Joint ICTP-IAEA-MAMBA School on Materials Irradiation: from Basics to Applications

19 February 2025

Aliz Simon

Physics Section
Department of Nuclear Sciences and Applications
International Atomic Energy Agency

Aliz.Simon@iaea.org

Three Pillars
- Main Areas of Activity

Safeguards & Verification

Safety & Security

Science & Technology

IAEA
Aliz.Simon@iaea.org

Sustainable Development Goals

Atoms for Peace and Development

IAEA
Aliz.Simon@iaea.org

Organization

Departments (6)

Aliz.Simon@iaea.org

Science and Technology

Food & Agriculture

Promoting food security and sustainable agricultural development

Human Health

Improving the diagnosis and treatment of diseases and nutrition

Science & Industry

Providing knowledge & expertise for science & industry

Water Resources

Making more, and cleaner water available to more people

Environment

Understanding and protecting the environment

Aliz.Simon@iaea.org

Division of Physical & Chemical Sciences (NAPC)

Nuclear Data

- Data Development
- Data Services
- Atomic & Molecular Data
  Fundamental fusion data

Physics

- Accelerator & Research Reactor Applications
- Nuclear Instrumentation
- Nuclear Fusion

Radioisotope Production & Radiation Technology

- Medical Radioisotope production, Radiopharmaceuticals
- Radiotracers, NCS & NDT in industry
- Radiation technology applications
- Terrestrial Environment

Isotope Hydrology

- Isotopic methods for groundwater assessment
- Water resource management
- Scenario modelling

Aliz.Simon@iaea.org

Radiation damage of materials

RPRT Section

Electron, X-ray and Gamma irradiation of heritage objects

Nanoscale radiation engineering of advanced materials for potential biomedical applications

Physics Section-Accelerators

Radiation effects on
Heritage objects and materials

Physics Section-Materials Science

Neutron-induced damages to materials
High dose radiation effect on core structural materials
in advanced nuclear systems

Physics Section-Accelerators

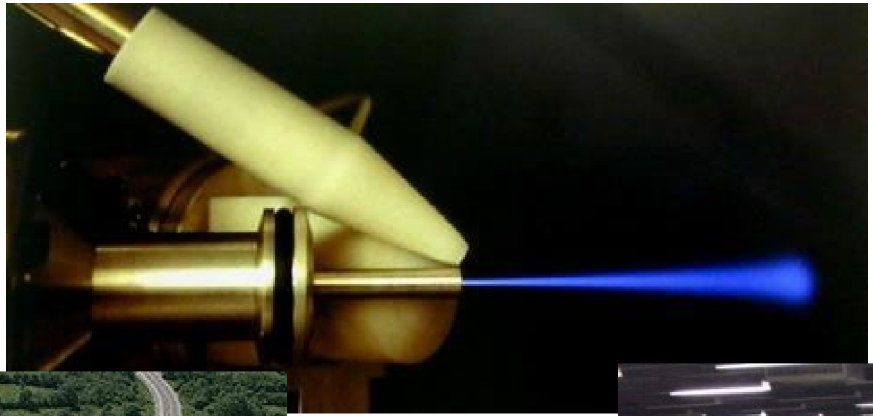
Ion beam-induced damages of semiconductors and insulators
Radiation hardness of microelectronic devices

