restaurant, where you find a varied menu of fish, meat and seafood dishes and a careful wine selection.

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Complete x- and ɣ-ray spectrometers with unprecedented resolving power. Compact, cryogenic infrastructure with novel superconducting detector technologies, extremely high-resolution, single-photon detection with no dark counts, no-noise detectors.
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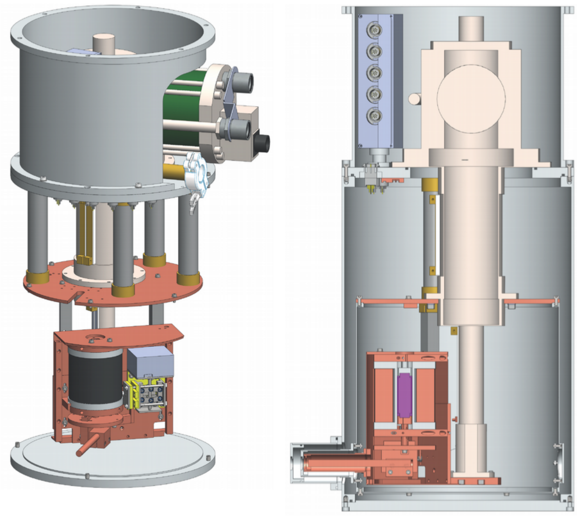

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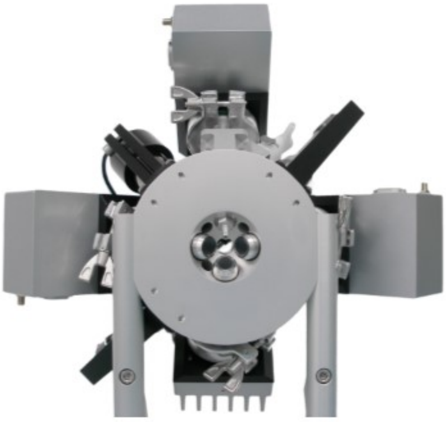

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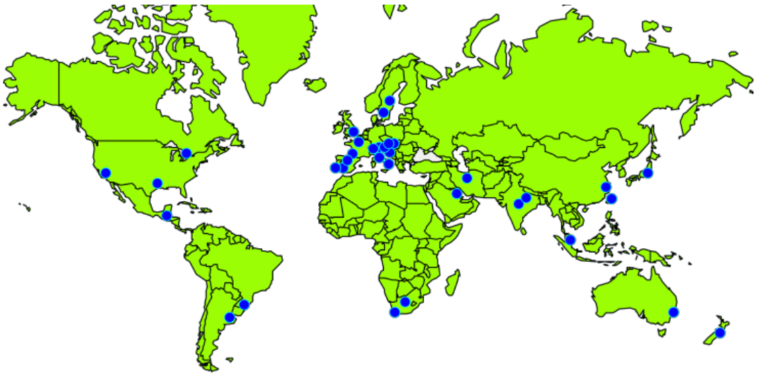
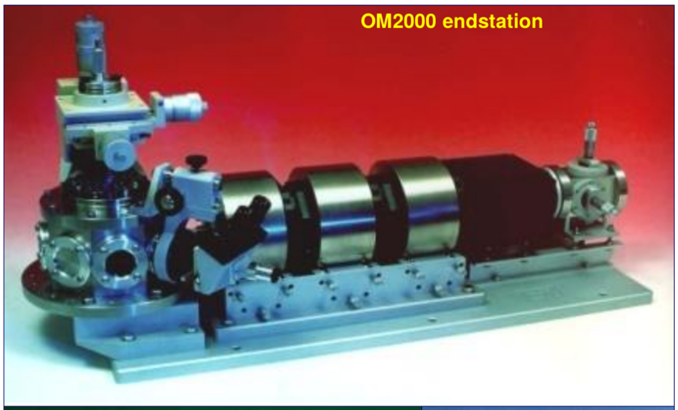
Precision • Experience • Expertise

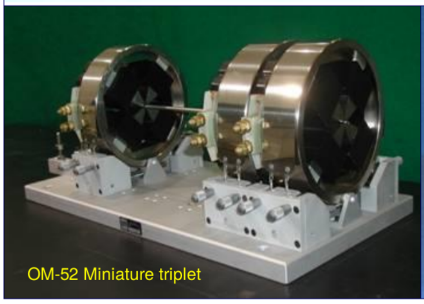
High precision magnetic quadrupole lenses • Precision slits • High stability power supplies Beam scanning systems • Target chambers • External beam systems • Data acquisition electronics • Proton beam writing systems • Cell irradiation systems • High rigidity focusing systems • Fully integrated data acquisition, processing and control software • Customised designs



Established in 1986, Oxford Microbeams Ltd is the world's leading supplier of high energy ion micro-beam equipment and software, with over 40 systems sold in 5 continents.

OM is an approved supplier for the International Atomic Energy Agency [IAEA].


OM2000 endstation


OM-52 Miniature triplet


Vertical lens assembly

Application areas:

- PIXE and PIXE mapping
- RBS and RBS mapping
- MeVSIMS mapping
- Targeted single ion irradiation
- Proton beam writing
- External beams for cultural heritage studies
- Scanning Transmission Ion Microscopy
- Heavy ion microbeams (to 150 Mev.amu/q^2)
- Ionoluminescence microscopy
- Elastic Recoil Detection Analysis
- Ion induced secondary electron imaging
- Direct-write Ion Beam implantation and patterning of materials
- Channeling Contrast microscopy
- Ion Beam Induced Charge microscopy

Performance of OM systems:

OM2000 Oxford triplet endstation:

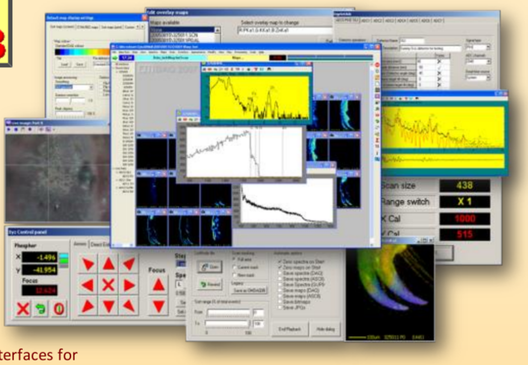
***300 x 450 nm* at 50pA** (2MeV protons).
***900 x 900 nm* at 1 nA** (2.5MeV protons)

Oxford triplet configuration of OM-52 lenses:

Spot sizes of ***20 x 25nm*** have been achieved for low current applications, and **20nm** high aspect ratio structures have been written using proton beam writing.

Data acquisition and control software

OM DAQ 3



Now with interfaces for

- High speed digital pulse processors
- High speed TDC for ToF MeVSIMS applications

Pelletron Accelerator Systems

NATIONAL ELECTROSTATICS CORP.

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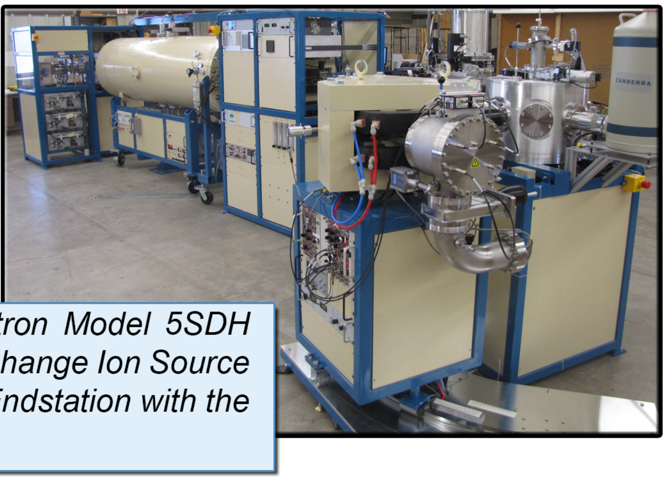
National Electrostatics Corp. offers complete IBA systems with all hardware and software for automation of **RBS, HR-RBS, channeling, PIXE, ERD and NRA and IBIL**. Analytical software is also included.

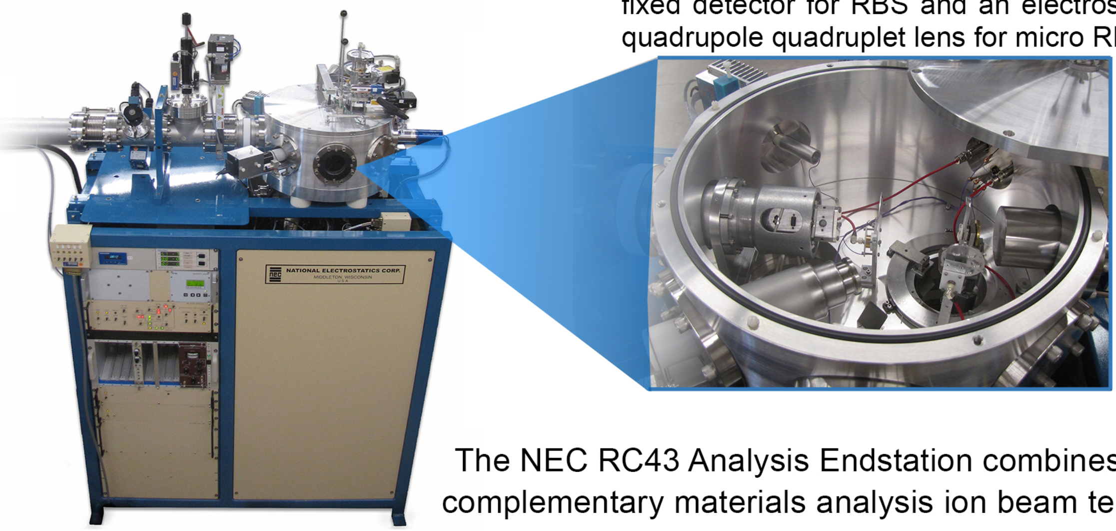


The system shown to the right is a Pelletron Model 5SDH (1.7MV) equipped with NEC RF Charge Exchange Ion Source (Alphatross) and the NEC RC43 Analysis Endstation with the High Resolution RBS detector.

Techniques available: RBS, Channeling, ERD, ToF ERD, PIXE, PIGE, NRA, IBIL

RC43 Analysis Endstation

The interior of the RC43 can be equipped with moveable detectors in addition to a fixed detector for RBS and an electrostatic quadrupole quadruplet lens for micro RBS.



The NEC RC43 Analysis Endstation combines several complementary materials analysis ion beam techniques with automation software to yield a fast, complete, materials analysis. The software allows several techniques to be simultaneously “live”. Also, the RC43 generates mappings of surface elemental concentrations and crystal structure as images yielding a true 3D analysis.

Representatives from NEC are available at PIXE 2019

For further information please contact NEC at nec@pelletron.com

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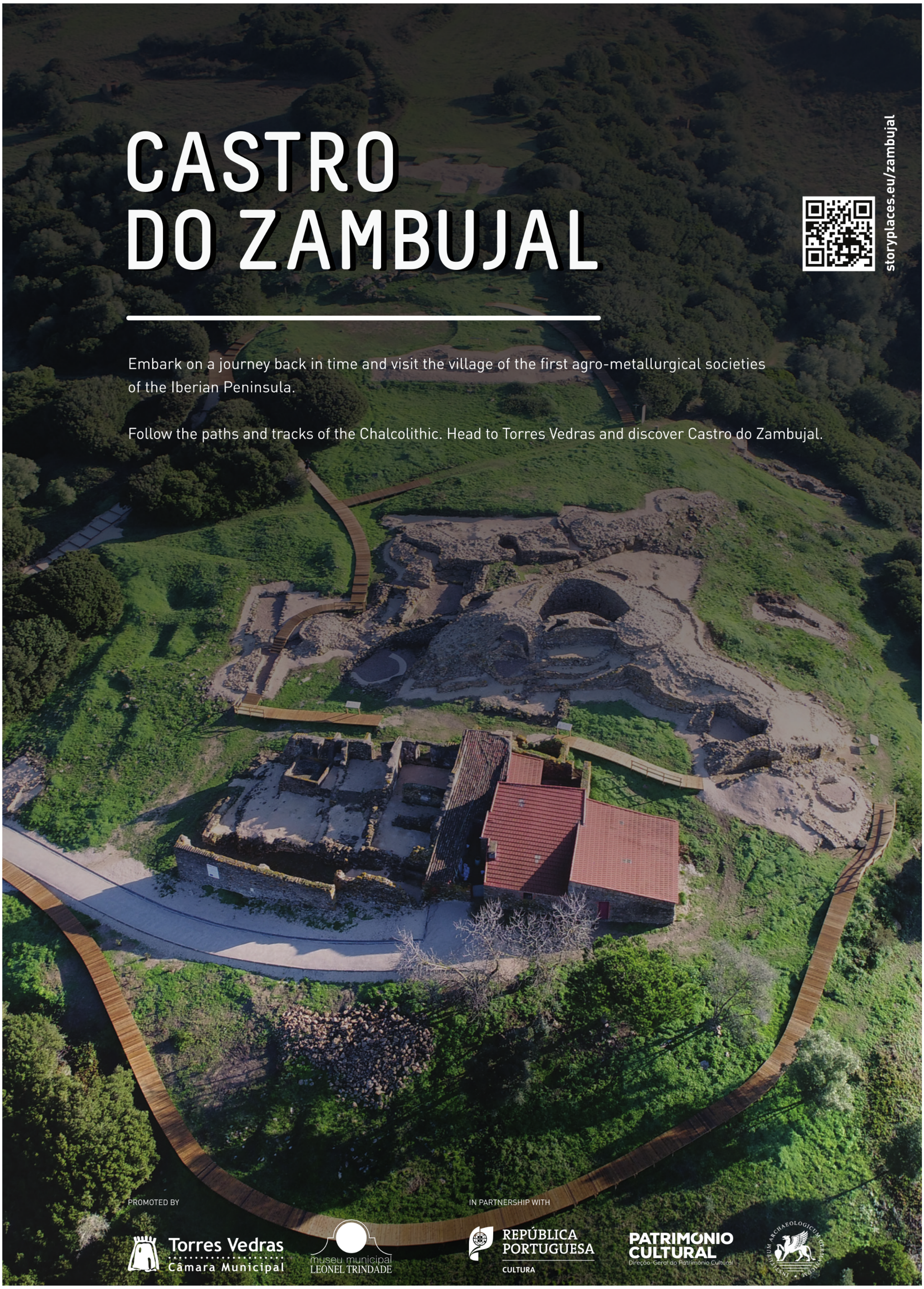

CASTRO DO ZAMBUJAL

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Embark on a journey back in time and visit the village of the first agro-metallurgical societies of the Iberian Peninsula.

Follow the paths and tracks of the Chalcolithic. Head to Torres Vedras and discover Castro do Zambujal.

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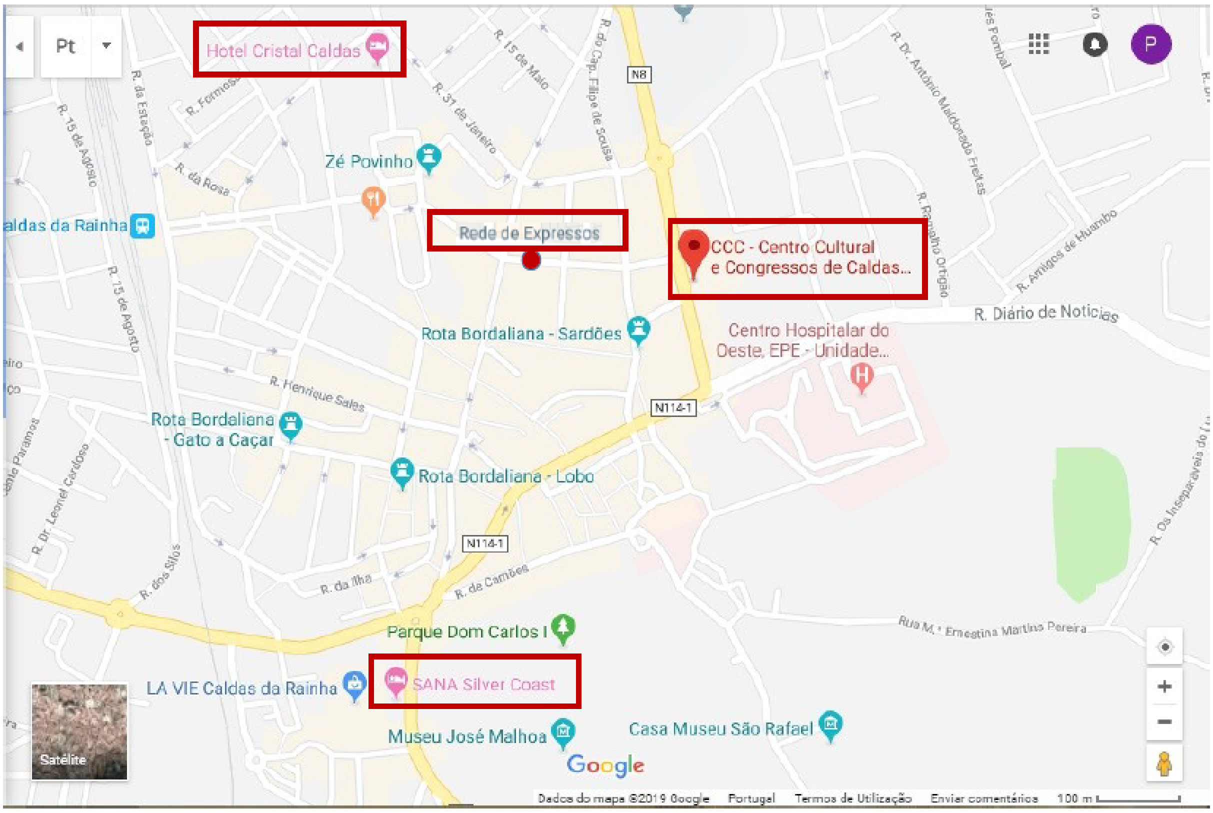
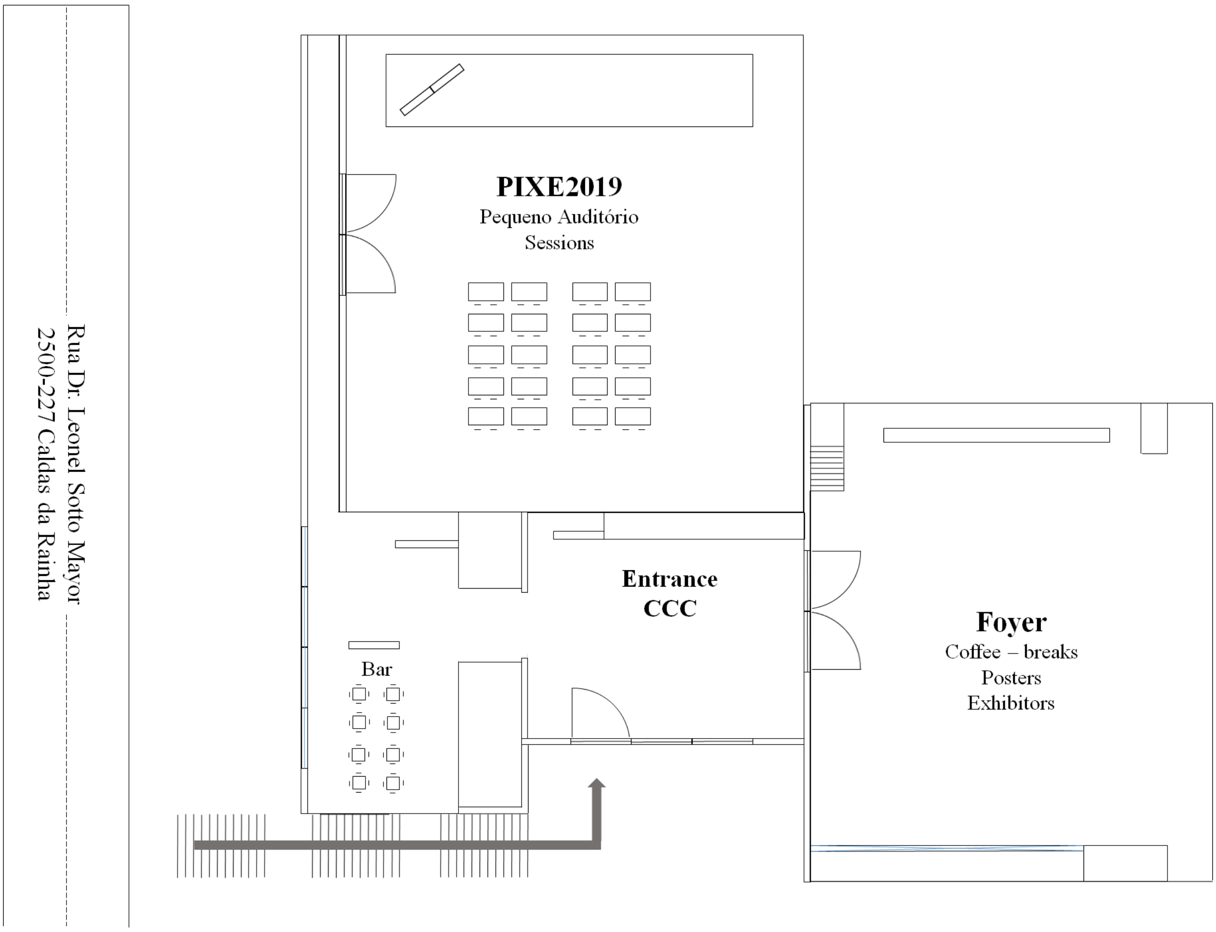
Location

The conference will be held at Cultural and Congress Centre (CCC) of Caldas da Rainha, in the centre of the city, and the conference dinner will be held at SANA Silver Coast Hotel.