Nuclear Data Section

Development, maintenance and dissemination of the relevant databases and models

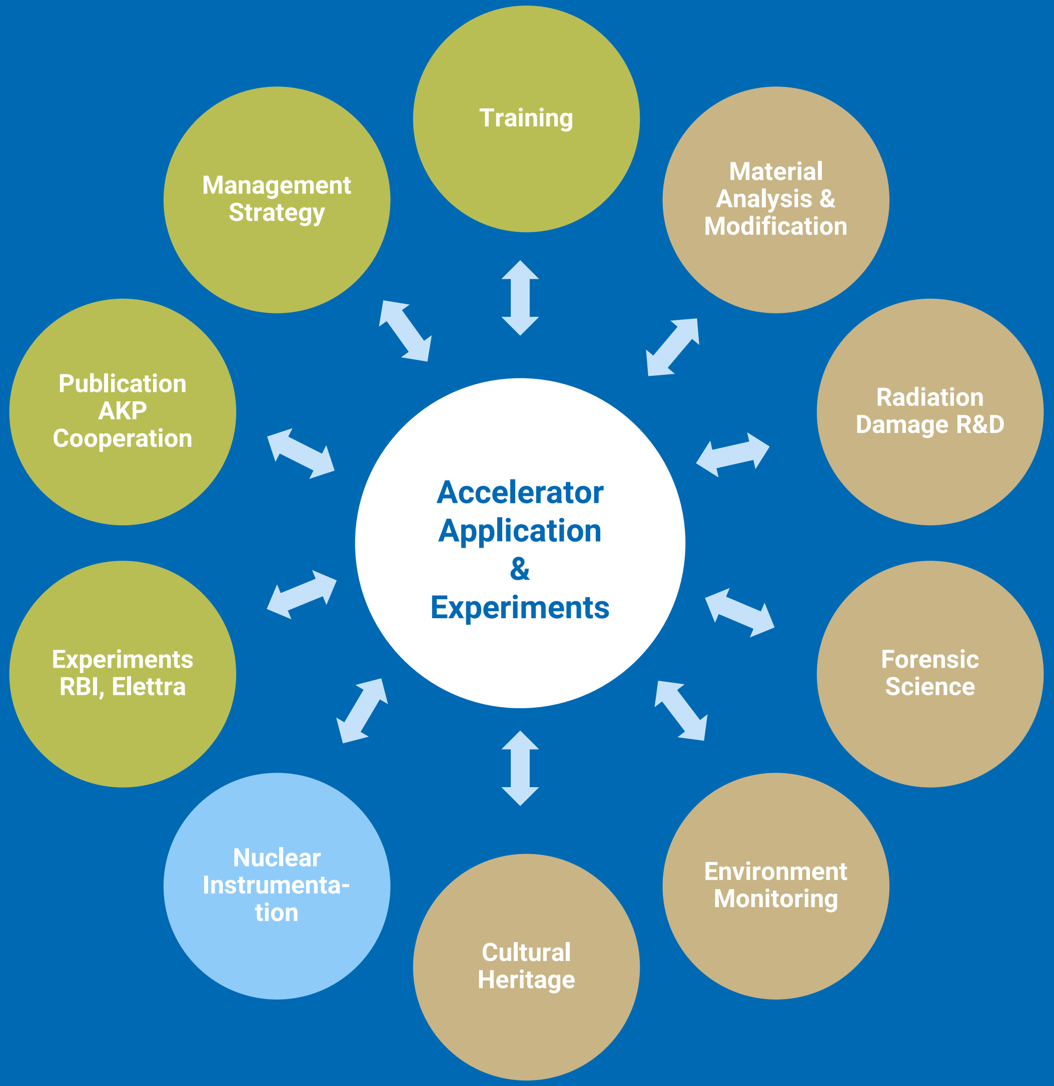
http://www-nds.iaea.org/

Small, Medium and Large-scale Research Facilities: Accelerators



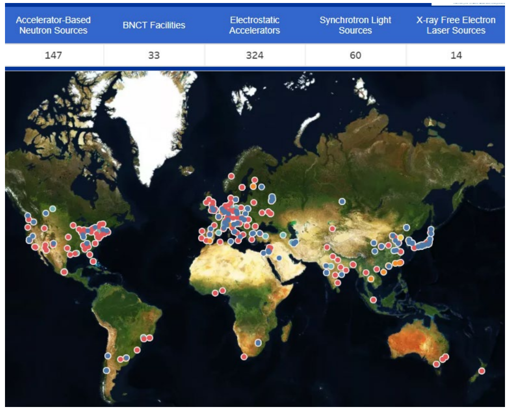
Aliz.Simon@iaea.org

Physics Section Accelerator Sub-programme

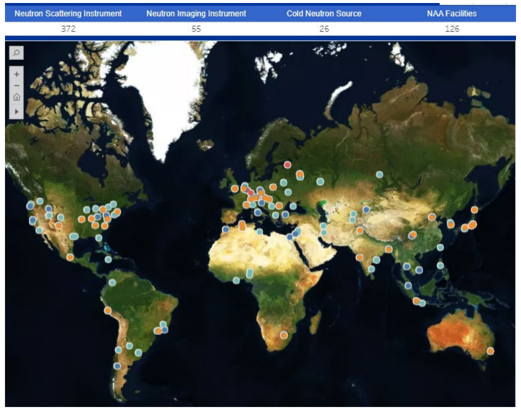


Aliz.Simon@iaea.org

IAEA Physics Section: Database of world-wide research infrastructure

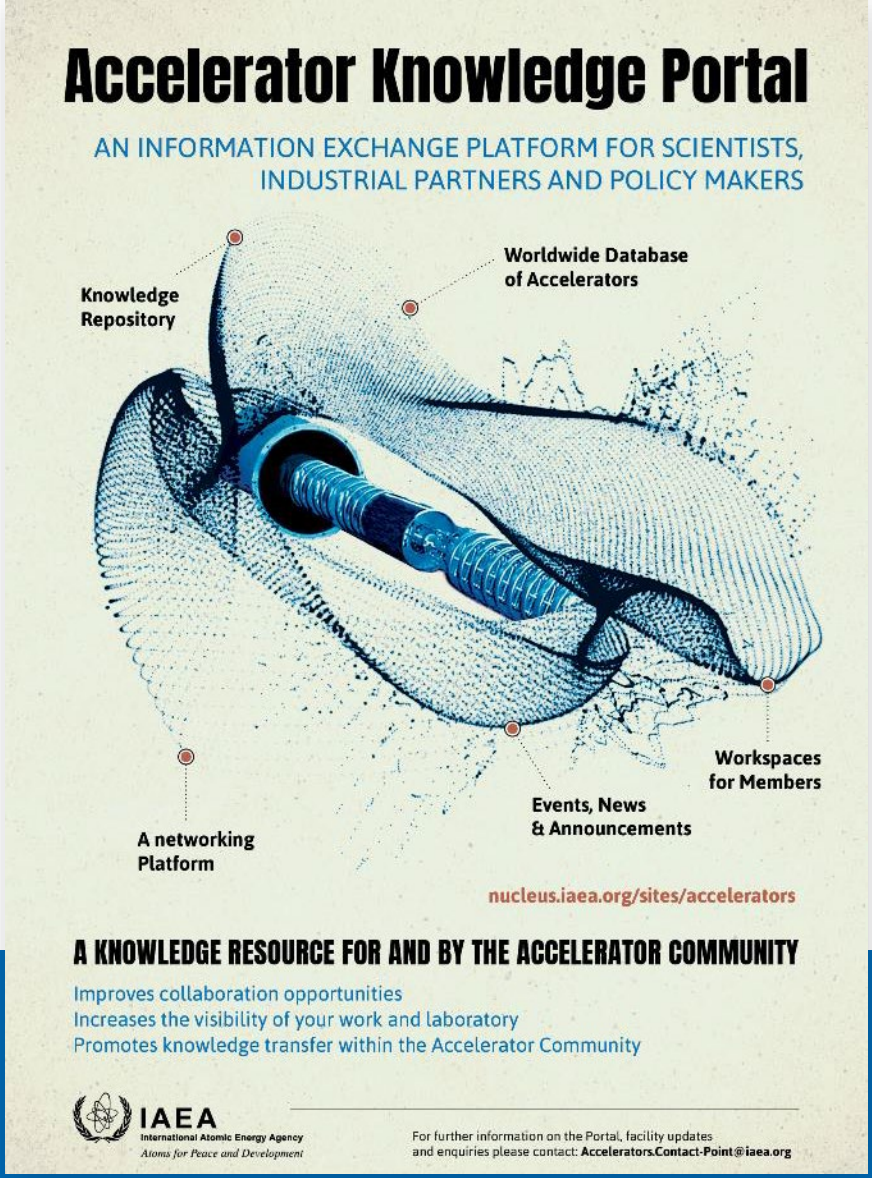


Accelerator Facilities
Total: 578 in 59 countries



Neutron Beam Instruments
Total: 579 in 58 countries

https://nucleus.iaea.org/sites/accelerators/

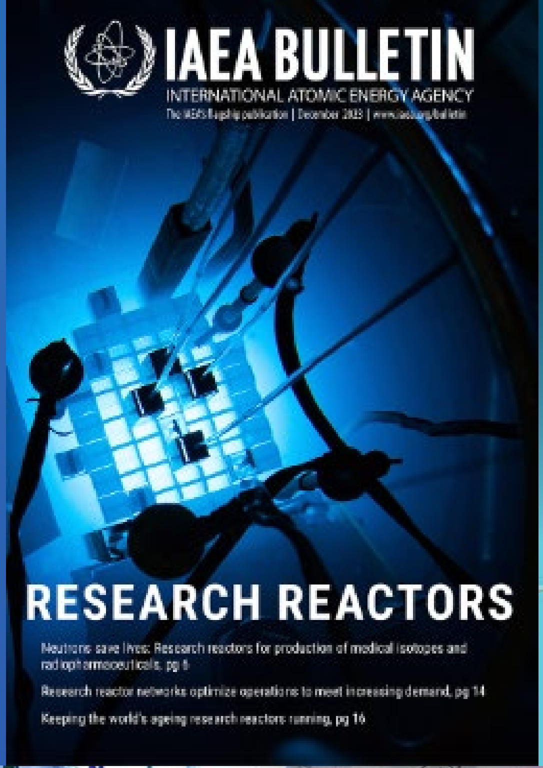


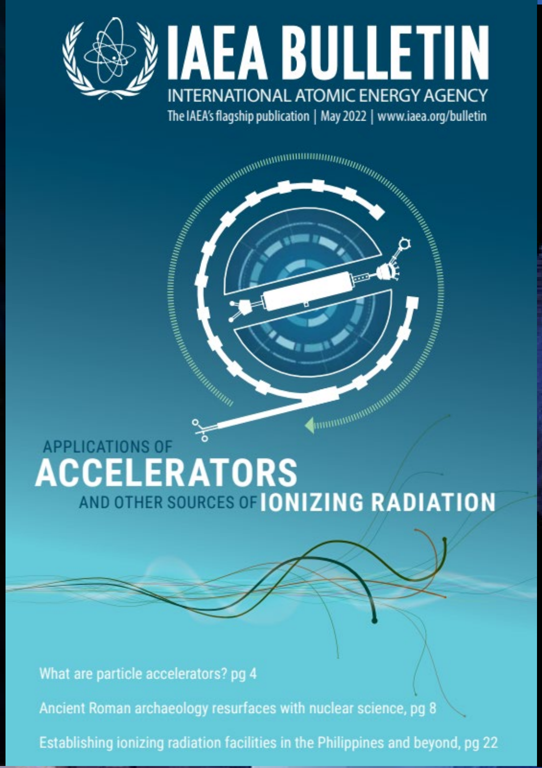
Neutrons: https://nucleus.iaea.org/sites/neutrons/
Fusion: https://nucleus.iaea.org/sites/fusionportal/
Instrumentation: https://nucleus.iaea.org/sites/nuclear-instrumentation/

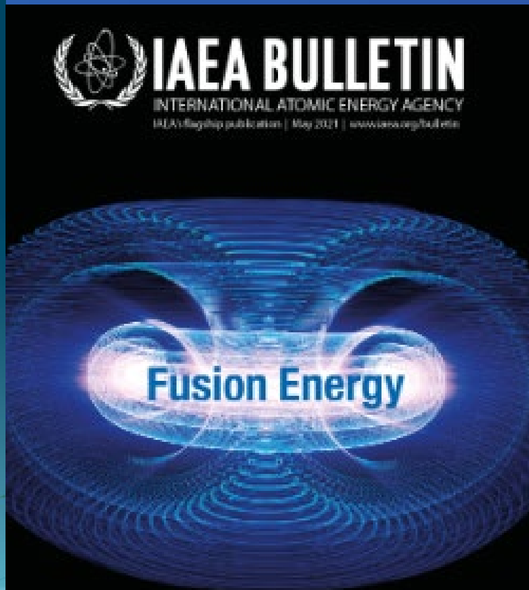
https://nucleus.iaea.org/sites/accelerators