CCC 2500-227 Caldas da Rainha Rua Dr. Leonel Sotto Mayor	**Welcome Drink by** Torres Vedras Câmara Municipal
SANA Silver Coast Hotel Av. Dr. Manuel Figueira Freire da Câmara 2500-184 Caldas da Rainha	**Gala Dinner**
Hotel Cristal Caldas R. António Sérgio 31 2500-130 Caldas da Rainha	**Lunch place**
Rede de Expressos	**Bus station**

CCC - Plant


Rua Dr. Leonel Sotto Mayor
2500-227 Caldas da Rainha
PIXE2019
Pequeno Auditório
Sessions
Entrance
CCC
Bar
Foyer
Coffee – breaks
Posters
Exhibitors

General Information

Oral Presentations

Invited talks are 40 minutes long (35 minutes presentation and 5 minutes discussion). Contributed talks are 20 minutes long (15 minutes presentation and 5 minutes discussion). All the talks should be accompanied by PowerPoint or PDF slides. Lecture Hall will be equipped with a PC and LCD projection system. The PC will accept USB drives and will have Microsoft Windows 10, Microsoft PowerPoint 2016 and Adobe Reader. Speakers are kindly requested to check the time alloted for their talk in the Conference Programme. Speakers are asked to load their presentations before the start of their sessions.

Poster Displays

All posters will be in display from Monday to Friday, in the coffee break launch, sharing space with the sponsors stands. Posters will be mounted on cork displays having 95cm in width and 117cm in height. ISO A0 posters in Portrait format (84cm width and 119cm height) will fit although the top and bottom regions of the poster may slightly overlay the cork metallic support. Notice that posters will stand side by side, therefore the maximum width of 95cm is strict and cannot be overcome.

There will be three poster session, that will be held on Monday, Tuesday and Thursday. Poster presenters should be available at their display during this time. All posters should be set up on Monday 25 March during the lunch. The posters will be on display until Friday 29 March 12:40. Please display your poster in the slot assigned with your number.

Conference Proceedings

The PIXE2019 conference proceedings will be published as a special volume of the journal ŞNuclear Instruments and Methods B: Beam Interactions with Materials and AtomsŤ. All submitted papers must be clearly written in excellent English and contain only original work, which has not been published by or is currently under review for any other journal or conference. All manuscripts and any supplementary material should be submitted through the Elsevier Editorial System (EES). Papers will be reviewed to the same standards as for the regular NIMB papers. Please contact the organization (info@pixe2019.com) for other publication related questions.

Internet Access

Free internet access is available in congress center.

Registration and Welcome Reception

Conference delegates and accompanying persons are invited to attend a Welcome reception at the **Centro Cultural e de Congressos das Caldas da Rainha** on Sunday, 24th March, where a welcome drink will be offered from 18:00 to 20:00 by the **Câmara Municipal de Torres Vedras**. Registration will be open on Monday from 9:00.

Lunches

Lunches will be provided on Monday, Tuesday and Thursday at the **Hotel Cristal**. On Wednesday, lunch will be provided during the conference outing. Lunches are included in the conference fee.

Conference Outing

The Conference outing will be held on Wednesday, 27th March. We will meet at the CCC at 9h00.

Conference Banquet

The conference banquet will be held in the **SANA Silver Coast Hotel**, 28^{th} March with the start at 19:30. The restaurant hotel is located at the walking distance from the **Centro Cultural e de Congressos das Caldas da Rainha**. Banquet is included in the conference fee.

Meeting Questions

If you have any questions, please contact P. Cristina Chaves or anyone from the local organizing committee.

Conference Outing

The conference outing will be held in Wednesday, 27^{th} March. In this day we will have a special day, where we will join lectures, outreach, and become acquainted with a little bit of the Portugal West region landscape, history and recent development. We will departure from CCC at 9h00.

Prof. John L. Campbell lecture

Well before 10h00 we will arrive at Escola Superior de Turismo and Tecnologias do Mar (ESTM, the Leiria Polytechnic Institute School for Tourism and Sea Technologies), located just by the see, in Peniche where we will see the Berlengas archipelago in the horizon. A special room having a window to these Portuguese Sea, to enjoy Prof. John L. Campbell's talk on "α-particles PIXE".

We will leave ESTM before 11h30 and will follow coastal roads to São Martinho do Porto, where we will arrive by 12h30 for lunch.

São Martinho do Porto

São Martinho do Porto is a very beautiful natural bay, with a long sand margin, and where we hope to be able to enjoy a nice Spring weather and a Portuguese sea food lunch. We will leave to Alcobaça, after lunch.

The Alcobaça Monastery

Having a church built between 1178 and 1233-52, in three phases, the Alcobaça Monastery, presents a facade reflecting a baroque restoration completed in 1725.

House to the Order of Cistercians, since 1223, its location was well tune with the Cistercian policy of agricultural development. The entire surrounding region being rich in farms, vineyards, orchards and swamps that would be transformed into arable lands through trenching.

In the Monastery, were we will have guided tours, one can see the tombs of King Pedro I, who died in 1367, and of his passion, Inês de Castro executed in 1355 by order of King Afonso IV, the father of King Pedro I.

Nazaré, fishing, surfing and a geological peculiarity

Before 16h00 we will leave to Nazaré, a fishers village just half an hour away from Alcobaça.

Buses will stop at the Sítio da Nazaré, where the legend states that D. Fuas Roupinho was saved by Our Lady of Nazaré from falling into the cliffs while hunting a deer. At Nazaré we will have between one and a half to two hours to go around. Sunset will be at 18h30 and we should be leaving before, or just after depending on the weather. You may go shopping for souvenirs, but you should notice that there is a lot to see in Nazaré, beyond the square where we will leave the buses.

Nazaré, besides being a fishers village, is also a peculiar place in Earth where giant waves form. You should go down to Praia do Norte, where these waves end. Take care and comfortable or even winter clothes, as it may be quite cooler than you might expect for a Spring evening in Portugal, and the wind will enhance the cooling significantly.

In the end of the walk, you will find the lighthouse, and a small surf Museum, worth having a look by 1 Euro. Do NOT walk around the lighthouse walls, cliffs are not stable and are dangerous, therefore walking around it, on the see side is forbidden.

Nevertheless, the see is amazing, and the details why waves form so big, are well described in the small museum. Nazaré holds the record of the highest wave ever surfed. Nearly 30 metres high. Once there, you will feel the reason why this is possible.

Then, return safe up to the square where the buses will be waiting for us to take us back to Caldas da Rainha, before or after sunset if the weather allows.

We will arrive in Caldas da Rainha around 19h00!

Programme

PIXE2019 - Oral Presentations

	Sunday, March 24, 2019	
18:00-20:00	PIXE2019 Welcome Reception and registration	
	Monday, March 25, 2019	
9:00-9:20	Registration	
9:20-9:40	Opening	
Session - Fundamentals 1 Chair: J. Miranda		
9:40-10:20	Ž. Šmit Physics beyond PIXE	**I.1**
10:20-10:40	S. Fazinić Multiple ionization X-ray satellites of Ti and its binary oxides in alpha particle PIXE compounds induced by MeV protons and comparison with Kβ lines	**O.01**
10:40-11:00	J. F. Dias Total X-ray production cross sections induced by heavy ion bombardment	**O.02**
	Coffee/Tea break	
11:20-11:40	M. Kavčič Multiple ionization X-ray satellites of Ti and its binary oxides in alpha particle PIXE	**O.03**
11:40-12:00	M. Msimanga Multiple ionisation and X-ray fluorescence yield modification in $_{23}$V and $_{50}$Sn atoms due to 0.2-1.0 MeV/u C^{q+} and Cl^{q+} projectile ions	**O.04**
12:00-12:20	F. S. Olise Calculation of proton-induced L-shell ionisation and x-ray production cross sections for some trans-uranium targets	**O.05**
12:20-14:00	**Lunch & Poster mounting**	
Session - Detectors, Software and Experimental Systems 1 Chair: S. Fazinić		
14:00-14:40	A. Fleischmann Magnetic micro-calorimeters for hi-res x-ray and gamma ray spectroscopy	**I.2**
14:40-15:00	J. M. Fernández-Varea Contribution of Rayleigh- and Compton-scattered photons to the full-energy peak efficiency	**O.06**
15:00-15:20	M. Nogami Feasibility study of TlBr semiconductor detectors for PIXE applications	**O.07**
	Coffee/Tea break	
15:40-16:00	K. Ishii Application of a medical PET cyclotron to PIXE analysis	**O.08**
16:00-16:20	I. Vickridge PIXE combined with Kossel diffraction for the analysis of thin film multilayers	**O.09**
16:20-16:40	J. Restrepo Analytical formalism for the determination of hydrogen in biological and organic samples by PIXE	**O.10**
16:40-18:00	**Poster Session 1**	
18:00-19:00	Questions & Answers for Gupix users J. L. Campbell	

	Tuesday, March 26, 2019	
Session - Detectors, Software and Experimental Systems 2 Chair: M. Kavčič		
9:20-10:00	A. Mantero PIXE Simulation in Geant4, an Update	**I.3**
10:00-10:20	V. Bilyk PIXE depth profiling of components in heavy-ion irradiated Zr alloys	**O.11**
10:20-10:40	E. Obiajunwa Ion beam analysis facility at the centre for energy research & development at Ile-Ife Nigeria and its application in research	**O.12**
10:40-11:00	K. Phelan CryoGenX - A High-resolution Spectrometer for Advanced Nuclide Analysis	**O.13**
	Coffee/Tea break	
Session - Simulation and Techniques Combination 1 Chair: T. Calligaro		
11:20-11:40	M. Bailey Ion Beam Analysis for the 2020's : An Integration of Elemental Mapping and Omics	**O.14**
11:40-12:00	D. Strivay Analysis of archeological artefacts from Ostia and Arena Roman sites by PIXE-PIGE and Proton Activation Analysis	**O.15**
12:00-12:20	V. Corregidor PIXE and RBS on CIGS solar cells to study the elemental distribution	**O.16**
12:20-14:00	**Lunch**	
Session - Simulation and Techniques Combination 2 Chair: J. F. Dias		
14:00-14:40	C. Ryan PIXE and synchrotron XRF imaging: Comparisons using the Maia detector array	**I.2**
14:40-15:00	J. Cruz μ-PIXE/μ-EBS and SEM analysis of surface spots in gold coins/discs from the Portuguese Mint House	**O.17**
15:00-15:20	Z. Kertész What killed the apothecarius of Vác in 1763? Micro-PIXE study of mummified bones	**O.18**
	Coffee/Tea break	
Session - Cultural Heritage & Geological Applications 1 Chair: Ž. Šmit		
15:40-16:00	Z. Szőkefalvi-Nagy Ancient glass analysis by milli-PIXE and PGAA - the case of late Roman and Byzantine glasses	**O.19**
16:00-16:20	F. Munnick Characterization of Goethe's prisms by external ion beam	**O.20**
16:20-16:40	H. Hofsäss PIXE analysis of antique pottery from the Mediterranean sea area	**O.21**
16:40-17:40	Round Table on Detectors & Software C. Jeynes	
17:40-19:00	**Poster Session 2**	
19:00-20:00	IAC - IHC Meeting	
	Wednesday, March 27, 2019	
9:00-10:00	Buses to ESTM	
Open Session Chair: M. A. Reis		
10:00-11:00	J. L. Campbell Alpha particle PIXE on Earth and Mars	**I.5**
11:00-19:00	Conference outing	

	Thursday, March 28, 2019	
Session - Cultural Heritage & Geological Applications 2 Chair: Z. Szőkefalvi-Nagy		
9:00-9:40	P. Mandò MACHINA: Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis	**I.6**
9:40-10:00	T. Calligaro The origin of garnets set on Dark Ages jewelry: twenty years of PIXE on cultural heritage	**O.22**
10:00-10:20	M. A. Reis Speciation of Cu pigments by Energy Dispersive High Resolution PIXE	**O.23**
10:20-10:40	M. I. Dias Chronological assessment of della Robbia sculptures by using PIXE and Luminescence techniques	**O.24**
	Coffee/Tea break	
Session - Biological and Environmental Applications 1 Chair: W. Kada		
11:00-11:20	E. Fournière MicroPIXE analysis of removal of aqueous U(VI) by S. intermedia and P. stratiotes in the presence of Th(IV)	**O.25**
11:20-11:40	C. dos Santos Study of silver nanoparticles uptake and internalization by crop plants	**O.26**
12:00-13:00	IAC Meeting	
12:40-14:20	**Lunch**	
Session - Biological and Environmental Applications 2 Chair: C. Ryan		
14:20-15:00	P. Barberet Using μ-PIXE for biological applications at the single cell level	**I.7**
15:00-15:20	G. Grime New insights in metalloprotein biochemistry revealed using microPIXE analysis	**O.28**
15:20-15:40	K. J. Cloete Physico-elemental analysis of organically produced roasted coffee beans from Ethiopia, Colombia, Honduras, and Mexico	**O.29**
15:40-16:00	R. Virk Tracing biodistribution of essential and toxic elements through PIXE spectroscopy	**O.30**
	Coffee/Tea break	
Session - Aerosol and Toxicological Applications 1 Chair: D. Cohen		
16:20-16:40	F. Lucarelli Analysis of particulate atmospheric matter samples collected with high time resolution: some examples of recent applications	**O.31**
16:40-17:00	K. Sera Long-term Variations of Toxic-Element concentrations over eight years by Means of Quantitative Analyses of Beard Samples Collected Every Day	**O.32**
17:00-17:20	H. Sa'adeh Current Status of Aerosol Analysis at the PIXE-RBS Beamline in the University of Jordan Van de Graaff Accelerator (JUVAC)	**O.33**
17:20-18:40	**Poster Session 3**	
19:30	**Conference Dinner**	

	Friday, March 29, 2019	
Session - Aerosol and Toxicological Applications 2 Chair: F. Lucarelli		
9:00-9h:00	D. Cohen Ion Beam Techniques for Source Fingerprinting Fine Particle Air Pollution in Asian Megacities	**I.8**
9:40-10:00	Z. Kertész Elemental composition and sources of PM2.5 pollution in 16 European cities in 2014-15	**O.34**
10:00-10:20	A. Terakawa Concentrations of alkali and alkaline-earth elements in tea leaves and their elution into green tea	**O.35**
10:20-10:40	W. Kada Time resolved elemental composition characterization of air-borne particulate matters by in-air micro-PIXE analysis	**O.36**
	Coffee/Tea break	
Session - Forensic Chair: L. Carvalho		
11:00-11:40	A. Simon Ion Beam Techniques for Source Fingerprinting Fine Particle Air Pollution in Asian Megacities	**I.9**
11:40-12:00	J. F. Dias Signature of the Himalayan salt	**O.37**
12:00-12:20	R. Debastiani Elemental Extraction Profile of Ground Coffee	**O.38**
12:20-12:40	**Closing**	

12:40-14:00	**Poster Removal**	

PIXE2019 - Posters List

16:40-18:00 Monday, March 25, 2019 Poster Session 1	
A. D. Aladese Calculated Proton-Induced L-shell Ionisation and X-ray Production Cross Sections for Tc, Pm, Os, Po, At, Rn, Ra and Ac	**PS1.01**
M. C. Masekane Measurement of $^{12}C^{q+}$ and $^{35}Cl^{q+}$ ion induced X-ray production cross sections in V, Zr and Sn metal oxide targets at 0.1-1.0 MeV/u ion velocities.	**PS1.02**
J. Miranda Total L x-ray production cross sections of Sr, Y, Zr, Nb, and Mo induced by impact of 1.3 MeV to 1.8 MeV protons	**PS1.03**
J. J. Hussain The Measurement of Cross Section of Characteristics X-ray from K, L and M Shell of Thick Targets Si, Ti, Fe, Ni, Cu, Ag, Ta and Au using Ion Beam Techniques	**PS1.04**
S. Fazinić W and Tl M-shell X-ray emission cross sections induced by carbon ions between 2.6 MeV and 5 MeV	**PS1.05**
H. Hofsäss Evaluation of the radiation hazard for ion-beam analysis with MeV external proton beams	**PS1.06**
L. D. Yu Measurement of x-ray production cross sections for Fe K-line, Nb, Ru and Ce L-line, and Ta M-line induced by 1-MeV C-ion beam	**PS1.07**
F. Munnik Characterization of the X-ray optics of a full-field PIXE-camera	**PS1.08**
J. M. Fernández-Varea Intrinsic efficiency of semiconductor spectrometers for divergent photon beams	**PS1.09**
L. D. Yu Development of a tapered glass capillary microbeam system and preliminary application in PIXE-mapping of local plant leaves	**PS1.10**
J. J. Hussain The Study of Intrinsic point defect using Ion beam induced luminescence using Proton and Helium ion the energy range 0.7 MeV to 2.0 MeV	**PS1.11**
F. Lucarelli Silicon Drift Detector response function for PIXE spectra fitting in the high energy X-ray region	**PS1.12**
Y. Arai Microscopic analyses on Zr adsorbed IDA chelating resin by PIXE and EXAFS	**PS1.13**
S. Watanabe Structural characterization of Eu-HONTA complexes by IBIL and EXAFS analyses	**PS1.14**
V. Levenets External PIXE measurements of concentrations U in materials nuclear fuel cycle	**PS1.15**
W. Kada Utilization of micro-PIXE and micro-IBIL analysis for the evaluation of SiAlON scintillators	**PS1.16**

Tuesday, March 26, 2019

16:40-18:00 **Poster Session 2**

L. D. Yu PIXE dating of Thai ancient burnt clay ages	**PS2.01**
M. L. Carvalho Still lifes in earth materials: technical and ideological evolution from Baltazar Gomes Figueira to Josefa d'Óbidos	**PS2.02**
M. Bandiera Roman opaque red glass, considerations and improvements on the application of PIXE analyses on archaeological glass	**PS2.03**
Ž. Šmit Analysis of Celtic small silver coins from Slovenia by PIXE and PGAA	**PS2.04**
V. Bilyk Characterization of pottery fragments of Scythian period by PIXE method	**PS2.05**
S. Fernandes Ion beam analysis of historic tesserae glass using combined RBS-PIGE-PIXE and μ-PIXE methods	**PS2.06**
D. Ceccato Scientific investigations on byzantine pottery from Castrul 22, Romania	**PS2.07**
J. Cruz μ-XRF and μ-PIXE/μ-EBS analysis of XV-XVI Portuguese copper coins	**PS2.08**
P. A. Mandò Upgraded external-beam "Total IBA" set-up for in cultural heritage applications at LABEC	**PS2.10**
N. Hagura Trace elements analysis of natural mineral pigments for Japanese paintings	**PS2.11**
V. Foteinou The new PIXE setup of RUBION	**PS2.12**

Thursday, March 28, 2019

16:40-18:00 **Poster Session 3**

L. T. Ogundele PIXE characterisation of some natural and industrial spices for nutritional assessment study	**PS3.01**
V. Corregidor Heavy elements in chestnuts detected by PIXE	**PS3.02**
J.-O. Lill Information depths of analytical methods assessing whitefish otolith chemistry	**PS3.04**
P. C. Chaves Energy Dispersive High Resolution PIXE and Unilateral-RMN study of *Vinho verde* grapes	**PS3.05**
S. Fernandes Elemental analysis of roots and leaves from O. glaberrima at vegetative stage of growth using combined RBS-PIGE-PIXE methods	**PS3.06**
M. R. Caloni Elemental characterization and iron uptake evaluation of zebrafish larvae exposed to iron oxide nanoparticles	**PS3.07**
E. G. Hatam PIXE analysis of atmospheric aerosol in Arak city and identification of polluting sources	**PS3.09**
E. Papp Investigation of aerosol pollution on trams in Debrecen (Hungary)	**PS3.10**
J. F. Dias Elemental Concentration of Whole Milk Cream	**PS3.11**
F. Lucarelli PIXE analysis of aerosol crustal elements collected on Whatman paper filters	**PS3.12**
C. E. I. dos Santos *Ilex paraguariensis* geochemical marker's determination by PIXE	**PS3.13**
Z. Kertész Characterization of urban aerosol pollution under a smog episode in Debrecen by size distribution, PIXE and radiocarbon analysis	**PS3.14**

Abstracts

Invited Talks and Round Table

Physics beyond PIXE

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I.1

Abstract

PIXE was introduced as a semi-quantitative method as the induced X-ray yields depended on so many hard-to control parameters. Today's knowledge of physical principles overcame this difficulty. Modeling of thick targets requires databases of X-ray production cross sections, projectile stopping powers, and X-ray attenuation coefficients. The collected experimental cross sections are now generalized to reference cross sections and the procedure is based on reliable theoretical cross sections. Although the working horse is still provided by the ECPSSR theory and its later developments, one has to reconsider the possibilities of the semi-classical approaches for the adiabatic collisions and coupled-channel models. Furthermore, development is expected in using more complex multi-electron wave functions. As the calculations can only be performed on large tables of numerical values, construction of simple semi-empirical fits seems perspective for practical work. Due to absorption of X-rays in the target, thick targets yields depend on the surface target geometry, with smooth plane target being an idealistic approximation. Even a small misalignment from the selected geometry may change the escape length noticeably, while the surface roughness changes the whole distribution of escape lengths; a generalized consequence is that roughness increases the mean escape length. PIXE is not depth sensitive, though variation of the ionization cross sections with projectile energy results in the main X-ray production from the very surface. Limited depth-dependent information can be obtained from the differential measurements. PIXE is even stronger in combination with other methods. In combination with PIGE it provides complete analysis of glass; in combination with RBS elemental profiling and information about light elements becomes available; and with high resolution detectors, chemical speciation is possible. Most facilities also allow mapping measurements, using vacuum or in-air mode.

Magnetic micro-calorimeters for hi-res x-ray and gamma ray spectroscopy

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I.2

Abstract

Metallic magnetic calorimeters (MMC) are calorimetric particle detectors, typically operated at temperatures below 50mK, that make use of a paramagnetic temperature sensor to transform the temperature rise upon the absorption of a particle in the detector into a magnetic flux change in a SQUID. During the last years a growing number of groups started to develop MMC for a wide variety of applications, ranging from alpha-, beta- and gamma-spectrometry over kilo-pixels molecule cameras to arrays of high resolution x-ray detectors. For soft x-rays an energy resolution of 1.6 eV (FWHM) has been demonstrated. We give an introduction to the physics of MMCs and summarize the presently used readout schemes for single channel read-out and multiplexing. We discuss design considerations, the micro-fabrication of MMCs and the performance of micro-fabricated devices in the fields of atomic and particle physics as well as applications like PIXE.