IAEA
International Atomic Energy Agency

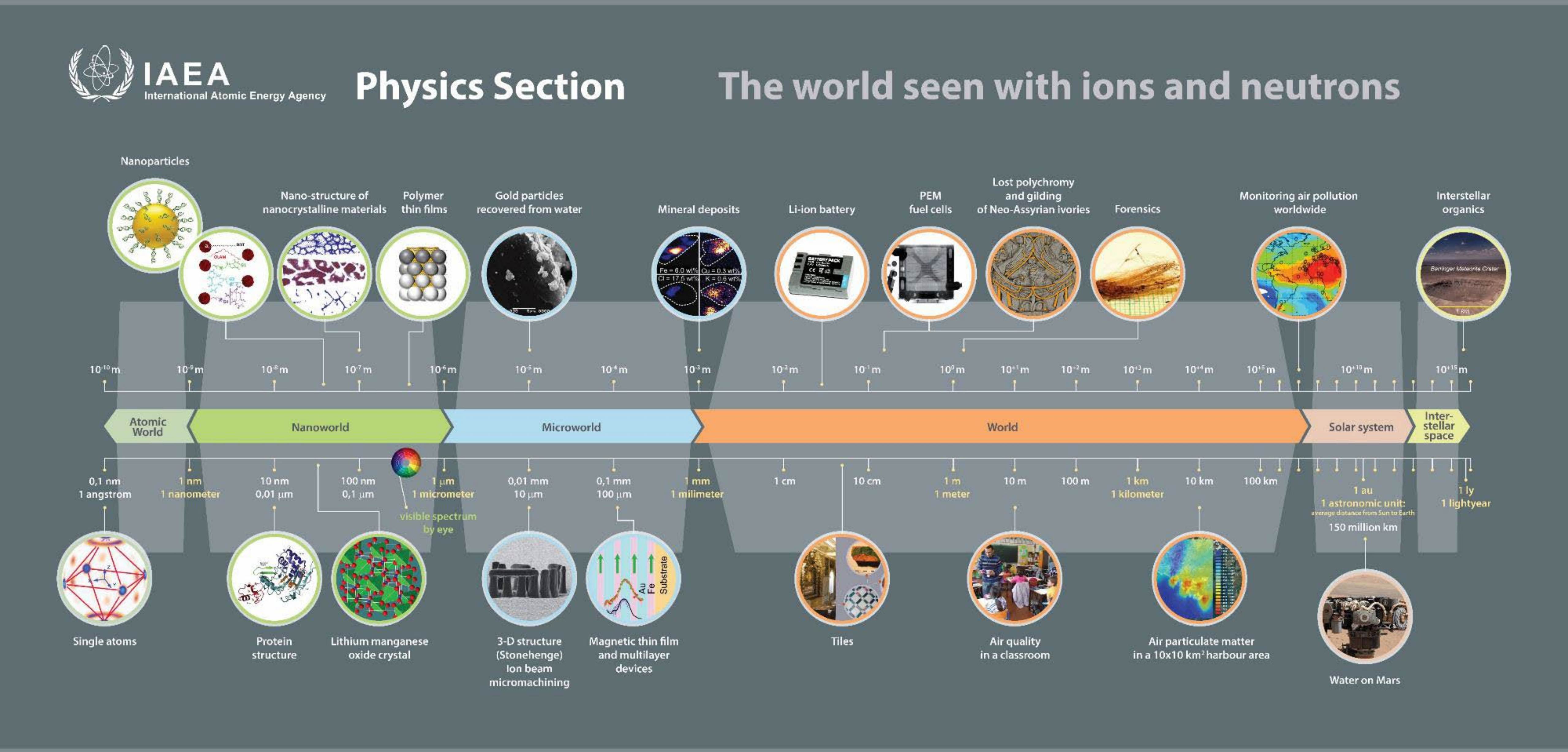
[Scientific, technical publications in the nuclear field | IAEA]







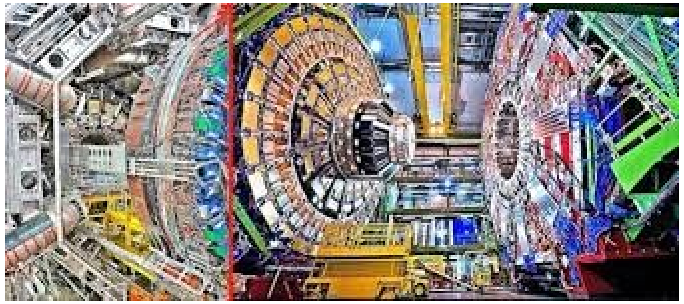
A new version is in preparation

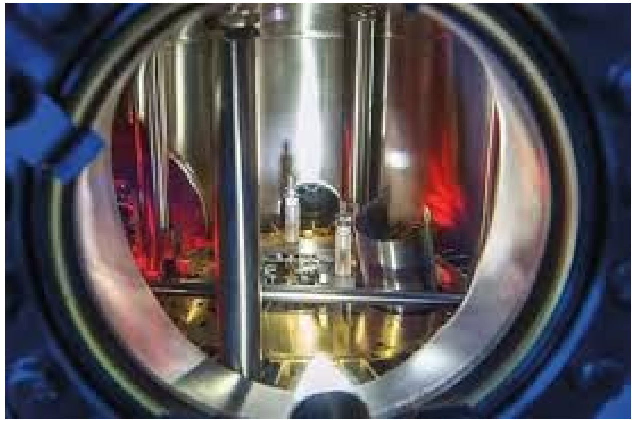


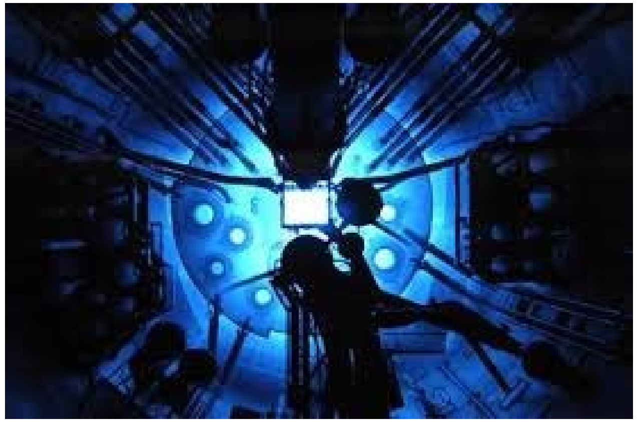
Visit the IAEA Accelerator Knowledge Portal "Case Studies" page

IAEA
Aliz.Simon@iaea.org

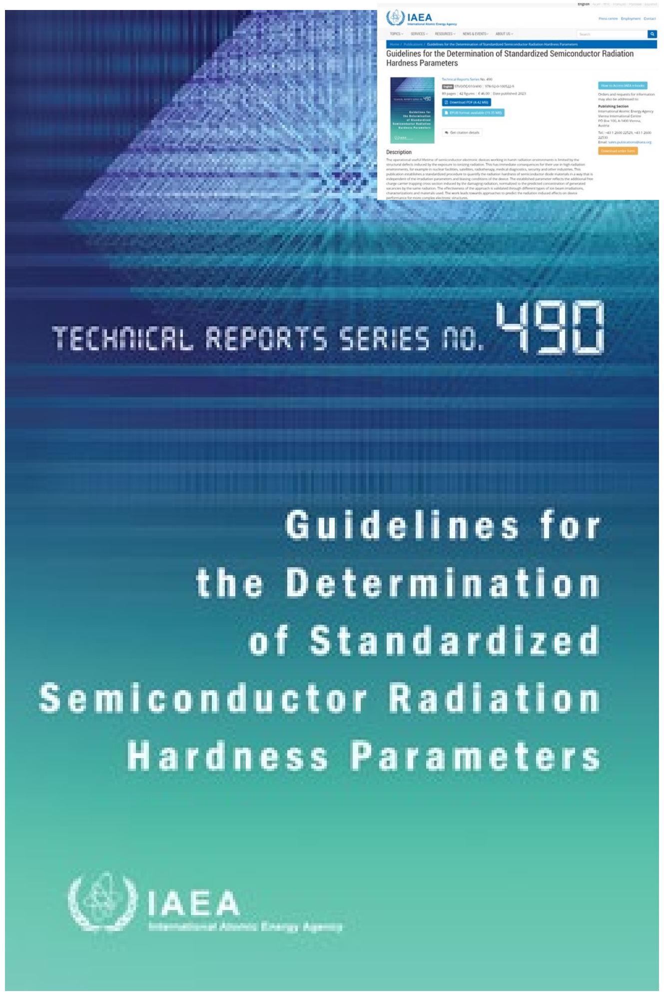
Radiation hardness – lifetime of semiconductor devices



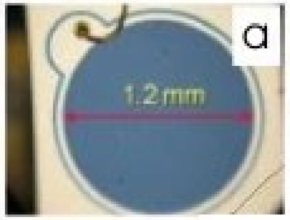


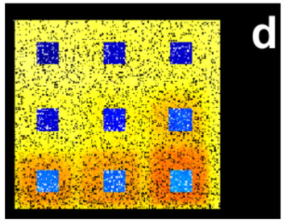


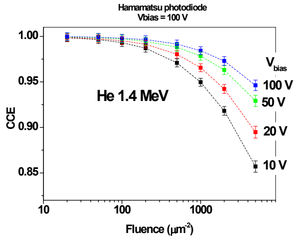
Guidelines for the Determination of Standardized Semiconductor Radiation Hardness Parameters

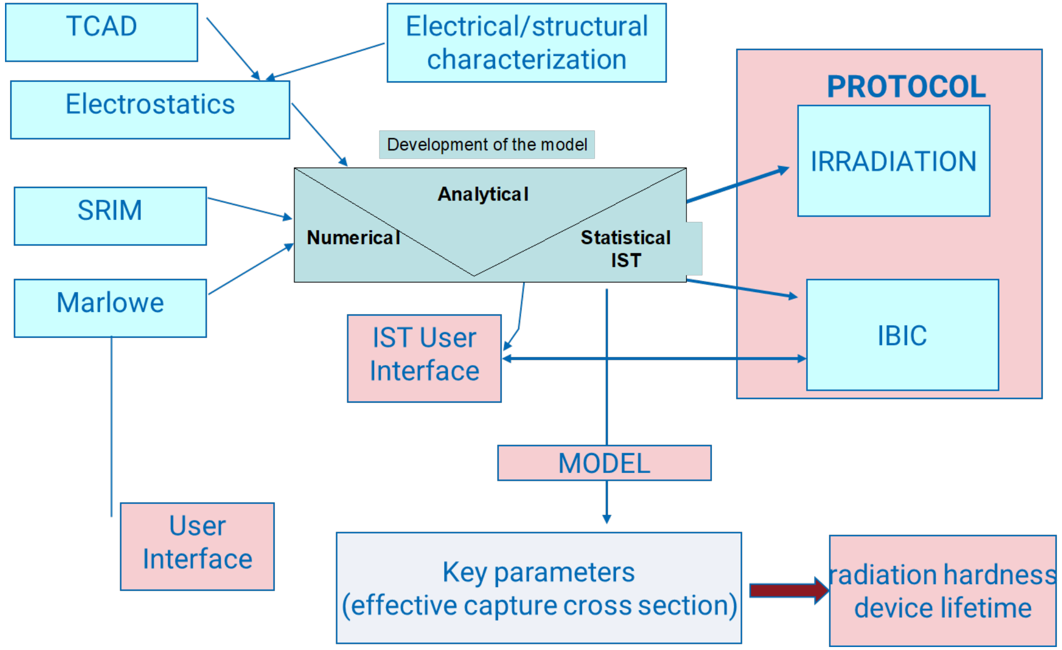


Can be downloaded for free of charge from the IAEA website.









Prof. Ettore Vittone
University of Turin, Italy

IAEA
Aliz.Simon@iaea.org

The Abdus Salam International Centre for Theoretical Physics

ICTP Celebrating International Year of Quantum Science and Technology

SEE OUR CALENDAR OF QUANTUM EVENTS!