PIXE Simulation in Geant4, an Update

A. Mantero[a,b*]
a. Shward srl
b. Geant4 Collaboration

I.3

Abstract

Geant4 is a software toolkit for Monte-Carlo simulations for tracking particle interactions in matter, developed to be applied to LHC experiments. The toolkit is characterized by a high modularity and flexibility levels, enabling the user to define geometries and physics processes combinations to meet his needs. Geant4 has extended and been applied well outside the high-energy physics environment: from space to health (two of the widest application areas) and biology. Atomic Deexcitation simulation (radiative and non-radiative) has been present since more than 15 years in Geant4. During the years it has been continuously developed, with the extension from photoelectric effect to continuous process, radioactive decay and numerous atomic cross sections models for PIXE simulation. Regarding PIXE, there are actually a wide number of available models among which the user can choose the shells in which a vacancy appears upon interaction with protons or ions. The user can also choose the data used to simulate the deexcitation chain, according to his/her preferences. A brief overview of the Geant4 Simulation Toolkit capabilities and characteristics will be presented as well a description of the Atomic Deexcitation package, with emphasis on recent and future developments on PIXE and their applications for the PIXE community.

PIXE and synchrotron XRF imaging: Comparisons using the Maia detector array

C. Ryan[a]*, J. Laird[b], A. van der Ent[c], S. Hu[a], R. Kirkham[a], P. Siddons[d], D. Paterson[e], M. de Jonge[e], D. Howard[e], A. Pagès[a], L. Fisher[a], M. Pearce[a], S. Barnes[a], A. Kuczewski[d], G. Moorhead[a], D. Parry[a], R. Szymanski[b]

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d. Brookhaven National Laboratory, e. Australian Synchrotron

I.4

Abstract

Both PIXE, using MeV energy ions, and synchrotron XRF, using many keV X-rays, provide deeply penetrating beams with low scattering rates that maintain spatial resolution with depth. Both excite characteristic element X-rays that can be used for imaging when the detection of the X-rays is correlated with spatial position in a scan of a sample. And both offer varying detection sensitivities often down to ppm trace levels and below. However, differences between the two probes in terms of atomic shells excited, background spectrum effects and contrasts in cross-sections, offer aspects of complementarity, with one or the other excelling in certain applications. In this paper, we compare applications involving complex natural materials imaged using PIXE and/or SXRF on ion-beam and X-ray microprobe beamlines incorporating an equivalent Maia detector array. In both cases, Maia provides an efficient platform for imaging with a large solid-angle and high count-rate capacity shared amongst 384 detectors [1,2], which is optimized for event-mode data collection [3]. Using both 3 MeV protons and 17-19 keV X-ray microbeams, count-rates are typically 1-4 M/s with peak rates exceeding 10 M/s while maintaining low dead-time and pileup loss rates. This enables imaging using a fly-scan approach, with pixel transit times from milliseconds down to 50 μs and the acquisition of images of $\sim$100 M pixels (largest 1 G pixels) that capture fine details as well as many orders of magnitude of hierarchical spatial context. Applications in the geological [4] and biological [5,6] research spheres illustrate Maia capabilities, provide contrasts between PIXE and SXRF involving both high and low density and mean atomic number samples, illustrate aspects of complementarity and point to different issues in sample preparation and presentation.

References

[1] D. P. Siddons et al., Journal of Physics: Conference Series 499 (2014) 012001.

[2] R. Kirkham et al., AIP Conference series 1234 (2010) 240.

[3] C. G. Ryan et al., Synchrotron Radiation News 31 (2018) 21-27.

[4] J. S. Laird el al., "High throughput Large Area Mapping of Geological Samples Using a Maia Detector Array on the Nuclear Microprobe", NIMB, accepted.

[5] J. S. Laird el al., "PIXE Imaging of Hyperaccumulator Plants Using the Maia Detector Array", NIMB, accepted.

[6] A. van der Ent et al., New Phytologist 218 (2018) 432-452.

Alpha particle PIXE on Earth and Mars

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I.5

Abstract

In 2002 Johansson [1] demonstrated a factor 3-4 improvement in detection limits for 5 MeV alpha particles relative to 3 MeV protons. He surely would not have anticipated that within two decades, 5 MeV alphas would have partnered with XRF in $\sim$1500 analyses of rock, soil and dust on Mars [2]. In 2005 Beck [3] compared 1-2 MeV H and He beams in various applications; for example she observed a factor 2 improvement in DLs for Mg in calcite, due in large part to the reduced threshold of electron bremsstrahlung background in alpha-PIXE. Subsequently to these works, alpha beams have not been used for PIXE on Earth nearly as widely as protons. A number of these alpha works will be mentioned. Of special interest is the second generation of the Catania group's portable alpha-PIXE spectrometer. This is being applied in archaeological projects involving ancient pottery, obsidian artefacts and coins. There are, however, issues within alpha-PIXE that are not fully resolved. One is the KLn (n=1,2,3) satellites, which are shifted by tens of eV and whose summed intensity can exceed that of the Kα diagram line. They shift the Kα peak observed in an SDD detector, broaden it and render it asymmetric. They are now under study by a Ljubljana-Zagreb-Guelph collaboration. Until this issue is resolved within spectrum-fitting codes alpha-PIXE will not reach its optimal accuracy. The talk will also touch on our current work at Guelph using 2.5 MeV proton PIXE to emulate Martian alpha-PIXE [4].

References

[1] S. A. E. Johansson. Int. J. PIXE 2: 33, 1998.

[2] R. Gellert, B. C. Clark. In situ compositional measurements of rocks and soils with the alpha particle X-ray spectrometer on NASA's Mars rovers. Elements 11: 39-44, 2015.

[3] L. Beck. Improvement in detection limits by using helium ions for particle-induced x-ray emission. X-Ray Spectrom. 34: 393-399, 2005.

[4] J. A. Berger, M.E. Schmidt, R. Gellert, J. L. Campbell, E. L. Flannigan, D. W. Ming, R. V. Morris. PIXE analysis of Hawaiian volcanics: an analogue for APXS in Gale Crater. 49th Lunar and Planetary Science Conference, Abstract # 2613, 2018.

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Unravelling secrets from atoms to planets

MACHINA: Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

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I.6

Abstract

The increasing demand for *in-situ* nondestructive compositional analyses in the field of Cultural Heritage (CH) has led to more and more studies being performed with mobile XRF systems, often adequate to provide the required information. However, some significant problems of XRF versus PIXE in the analysis of CH cannot be overcome, being intrinsic in the physics of the processes at the basis of the two techniques. For instance, the lower sensitivity to low−Z elements, as well as the “confusing” information from the preparation layer in a painting: differential PIXE has no effective counterpart in XRF. Finally, using a particle beam is a “multi-messenger” approach, which simultaneously exploits different interaction products (PIGE, BS) complementing the information supplied by X rays only. Triggered by this idea, INFN and CERN started a challenging project: developing a transportable system for *in-situ* Ion Beam Analysis of materials, based on a very compact RFQ accelerator for 2 MeV proton beams. We rely on the long-lasting expertise developed at CERN on RFQ’s and that of INFN-Labec on IBA applied to CH. We are aware of the problems, but confident to solve them, in particular exploiting the capability of last generation X ray SDD’s to cope with the instantaneous large count-rate during the beam pulses from the RFQ. The project MACHINA, started in 2018, is scheduled to last two years. After the design and functional test of the separate parts to be assembled in MACHINA, an operational prototype is now being developed, including the high energy beamline and the detection set-up. MACHINA will be then tested at INFN-Labec for tuning and characterization, before being moved to the Opificio delle Pietre Dure (OPD) for real artwork studies. The OPD, where so many art treasures are continuously taken for restoration, will be its standard seat. It can be envisaged that MACHINA might be moved and installed for certain periods also in different sites (e.g. Museums).

Using μ-PIXE for biological applications at the single cell level

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I.7

Abstract

Chemical element imaging and quantification at the micrometer scale are often required to study the impact of exogenous compounds in living cells. This can be achieved by implementing analytical techniques on ion microbeam lines. The combination of several of these techniques such as particle induced X-ray emission (PIXE), Rutherford backscattering spectrometry (RBS) and scanning transmission ion microscopy (STIM) enables both the localization and quantification of the chemical composition at the cellular level. This presentation will show how these micro-analytical techniques, correlated with complementary microscopy techniques, can bring more insight in the study of cellular homeostasis at the single cell level. A particular focus will be made on studies related to the internalization of metal oxide nanoparticles. We will illustrate that μ-PIXE can quantify how this internalization influences the endogenous cellular content variation of some specific ions such as Ca^{2+}, and that this variation can be correlated to an endoplasmic reticulum stress-dependent toxicity. Limitations inherent to ion beam techniques such as the data acquisition on a limited number of cells will be discussed. In this talk, mainly focusing on single cells studies, first experiments on multicellular organisms such as the *C.elegans* nematode will be presented as well. Finally, the latest developments performed to achieve 3D elemental imaging by μ-PIXE tomography will be detailed.

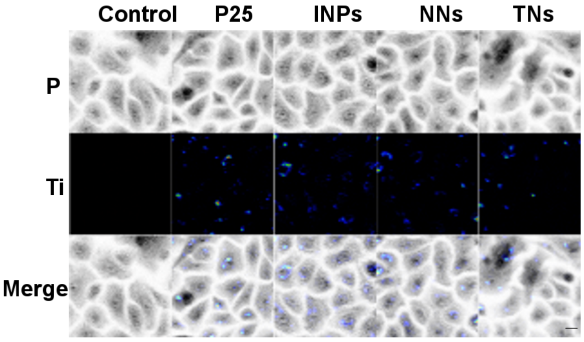

Figure 1: μ-PIXE analysis Human Epidermal Keratinocytes after incubation with different TiO_2 nanoparticles (NPs): (P25, Isotropic NPs, NanoNeedles (NNs), Titanate scrolled nanosheets (TN)). Scale bar: 10μm. Extracted from [1]

Reference

[1] M. Simon et al., "In Situ Quantification Of Diverse Titanium Dioxide Nanoparticles Unveils Selective Endoplasmic Reticulum Stress-Dependent" Nanotoxicology, vol. 11, pp. 134-145, 2017.

Ion Beam Techniques for Source Fingerprinting Fine Particle Air Pollution in Asian Megacities

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I.8

Abstract

Fine particle air pollution is a significant problem in megacities across the Asian region. With funding from the International atomic Energy Agency (IAEA) fifteen countries across Asia have been collecting weekly samples on filters of fine and coarse particles in major cities for the past 15 years. These filters have been analysed for over 20 different chemical species from hydrogen to lead using a range of analytical techniques including PIXE, PIGE, PESA, RBS, XRF and NAA. These data have been included into a major database, which is generally available, containing over 17,000 combined sampling days from these 15 countries spanning an area from ±50° latitude and from 70° to 180° longitude. That is, the sampling covers and area north-south from Mongolia to New Zealand and west-east from Islamabad, Pakistan to Wellington, NZ. This database has been used with source apportionment techniques like positive matrix factorisation (PMF) to generate between 6 and 9 different source fingerprints contributing to the measured mass at each sampling site on each day. The combination of these fingerprints with wind speed and direction back trajectory (HYSPLIT) methods has identified a wide range of long range transport events including soil movements from the Gobi desert across China and into Vietnam as well as sulfate transport from China's coal fired power stations into Hanoi. These data can be used by health and environment organisation to study the effects of air pollution on large populations as well identifying the major source contributors.

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Unravelling secrets from atoms to planets

PIXE in Forensic Science

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I.9

Abstract

The IAEA Physics Section is fostering application of ion beam accelerators in forensic science [1-2]. An ongoing coordinated research project (CRP F11021) targets to further develop and utilize the unique capabilities of ion beam analytical techniques and accelerator mass spectrometry complemented by neutron activation analysis towards recognized needs of forensic sciences that could not be efficiently addressed by other methods [3]. Three key areas were selected for forensics applications covering both criminal investigations and law enforcement with a special emphasis on a) food security and provenance b) forgery of cultural heritage objects and c) glass analysis. This talk will present the key features and some of the recent results of the new CRP, with emphasis on the application of PIXE in forensic science. It will also give a glimpse into some strategic aspects that the accelerator facilities need to consider and clarify during the pathway to adoption for new forensic methods; e.g. end-user requirements, standardization, data interpretation, chain of custody, and nature of the relationship between IBA scientists and forensic stakeholders.

References

[1] https://twitter.com/iaeaorg/status/1058716173079142400

[2] Joint ICTP-IAEA Advanced Workshop on Enhancing Accelerator-Based Analytical Techniques for Forensic Science, 20-24 May 2019, Trieste, Italy, http://indico.ictp.it/event/8681/

[3] https://www.iaea.org/newscenter/news/new-research-project-to-focus-on-use-of-nuclear-techniques-in-forensic-science

Round Table: Detectors & Software

C. Jeynes*
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RTable

Abstract

There have been remarkably wide-ranging and interesting applications of PIXE recently involving innovative detectors and software which I summarise on the Round-Table page of the Conference website. We believe that an opportunity to discuss these developments would be valuable for the community. Reports of new codes (PAMPA, Argentina, JAAS 2017), are encouraging since they indicate the perceived importance of the field. But imaging, chemical speciation, and progress in quantitation (spectrometry) are central to recent developments. Detectors include the classical Si(Li) devices, now largely replaced by SDDs, with Si array detectors (Maia or CCD) for high speed, and CdTe (or HPGe) available for higher energies. Superconducting devices look likely to be feasible for routine high resolution analysis fairly soon. I believe a wider view should also be taken of these developments: which new applications do the improved detectors serve? how can new software promote more demanding applications? how do we use the software advances to support better protocols for spectrometry (and spectroscopy)? Please look through and consider my Introduction document on the website. We anticipate significant interest, and invite Abstracts for proposed three minute contributions. We will select six or seven of these, but all submitted proposals will be published on the website. The Round Table format (one hour) will be half presentations and half discussion. I will briefly introduce the issues, then there will be the invited presentations, and then we will discuss - where I shall invite those not selected for three-minute presentations to also have their say. If it seems worthwhile I shall write a Report for the Proceedings. Ion Beam Analysis (including PIXE) confronts the danger of a mature field: being overtaken by the enthusiastic development of younger, but very powerful, techniques - which today proliferate. How much difference will a proper use of PIXE make to the world? And can we get excited about it? I hope this Round Table discussion will reflect the excitement I feel.

Part 1 - Oral Presentations

Fundamentals

Chemical effects on the Kα X-ray lines of Ti and Cr compounds induced by MeV protons and comparison with Kβ lines

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O.01

Abstract

Recently we measured high resolution Kβ spectra of 3d metals and their selected compounds using 2 MeV proton beams. The results [1-4] showed that high resolution Kβ PIXE spectroscopy is sensitive to chemical effects and that deviations between X-ray energies and intensities can be correlated with structural characteristics of investigated compounds, like metal oxidation state, type of ligand (C, O, N, F), and average metal-ligand bond lengths. However, intensities of Kβ components of K X-ray spectra are low when compared with Kα components, which limits possibilities for practical applications of the Kβ HR-PIXE spectroscopy (i.e. increases the measuring times or beam current on a target that can in some cases introduce chemical changes within the target). Therefore in this work we measured high resolution Kα X-ray spectra of selected Ti and Cr compounds using 2 MeV protons. The measured spectra were analysed in order to extract X-ray energies and intensities of main individual components, including Kα diagram lines (Kα_1, Kα_2) and KL^1 satellite peaks (Kα_3, Kα_4). The results have been compared with the results of previous studies and with results of ab-initio quantum chemical calculation based on density functional theory (DFT). Possibilities for chemical speciation have been discussed and compared with the capabilities of the Kβ HR-PIXE spectroscopy.

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Total X-ray production cross sections induced by heavy ion bombardment

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O.02

Abstract

In this work we present some results concerning the X-rays emitted by heavy ions during target bombardment. In this case, Cl^{4+} and Cl^{5+} ions with energies from 4 MeV to 10 MeV were employed to irradiate vitreous carbon planchets. Moreover, total X-ray production cross sections of Ti, Cr, Ni and Zn X-rays induced by chlorine ions were obtained as well for the same energy range. Only inner shell transitions were considered in the present work. The targets consisted of thin films deposited over vitreous carbon planchets. The results indicate that the projectile X-ray yields increase as a function of the bombarding energy for the present energy range. Effects due to projectile charge state appears to be of minor importance at these low ion velocities. As far as the total X-ray production cross sections induced by chlorine ions are concerned, perturbation theories like ECPSSR underestimates the experimental results for all targets. The disagreement varies from several orders of magnitude for inner shell transitions of Ti to a factor 5 for inner shell transitions of Zn. Although coupled channels calculations improve the agreement between experiment and theory, it still fails to describe the experimental results at such low bombarding energies. The role of electron capture and possible mechanisms responsible for these effects are discussed.

Multiple ionization X-ray satellites of Ti and its binary oxides in alpha particle PIXE

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O.03

Abstract

Recently, wavelength-dispersive spectroscopy was used to study the multiple ionization satellites in the K X-ray spectra of magnesium, aluminum and silicon bombarded by alpha particles having energies of 3-5 MeV [1]. The measured energy shifts and intensities relative to the diagram lines of the groups with one, two and three L-shell vacancies were extracted from the spectra and compared with the interim database values [2]. The main goal of the work was to refine the database so that it may be used to improve the accuracy of PIXE analysis using alpha particle beams, including the PIXE mode of the Mars alpha particle X-ray spectrometers. In next step the current multiple ionization satellite database could be extended to heavier elements. In our work we have explored this possibility by recording the He induced Kα and Kβ spectra of titanium. Beam energies of 3-5 MeV were used to explore the beam energy dependence. Finally, several titanium binary oxides excited with 5 MeV beam were measured to study also the chemical bonding effects on the multiple ionization satellite intensity. The results of this work can be used to plan a further more extensive experimental campaign of extending the multiple ionization satellite database over large span of elements.

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Multiple ionisation and X-ray fluorescence yield modification in $_{23}$V and $_{50}$Sn atoms due to 0.2-1.0 MeV/u C^{q+} and Cl^{q+} projectile ions

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O.04

Abstract

Multiple ionisation of target atoms is a well-known effect in heavy ion-atom collisions at MeV energies. This phenomenon leads to a modification of fundamental interaction parameters associated with single hole collision events. The sustained interest in developing heavy ion PIXE in many IBA labs points to a need for a comprehensive database of experimental data to test and validate codes used for PIXE spectra analysis. This work presents an evaluation of experimental multiple ionisation probabilities of outer shells (L, M, N) in $_{23}$V and $_{50}$Sn target atoms bombarded by C^{q+} and Cl^{q+} ion beams of 0.2-1.0 MeV energies. The probabilities are obtained and compared using two methods; the energy and yield ratio shift method of Tanis et.al. [1] and the heuristic formula by Lapicki et.al [2]. The effects of the multiple ionisation on the fluorescence and Coster-Kronig yields and radiative emission rates, which are used to relate X-ray ionisation and production cross sections, are discussed.

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Calculation of proton-induced L-shell ionisation and x-ray production cross sections for some trans-uranium targets

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O.05

Abstract

L-shell ionisation and x-ray production cross sections were calculated for Np, Pu and Am (trans-uranium targets). This was considered for induced proton energies of 5.00-20.00 MeV; and the cross sections for the targets were obtained using computer codes based on the energy loss coulomb repulsion perturbed stationary state relativistic (ECPSSR) theory. Since the considered targets are radioactive, toxic and unstable in nature resulting in their scarce experimental cross section data, the calculated cross sections were validated using Uranium. This was achieved using the Smit's [1], ERCS08 and ISICSoo codes to calculate the ionisation cross sections of Uranium (Z = 92) and the Feat-code to determine the x-ray production cross sections for incident protons of 1.00-20.00 MeV energy range. The observed deviations notwithstanding, we obtained a good agreement between the experimental and calculated ionisation and x-ray production cross sections for Uranium. Therefore, we deduced that the calculated ionisation cross sections and x-ray production cross sections for the trans-uranium targets are reliable and can be used for spectroscopic analytical applications.

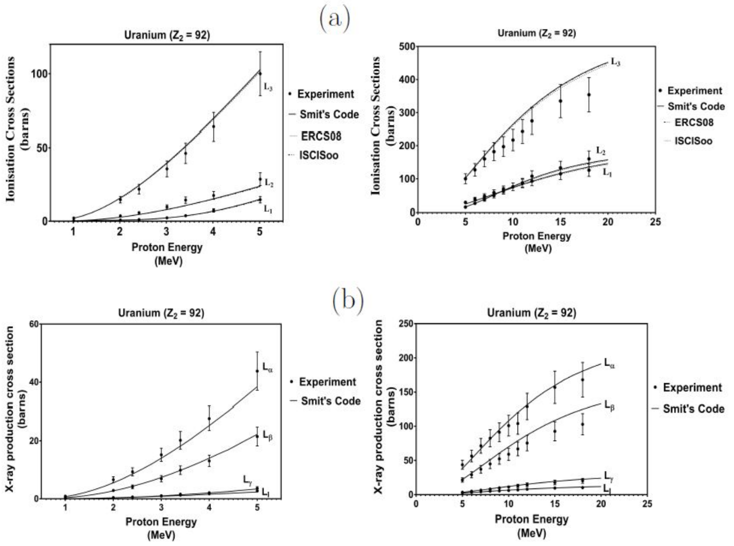

Figure 1: L-shell (a) Ionisation; (b) x-ray Production Cross Sections of Uranium induced by Proton Energies of 1.00-20.00 MeV

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Detectors, Software and Experimental Systems

Contribution of Rayleigh- and Compton-scattered photons to the full-energy peak efficiency

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O.06

Abstract

The accurate determination of a spectrometer's full-energy peak efficiency $\varepsilon_{\mathrm{FE}}$ is essential for quantitative analysis with PIXE and for other applications such as the measurement of ion-impact ionization cross sections. Most of the models that describe the dependence of $\varepsilon_{\mathrm{FE}}$ with energy E, like the one by O'Meara and Campbell [1] (see also [2]), only consider photons that are directly absorbed by photoeffect. The contribution to $\varepsilon_{\mathrm{FE}}(E)$ of photons that have undergone at least one Rayleigh (coherent) or Compton (incoherent) interaction in the active volume prior to photoabsorption is accounted for by means of an empirical "multiple-interaction" correction factor F_{MI}. O'Meara and Campbell [1] evaluated F_{MI} for Si(Li) and Si drift detectors using Monte Carlo simulations, providing tables for various combinations of photon energy, source-to-detector distance and spectrometer geometry (thickness and radius of the active volume).

In the present work we propose a semi-analytical model for the dominant contributions of scattered photons to $\varepsilon_{\mathrm{FE}}(E)$, namely photoabsorption after one Rayleigh or one Compton interaction within the active volume, $p_{\mathrm{coh+pe}}$ and $p_{\mathrm{inc+pe}}$, in the case of a well-collimated photon beam. The expressions obtained for $p_{\mathrm{coh+pe}}$ and $p_{\mathrm{inc+pe}}$ are simple integrals that involve, besides the Rayleigh, Compton and photoeffect attenuation coefficients, the Thomson and Klein-Nishina differential cross sections. It is found that the sum of $p_{\mathrm{coh+pe}}$ and $p_{\mathrm{inc+pe}}$ accounts for around 80% of the total multiple-interaction effect. Analytical $\varepsilon_{\mathrm{FE}}(E)$ curves of typical Si(Li) and Si drift spectrometers calculated including the contribution of singly-scattered photons differ by less 1% from the corresponding Monte Carlo results.

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Feasibility study of TlBr semiconductor detectors for PIXE applications

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O.07

Abstract

Thallium bromide (TlBr) is a compound semiconductor with wide bandgap energy of 2.68 eV. It exhibits very high photon stopping power because of its high atomic number (81, 35) and high density ($7.56 g/cm^3$). Therefore, TlBr has been studied as a gamma-ray detector material. Gamma-ray detectors fabricated from TlBr crystals have exhibited an energy resolution of 1% FWHM for 662-keV gamma rays at room temperature. In this study, TlBr detectors were fabricated and evaluated for PIXE applications. Commercially available TlBr materials were purified with the zone refining method. Single crystals of TlBr were grown by the traveling molten zone method with the purified materials. The grown crystals were cut into wafers with a wire saw. The surfaces of the wafers were polished mechanically with a polishing machine. Metal electrodes were constructed on the wafers by the vacuum evaporation method. Thin gold wires were attached to the electrodes with conductive paste for signal read out. Charge sensitive preamplifiers were connected to the detectors. The output waveforms were recorded with a 14-bit digitizer. Pulse height spectra were obtained by analyzing the pulse waveforms obtained from the detectors. In order to reduce the electronics noise, the detectors and the charge sensitive preamplifiers were placed in a constant temperature box and were cooled to -20 °C. Gamma-rays from ^{241}Am and X-rays from ^{109}Cd sources were irradiated on the cathode of the detectors. Pulse height spectra were obtained from the detector system. The TlBr detectors were exhibited clear full-energy peaks of 22 keV from ^{109}Cd and 60 keV from ^{241}Am.

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Unravelling secrets from atoms to planets

Application of a medical PET cyclotron to PIXE analysis

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O.08

Abstract

There are currently many positron emission tomography (PET) centers, but they are mainly used to diagnose cancer and brain damage. We investigated the application of cyclotron proton beams to PIXE analysis. However, PET facilities usually generate cyclotron protons with energies in the 10-20 MeV range. We reported the PIXE analysis detection limit using 20MeV proton beams and showed that they can be used to analyse biological samples [1]. The Aomori prefecture quantum science center (QSC) is a research institute in the northern part of Aomori prefecture that actively engages in resource development and research in the field of nuclear engineering and nuclear medicine. The QSC has a multi-purpose cyclotron that provides 20MeV proton beams at current 140μA and 10MeV deuteron beams at 50μA to produce positron emission radioisotopes for PET diagnosis. It also produces neutrons for neutron radiography testing and the fundamental study of boron capture therapy. We investigated the potential applications of this cyclotron to PIXE analysis. The first technical challenge was to determine how to generate nA proton beams. We solved this problem by using hydrogen gas impurities from the deuteron gas, and succeeded in carrying out elemental analysis of biological samples. The following figure shows a PIXE spectrum of a scallop, for which Aomori prefecture is well-known. This spectrum was obtained using 20MeV proton beams with 0.5 nA currents for a measuring time of 3 min and an X-ray SDD detector. We clearly observed the mineral elements in the scallop. The continuous background is the quasi-free electron bremsstrahlung [2]. We confirmed that 20MeV proton PIXE analysis is useful for analyzing biological samples.

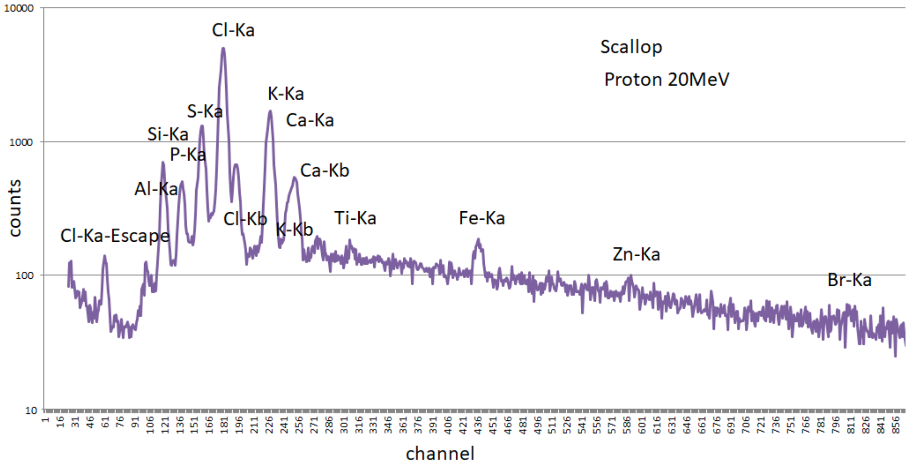

Figure 1: A typical 20MeV PIXE spectrum of biological sample.

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PIXE combined with Kossel diffraction for the analysis of thin film multilayers

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O.09

Abstract

We present a method combining PIXE and Kossel diffraction to characterize periodic multilayers. These structures are made of an alternation of nanometer thin films and are widely used as dispersive elements designed for the x-ray and extreme UV ranges. Their excitation with protons results in emission of characteristic x-rays by the atoms within the stack. That radiation presents significant interference effects when observed in the vicinity of the Bragg angle corresponding to the x-ray wavelength and multilayer stack period. This is called Kossel diffraction. Thus, when the intensity of this radiation is measured as a function of the detection angle, i.e. in grazing exit condition, around the Bragg angle, a modulation is observed whose amplitude, shape and width depend on the depth distribution of the emitting atoms inside the multilayer. Thus, owing to the precise positioning of the corresponding x-ray standing wave of the emitted radiation, the Kossel curve is sensitive to the stacking order, interface diffusion and layer roughness in the stack. In the present work, we feature PIXE Kossel interference curves obtained with an energy dispersive x-ray CCD camera. Each pixel of such a camera provides an x-ray spectrum in each of its pixels, acquiring the Kossel curves with a high angular resolution and without any scanning of the photon energy or of the detection angle. This makes the experimental setup simple and lowers the acquisition time. From a series of Pd/Y multilayer stacks with various stacking orders and interface structures, we show that PIXE Kossel measurements can be a reliable alternative to x-ray standing wave methods for the characterization of nanometer periodic multilayer structures.

Analytical formalism for the determination of hydrogen in biological and organic samples by PIXE

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O.10

Abstract

Particle Induced X-Ray Emission (PIXE) is an effective and practical method for the determination of the elemental mass concentrations in a sample measuring the characteristic X-rays emitted during the interaction with MeV ions. Due to current experimental limitations, low Z ($Z<11$) elements remain undetected by PIXE and must be evaluated either by complementary techniques or by evaluating ad hoc, supposing some a-priori chemical composition of the sample. Here we suggest an analytical procedure to fully calculate the concentration of hydrogen and of a carbon-oxygen-nitrogen $[C-O-N]_{eq}$ equivalent mass, analyzing the high Z ($Z>11$) X-ray lines already detected. With at least two high Z elements, it is proven that we can quantify the hydrogen contained in the sample. Taking advantage of the similar features of the mass absorption coefficients and the stopping power curves of carbon, oxygen and nitrogen, and the very different behavior of the same data for hydrogen, the masses of hydrogen and of a $[C-O-N]_{eq}$ can be retrieved. Numerical calculations show that the calculated mass concentrations of hydrogen agrees with the actual mass concentration of hydrogen in the sample's composition. However, the results are very sensitive to experimental uncertainties. Using only two high Z characteristic X-ray lines, the calculated uncertainty of the hydrogen concentration is about ten times the uncertainty of the input data. This uncertainty can be lowered including more high Z characteristic lines in the calculation. The proposed method is potentially able to quantify the hydrogen in PIXE analysis but to be really useful the experimental uncertainties of PIXE quantifications must be reduced to a few percent, hence stressing the need of better sample modeling and PIXE spectra analysis.

PIXE depth profiling of components in heavy-ion irradiated Zr alloys

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O.11

Abstract

The non-destructive determination of the concentration profile of an element in the near-surface layers of a material is often necessary for studying different processes. This is essential when studying physical surface phenomena which may perturb this profile, such as corrosion, thermal diffusion or evaporation, radiation induced segregation in alloys etc. Among the classical techniques, the PIXE analysis s advantageous in a very good sensitivity and possible simultaneous detection of all heavier elements. The multielemental PIXE method also allows one to reach distinctly greater depths. Experiments on impurities concentration detection in subsurface layer of zirconium alloys have been performed with the PIXE technique at Institute of Applied Physics NAS of Ukraine. Zirconium alloy samples were subjected to Fe ion irradiation of various dose (0, 5, 50, 100 dpa). PIXE experiments were carried out in two stages. At the first stage, averaged elements concentrations of Zr, Fe, Sn, Cr, Nb in N18 and Zr-4 alloys at different irradiation dose were determined. Concentration was calculated from obtained spectra with the GUPIXWIN package. There is some change of concentration for Sn when the dose is increased. Concentration of Cr is stable. At the second stage, a depth profiling method based on the PIXE technique with the variation energy [1-3] has been adapted for studying multicomponent zirconium alloys. The concentration profile cannot be calculated simply because matrix A is extremely ill-conditioned. The above mentioned challenges were overcome with several methods applied: the Tikhonov's regularization method, the method of extended regularized system and the maximum-likelihood method [4,5]. The study of concentration profile of impurities in Zr-alloys shows uniform distribution of Sn and depletion of Cr in the near-surface layers. The depletion becomes more pronounced with increasing irradiation dose.

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Ion beam analysis facility at the centre for energy research & development at Ile-Ife Nigeria and its application in research

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O.12

Abstract

The Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile−Ife, Nigeria, acquired a NEC 1.7 MV Pelletron accelerator with one beam line in 2008 for Ion Beam experiments. This was upgraded in 2014, with the addition of a second beam line equipped with NEC RC 43 end station. This paper presents an overview of the accelerator, its capabilities and its applications in research. A full description of the end-station designed and built at iThemba Labs, South Africa, is also presented. A number of preliminary PIXE and RBS experiments have been carried out using this facility and the results are also presented. This paper further discusses the other diverse areas of application of the accelerator, including solid minerals/geology, biomedical samples, materials science, environmental pollution, and agriculture.

CryoGenX - A High-resolution Spectrometer for Advanced Nuclide Analysis

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O.13

Abstract

The EuroStars CryoGenX project is developing a complete, cryogenic detector system for x- and gamma-rays up to 200 keV. Target markets are non-destructive analysis for nuclear forensics, materials analysis and nuclear metrology for medical applications. Cryogenic detectors can resolve energies where nuclear forensics communities have difficulty identifying the content and origin of nuclear active materials. A commercially available system could prove to be very useful for nuclear metrology, non-proliferation inspection and medical radiology. There are currently two approaches for quantifying radioactive samples. Mass spectrometry with wet-chemistry is accurate but costly and complicated. Semiconductor detectors are easy but inaccurate. CryoGenX combines the advantages of both, ensuring fast, accurate results without destroying the samples, and with no radioactive waste. The cryogenics is based on a very small ADR. The detectors are based on the MMC / MPT concept and will be tailored for a combination of energies and working temperatures. The SQUID read-out, cryostat automation and extensive data analysis including spectral information, peak identification and high-level analytics and file handling are all highly integrated.

Simulation and Techniques Combination

Ion Beam Analysis for the 2020's : An Integration of Elemental Mapping and Omics

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O.14

Abstract

Here we present a newly awarded EPSRC Fellowship (EP/R031118/1) worth EUR 1.3 M, which aims to develop a toolbox for co-locating proteins, metabolites and trace elements in biological samples at the micron scale, under ambient pressure. Our community will be well aware that microbeam PIXE has been used for many years in biomedical investigations due to the ability to map trace elements (and, more recently, small molecular fragments) under ambient pressure. In the fellowship project, our team will be developing a novel toolbox for molecular speciation, to be used alongside microbeam PIXE imaging. The Fellowship project is tackling this challenge with three interconnecting work packages, each investigating a different approach to augmenting the molecular speciation that can be provided alongside or with IBA techniques. These approaches can be summarised as follows: 1. Multimodal mass spectrometry (using laser desorption and electrospray sources) and ion beam trace element imaging; 2. Microscale (point) protein and metabolite characterisation alongside ion beam trace element imaging; 3. Multiplexed ion beam imaging of biomolecules and proteins using antibody-lanthanide tags. These approaches and progress towards the project objectives will be summarised in this presentation. These include a study of the damage to metabolites and lipids caused by performing ion beam irradiation first; a study of the impact of prior MALDI and DESI analysis on the trace element content of tissues; and development of methodologies for locating and quantifying drug molecules in tissue.

Analysis of archeological artefacts from Ostia and Arena Roman sites by PIXE-PIGE and Proton Activation Analysis

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O.15

Abstract

A combination of 3MeV proton PIXE-PIGE, MA-XRF and 10-15 MeV proton activation analysis has been recently applied on the external beam line of the cyclotron of IPNAS/CEA laboratory from the University of Liège, and thus, to a wide variety of archaeological specimens (glass, pottery (terra sigillata), mortars and pigments) all provided by on-going studies and excavations of housing materials, wall decorations, and vessels led on two remarkable Roman sites: First, from an important agricultural complex excavated on an artificial terrace from a republican town, Artena, located, 40 km South-East from Rome, near the Via Latina and the Campania and second, from the Domus dei bucrani, a house dating from the end of the Republican era discovered on the site of the Schola of the Trajan in Ostia. The aim of the present work is to explore and report the specific analytical interests of Charge Particle Activation Analysis implemented with protons ranging from 10 to 15 MeV, as a non-invasive analytical technique for the detection of elements with Z = 11-40 and beyond, and to address its suitability to solve questions raised by archaeologists. We present in this paper the preliminary results obtained following methodologies reported in recent pioneering and more recent works [1-4] and emphasize on the achieved sensitivities (Limits of Detections) for elements as Ca, Ti, V, Cr, Fe, Cu, Zn, As, Sr, Y, Zr and Sb ranging from percentage to parts per million (ppm) levels.

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PIXE and RBS on CIGS solar cells to study the elemental distribution

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O.16

Abstract

Among thin film solar cells materials CIGS materials (CuIn1-xGaxSe2) are the most used, jointly with CdTe, having the advantages of their application in flexible substrates, long term stability, high electrical performance and production versatility. Although they are available in the photovoltaic market, at the same time a lot of research is on-going in order to increase the cell photo conversion efficiency (about 23 % at the moment) not only in lab conditions, but also under real conditions. Active optoelectronic defects, as composition inhomogeneities, created during the manufacturing process, are the main responsible for efficiency limitations. For instance, even small changes in the In-Ga depth distribution inside the CIGS layer will influence the bandgap and thus, the light to power conversion efficiency of the solar cell. RBS and PIXE techniques coupled to a nuclear microprobe can reliably accomplish both the determination of the elemental surface distribution and their depth distribution even in the final electronic device. Three different solar cell devices (two of them belonging to the same substrate) were irradiated with 900 keV proton beam and the NDF software code was used to perform the Total-IBA approach through the simultaneous and self-consistent analysis of the data collected from PIXE and RBS spectra. Results will be presented and discussed.

μ-PIXE/μ-EBS and SEM analysis of surface spots in gold coins/discs from the Portuguese Mint House

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O.17

Abstract

The appearance of red/brown spots in 99.9% pure gold coins is a phenomenon well known to all of the world's mints. In 2017, the Portuguese Mint House (INCM) commissioned a study to determine whether the contamination that originates the spots occurs during the blank production (external supplier) or during the minting process at the INCM facility. The requirements were that for each spot the elemental composition and depth extension were precisely known. PIXE, EBS and SEM techniques were used to characterize 1 disc and 4 coins, all 99.9% pure gold. The first two techniques, conducted at the microprobe beam line of the 2.5 MV Van de Graaff accelerator located at LATR (Laboratory of Accelerators and Radiation Technologies, IST-UL) [1], used two proton energies: 700 keV and 2 MeV (lower energies probe shallower in the sample but with better depth resolution). SEM-EDS examinations were conducted at CENIMAT (FCT-UNL) in a Zeiss DSM 962, with a secondary electrons detector (SE), backscattered electrons detector (BSE) and an energy dispersive spectrometer (EDS). Particle Induced X-ray Emission (PIXE) and Elastic Backscattering Spectrometry (EBS) spectra were obtained simultaneously and analyzed in a self-consistent manner using the Datafurnace code [2]. This methodology, supported on SEM data whenever necessary, allowed the determination of elemental depth profiles, giving accurate spot's 3D spatial information. These results lead to the conclusion that the majority of the spots came from contaminations prior to reaching the INCM facility.

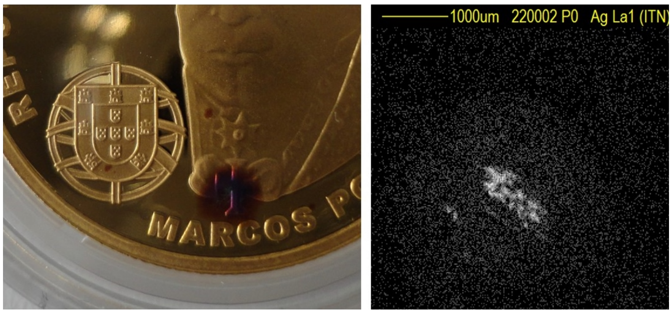

Figure 1: Photograph: detail of one of the 4 studied coins showing a dark spot. PIXE map: Silver signal.

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What killed the apothecarius of Vác in 1763? Micro-PIXE study of mummified bones

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O.18

Abstract

During the reconstruction of the Dominican church "Váci Fehérek temploma' in Vác, Hungary coffins containing mummified bodies of 265 individuals were found in the crypt in 1994-95. The bodies were mummified due to natural processes in the special microclimate of the crypt. The names, the date of death and other information were marked on the coffins. This, together with the contemporary archives made the exploration of individual histories possible. As a part of a complex multidisciplinary research chemical composition down to the trace element level were determined in bones using first nondestructive and later destructive analytical methods. Micro-PIXE test measurements were carried out on a 1st rib from the mostly skeletonized remains of the late Johann Adam Kolb in the Laboratory for Heritage Science, Atomki. A focused proton beam of 2 MeV energy and of 200 pA current was used for the irradiation of the samples at the Debrecen scanning nuclear microprobe. PIXE spectra and elemental maps of two 1mm x 1mm regions were recorded for $Z > 5$. To our greatest surprise significant amount of lead (700-2000 ppm) was found in the bone. This finding was strengthened by micro-XRF and FAAS measurements, too. It was discovered from the archive documents that Johann Adam Kolb was the owner of an apothecary in Vác, and died in the age of 63 in 1763. Lead poisoning was a frequent disease among pharmacists those time, since lead-containing drugs (e.g. Urgentum plumbi aceti, Urg. diachylon, Urg. diachylon salicylatum, Acetum lithargi, Aqua goulardi, etc.) were common and the lead paste was recommended for almost all exterior injuries. While preparing these druges, there was plenty of time to be poisoned. After more than 250 years of the apothecarius's death micro-PIXE measurement gave evidence of the lead poisoning. Recently, bones of several family members of the apothecarius was measured by PIXE, these results will be also presented.

Cultural Heritage and Geological Applications

Ancient glass analysis by milli-PIXE and PGAA - the case of late Roman and Byzantine glasses

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O.19

Abstract

Compositional analyses were performed on glass samples found in archaeological excavations from Dobroudja at the border of Black Sea. The samples were shards of late Roman glass (III-V Centuries AD) and fragments of coloured Byzantine bracelets (X-XI Centuries). The analyses were performed both by external milli-beam PIXE with 3 MeV protons of the Van de Graaff accelerator at Wigner Research Centre for Physics and by PGAA (Prompt Gamma Activation Analysis) at Budapest Research Reactor. From milli-PIXE information on elements from aluminum to uranium and from PGAA information especially on light elements as sodium or boron were obtained. For Roman glass samples (all transparent, only few with a pale greenish aspect) we focused on sodium, magnesium, aluminium, chlorine, potassium, calcium, manganese, antimony and boron concentrations characteristic for the antique recipes. For Byzantine samples (coloured - blue, black, green, brown - fragments) we focused on sodium, potassium, calcium and on colourant agents as metallic oxides (iron, cobalt, copper, manganese, lead, tin). Discussion about the evolution of recipes in Balkan Peninsula during the First Millenium is presented.

Characterization of Goethe's prisms by external ion beam

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O.20

Abstract

Johann Wolfgang von Goethe is known the world over as a renowned writer. However, he was also involved in scientific studies and has written several scientific books, of which he considered the "Theory of colours" ("Farbenlehre", 1400 pages published in 1810) his most important work overall. In this work, he characterises colours as arising from the interplay between light and dark. This is in contrast to Newton's analytical treatment of colour from one century earlier, which is based on the observation that white light can be separated into colours with a prism, that Goethe opposed. Over the centuries, Goethe's theory was discredited and Newton's theory prevailed. However, Goethe performed systematic and accurate optical measurements. For these experiments, he and his partner J. Ritter, who discovered UV-light, used water prisms and glass prisms ordered from a glassmaker in Jena. The aim of current research is to reconstruct these optical experiments and the observed spectra [1]. For this, detailed knowledge of the composition of the glass prisms is important. This knowledge is, for example, also important to evaluate how innovative his prisms were. Therefore, eleven prisms from Goethe's estate or from contemporary sources belonging to the Klassik Stiftung Weimar have been analysed at the external beam setup of the Ion Beam Center at the HZDR. A 4 MeV proton beam has been used to acquire PIXE, PIGE and RBS spectra, sometimes on several areas. Care had to be taken to minimise damage by using short measurement times and measuring on inconspicuous areas because the glass quickly showed dark spots under irradiation. The PIXE and PIGE spectra have been used for quantitative analysis in an iterative procedure and the RBS spectra have only been evaluated quantitatively. The results of this analysis and the interpretation are presented in this work.