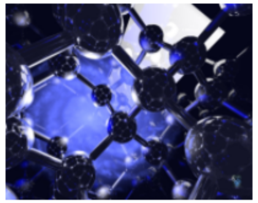
IAEA E-learning on Quantum Science

IAEA | Learning Management System
powered by CLP4NET

OPEN-LMS English (en)

Prof. Paolo Olivero, University of Turin, Italy

Ion-beam Engineering of Materials for Quantum Technologies



New quantum technologies could open the door to transformational advances in secure communications, information technology and high precision sensors and provide new solutions to pressing challenges in fie
and security, shaping global development in the 21st century.

Accelerator-based techniques involve high-energy ions that allow us to create atomic-scale modifications, or defects, in materials such as silicon and diamond, or two-dimensional materials, such as graphene. It is t
quantum states of these individual atomic-scale defects in the materials, which in turn gives us the capability to control single atoms, including the spin of electrons or nuclei. The result is new materials with the ch
advancing quantum technology.

The purpose of this e-learning course it to provide an overview and knowledge on fundamentals of materials

This tool is an output of the IAEA Coordinated Research Project F11020 "Ion beam induced spatio-temporal structural evolution of materials: Acc

For additional information please contact: Aliz.Simon@iaea.org

Click to enter this course

Joint ICTP-IAEA Advanced School on
Ion Beam Driven Materials Engineering: Accelerators for a New Technology Era
1 - 5 October 2018, Miramare - Trieste, Italy

Ion-beam Engineering of Materials for Quantum Technologies

1. Fundamentals in Ion-Matter Interaction
2. Ion-beam fabrication and lithography
3. Basic concepts in quantum technologies
4. Single-photon emitters for quantum communication
5. Ion-induced defect engineering for quantum technologies

https://elearning.iaea.org/m2/course/index.php?categoryid=175

Example I.

IAEA Research project:

Ion beam induced spatio-temporal structural evolution of materials: Accelerators for a new technology era CRP F11020

Univ. Melbourne

ANSTO Australia

Berkeley Laboratory

USA

University of Illinois USA

IAEA F11020 CRP

Ruđer Bošković Inst. Croatia

Helsinki University Finland

CNA Spain

IAEA
International Atomic Energy Agency

JAEA Japan

NUS Singapore

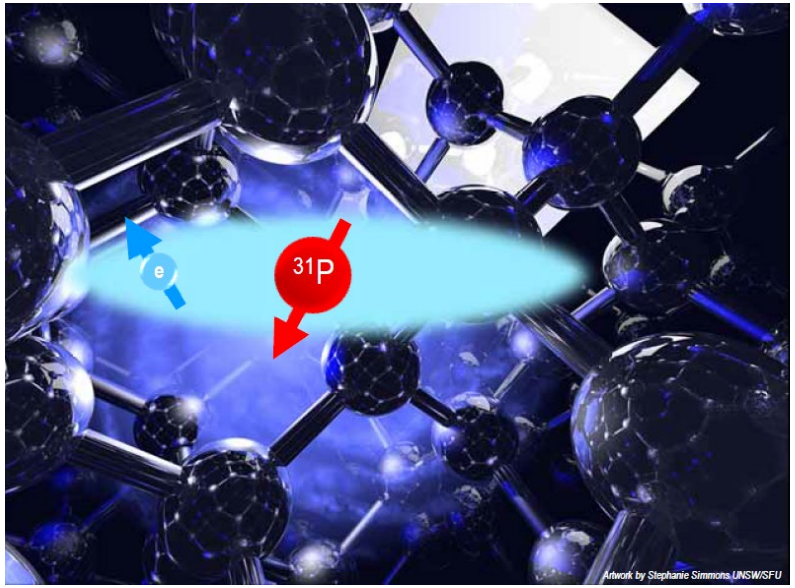
2016-2022

Peking University China

University of Turin, Italy

Project objectives

To develop novel accelerator-based ion beam tools to induce and characterise effects in the spatial and time domains for tailoring materials properties and thus creating new materials towards quantum technologies.