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PIXE analysis of antique pottery from the Mediterranean sea area

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O.21

Abstract

We have used the external proton beam setup at Göttingen University to analyze the elemental composition of about 600 antique pottery samples collected in Sicily and neighboring islands. The samples can be categorized in groups of Terra Sigillata (roman ceramic table ware), Mediterranean cooking ware, African cooking ware, amphores, greek laquer ware (greek fine ceramics), domestic pottery, ceramics from Pantelleria (Italy), and pre-historic pottery. For each recovered pottery fragment representative small pieces of few mm diameter were collected and analyzed using PIXE with a 2.5 MeV proton beam of 1 mm^2 size and 5 nA beam current, extracted into air through a 200 nm Si_3N_4 membrane. Relative concentrations of elements starting from Si up to Pb were analyzed, including oxygen as additional invisible element. Besides the main components Si, K, Ca and Fe we focus on the concentrations of trace elements (few hundered ppm) like Ti, V, Sc, Sr, Sn and the metals Cr, Ni, and Zn, which show significant variations even within one group of pottery samples. The results are discussed and compared with literature data from neutron activation analysis.

The origin of garnets set on Dark Ages jewelry: twenty years of PIXE on cultural heritage

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O.22

Abstract

Red garnet is the emblematic gemstone set on the *cloisonné* style of jewelry that characterized almost all the Western world of the 5^{th} and 6^{th} centuries, known as the Dark Ages period, from the Black sea to Anglo-Saxon territories and from Scandinavia to North Africa. The archaeological issues of the provenance and trade networks of this large scale garnet supply have been speculated since the 19^{th} c. The massive *in-situ* PIXE characterization of garnet crystals set on precious objects showed that most were mined in India and Sri Lanka, while European deposits in Bohemia and Portugal were exploited from the end of the 6^{th} century onwards, pointing a dramatic change in the Indo-European trade around 600 CE. The contribution surveys twenty years of PIXE analysis of garnets sets on Merovingian objects from all over Europe. Featured at the PIXE conference in Guelph in 2001, the pioneer study focused on Merovingian objects from the collections of the Musée d'Archéologie Nationale in France using the AGLAE accelerator of the Centre de Recherche et de Restauration des Musées de France [1]. This work rapidly triggered garnet investigation programs on Merovingian collections in Belgium, Germany, Netherlands, Romania and United Kingdom, which benefited from the European transnational access to the AGLAE accelerator open to heritage scientists, as well as from other facilities. The comparison of the composition of more than 4000 archaeological garnets set on hundreds of artefacts with those of reference geological garnets recovered from quarries and mines yielded a detailed picture of the garnet supply in early medieval times and underlined the suitability of external beam PIXE. The merits and limitations of the PIXE analysis of garnets will be discussed and compared to alternative approaches based on XRF and EMPA.

Figure 1: External beam PIXE analysis of garnets set on a 7^{th} century fibula (Wittislingen, Germany).

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Speciation of Cu pigments by Energy Dispersive High Resolution PIXE

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O.23

Abstract

C^{2}TN-XMS system, set operational in 2008 [1] lead to various developments necessary to optimize the use of a first generation X-ray Microcalorimeter Spectrometer (XMS) having 1.5% relative energy resolution at Si Kα 1.739 keV and 0.5% relative energy resolution at Fe Kα 6.340 keV. This having been accomplished, new applications are now at stake. In the present work, results on the analysis of different copper compounds are presented, and used to address the problematic of speciation of copper pigments for Cultural Heritage studies using XMS systems. The need for detailed calibration and details of spectra generation are pointed out. Limitations of a first generation system, and the overcome of all or some of these by the use of second and third generation systems will be discussed.

Acknowledgements
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Chronological assessment of della Robbia sculptures by using PIXE and Luminescence techniques

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O.24

Abstract

Portuguese museums and private collectors assembly a variety of Italian glazed terracotta sculptures comprising objects for private use (devotional images, altarpieces) and decorative (big medallions) attributed to the della Robbia workshop of Florence. In the frame of a wider research project concerning the study (iconographic, historic, ceramic body composition, etc.) of the della Robbia known collections in Portugal, a chronological debate was established. In this way, compositional studies of the paste by using INAA, PGAA and XRD and of the enamel glaze by using PIXE, and luminescence protocols were used as a tool to attribute the sculptures to della Robbia workshop. Regarding the chemical composition, the most evident differences were observed for the chemical contents of Zn, Rb, Zr, Ba, and REE. Two mineralogical associations were found: (i) different proportions of quartz, calcite, gehlenite, diopside/wollastonite, and traces of phyllosilicates, feldspars and hematite; (ii) quartz and phyllosilicates and traces of feldspars and calcite. The luminescence ages obtained for the production of the sculptures are between 1380 and 1640 in some cases with high uncertainties. The composition of the blue glazes is similar to other measured on Della Robbia sculptures from French and Italian collections with all the blue based on cobalt pigments. The behaviour of arsenic, which is associated to cobalt in most cobalt-minerals, is rather peculiar, as already found for other della Robbia sculptures enabling a chronological framework. In some of the analysed objects, arsenic was below detection limits, but in three objects it was above detection limits, as already found for all della Robbia sculptures dated after 1520. Based on the results most of the analyzed sculptures point to a della Robbia production, and only a few of them point to a composition and chronology not related with the workshop.

Acknowledgments
Fundação para a Ciência e Tecnologia (FCT) support through the UID/Multi/04349/2013 and the PTDC/HIS/HEC/116742/2010 projects, and the CHARISMA funded (Grant Agreement no. 228330) project at the Budapest Neutron Center.

Biological and Environmental Applications

MicroPIXE analysis of removal of aqueous U(VI) by S. intermedia and P. stratiotes in the presence of Th(IV)

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O.25

Abstract

Conventional water treatments for uranium removal, such as ion exchange, oxidation processes, coagulation or adsorption, are expensive or inefficient[1]. In this work, *Spirodela intermedia* and *Pistia stratiotes*, autochthonous floating macrophytes, were used to remove U(VI) with concentrations of 1 and 10 mg.L^{-1} from mineral water under laboratory conditions in the presence of Th(IV) (1 mg.L^{-1}). Exposures were performed during at least 2 weeks. All the parameters of the bioremediation process as uptake rate, bioconcentration factors (BCFs) in roots and leaves and translocation factors (TFs), were achieved by microPIXE quantification. This analysis was carried out using a ^{16}O beam (50 MeV) with the aid of the heavy-ion microprobe at the TANDAR Laboratory in Buenos Aires. The beam spot was about 3-5 μm in diameter with a maximal scanning area of 1×1 mm on cross-sections of roots and aerial parts both for U- and Th- contaminated and noncontaminated controls. High resolution 2D maps of the in vivo elemental distribution in macrophytes for different conditions were obtained. This study shows that both plants behave at least as hyperaccumulators of U(VI) in the selected conditions.

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Study of silver nanoparticles uptake and internalization by crop plants

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O.26

Abstract

Engineered nanoparticles (NPs) are used in different industrial products, including cosmetic, pharmaceutics, clothes, electronic and agriculture products [1]. In the past years the use of AgNPs expanded significantly, especially due to their antibacterial and antifungal properties, therefore the probability to become a source of occupational exposure to those nanomaterials encreased. Despite the benefits in using NPs to different purposes, they enter in the environment can be problematic and have different mechanisms of accumulation, internalization and toxicity in living organisms [2, 3]. In this context, the aim of this study was to track the uptake of AgNPs by the roots of commonly consumed crop plants and the possible translocation and/or bioaccumulation of them in those plants. For this, sunflower (*Helianthus annuus*) plants were crop in hydroponics medium with different concentrations of AgNPs solution (0 (control group), 5 and 100 ppm) and different levels of NaCl (0.5 mM and 100 mM). The exposure time to AgNPs was one week. Harvested plants were separated in roots, shoots and leaves and prepared as samples for nuclear microprobe and bulk analysis using XRF. Results obtained with micro-PIXE showed the internalization of Ag in roots of sunflower, mainly in the cortex, of the plants treated with 100 ppm on AgNPs. However, we did not observed the presence of silver in stems and leaves, as well in samples of plants treated with 5 ppm of AgNPs. Also the possible redistribution of physiological important elements in plant samples has been checked.

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New insights in metalloprotein biochemistry revealed using microPIXE analysis

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O.28

Abstract

The Protein Data Bank (PDB) [1] is an archive for the three-dimensional structural data of large biological molecules, such as proteins and nucleic acids, and contains information on almost 150,000 proteins. Of these, approximately 50,000 are metalloproteins, which are either molecules in which a small number of metal atoms are critical to the folded three-dimensional shape (and hence function) or those which are involved in metal transport or metabolism. In virtually all metalloprotein entries, the identity of the metal atoms in the PDB entries has been inferred indirectly from the X-ray diffraction data or by other methods. In the 1990s, two of the authors developed a method for unambiguously identifying and quantifying the metal atoms using microbeam PIXE in combination with RBS [2] which has since been used in many important studies of metalloproteins. One limitation of this method is the low speed (less than 10 samples per day) and we have recently automated the process to permit the analysis of up to 100 samples deposited in an array of small ($\sim 60\ \mu$m diameter) spots using non-contact inkjet printing methods. As a demonstration of this method we analysed 32 previously structurally characterized metalloproteins with the surprising result that over a third of the models deposited in the PDB had misidentified metals and another third contained additional metals. This talk will review the current state of our method and will discuss possible explanations for the misattributed metals. Crucially, it has been demonstrated that using the correct metal in the metalloprotein structure allows the structural model derived from the X-ray diffraction data to be improved, so revealing previously unknown insights into biological function of the proteins studied.

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Physico-elemental analysis of organically produced roasted coffee beans from Ethiopia, Colombia, Honduras, and Mexico

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O.29

Abstract

Coffee is a one of the most popular and desired beverages worldwide, known for its hedonistic, psychostimulant, and health benefits. Hence, assessing the chemical signature of this popular beverage is important as xenobiotics such as toxic metals originating from anthropogenic activities or soil pollution may enter the coffee bean before availability of the commercial product. Of the factors that may influence the elemental signature of coffee, farming and processing practices has been cited to have the greatest effect. The aim of this work was to compare the physico-elemental profiles of organically produced roasted coffee beans from four top coffee production regions that are commercially available in South Africa. In-air PIXE and microscopy was used to compare the physico-elemental characteristics of the beans. All beans contained P, S, Cl, K, Ca, Ti, Mn, Fe, Cu, Zn, Br, Rb, and Sr, whilst linear discriminant analysis showed that there was no strong association between elemental data and production region. Soil environmental properties may however play an important role in determining regional elemental profiles, as shown by hierarchical clustering analysis using a heatmap. Based on the physical properties of the beans, coffee beans from Mexico weighed significantly more than beans from other regions, whilst coffee beans from Honduras had the highest width. To our knowledge, we are not aware of any other scientific works focused on analyzing organically produced coffee with in-air PIXE. Such physico-elemental analysis of food products may present a promising tool in providing information on the nutritional and commercial value as well as the geographical origins of coffee.

Tracing biodistribution of essential and toxic elements through PIXE spectroscopy

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O.30

Abstract

Trace element like manganese, copper, iron, molybdenum, iodine, zinc etc are required by the body at a level of up to 100 ppm. Within a living organism, these elements are either present as a free pool or are bound to some biomolecules. It is estimated that about one-third of the total proteome of an organism has metal(loid) binding motifs. Through quantitative assessment, any alteration in essential trace elements from the normal physiological levels has also been related to the etiopathogenesis of various diseases. Moreover, multielemental analysis of biological samples such as whole tissue, bio-fluids and purified proteins has also been advantageous in the diagnosis of acute/chronic exposure to elements that are foreign to the body. These xenobiotics may induce toxicity either by generation of reactive oxygen species or may even displace a native element from its binding site rendering the protein/peptide inactive. Monitoring, such reactions seems to be beneficial in order to develop methods for targeted drug designing. Also, it can be implicated that by incorporation of a methodology to segregate the biological extracts on the basis of their molecular weight prior to elemental analysis, additional information about the binding environment of the element of interest could be extracted. Thus, in order to explore this proposition, herein, Particle Induced X-ray Emission (PIXE) spectroscopy was used to quantitatively map the distribution of elements in various molecular weight fractions of rat liver tissue as well as the whole tissue. This procedure will be beneficial in tracking biological binding site of a xenobiotic which may further assist in the elucidation of its metabolic pathway and drug design. Furthermore, a quantitative comparison of the elemental distribution between normal and pathophysiological condition may assist in deduction of the biological pathways being altered by the same.

Aerosol and Toxicological Applications

Analysis of particulate atmospheric matter samples collected with high time resolution: some examples of recent applications

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O.31

Abstract

Most air quality studies on particulate matter are based on 24-h averaged data; however, many PM emissions as well as their atmospheric transport and dilution change within a few hours and daily samples are not capable of tracking these rapid changes. Elemental concentration obtained with 1-h time resolution can give invaluable information for the study of episodic events, lasting a few hours which may lead to an exposure problem . Source apportionment receptor models need a series of samples containing material from the same set of sources in differing proportions; increasing the measurement time resolution provides samples that have greater between-sample variability in the source contributions than samples integrated over longer time periods. Furthermore, a more direct correlation with wind direction and speed is possible, since on a daily scale the wind direction may have strong variations. Finally, the choice of the sampling sites, along the prevalent wind direction and in opposite position with respect e.g. an industrial site, allows to follow the impact of the plume as a function of wind direction. There are only a few devices available for sampling aerosol with hourly resolution. At LABEC laboratory at Florence since many years we use the so called "streaker" samplers by PIXE International Corporation, which are designed to separate the fine (<2.5 μm) and the coarse (2.5-10 μm) fractions of PM. These samples are effectively analyzed in a short time by PIXE technique at the LABEC laboratory, equipped with a 3MV particle accelerator, thanks to an optimized external-beam set-up, a convenient choice of the beam energy and the choice of suitable collecting substrata. Examples of recent application of the combined use of streaker samplers and PIXE analysis (eventually complemented by other hourly data) will be reported, regarding industrial sites, heavy polluted towns (like Bejing or Delhi) or natural events (like Saharan dust transport episodes).

Long-term Variations of Toxic-Element concentrations over eight years by Means of Quantitative Analyses of Beard Samples Collected Every Day

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O.32

Abstract

We have collected beard samples from one person (male) over 8 years every day, and analyzed them on the basis of a standard-free method for beard samples [1]. In this study, it was found that the concentrations of arsenic showed rapid short-term changes, while mercury did not show short-term changes but only show long-term changes. According to our preceding studies of hair analyses taken from more than 1200 healthy people, it was found that mercury concentration showed changes with age [2]. It clearly increases with aging. The mercury concentrations in hair and beard of this person are significantly higher than the average values for normal Japanese people. It is expected that observations of elemental changes in beard over eight years would give us information about changes of toxic-element concentrations depending on ages and seasons [3]. Arsenic is expected to reflect intakes of foods containing a large amount of arsenic such as marine products. Figures show typical spectra of beard samples, where samples were bombarded with a 2.9 MeV proton beam accelerated with a small-size cyclotron at Nishina Memorial Cyclotron Center. In Fig. a), the peak corresponding to mercury is clearly seen.

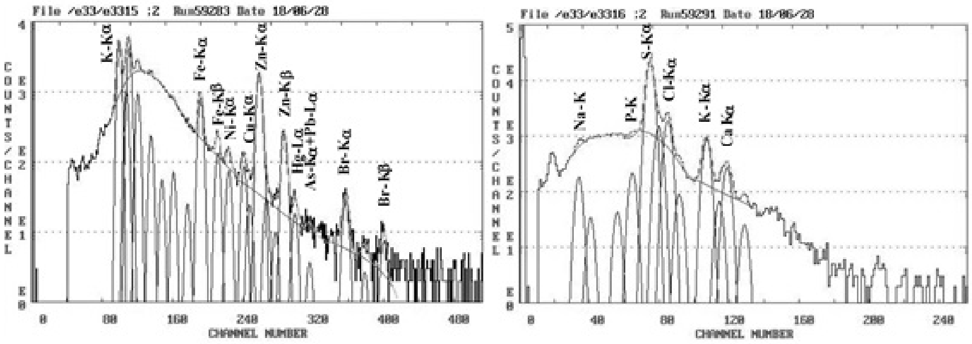

Figure 1: Typical spectra of a beard sample, obtained with a 300 μm-thick Mylar absorber (a) and without absorber (b).

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Current Status of Aerosol Analysis at the PIXE-RBS Beamline in the University of Jordan Van de Graaff Accelerator (JUVAC)

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O.33

Abstract

In this contribution we report the current status and challenges of aerosol analysis at the PIXE-RBS beamline in the University of Jordan Van de Graaff accelerator (JUVAC) facility in Amman, Jordan. The beamline has been upgraded in the framework of the International Atomic Energy Agency (IAEA) regional technical cooperation project (IAEA TC project RAS/0/076 [1]) for ARASIA member states. Apart from technical limitations, the setup has been tested for the analysis of atmospheric particulate matter samples, and optimized for the best possible proton beam conditions attainable at JUVAC. The preliminary results [2] obtained so far confirm that the system is operational and can be used for aerosol analysis, but still needs an additional upgrade.

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Unravelling secrets from atoms to planets

Elemental composition and sources of PM2.5 pollution in 16 European cities in 2014-15

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O.34

Abstract

Fine particulate matter (PM2.5) pollution, i.e. aerosol particles with aerodynamic diameter less than 2.5 micrometer, is a key risk factor in densely populated urban areas around the world due to their adverse health effects. In this work the first results obtained in the frame of the IAEA regional technical cooperation project "Supporting air quality management I-II" are presented. PM2.5 concentrations, elemental composition, sources and source contributions in 16 European and Eurasian cities were determined. PM2.5 sampling were carried in urban background sites in 16 counties all over Europe and Eurasia for a 1-year long period in 2014-15. The elemental composition of 2200 filters were determined by PIXE, XRF, EDXR or ICP-MS. EPA PM5.0. receptor model was used to identify the sources of pollution and to determined source contributions. The average PM2.5 concentrations were under 20 microg/m3 for most of the sites except in Banja Luka (BIH), Sofia (BUL), Skopje (FYROM), Krakow (POL), Ankara (TUR) and Dushanbe (TAJ). In the heating season the PM2.5 pollution level were 2-3 times higher than in summer in the middle European cities and the urban areas in the Balkan. In Mediterranean countries like Portugal and Greece this ratio was around 1. Nine major sources contributed to the PM2.5 pollution in this region in 2014-15: biomass burning, secondary sulfates, traffic, fuel oil combustion, industry, coal combustion, soil, sea-salt and "other". The effect of long range transport was also studied by observing emission episodes (e.g. Saharan dust intrusion) throughout many sampling sites within a short period.

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Unravelling secrets from atoms to planets

Concentrations of alkali and alkaline-earth elements in tea leaves and their elution into green tea

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O.35

Abstract

Radioactive cesium released into the environment due to the Fukushima nuclear disaster that occurred in March 2011 has raised concerns about food safety and long-term radiation effects. Because growing plants require large amounts of potassium and calcium, heavy alkali and alkaline-earth elements including radioactive cesium and strontium are also taken up and accumulated in the plants. If we consume food and drink contaminated with radioactive cesium, it can be eliminated from the body easily. However, radioactive strontium gives rise to a serious problem because it accumulates in bone over a long period and causes bone cancer. Thus, great attention to food safety has been paid not only to rice[1] as a staple food in Japan but also to Japanese green tea because tea leaves are produced across Japan and consumed on a daily basis. In this work we aimed to measure the concentration of cesium and strontium in unused and used tea leaves using particle-induced X-ray emission (PIXE) analysis to investigate the elution of these elements in the leaves into green tea. We used tea leaves which were grown in soil with stable cesium and strontium added. The tea-leaf samples were prepared by placing the tea leaves (2.0␣g) in distilled water (200 mL) of 90°C for 1 min. for percolation. The conventional PIXE analysis was performed on the basis of the internal standard method. The relative concentrations of elements for the used and unused leaf samples (the ratio of elemental concentration in the used leaves to that in the unused leaves) are shown in Figure 1. The results indicate that 20 to 40 % of potassium, rubidium and cesium are released from the leaves into hot water, and that calcium and strontium remain in the leaves. It is expected that if tea leaves are contaminated with radioactive cesium and strontium, radioactive strontium remains in the leaves and we do not take it from tea.

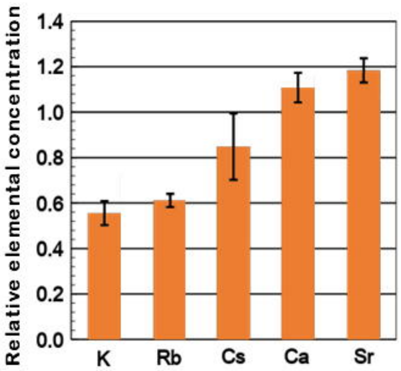

Figure 1: Relative elemental concentrations for the used and unused tea-leaf samples.

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Time resolved elemental composition characterization of air-borne particulate matters by in-air micro-PIXE analysis

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O.36

Abstract

Long-distance propagation of air pollution is one of an important global environmental issue that cause long-term health risk for human being. Since propagations are often affected by meteoritical and environmental factors, time resolution of sampling would be a key factor. However, more sampling time domain shorten, more it would be difficult while collective amount of pollutant would be in range of 50-200 μg[1], which is below detection limit of conventional elemental composition analysis. On the other hand, Particle Induced X-ray Emission (PIXE) method has been proposed as a method for highly sensitive multi-elemental composition analysis technique[2,3]. Furthermore, external focused proton probe allows us to characterize various targets with inorganic and organic complexes[4]. These features might play a key role for characterization of airborne matters collected in short term period from atmosphere. In this study, micro-PIXE analysis was utilized for the analysis of PM 2.5 and PM 2.5 - 10 particulate matters (PM). Two automatic PM sampler of DKK FPM377B and KIMOTO PM-712 were placed at different sites and collected samples in March 2018. Then filter was cut into 1/4 piece to be placed in analytical area with maximum size of 800 x 800 [μm]. Typical PIXE spectra of PM samples were shown in Fig. 1. Elemental compositions were differed between particle sizes, however, fundamentally it was evaluated that micro-PIXE analysis is able to be utilized for characterization of atmospheric matters collected in hourly basis. From micro-PIXE imaging it was also revealed that there would be accumulation of particular elemental composition in those samples which could lead over or under estimate of elemental concentration of PM.

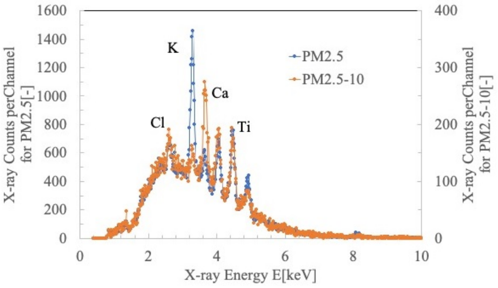

Figure 1: Comparison of PIXE spectra obtained from PM samples with different diameter range of PM2.5 and PM2.5-10.

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Forensic Applications

Signature of the Himalayan salt

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O.37

Abstract

Chlorine is one of the seven micronutrients essential for plants. Together with sodium, it figures among those elements essential to living organisms including humans. In this way, sodium chloride present in salt becomes an important dairy source of these elements. Salt is usually used as seasoning and food preservative and can be found in different granule sizes, varying from a relatively fine powder to small crystals. The most common salt is table salt which is usually refined through different processes. Himalayan salt, also known as pink salt, is becoming more and more popular not only in *haute cuisine* but also in several homes due to its allegedly properties including richness in mineral content. The aim of the present work is to measure the elemental content of different salts sold in the Brazilian market and compare them with Himalayan salt. To that end, PIXE (Particle-Induced X-ray Emission) was used to characterize salt samples. The experiments employed 2 MeV protons with typical currents of 0.5 nA at the target. X-rays were detected by a Si(Li) detector placed at 135° with respect to the beam direction. The results indicate that besides Na and Cl, the salts have trace elements like Mg, Al, Si, S, K, Ca, Ti, Fe, Br and Sr in different proportions. The pink salt appears to be characterized by relatively large amounts of Mg, Si, K and Ti. The differences observed are discussed in terms of origin and quality of the product.

Elemental Extraction Profile of Ground Coffee

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O.38

Abstract

Several factors influence the elemental composition of drinking coffee including the method of preparation, the grain size of the ground coffee and the water temperature. In the present study, the extraction of elements from ground coffee during the drip brewing process was evaluated as a function of the water temperature. Drip brewing coffee was prepared using Brazilian ground coffee and water temperatures varying from 20 °C to 90 °C. Samples of ground and spent coffee were prepared for each temperature and analyzed with Particle-Induced X-ray Emission (PIXE). The results indicate different extraction factor patterns for each element, even though some elements like K and P have similar extraction profiles. The extraction of these elements from the ground coffee increased linearly up to the water temperature of 45 °C, then reduced from 45 °C to 70 °C, with a slightly increase at 80 °C. At 90 °C, the extraction factor reduced to the levels observed at 70 °C. Chlorine and rubidium also seem to have similar extraction patterns with different extraction levels for each temperature. The absorption of elements from the water by the ground coffee was observed for Ca, Si and Cu.

Part 2 - Poster Presentations

Poster Session 1

Calculated Proton-Induced L-shell Ionisation and X-ray Production Cross Sections for Tc, Pm, Os, Po, At, Rn, Ra and Ac

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PS1.01

Abstract

L-shell ionisation and x-ray production cross sections of the elements: Tc, Pm, Os, Po, At, Rn, Ra and Ac, whose experimental cross sections are scanty have been calculated. This was achieved using computer codes [1,2] for incident protons of 1.00-10.00 MeV energy range. The obtained cross sections were validated using the computer codes to determine the ionisation and x-ray production cross sections for Osmium (Z2 = 76) induced by protons of energies 0.1-1.00 MeV and compared with experimental data [3]. The calculated cross sections for the Osmium target were in good agreement with the experimental data. Hence, the calculated cross sections for the considered industrially relevant targets will be a valuable addition to existing database of elements induced by protons.

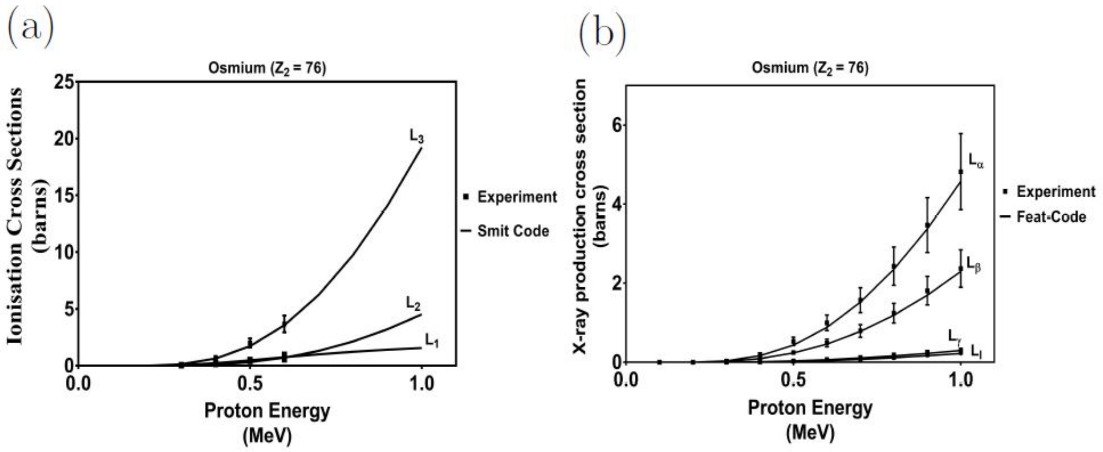

Figure 1: L-shell (a) Ionisation Cross Sections and (b) X-ray Production Cross Sections of Osmium induced by Proton of Energies 0.10-1.00 MeV obtained using [1,2] Codes in Comparison with Experimental Values [3]

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Measurement of $^{12}C^{q+}$ and $^{35}Cl^{q+}$ ion induced X-ray production cross sections in V, Zr and Sn metal oxide targets at 0.1-1.0 MeV/u ion velocities.

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PS1.02

Abstract

Experimental X-ray production cross sections are useful not just for fundamental ion beam - matter interaction studies, but also for the development of new ion beam materials analysis techniques such as Heavy Ion PIXE spectroscopy. Unfortunately, while theoretical predictions of X-ray production cross sections due to light ($Z<6$) projectile ions are generally in good agreement with experiment, this is not the same for heavier projectiles. Experimental studies show that heavy ions induce higher X-ray yields in targets compared to light ions of the same velocity, hence higher sensitivity for Heavy Ion PIXE. There is therefore need for substantial experimental data to improve theoretical models. This presentation describes measurements carried out to determine X-ray production cross sections in Zirconium (Zr), Tin (Sn) and Vanadium (V) metal oxide films due to carbon and chlorine MeV ion beams. The measured cross sections are compared to predictions by the modified Plane Wave Born Approximation (PWBA) and the ECPSSR theory. The observed agreements and discrepancies between experiment and theory are discussed in terms of the atomic ionization mechanisms for each projectile-target collision.

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Total L x-ray production cross sections of Sr, Y, Zr, Nb, and Mo induced by impact of 1.3 MeV to 1.8 MeV protons

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PS1.03

Abstract

Recently, a new beam line for multipurpose applications, mainly Nuclear Physics experiments, was installed at the Laboratory for Accelerator Mass Spectrometry (LEMA), Instituto de Física, Universidad Nacional Autónoma de México. Among the proposed studies related to Atomic Physics, the measurement of x-ray production cross sections (XRPCS) by impact of different ions, such as ^{1}H, ^{12}C, or ^{13}C, started recently. In a first experiment, aimed to evaluate the capabilities of the new setup for x-ray spectrometry, total L XRPCS due to the impact of 1.3 MeV to 1.8 MeV protons on Sr, Y, Zr, Nb, and Mo were measured. Thin films of compounds of these elements, deposited onto Mylar® substrates, were used as targets. A Si-PIN x-ray detector was used, together with a PIPS particle detector to determine the number of incident ions. The efficiency was measured also with a set of MicroMatter thin film standards. The measured XRPCS were compared to the predictions of the ECPPSR theory [1, 2], the universal fitting proposed by Lapicki [3], as well as to other experimental data obtained through the compilation by Miranda and Lapicki [4, 5]. Cross sections from the present work are in good agreement with previous experiments, although there is an important difference with the ECPSSR estimates.

Acknowledgments

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The Measurement of Cross Section of Characteristics X-ray from K, L and M Shell of Thick Targets Si, Ti, Fe, Ni, Cu, Ag, Ta and Au using Ion Beam Techniques

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PS1.04

Abstract

To improve the quantitative analysis of elemental composition of thick samples by PIXE technique, we need to acquire the most reliable data related to fundamental methods like production cross section of characteristic X-rays, detection efficiency of detector. We have conducted a series of fundamental research based experimentations aiming to evaluate the X-rays cross section of K-, L-, and M-shell from thick target elements at Experimental Physics department at NCP Islamabad. All experiments were accomplished on the 5 MV Pelletron tandem accelerator. Cross section study of K-shell from thick targets, Si, Ti, Fe, Ni, and Cu elements were determined and similarly, L-shell cross section from Ag and Ta and M-shell from Au and Pb, were also investigated in energy array from 0.7 MeV to 3.5 MeV. The obtained results were associated with published papers of co-workers and literature. The comparison of data was also made with the theoretical model of Plane Wave Born Approximation (PWBA) and advance model ECPSSR. Calculated results from Si, Ti, Fe, Ni and Cu were found in good agreement with experimental results of co-workers at low energy from 0.7 MeV to 1.5 MeV. However, the results deviates from the experimental data as well as theoretical Models PWBA and ECPSSR in the energy slot 2.0 MeV to 3.5 MeV. Fe and Ag results are in good agreement with these theoretical models. Principal L-shell and M-shell cross section's results were also discussed and found in close agreement with literature and theoretical models in the order of 10. The intensity ratios of K-shell were also investigated and found in good agreement with other experimental work. Decreasing trend in ratios $K\alpha/K\beta$ is observed as a function of ascending order of element Z.

W and Tl M-shell X-ray emission cross sections induced by carbon ions between 2.6 MeV and 5 MeV

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PS1.05

Abstract

Considering the importance of ion beam interactions with mater for applied physics in several fields namely in elemental analysis by Particle Induced X-ray Emission (PIXE), during the recent decades many experimental studies on the M-shell X-ray production cross sections have been performed for understanding excitation and ionization of M-shell electrons by impinging charged particles. Although PIXE is usually performed by protons, experimental data on X-ray production by heavier ions is also of practical interest to exploit the fact that Ion Beam Analysis (IBA) methods can be performed simultaneously. Good knowledge of X-ray production with heavier ions would be helpful for simultaneous use of PIXE with heavy-ion analytical techniques, such as ERDA (Elastic Recoil Detection Analysis), NRA (Nuclear Reaction Analysis), AMS (Accelerator Mass Spectrometry), and MeV-SIMS (MeV Secondary Ion Mass Spectrometry). Therefore we have recently started with the systematic study of M-Shell X-ray production induced by medium energy carbon ions from heavy elements in the range between W and Bi [1,2]. In this work, we have measured particularly $M_{\alpha\beta}$, M_γ and total M-shell cross sections for tungsten and thallium induced by carbon ions of energy rang 2.6 MeV to 5 MeV on respective thin targets. The obtained new experimental data of $M_{\alpha\beta}$, M_γ and total M-shell cross section are compared to the theoretical predictions given in the frame work of the models Plane Wave Born Approximation (PWBA) [3], ECPSSR [4] and the Semi-Classical Approximation with united atom (SCA-UA) and separated atom (SCA-SA) correction [5].

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Evaluation of the radiation hazard for ion-beam analysis with MeV external proton beams

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PS1.06

Abstract

MeV ion beams which are extracted into air or He atmosphere are used in many labs for proton-induced X-ray emission (PIXE), proton induced gamma ray emission (PIGE) or Rutherford backscattering (RBS) to analyze samples which are difficult or impossible to handle in vacuum. When MeV proton beams are extracted into air through thin Kapton foils or nowadays thin silicon nitride membranes, the protons will interact with air, as well as elements present in the analyzed samples. Typically the range of MeV protons in air is several cm, in Helium atmosphere several 10 cm and in human skin around 100 μm. Besides the severe radiation hazard in case of a direct exposure of skin with protons, there are a manifold of nuclear reactions or inelastic proton scattering processes which may cause activation of air and target materials but also prompt radiation. The radiation hazard associated with the direct and scattered beam, nuclear reaction products and radionuclide production in air have been discussed in a publication by Doyle et al in 1991 which was used as a reference in several later publications. I have reevaluated the radiation hazards for external proton beams with up to 4.5 MeV using proton reaction cross sections taken from the JANIS book of proton induced cross sections. The radionuclide production in air is about 3 orders of magnitude lower compared to values given in the 1991 publication. Radionuclide production as well as generation of prompt alpha, gamma and neutron radiation in target materials for elements up to molybdenum is also evaluated.

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Measurement of x-ray production cross sections for Fe K-line, Nb, Ru and Ce L-line, and Ta M-line induced by 1-MeV C-ion beam

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PS1.07

Abstract

MeV heavy ion beam induced x-ray production cross sections are interesting for applications of MeV heavy-ion particle induced x-ray emission (PIXE) in material near-surface analysis and imaging. While the cross sections of heavy ion beams at energy of a few MeV and above have been measured and reported, experimental data, especially of those minor lines from uncommon materials, for lower-energy heavy ion beams around 1 MeV are lack, though only theoretical prediction available. In this study, we used 1-MeV C-ion (83 keV/amu) PIXE to measure the x-ray production cross sections of Fe K-line, Nb, Ru and Ce L-line, and Ta M-line from thin films of the materials. The literature-reported experimentally measured Fe Ka x-ray cross section induced by standard 2-MeV proton beam was used as a reference, as the measured cross section data of L-line and M-line of the relevant materials for references were not available. The measured data were compared with those PWBA- and ECPSSR-calculated by program ISICS11 and found their deviations from the theoretical predictions in acceptable ranges and atomic-number (Z) dependent. The Z-dependence was discussed in terms of the ion path relative to the electron shells of the target atom.

Characterization of the X-ray optics of a full-field PIXE-camera

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PS1.08

Abstract

A PIXE-camera, consisting of an energy-dispersive pixel detector and a poly-capillary X-ray optics has been installed at the Ion Beam Center of HZDR [1]. The ultimate aim of this system is the quantitative determination of trace elements in large geological samples. The X-ray optics makes the laterally resolved imaging possible by guiding locally produced X-rays in the sample towards corresponding pixels of the detector. Aspects of this full-field imaging and improvements of the quality and resolution of the images have recently been reported [2]. For the quantification, the characteristics of the X-ray optics are an important aspect and this is investigated in this work. The transmission through the capillaries is governed by total external reflection on its inner surface. The transmission probability is based on the efficiency of the reflection and the number of bounces, both of which are dependent on the large X-ray energy. A simple model and calculations based on this model are presented and compared to experimental data. A further point to be considered is the energy dependence of the critical angle for total reflection because this is the main contribution to the solid angle. This effect is also included in the model. In the near future, this setup will be used with an X-ray source for X-ray Fluorescence measurements; however, the characterization of the X-ray optics remains valid and useful.

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Intrinsic efficiency of semiconductor spectrometers for divergent photon beams

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PS1.09

Abstract

The commonly-used analytical models for the intrinsic efficiency of semiconductor spectrometers assume that the photon beam impinges perpendicularly on the front surface of the active volume. O'Meara and Campbell [1,2] presented and assessed an approximate expression that accounts for the divergence of the beam. Their formula depends on the thickness and radius of the active volume, the source-to-detector distance and the photon energy. The purpose of this work is to compare the O'Meara-Campbell formula to the exact solution (neglecting however the contribution of scattered photons) and to the simple expression used by Abbas, see e.g. [3]. It is found that the latter performs quite well for a wide range of beam apertures, active volume thicknesses and photon energies. Monte Carlo simulations with a minimalistic, pedagogical algorithm are also presented and discussed.

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Development of a tapered glass capillary microbeam system and preliminary application in PIXE-mapping of local plant leaves

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PS1.10

Abstract

A low-cost tapered glass capillary microbeam system was home-developed based on our 1.7-MV tandem accelerator and its ion beam analysis beamline at Chiang Mai University, Thailand. All technical details of the system, including characteristics, installation, alignment and quality tests, are described. The system consisted of the capillary itself, a capillary holder, a holder swing mechanism, and a system support frame with a micrometer for vertical micro-adjustment. The capillary horizontal swing and the sample stage translation were both computer-controlled to a resolution of μm. The glass capillaries, either homemade by an induction puller or from other suppliers, had various sizes in a range of 0.1 - hundreds μm in the outlet inner diameter. A preliminary application of the system was conducted for elemental distribution mapping of local plant leaves using particle induced X-ray emission (PIXE) analysis with 2-MeV proton beam. The studying interests were focused on the difference in the elemental concentrations distributed between the leaf vein and lamina areas of local longan leaves which were normally sprayed by chemical fertilizer and pesticide and the elemental absorption efficiency in the leaves of Peperomia pellucida which was cultured by dissolved supplement solution of various nutrients. Mapping results are reported and discussed.

The Study of Intrinsic point defect using Ion beam induced luminescence using Proton and Helium ion the energy range 0.7 MeV to 2.0 MeV

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PS1.11

Abstract

The study of point defect is carried out by new established technique ion beam induce Luminescence. The system was calibrated by Hg laser light spectrometer. The bulk and single crystal Al_2O_3 samples were irradiated by neutron and Phosphorous ions. The variation in F and F^+ centre is observed at 329 nm and 413 nm. The intrinsic defect of Cr^{+3} is also noticed at 700 nm. Increasing trend of F^+ center is also observed relative to F center. Energy and dose dependent study was also carried out and results were found in good agreement with literature.

Silicon Drift Detector response function for PIXE spectra fitting in the high energy X-ray region

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PS1.12

Abstract

The accurate determination of the X-ray peak areas in PIXE spectra by fitting with a computer program requires an adequately good parametrization of the detector response function. In the Guelph PIXE software package, GUPIXWIN, the most used PIXE spectra analysis code, the response of a semiconductor detector to monochromatic X-ray radiation is described by a linear combination of several analytical functions: Gaussian or Voigt for the X-ray line itself, and additional tail contributions (exponential tails and step functions) on the low-energy side of the X-ray line to simulate incomplete charge collection effects. In a previous paper [1] the spectral response of Silicon Drift Detectors (SDD) was studied for the X-ray energy range 1-15 keV. In this work we present the extension of the characterization of the behaviour of the parameters involved in the SDD tailing functions to higher X-ray energies, up to 25 keV, and the study of the origin of incomplete charge collection in the high X-ray energy region. Following the same experimental procedure employed in [1], a series of thick ultra-pure (99.99+%) high-Z mono-elemental targets were irradiated with low intensity MeV energy protons and the corresponding X-ray spectra from 15 to 30 keV were measured using several SDD devices used for routine PIXE analysis at the INFN LABEC laboratory in Florence, differing for active area (from 10 up to 150 mm^2) and thickness, and for preamplifier layout. Using the analytical functions implemented in GUPIXWIN, the SDD response functions were satisfactorily reproduced for the X-ray energy range 15-25 keV.

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Microscopic analyses on Zr adsorbed IDA chelating resin by PIXE and EXAFS

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PS1.13

Abstract

Used organic solvent generated from reprocessing process of spent nuclear fuel contains a small amount of radioactive nuclides including U and Pu, and the solvent degradation product. The radioactive nuclides should be removed from the used solvent for its appropriate storage or disposal. We have been developing adsorbent for U and Pu recovery from spent PUREX solvent which is employed in commercial reprocessing plants for U and Pu extraction. Our previous study on applicability of commercial adsorbents for cation recovery from the used organic solvent showed that Zr, which was a simulant of Pu, was successfully adsorbed from the simulated spent PUREX solvent onto the chelating resin introduced iminodiacetic acid (IDA) group [1]. In order to design structure of practical adsorbent for the spent solvent treatment, adsorption mechanism should be precisely understood. In this study, Particle Induced X-ray Emission (PIXE) and Extended X-ray Absorption Fine Structure (EXAFS) analyses on the IDA type chelating resin extracting Zr from nitric acid solution and from simulated spent PUREX solvent were carried out to investigate distribution of Zr in the particle and local structure of Zr complex formed in the adsorbent, respectively. PIXE analysis revealed that the adsorption sites occupied from outside of the particle and that adsorption kinetics from the solvent was slower than that from the aqueous solution. Characteristic X-ray of P atom was also observed. Since only the PUREX solvent includes P atom in its molecule, this observation result indicates that not only cations but also organic molecules are trapped. Moreover, some of the adsorption sites were possibly occupied by the molecules. On the other hand, Zr-K edge EXAFS analysis suggested that extraction mechanism of Zr from the aqueous solution and the solvent was different. Part of the functional group contributing to the extraction of cation might be different according to the medium of the target liquids.