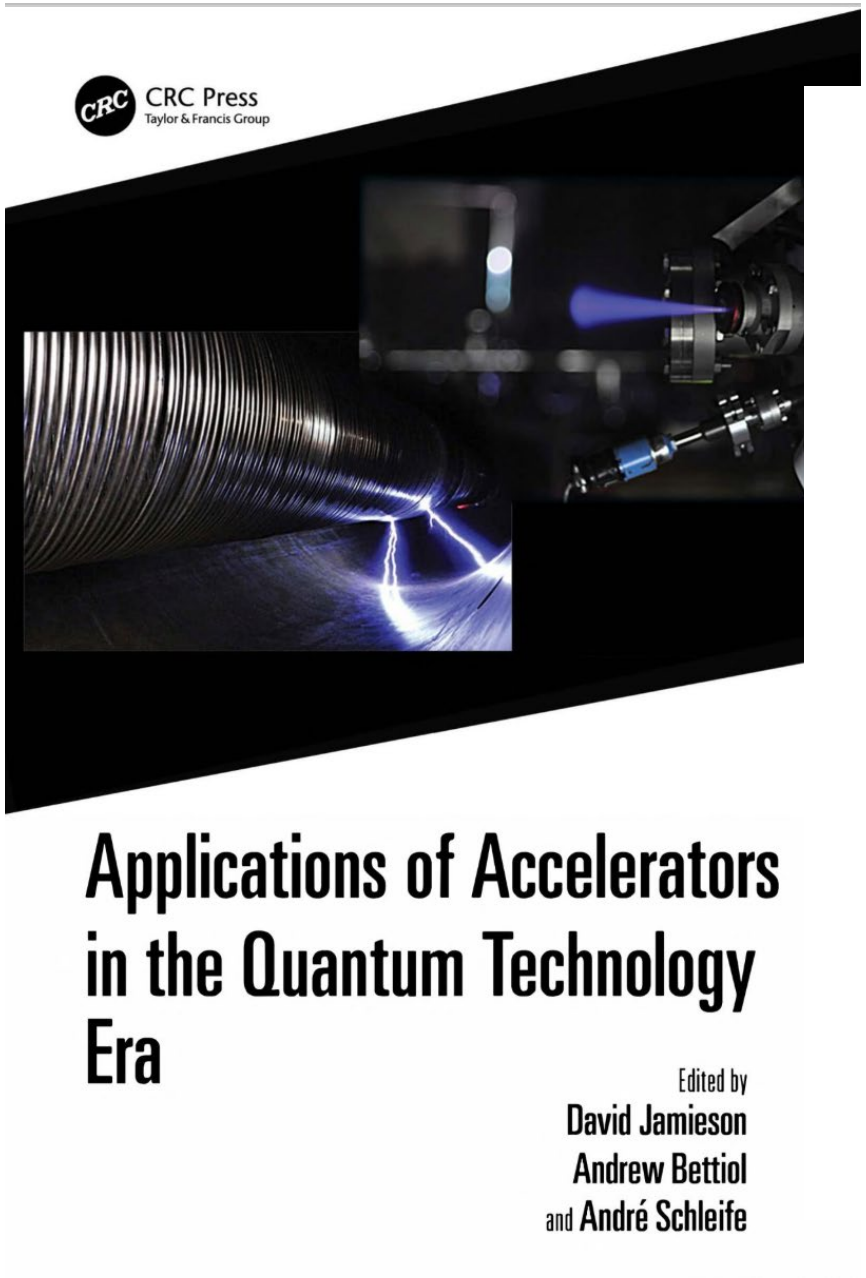
Key unifying theme: Accelerator techniques in the context of technological applications, near and far term

- Ion beam driven materials design with predictive capabilities
- Ion energies from keV to GeV
- Spatial resolution: atomic scale
- Time resolution: from femtosecond
- In-situ modification and analysis

Accelerator types:

- single-ion implanters
- ion beam accelerators
- laser-plasma accelerators

Aliz.Simon@iaea.org



Contents

Example I.

IAEA F11020 CRP Results

100+ scientific papers

100+ scientific talks

25 Master or PhD thesis

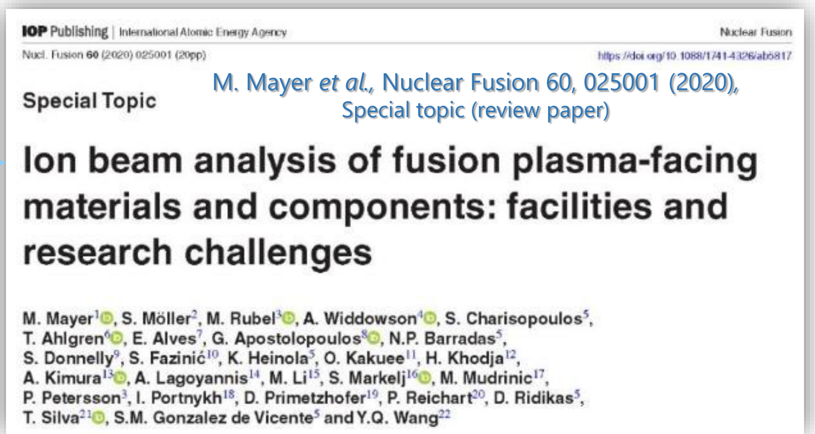
20 national workshops

15+ new projects

by the project partners

Example II.

Development and Application of Ion Beam Techniques for Materials Irradiation and Characterization relevant to Fusion Technology (F11023 CRP)



IOP Publishing | International Atomic Energy Agency — Nuclear Fusion

Nucl. Fusion **60** (2020) 025001 (20pp) https://doi.org/10.1088/1741-4326/ab5817

Special Topic

Ion beam analysis of fusion plasma-facing materials and components: facilities and research challenges

M. Mayer[1], S. Möller[2], M. Rubel[3], A. Widdowson[4], S. Charisopoulos[5], T. Ahlgren[6], E. Alves[7], G. Apostolopoulos[8], N.P. Barradas[5], S. Donnelly[9], S. Fazinić[10], K. Heinola[5], O. Kakuee[11], H. Khodja[12], A. Kimura[13], A. Lagoyannis[14], M. Li[15], S. Markelj[16], M. Mudrinic[17], P. Petersson[3], I. Portnykh[18], D. Primetzhofer[19], P. Reichart[20], D. Ridikas[5], T. Silva[21], S.M. Gonzalez de Vicente[5] and Y.Q. Wang[22]

M. Mayer *et al.*, Nuclear Fusion 60, 025001 (2020), Special topic (review paper)

Major Topics

- IBA in fusion plasma-facing components and materials, including combinations of different Ion Beam methods;
- Fundamental aspects for simulating radiation damage phenomena in materials for fusion energy production;
- Modelling tools and software development
- A cross-section database for IBA in fusion applications;
- A roadmap for future studies of fusion relevant materials using ion-beam accelerators