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Unravelling secrets from atoms to planets

Structural characterization of Eu-HONTA complexes by IBIL and EXAFS analyses

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PS1.14

Abstract

Partitioning and transmutation of trivalent minor actinides (MA(III)) is an important and challenging task for reduction in volume and radiotoxicity of nuclear waste. Extraction chromatography technology is effective for efficient MA(III) recovery from nitric acid medium [1]. Hexaoctyl-nitrilotriacetamide (HONTA) is one of the most promising extractants for separation of MA(III) from trivalent lanthanides (Ln(III)) which have chemically similar properties with MA(III) [2], and systematic investigation on its applicability for the extraction chromatography is currently underway. Extraction behavior of Ln(III) onto HONTA in solvent and adsorbent showed different dependence on acidity of the nitric acid. Difference in extraction mechanism between those two systems is one of our interests to establish efficient MA(III) recovery process. In this study, structural information of Eu-HONTA complexes formed in the adsorbent and in the solvent system was investigated by Particle Induced X-ray Emission (PIXE) combined with Ion Beam Induced Luminescence (IBIL). For further chemical composition analysis, Extended X-ray Absorption Fine Structure (EXAFS) analysis was also carried out. Elemental composition of target complexes were identified by PIXE analysis. IBIL spectra of Eu(III) loaded HONTA solvent and adsorbent showed characteristic profile between 550-750 nm, and those peaks were attributed to 5D0→7F transitions of Eu(III). Shapes of the spectra were different from those obtained for Eu compounds and only the adsorbent or the extractant did not show any line or band spectra, therefore the characteristic peaks could be relegated to be luminescence from Eu(III) forming complexes with HONTA. Slight change was observed in adsorbents loading Eu(III) from different acidity solutions. According to local structure evaluated by Eu-LIII edge EXAFS, the difference might be caused by change in the number of ligands surrounding Eu(III). Additional experiments are currently progressing.

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External PIXE measurements of concentrations U in materials nuclear fuel cycle

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PS1.15

Abstract

The functioning of the nuclear power industry must be accompanied by the control of the uranium content as the main element at all stages of the nuclear fuel cycle. The PIXE method was used for non-destructive testing of the U content in uranium ore processing products and environmental monitoring samples. Preliminary studies have shown that for this purpose it is preferable to use the L-series U, which is associated with a high x-ray yield for this subshell. A proton beam with an energy of 1600 keV was used. An Si-pin detector with an energy resolution of 150 eV was used to record X-ray radiation. But the analysis on the beam showed a significant overlap of the $L\alpha$ - line U and $K\alpha$ - line Ru. To reduce the effect due to overlapping lines and lowering the detection limit for U, an x-ray filter from pyrocarbon was used. The filter was in the form of a cylindrical assembly of plane-parallel pyrolytic carbon plates 3 mm × 1 mm × 36 mm in size. These plates were cut along the plane of the reflecting surface with the (002) orientation, with a mosaic pattern of 0.5 nm and a lattice constant of 6.619 Å. In order to avoid direct X-rays, two tungsten discs with a smaller diameter are placed axially at each end of the cylinder. Measurements for a series of samples showed good linearity between the x-ray yield and the uranium content. For these measurement conditions, the detection limit for uranium was 4 ppm.

Utilization of micro-PIXE and micro-IBIL analysis for the evaluation of SiAlON scintillators

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PS1.16

Abstract

Among various phosphors, recently developed SiAlONs are known for its advantageous properties even at high temperatures. Since their crystal structures are robust thus it would be utilized in charged particle detection in harsh conditions. Preliminary, scintillation properties of α-SiAlON and β-SiAlON powders were evaluated by in-situ ion beam induced luminescence (IBIL) analysis under focused proton microbeam exposure [1,2]. Both SiAlON showed excellent luminescent yield comparable with conventional scintillator of ZnS:Ag. As irradiation progresses, IBIL intensity of both SiAlONs was not drastically changed while that from ZnS:Ag had strongly degraded. Moreover, scintillation properties of β-SiAlON at high temperature was well evaluated [3]. These experimental results suggested that SiAlON has advantageous properties for charged particle detection. Additionally, it is also possible to control peak wavelength by changing the structures and activators in SiAlON. In this study, we have additionally prepared other species of SiAlON scintillators (α- SiAlON YL600A, β-SiAlON MW540H, and CASN RE-650XMD, Denka co ltd) and evaluated under 3 MeV H^+ microbeam excitation conditions. Combined analysis and imaging technique of particle induced X-ray emission (PIXE) and IBIL utilizing focused proton microbeam was employed for the characterization of powder and plate type SiALON scintillator families. In spectra we could find out peak wavelength varies from 540 -650 nm. These experimental results suggested that different peak wavelength of SiAlON scintillators could be utilized in different kind of application as scintillation monitoring tool for intense radiation exposure environments.

Acknowledgments

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Poster Session 2

PIXE dating of Thai ancient burnt clay ages

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PS2.01

Abstract

This is a case study on applying particle induced X-ray emission (PIXE) for dating ages of burnt clay from antiques of our local customer. A 2-MeV proton beam from our 1.7-MV tandem accelerator was used for the analysis. From the PIXE spectra, no standard common elements could be found for the dating, but instead, actinium (Ac) was found the only element available and thus used as the dating element which had a relatively short half-life compared with other stable elements. A sample with its known age, given by the customer, was used as the reference. A calculation process was presented based on the formula of the element half-life decay for dating estimation using relative data. The result showed reasonable age ranges, confirmed by the customer. Although PIXE analysis for dating has been internationally popular, it was the first time for our Thai nuclear technology physicists to carry out this application and our performance demonstrated the application successful by using our home-developed PIXE technique.

Still lifes in earth materials: technical and ideological evolution from Baltazar Gomes Figueira to Josefa d'Óbidos

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PS2.02

Abstract

In the seventeenth century, the art of the protobaroque in Portugal thrives at a stage when the profession of painter asserts itself in the face of the work of a craftsman. The search for the imitation of the natural (including natural earth materials) is explored in the effects of light by the new generation of painters, of which André Reinoso, Domingos da Cunha, José de Avelar Rebelo, Baltazar Gomes Figueira and later Josefa d'Óbidos stand out. These artists work in naturalistic ways, which surpass and oppose the counterreformation models employed by the last generation of Mannerist painters in Portugal. Alongside the traditional painting of religious character is the evolution of other genres - such as Portrait, Landscape and Still Life, a reflection of the economic and ideological vitality of the time. Protobaroque painting emerges under the Castilian political domination, reflecting the modernity of the beginning of the Spanish "Siglo d'Oro", assumed by the Portuguese painters during the first half of the seventeenth century. Some of them lived and learned to paint in Seville, as is the case of Baltazar Gomes Figueira. Zurbarán and Murillo have a profound influence on the so-called Óbidos painting workshop, including the work of Baltazar Gomes Figueira as well as his daughter, Josefa d'Óbidos. In this work we study and compare the materials and technique of five still life paintings assigned to Baltazar Gomes Figueira and Josefa d'Obidos, his daughter and follower. The analytical study was achieved by the complementary information given by the techniques of μ-Raman and μ-FTIR in combination with XRF, μ-XRD, and SEM-EDS. Assessment to these results allow to compare to other still life paintings of Spanish origin and understand the evolution between father and daughter materials and technique in Óbidos painting workshop, one of the most important workshops of the Portuguese 17^{th} century.

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Roman opaque red glass, considerations and improvements on the application of PIXE analyses on archaeological glass

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PS2.03

Abstract

Ion-Beam Analysis is an important tool in the archaeometric studies for the identification of the major and minor constituent element in archaeological glass [1]. Chemical composition obtained by PIXE analysis can give fundamental information about the glassmaking technology and so advance hypothesis on the production process. Accurate results cannot be obtained just using one analytical method and the comparison of several analytical techniques should be the ordinary procedure to have the more possible accurate data analysis [2]. This work aims to characterize the quantitative chemical composition of Roman opaque red glass sectilia dated to the 2nd century A.D. [3]. Due to the lack of technical historical sources regarding this period, a multi-disciplinary approach is in progress to investigate the glassmaking and the technological methods used by Roman glassmakers. Red glass sectilia in several hues (fig.1) from the Imperial Villa of Lucius Verus (161-169 A.D.) in Rome are investigated (fig. 2). In this project PIXE measurements are of fundamental importance for the chemical characterization of the samples. Aim of this work is to highlight the advantages and the limits of this technique by comparison between the PIXE analyses and the results collected by SEM-EDS (performed in the Louvre laboratory), and EMPA measurement (Stazione Sperimentale del Vetro, Murano), two laboratories with a long tradition of analysis of glass samples. The type of glass (natron glass, soda-ash glass and soda-lead glass) and the variable amounts of colorants and opacifiers require the analysis of several glass standards to make the PIXE results more certain and accurate. The quantitative analysis of this opaque red glass will be used as reference for the future analysis on 2nd century Roman opaque red glass.

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Analysis of Celtic small silver coins from Slovenia by PIXE and PGAA

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PS2.04

Abstract

The small Celtic coins discovered in Slovenia are of different types and masses. It is a basic question if physical data of the coins are related to their chemical composition, notably the grade of silver. Destructive measurements made by PIXE decades ago showed that the coins exhibit non-homogeneous metal distribution, which results in silver-rich mantle and base silver core; the mechanism for creating such a structure is very likely inverse segregation during solidification of coin blanks. PIXE measurements typically yield also their trace element pattern, consisting of Zn, As, Mo, Au, Sn, Pb, Bi, which provide a basis for application of discriminative statistical methods. It is however necessary to test the surface values obtained by PIXE by some other bulk-sensitive method. Prompt gamma neutron activation analysis (PGAA) seems attractive as its approach is non-destructive, leaving in the coins a small residual radioactivity which rapidly vanishes with time. A series of 70 coins was then selected and analyzed by PIXE in Ljubljana and by cold neutron PGAA in Budapest Neutron Center. PGAA is less sensitive for certain elements than PIXE, so it was possible to determine the concentrations of the two major components, Ag and Cu. Of the trace elements, a few coins were subject to gamma spectroscopy after irradiation, which allowed determination of Au. The data were statistically treated by kernel density estimate for the silver content, and it was found out that certain coin types were made of two types of alloys, fine grade silver (the same content of Ag was found by PIXE) and low-grade silver (PIXE overestimated Ag content). In one low-Ag coin, the base-silver core was monitored by neutron tomography.

Characterization of pottery fragments of Scythian period by PIXE method

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PS2.05

Abstract

68 samples of pottery fragments from an ancient settlement near the Shyriayeve village, 28 samples from the Skytok settlement and 16 samples from the Ionine settlement were selected for analysis. In this collection there were two fragments of the ancient amphoras: one of them was produced in Samos, other - in one of the centers of the North Aegean. 10 fragments of the pottery belong to Yukhniv culture, others - to the local agricultural population of the Scythian period from the Seim river region. Elemental composition of the above mentioned samples was determined by PIXE technique at the IAP NASU analytical accelerator-based facility with 1 MeV proton beam used [1]. Concentration calculation was performed with GUPIXWIN software package [2]. Accuracy of the PIXE analysis results was verified with certified reference materials (ISE 952 and ISE 886). As expected, the major chemical compounds of samples are oxides of aluminium, silicon, potassium, calcium, titanium, iron. The relationships between the pottery attributes were determined with the principal component analysis (PCA) performed. Samples from the Skytok and the Ionine settlements form two local groups are in PC1-PC2 graphs. The greatest variety of chemical composition of samples from the Shiriayeve settlement can be explained by the long life of the monument (in the middle of the 6th - the 4th century BC) and by active contacts with the neighbors. For example, among samples, there were fragments of black-glazed ceramics which was not produced in the Seim river region but could be possibly brought from the regions of the Vorskla river or the Dnipro river. Results of the pottery morphology studies prove the above-mentioned facts (it is impossible to identify mathematically justified types).

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Ion beam analysis of historic tesserae glass using combined RBS-PIGE-PIXE and μ-PIXE methods

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PS2.06

Abstract

Elemental analysis using simultaneous ion beam techniques, is a powerful tool for qualitative elemental analysis using Rutherford backscattering spectrometry (RBS), particle induced X−ray emission spectroscopy (PIXE) and proton induced gamma-ray emission (PIGE) techniques. The PIXE setup existent at the PIXE beam line of the Tandetron Laboratory, was calibrated at 2.9MeV with protons for accurate macro PIXE analysis using thin standards and thick certified materials. The elemental analysis of selected historic tesserae glasses from Holovousy Castle (Czech Republic) mosaic panels in Art Nouveau style using combined RBS-PIGE-PIXE and μ-PIXE methods is going to be presented here.

Scientific investigations on byzantine pottery from Castrul 22, Romania

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PS2.07

Abstract

Forty five ceramic shards discovered in excavations at the archaeological site Castrul 22 from southeastern Romania and dated to the 10th - 11th centuries AD, were subjected to archaeometric investigations, in a trial to decipher the raw materials and the manufacturing techniques employed by the potters from the Lower Danube zone during the Byzantine ruling. The shards chosen selected for analyses were initially grouped according to stylistic criteria. In a subsequent stage, Optical Microscopy (OM) was used to detail the fabric characteristics - texture, porosity and microstructure, as well as surface treatments and firing of the potteries. Micro-PIXE analyses of ceramic fragments were performed at AN2000 accelerator of LNL, INFN Italy, to obtain the chemical composition of the ceramic bodies and in some cases, of the decorations (glaze, engobe). For some shards, the micro-PIXE maps of the interfaces between the glaze and the ceramic body provided clues about the composition of the green decorative layer that turned out to be characterized by a strong enrichment of the lead content with respect to the corresponding ceramic body. Statistical analysis - Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) - of the PIXE data highlighted several categories of shards with distinct compositional signatures, as well as some outliers. The results of these investigations were compared to the ones previously obtained on coeval pottery from the nearby archeological sites from Hârsova [1] and Oltina [2], in a trial to provide hard science evidences for the commercial networks in the Lower Danube region during the Byzantine period.

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μ-XRF and μ-PIXE/μ-EBS analysis of XV-XVI Portuguese copper coins

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PS2.08

Abstract

In centenary copper coins, the corroded surface is usually an inhomogeneous and multielemental layer with a thickness that ranges from a few micrometers to the full coin thickness (in extreme cases). A non-destructive study of these surfaces with depth distribution information is complex due to the profusion of detected elements and their concentrations, which can be as low as a few dozens of ppm. The simultaneous μ-PIXE/μ-EBS and self-consistent analyses allowed obtaining these distributions in regions with different patterns of surface alteration for silver and copper coins [1]. However, the depth distribution of elements whose concentration is below $\sim$1%, is not unambiguous, despite the restrictions imposed by the PIXE yields, since small concentration fluctuations usually do not contribute significantly to the variation of global EBS spectra. It is possible to lower this uncertainty by including data obtained by μ-XRF, which probes deeper into the coin volume as compared to PIXE. This information can be used to disentangle the trace elements that form the bulk material [2] from foreign material. This work presents the results obtained by the combination of μ-XRF and μ-PIXE/μ-EBS analysis for two Portuguese copper coins: a XV Century Real Preto and a XVI Century 2 Reais, both in a fine state of preservation and both presenting a corrosion layer of unknown thickness and composition. μ-XRF probed the surface of the coins and for regions where iron content was below 0.08%, the bulk elemental composition was determined. These data, alongside with μ-PIXE information, were used as inputs to simulate the μ-EBS spectra in a self-consistent manner using the Datafurnace code [3]. The conclusion of this work is that the combination of these three techniques gives a precise elemental quantification and a good corresponding distribution in depth.

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Upgraded external-beam "Total IBA" set-up for in cultural heritage applications at LABEC

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PS2.10

Abstract

The capabilities of external ion beam analysis (IBA) methods at INFN LABEC laboratory for cultural heritage studies have been improved implementing a "Total-IBA" analytical approach. Whereas Particle Induced X-ray Emission (PIXE), Particle Induced Gamma-ray Emission (PIGE) and Elastic/Rutherford Backscattering Spectrometry (EBS/RBS) separately give only partial information on the composition and layering of artistic and historical artefacts, these analyses can be performed simultaneously on the sample and their synergistic use allows gathering detailed and complete data about elemental composition and depth distribution of the analysed material. Moreover, IBA techniques can be performed while maintaining the object in atmosphere, avoiding the need of picking up samples and greatly easing the object positioning, thus precious and big artefacts can be studied. To this purpose the existing PIXE set-up installed at the +45° external collimated beam line of the 3 MV Tandetron accelerator of LABEC laboratory was upgraded for Total-IBA measurements. The set-up includes now two X-ray detectors for PIXE, a 10 mm^2 Silicon Drift Detector (SDD) for light and major elements analysis and a 150 mm^2 SDD, for heavy and trace elements; one particle detector for EBS/RBS, a Si pin diode 10×10 mm^2 active area, placed at 135° scattering angle and mounted in an aluminium case, kept at 0.1 mbar pressure; and one gamma-ray detector for PIGE, a 20% relative efficiency HPGe detector with a mechanical cooler. Quantitative results are obtained by accurate charge-equivalent normalisation measuring the extracted beam weak currents using a rotating chopper [1]. The characterisation and the performances of the detectors of the upgraded external beam Total-IBA set-up at LABEC will be described, together with the results from some case studies.

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Trace elements analysis of natural mineral pigments for Japanese paintings

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PS2.11

Abstract

Historically and culturally valuable works should be preserved as cultural properties over the future. Although modern storage technology is excellent, there are cases where to repair is necessary. When repairing valuable historical materials should use the same materials as original as possible. It is therefore necessary in this repair work to clarify what the original material is. Natural mineral pigments are sometimes used in historically valuable Japanese paintings. They are composed of various elements depending on the production area and the age that was made, even if they are similar colors. Clarifying the constituent elements of the natural mineral pigment is also effective in identifying the production area and estimating the dated age. In this study, the natural mineral pigments were analyzed by the PIXE method performed by 1.7 MV pelletron tandem accelerator system at Tokyo City University (TCU-Tandem), and major elements and trace elements were clarified. We compared for some samples with the analysis results of the instrumental neutron activation analysis (INAA) method carried out in the previous study [1]. The cinnabar in a reddish pigments contains much mercury and it is difficult to quantify trace elements by INAA, because after activation radioactivity of mercury masks other trace elements. The PIXE method is effective for this type of trace element analysis.

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Unravelling secrets from atoms to planets

The new PIXE setup of RUBION

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PS2.12

Abstract

The PIXE setup of the RUBION Institute of the Ruhr University in Bochum has been recently upgraded. A 70 mm^2 SDD detector has been installed and thoroughly tested by means of a variable X-ray source and an up to 3 MeV proton beam. The proton beam was delivered by the 4 MV tandem Dynamitron accelerator of RUBION. For the determination of the instrumental constant H and the thicknesses of the absorbers, several mono-element standards as well as a NIST and a BAM certified multi-element glass were used. In order to avoid the entrance of backscattered beam ions into the detector, the energy of the proton beam was varied from 1.4 MeV to 3.0 MeV, depending on the thickness of the absorber used. The instrumental constant H was found to be energy independent within 4%. The results of this calibration will be presented along with some first applications in Garnet and Feldspar as well as in thin Ni-, Co-ferrite and GaSb layers deposited onto Si substrate. The Garnet and Feldspar mineral samples were provided by the Institute of Geology, Mineralogy and Geophysics of Ruhr University. The main objective was the quantification of rare-earth elements. The ferrite and GaSb layers were produced in the Faculty of Chemistry and Biochemistry of Ruhr University through chemical vapor deposition. The goal in this case was the determination of the concentrations of all the major elements (Fe, Co, Ni, Ga and Sb).

Poster Session 3

PIXE characterisation of some natural and industrial spices for nutritional assessment study

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PS3.01

Abstract

The elemental contents of the natural and industrially-processed spices were determined for the nutritional benefits [1,2] and assessment. The low temperature oven-dried samples were pulverised and self-supporting pellets made in triplicates. The elemental analysis was carried out using Proton beams from the Particle Induced X-ray emission (PIXE) channel of the Ion Beam Analysis (IBA) facility at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigerian. A total of 33 elements: Na, Mg, P, S, Cl, K, Ca, Mn, Fe, Co, Cu, Zn, Se, Zr, Mo, Ti, Cr, Ni, Nb, Sr, Bi, Ba, I, Si, V, Al, Rb, As, Ge, Pb, Po, Th and U were detected and quantified, which were classified as being essential or toxic. The concentrations of most of the elements were found to be below the recommended dietary allowance values, signifying their suitability for consumption. However, the presence of toxic elements like Pb could add to the toxic metal burden in human body, capable of posing serious health challenges [3,4]. A good quality control measures for the cultivation and processing of spices is suggested to ensure non-contamination and hence the nutritional safety of the consumers.

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Heavy elements in chestnuts detected by PIXE

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PS3.02

Abstract

Portugal is the third largest European producer of Chestnut fruit (Castanea sativa Miller), with an average production of 25 thousand tons [1]. Chestnut fruits are an important food resource and they can be consumed fresh, cooked, roasted or incorporated in several sub-products, such as flour, pastry or candies. Earlier studies on chestnuts elemental composition were performed by atomic absorption to detect low-medium elements such as Ca, Mg, Na, K, Cu, Fe, Mn and Zn or by UV-VIS spectrophotometry to detect P [2-3]. In this work the elemental composition of two cultivars (Longal and Judia) of Castanea sativa Miller were studied by means of PIXE (Proton Induced X-ray Emission), using a broad proton beam at CTN-IST, Lisbon. Element identification (from Si to Pb) and quantification was done following the method described in [4]. Results show different composition according with the cultivar, not only in the major and minor elements (as it is described in the bibliography) but also in the trace elements, which includes the presence of Pb. These preliminary results are part of a wider project that aims to evaluate chestnut fruits decontamination treatment with high energy electron beam and X-rays technology.

Acknowledgments

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Information depths of analytical methods assessing whitefish otolith chemistry

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PS3.04

Abstract

Otolith chemistry is a useful tool in the tracking of fish migration, in the discrimination of fish stocks and in the monitoring of aquatic environments. Prior to elemental analysis, a common preparation method is to embed the otolith in epoxy, sulcus side down, and polish it until the core is visible. The first annual growth ring is usually the largest, while the rest of the annuli are more densely spaced. The material within the first annual ring reveals the chemical environment during the first year of the fish. It is, however, important to look beneath the surface. The shallow structure of the growth rings in the sagittal plane of otoliths prepared in this way may pose a risk for interference from the outer growth rings, representing another part of the life history. The depth of the first growth ring is in fact smaller close to the core due to the shape of the sulcus. The information depth in the otoliths depends on the analytical method of choice. PIXE and XRF analysis are non-destructive methods well suited for measuring strontium and zinc distributions or multi-element mapping. The information depth in PIXE depends on the energy of the incident particles and on the element to be analysed while in XRF it depends mostly on the element to be analysed. LA-ICP-MSs are available in single- or multi-collector modes, the latter providing excellent information on isotopic ratios. These methods are sensitive enough to measure a wide variety of elements, but the calibration is demanding. The information depths can be determined from the depth of the laser-ablated craters that remains on the otolith surface after the analyses [1]. We compare the information obtained by analysing whitefish otoliths with these different instrumental methods. The whitefish (n=30) were captured in the Baltic Sea close to their spawning grounds [2]. Among these whitefish there are sea spawners, river spawners and stocked fish with different life history and different otolith chemistry.

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Energy Dispersive High Resolution PIXE and Unilateral-RMN study of *Vinho verde* grapes

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PS3.05

Abstract

The first energy dispersive high resolution PIXE (EDHR-PIXE) spectra were obtained more than 10 years ago [1] using a first generation X-ray Microcalorimeter Spectrometer (XMS) having 1.5% relative energy resolution at Si K_α 1.739 keV. During the passed decade, the sytem was used for material sciences applications, geological applications, and fundamental work. The use of more sensitive samples was avoided mostly due to the long time exposures necessary to obtain enough statistics. In the present work, EDHR-PIXE is used for a preliminary study of portuguese Vinho Verde grapes produced by young vineyards (seven years old) in organic farming mode and fourty year-old vineyards in conventional farming mode. Results are compared with relaxometry data obtained by unilateral nuclear magnetic resonance [2].

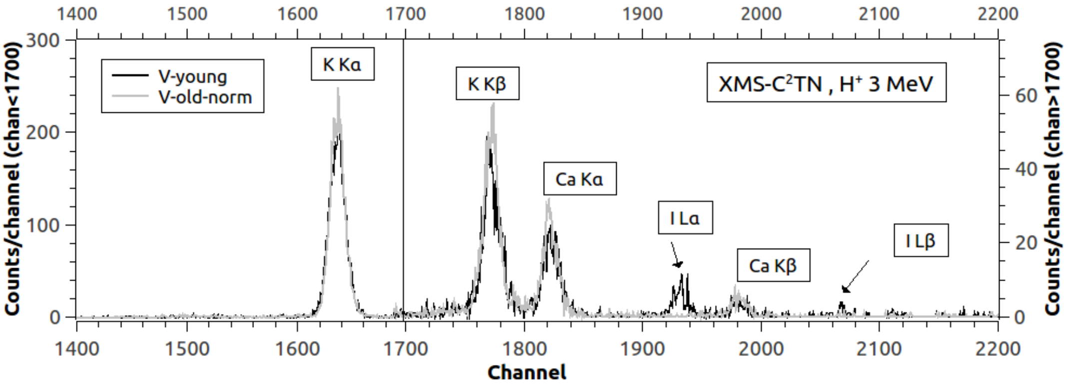

Figure 1: Comparison of EDHR-PIXE spectra of pressed powder samples of organic farming grown grapes (V-young) and conventional farming grown grapes (V-old-norm). V-old-norm data is normalized to V-young data at the maxima value measured in the K K_α peak.

Acknowledgements

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Unravelling secrets from atoms to planets

Elemental analysis of roots and leaves from O. glaberrima at vegetative stage of growth using combined RBS-PIGE-PIXE methods

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PS3.06

Abstract

Oryza glaberrima (Steud.) rice plants were domesticated 3500 years ago in the inland delta of the upper Niger River in present-day Mali. This endogenic plant is cultivated in West Africa, and is adapted to very different environments from the desert region of Mali to the humid forests of Sierra Leone. The aim of this study was to evaluate the suitability of O. glaberrima for phytoremediation, a sustainable agriculture technology used for removing toxic metals from contaminated soil, water and air, which is dependent on the plant roots and leaves capabilities to concentrate and metabolize the contaminants. A comparative analysis of the elemental composition of roots and leaves of O. glaberrima plants cultivated in Senegal during the vegetative growth stage provided information on the tolerance of this plant crops to accumulate micronutrients necessary for plant growth that become toxic at high levels. The elemental analysis of basic nutrients (C, O), macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Si, Al, Cl, Fe, Cu, Mn, Ni, Zn and Mo) in the roots and leaves of O. glaberrima was made possible by several ion beam techniques existent at the Tandetron Laboratory of the Nuclear Physics Institute from the Czech Academy of Sciences (Czech Republic). Proton induced gamma ray spectroscopy (PIGE) was applied for the quantification of micronutrients B, Al and Si and Rutherford backscattering spectrometry (RBS) for the determination of the basic nutrients of rice roots and leaves C and O and of the primary macronutrient N. Particle induced X-ray spectroscopy (PIXE) analysis was used for the elemental quantification of rice plant nutrients (P, K, Ca, Mg, S, Cl, Fe, Cu, Mn, Ni, Zn and Mo).

Elemental characterization and iron uptake evaluation of zebrafish larvae exposed to iron oxide nanoparticles

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PS3.07

Abstract

We report on micro-PIXE characterization of zebrafish larvae (danio rerio) exposed to dextran-coated superparamagnetic iron oxide nanoparticles (SPION@DX) in order to evaluate iron uptake and biodistribution. The larvae were exposed in the system water for five days to a SPION@DX solution in a range of iron concentrations between 0 and 8mM. Cryosectioning (60 μm-thick layers) was executed on pre-fixated larvae, according to well established histological protocols specific to zebrafish [1]. The sections were laid onto a polymeric substrate and dehydrated in an evacuated desiccator at room temperature. A semi-quantitative analysis of acquired micro-PIXE spectra was performed through charge normalization of counts. The major endogenous elements in the zebrafish spectra are C, O, P, S and Ca. No significant variation in the signal of such elements was observed in both control and exposed animals. In addition, the acquired elemental maps indicate a homogeneous distribution of those componentes throughout the larvae's body. While in the control samples there was no iron signal distinguishable from background, spectra of SPION@DX exposed larvae exhibited a clear iron peak, with no preferential localization observed in the maps. PIXE data was used to establish a curve correlating exposure level to iron concentration in the body.

Reference

[1] J. Copper et. al. Comparative analysis of fixation and embedding techniques for optimized histological preparation of zebrafish. Comparative Biochemistry and Physiology, Part C 208 (2018) 38-46

PIXE analysis of atmospheric aerosol in Arak city and identification of polluting sources

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PS3.09

Abstract

Samples of atmosphere aerosols were collected from October 2017 to April 2018 with the same period of gathering time in industrial city of Arak, Iran. The measurements were analysed with Proton Induced X-ray Emission (PIXE) method and in some cases the results were also compared with X-ray fluorescence (XRF) analysis. The result revealed that the samples are composed of various elements including Al, Ca, Cl, S, Si, Fe, K, Mg, Zn, Mn, Ti, Cu, Ce, As, Pb and Co. In this study the time trend, monthly and seasonal variations, the correlation between the elements, concentrations and sources of air pollution in the city of Arak have been discussed. It was indicated that the agents of Zn, Ti, Fe elements were increased in winter time due to the industrial activity and vehicular traffic. The most correlations coefficient were found between Ca:Fe, Ca:Si and Al:Si and the Cu and Mg have the lowest correlations coefficient with measured elements. Statistical positive matrix factorization model revealed that the main pollution sources in Arak city are dust, mineral salts company, aluminum factory, MSA factory and Shazand petrochemical company. Based on wind rose maps in different seasons and high concentrations of the dust agents it can be concluded that they are due to the origin of dust in Iran's inner deserts in SE and fine dust from SW direction of Arak.

Investigation of aerosol pollution on trams in Debrecen (Hungary)

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PS3.10

Abstract

The majority of the Earth's population lives in urban areas. One of the most important environmental issue is the atmospheric aerosol pollution.The problem is not specific only for metropolitan areas, it also means serious problem for the relatively small settlements. Hungary is a Central European country, where the second largest city is Debrecen with about 200 000 inhabitants.In the previous years a new tramline was built and parallel to this the old trams has been replaced by new, modern trams gradually. In the first tramline the new, CAF type of trams are started to run about 1.5 years ago, beside the old, KCSV trams, which have been in use for 20 years. In this study the PM2.5 and PMcoarse concentrations and elemental composition were determined on the old and new type of trams in heating and non-heating periods. In the same time we have collected aerosol samples using the same device in an urban background site (in the garden of Atomki) in order to compare the results of the trams to the outside air quality. Mass concentrations were determined by gravimetry and the elemental analysis of the collected samples was carried out by Particle Induced X- Ray Emission (PIXE) method. Our data shows, that the concentration of PMcoarse in heating season for the outdoor air was 27 ng/m^3 in average, 133 ng/m^3 for the old trams and 96 ng/m^3 for the new type of trams. The average concentrations of PM2.5 were 17 ng/m^3 (outdoor air), 44 ng/m^3(old tram) and 36 ng/m^3 (new tram). In non-heating season the concentration of PMcoarse for the outdoor air was 13 ng/m^3 in average, for the old tram was 74 ng/m^3 and for the new tram was 27 ng/m^3. The average concentrations of PM2.5 were 11 ng/m^3 (outdoor air), 42 ng/m^3 (old tram) and 31 ng/m^3 (new tram).

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Elemental Concentration of Whole Milk Cream

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PS3.11

Abstract

Food packaging and storage are human health issues. In the context of food science, analytical techniques capable of characterizing the elemental composition and monitoring modifications caused by different package types and storage conditions are highly desirable. Ion beam analysis proved to be a powerful tool for this kind of study. In particular, particle-induced X-ray Emission (PIXE) have already been employed in the investigation of canned food. In this work, we study the elemental composition of the whole milk cream, as well as the possible diffusion of elements from the packages to the milk according to the storage time using PIXE. Protons of 2 MeV delivered by a 3 MV Tandetron accelerator were used as an excitation source for X-rays. Two different brands of whole milk cream with different fat levels and expire dates were analyzed. Moreover, two types of carton (Tetra Pak® or steel) were examined as well. To prepare solid samples, the whole milk cream is homogenized, heated to low temperature to reduce the water content, cremated in a Bunsen burner and pressed into pellets. In the case of packages, small pieces were cut for analysis. The qualitative analysis showed the presence of 12 characteristic elements in the heavy cream, while other elements were identified in the packages. No particular pattern was observed for the elements present in the whole milk cream. Preliminary analysis of the packages and the whole milk cream does not indicate any possible diffusion of elements from the packages to the milk.

PIXE analysis of aerosol crustal elements collected on Whatman paper filters

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PS3.12

Abstract

The North Atlantic region receives aerosols from North Africa, where desert dust export is influenced by long term climate variability and, in some regions, by human use of soil. This aerosol may have implications on processes that have influence on climate, such as radiative forcing, clouds properties or rainfall. This influence on climate of the aerosols depends on their chemical composition and microphysical properties. It is important to know how aerosol properties may change during the trans-Atlantic transport. To this aim measurements of aerosol composition and physical properties have been performed in the eastern North Atlantic - Izaña - Tenerife Global Atmospheric Watch mountain observatory - and the western North Atlantic - Barbados and Miami during intensive campaigns. Samples of aerosol have been simultaneously collected at three sites on Whatman paper filters. PIXE is an unrivaled technique for the study of the dust component of aerosol, due to its high sensitivity to crustal markers (in particular Si, which is in principle detectable with chemical techniques such as Inductively Coupled Plasma - Atomic Emission Spectroscopy, ICP-AES, but whose quantification might be poor). However, it is necessary to correct the underestimation of PIXE in quantifying the concentration of the lighter elements due to X-ray self-absorption inside the individual aerosol particles and inside the filter itself. PIGE is not useful in this case because the energy loss within the depth of the deposit (a priori unknown) is higher than the width of any plateau region in the gamma-ray cross-section e.g. for Na or Al. We have determined the correction factor by comparing the concentrations obtained for the aerosol collected simultaneously on Teflon and Whatman paper filters, both by PIXE and ICP-AES.

Ilex paraguariensis geochemical marker's determination by PIXE

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PS3.13

Abstract

The knowledge about the geographical origin of a foodstuff is related to the consumer safety, besides to add value to the product. One way to identify the geographical origin is to determine the chemical composition of the foodstuff, looking for geochemical markers. In this context, the packaged tea leaves of *Ilex paraguariensis* (*yerba mate* tea leaves) from different South America regions were analyzed by Particle-Induced X-Ray Emission (PIXE). The aim of this work was to determine the elemental composition of the commercialized tea leaves and to verify the presence of geochemical markers through statistical tests. A total of nine production regions were studied. All measurements were performed using a 2 MeV proton beam in the PIXE experimental line from the Ion Implantation Laboratory (Porto Alegre, BR). Results showed that Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Br, Rb, Sr and Ba are present in the commercial product of yerba mate. The concentration data of these elements were submitted to the Analysis of Variance followed by Tukey test ($p = 0.05$). The comparison between the different packages, from each studied region, showed that they have some differences, instead be produced under some conditions. However, considering the elemental average concentration for each region, it was possible to observe statistical differences between the regions, for almost all quantified chemical elements, except for S, which did not differs among the studied regions. Based on the multivariate statistical tests, such as Hierarchical Clusters Analysis (HCA) and Principal Component Analysis (PCA), it was verified that the variability of the elements, considering different packages and regions, may be used to characterize the provenance of the commercial product of *Ilex paraguariensis*. Some elements, such as Mg, Cu, Sr, Mn, Ni, and S, are correlated, which could be used to differentiation of the geographical origin of this product.

Characterization of urban aerosol pollution under a smog episode in Debrecen by size distribution, PIXE and radiocarbon analysis

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PS3.14

Abstract

Size distribution and chemical composition are two of the key parameters in the characterization of atmospheric particulate matter pollution. These features provide information about particle formation, aging, transport, sources, they are closely related to the impact of APM pollution on human health and the effects on the global radiation budget. Mass size distribution of atmospheric aerosol pollution as well as its elemental components, total carbon, Fossil Carbon and Contemporary Carbon content were characterised using a nanoMOUDI-II type cascade impactor during a smog episode in January of 2017 in Debrecen, Hungary. To our best knowledge this is the first time when detailed mass size distribution of Fossil Carbon and Contemporary Carbon are presented, which was allowed by the recent developments on the 14C analysis with the EnvironMICADAS AMS in Debrecen. The elemental composition ($Z \geq 16$) was determined by PIXE. The daily average PM10 concentration was 105 μgm^{-3} during the investigated event. Droplet mode was accounted for $\sim$ 50% of the total particulate mass suggesting that growth processes of condensation mode particles were enhanced during this period characterised by high 90% RH. Carbonaceous aerosol contributed 31% to the total aerosol mass in which 18% was of contemporary and 13% was of fossil origin. Both carbon components showed peaks at the Aitken and the accumulation mode attributed to freshly emitted carbon containing particles. In the middle size ranges the contribution of Contemporary Carbon was higher, while in the ultrafine and the coarse size fractions Fossil Carbon was more dominant. Comparing the modal characteristics of trace elements and carbon components, the following sources were identified: biomass burning; vehicle exhaust, coal combustion, brake abrasion, road dust, tyre abrasion and mineral dust. Biomass burning via domestic heating was the most significant source of air pollution however, the effect of traffic was also not negligible.

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Papp	I.		O.18
Parry	D.		I.4
Pásztor-Török	Z.		PS3.14
Paterson	D.		I.4
Payr	P.		I.2
Pearce	M.		I.4
Pelemo	D. A.		O.12
Pelicon	P.		O.26, O.29
Petric	M.		O.01
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R			
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Radic	R.		O.34
Raisanen	J.		I.9
Ramos	M. M.		O.38
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Ridikas	D.		I.9
Rogalla	D.		PS2.12
Rohanová	D.		PS2.06
Rodrigues	A. L.		O.24
Rodriguez	S.		O.31, PS3.12
Rösemeier	S.		O.21
Ruberto	C.		PS2.10
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S			
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Saitoh	Y.		O.32
Salomé	P. M. P.		O.16
Samek	L.		O.34
Sano	Y.		PS1.14
Sato	M.		O.35
Satoh	T.		O.36, PS1.16
Scheffer	K.		O.18
Schiwietz	G.		O.02
Schmaus	D.		O.09
Schreiber	A.		O.20
Sega	K.		O.34
Seko	N.		PS1.13
Šemrov	A.		PS2.04
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Seznec	H.		I.7
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Shi	Z.		O.31
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Souza	V. S.		O.38
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Stefanovska	A.		O.34
Stegowski	Z.		O.34
Steydli	S.		O.09
Stoytschew	V.		PS1.10
Strivay	D.		**O.15**
Suzaki	J.		PS1.16

Suzuya	Y.		PS1.16
Szikossy	I.		O.18
Szikszai	Z.		O.18
Szilágyi	V.		O.19
Szoboszlai	Z.		PS3.10, PS3.14
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T			
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Tacconi	N.		PS2.10
Talmatchi	C.		PS2.07
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Török	Z.		PS3.10
Traoré	A.		PS3.06
Thopan	P.		PS2.01
Turatti	A. M.		PS3.13
Turchenko	D. V.		O.34
U			
Ugwumadu	C. E.		O.05
Unai	S.		PS1.10
Ushijima	H.		O.08, O.35
Usman	M.		PS1.11
V			
Valadas	S.		PS2.02
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Vanin	V. R.		O.06
Vaid	K.		O.30
Varga	T.		PS3.14
Vavpetič	P.		O.29
Vega	N. A.		O.25
Veleva	B.		O.34
Veritá	M.		PS2.03
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Vratolis	S.		O.34
Vretenar	M.		I.6
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Wu	L.		O.11
Wu	M.-Y.		O.09
Wu	X.		O.11
Y			
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Yamagata	R.		O.36
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Y			
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PIXE2019 - Caldas da Rainha 24-29 March 2019

PI•E 2019	24 Mar 2019	Monday 25 Mar 2019	Tuesday 26 Mar 2019	Wednesday 27 Mar 2019	Thursday 28 Mar 2019	Friday 29 Mar 2019
9h00 - 9h20		Registration		Buses to ESTM	I.6 - Cultural Heritage P. Mandò (C&G 2)	I.8 - Aerosol D.D. Cohen (ATA 2)
9h20 - 9h40		Opening	I.3 - PIXE in Geant4 A. Mantero (DSE 2)			
9h40 - 10h00		I.1 - Fundament & App. Z. Smit (F 1)			T. Calligaro O.22 (C&G 2)	Z. Kertesz O.34 (ATA 2)
10h00 - 10h20			V. Bilyk O.11 (DSE 2)	I.5 - α particles PIXE J.L. Campbell (at ESTM amphitheater)	M. A. Reis O.23 (C&G 2)	A. Terakawa O.35 (ATA 2)
10h20 - 10h40		S. Fazinic O.01 (F 1)	E.I. Obiajunwa O.12 (DSE 2)		I. Dias O.24 (C&G 2)	W. Kada O.36 (ATA 2)
10h40 - 11h00		J. Dias O.02 (F 1)	K. Phelan O.13 (DSE 2)		**Coffe break**	**Coffe break**
11h00 - 11h20		**Coffe break**	**Coffe break**		E. de la Fourniere O.25 (BEA 1)	I.9 - Forensic A. Simon (FA 1)
11h20 - 11h40		M. Kavcic O.03 (F 1)	M. Bailey O.14 (STC 1)		C. dos Santos O.26 (BEA 1)	
11h40 - 12h00		M. Msimanga O.04 (F 1)	D. Strivay O.15 (STC 1)		IAC Meeting	J. Dias O.37 (FA 1)
12h00 - 12h20		F. Olise O.05 (F 1)	V. Corregidor O.16 (STC 1)			R. Debastiani O.38 (FA 1)
12h20 - 12h40		Lunch & Poster mounting*	Lunch			Closing
12h40 - 13h00					Lunch	Poster removal*
13h00 - 14h00						
14h00 - 14h20		I.2 - XMS Detectors A. Fleischmann (DSE 1)	I.4 - PIXE & Synchrotron C. Ryan (STC 2)			
14h20 - 14h40					I.7 - Single cells & tomog. P. Barberet (BEA 2)	
14h40 - 15h00		J. Fernandez-Varea O.06 (DSE 1)	J. Cruz O.17 (STC 2)			
15h00 - 15h20		M. Nogami O.07 (DSE 1)	S. Kertesz O.18 (STC 2)		G. Grime O.28 (BEA 2)	
15h20 - 15h40		**Coffe break**	**Coffe break**		K. Cloete O.29 (BEA 2)	
15h40 - 16h00		K. Ishii O.08 (DSE 1)	Z. Szokefalvi-Nagy O.19 (C&G 1)		R. Virk O.30 (BEA 2)	
16h00 - 16h20		I. Vickridge O.09 (DSE 1)	F. Munnik O.20 (C&G 1)		**Coffe break**	
16h20 - 16h40		J. Restrepo O.10 (DSE 1)	H. Hofsass O.21 (C&G 1)		F. Lucarelli. O.31 (ATA 1)	
16h40 - 17h00		Poster Session 1 Fundam. , Detectors, Software & E.S.T.C.	Round table on Det. & Soft. C. Jeynes		K. Sera O.32 (ATA 1)	
17h00 - 17h20					H. Sa'adeh O.33 (ATA 1)	
17h20 - 17h40					Poster Session 3 B.E.A.T. & Foren. App.	
17h40 - 18h00			Poster Session 2 C.H. & Geo. App.			
18h00 - 18h20	Welcome party	**Questions & Answers for GUPIX users**				
18h20 - 18h40	Reception & Registration					
18h40 - 19h00						
19h00 - 19h30			IAC - IHC Meeting			
19h30 - 20h00					Conference Dinner	

* Posters will be in display during the whole conference period

F - Fundamentals (F 1 session 1)

DSE - Detectors, Software and Experimental Systems ; (DSE 1, session 1) (DSE 2, session 2)

STC - Simulation and Techniques Combination ; (STC 1, session 1) (STC 2, session 2)

E.S.T.C. - Experimental Systems, Simulation, Techniques Combination

C&G - C.H. & Geo. App. - Cultural Heritage & Geological Applications ; (C&G 1, session 1) (C&G 2, session 2)

BEA - Bio & Envir. App. - Biological and Environmental Applications ; (BEA 1, session 1) (BEA 2, session 2)

ATA - Aer. & Tox. App. - Aerosol and Toxicological Applications ; (ATA 1, session 1) (ATA 2, session 2)

B.E.A.T. & Foren. App. - Biological, Environmental, Aerosol, Toxicological and Forensic Applications

FA - Forensic Applications (FA 1 session 1)