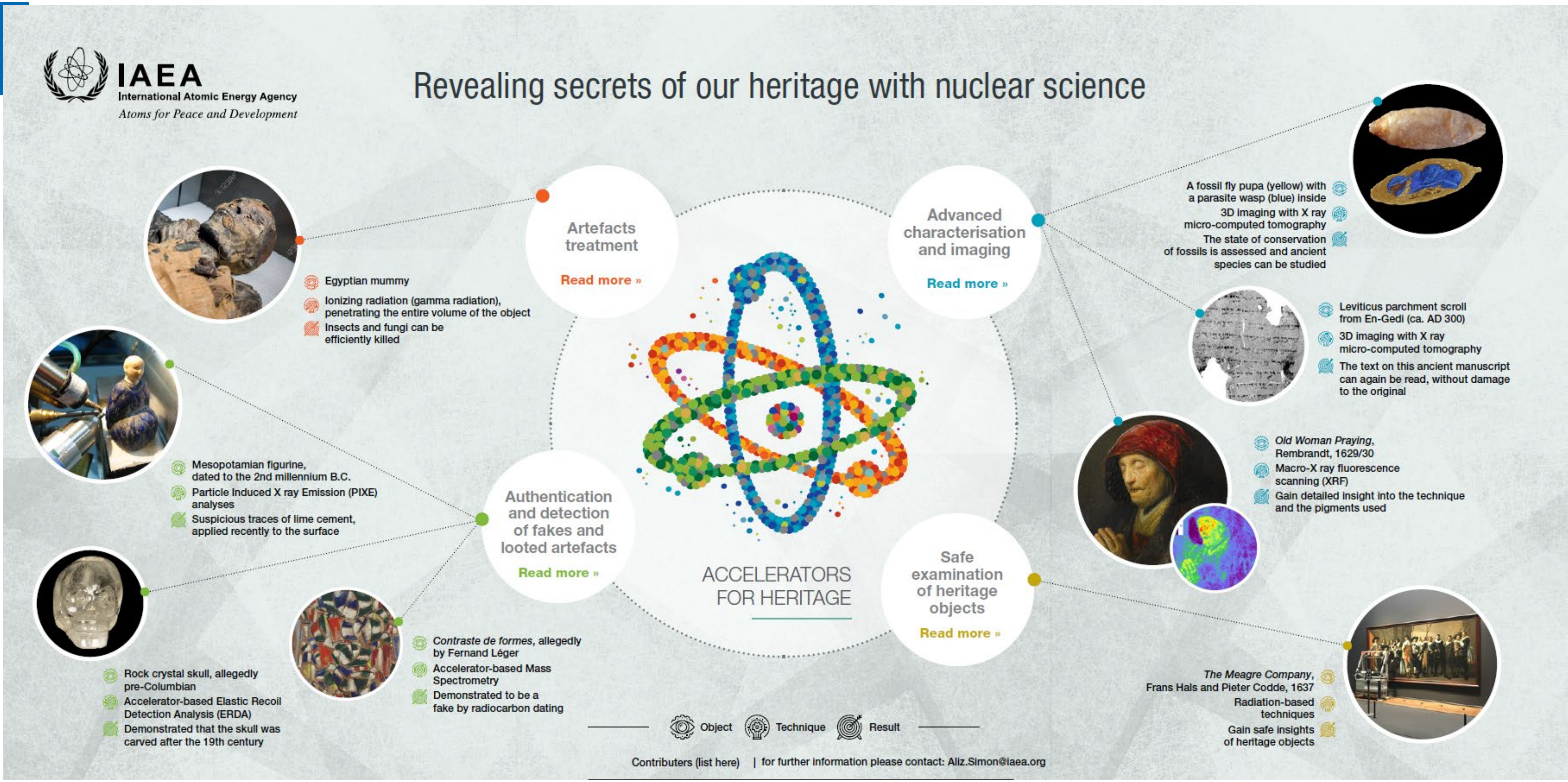
A new CRP was launched in 2020 (F11023)

- Identify data needs and measure fundamental cross-sections for nuclear reactions with fusion relevant materials
- Identify data needs & measure stopping powers in fusion relevant materials with Helium ions
- Define international standards for the analysis of fusion-relevant materials
- Define and produce reference samples and apply these samples for a Round-Robin Test in the IBA fusion community

Contact: S.Charisopoulos@iaea.org

Radiation Effects on Cultural Heritage Objects and Materials

Aliz.Simon@iaea.org


IAEA
International Atomic Energy Agency
Atoms for Peace and Development
Revealing secrets of our heritage with nuclear science
Artefacts treatment
Read more »
Egyptian mummy
Ionizing radiation (gamma radiation), penetrating the entire volume of the object
Insects and fungi can be efficiently killed
Mesopotamian figurine, dated to the 2nd millennium B.C.
Particle Induced X ray Emission (PIXE) analyses
Suspicious traces of lime cement, applied recently to the surface
Authentication and detection of fakes and looted artefacts
Read more »
Rock crystal skull, allegedly pre-Columbian
Accelerator-based Elastic Recoil Detection Analysis (ERDA)
Demonstrated that the skull was carved after the 19th century
Contraste de formes, allegedly by Fernand Léger
Accelerator-based Mass Spectrometry
Demonstrated to be a fake by radiocarbon dating
ACCELERATORS FOR HERITAGE
Advanced characterisation and imaging
Read more »
A fossil fly pupa (yellow) with a parasite wasp (blue) inside
3D imaging with X ray micro-computed tomography
The state of conservation of fossils is assessed and ancient species can be studied
Leviticus parchment scroll from En-Gedi (ca. AD 300)
3D imaging with X ray micro-computed tomography
The text on this ancient manuscript can again be read, without damage to the original
Old Woman Praying, Rembrandt, 1629/30
Macro-X ray fluorescence scanning (XRF)
Gain detailed insight into the technique and the pigments used
Safe examination of heritage objects
Read more »
The Meagre Company, Frans Hals and Pieter Codde, 1637
Radiation-based techniques
Gain safe insights of heritage objects
Object
Technique
Result
Contributers (list here)
| for further information please contact: Aliz.Simon@iaea.org

Disinfection and microbial decontamination

Brazilian weather conditions have been affected directly tangible materials




Insects







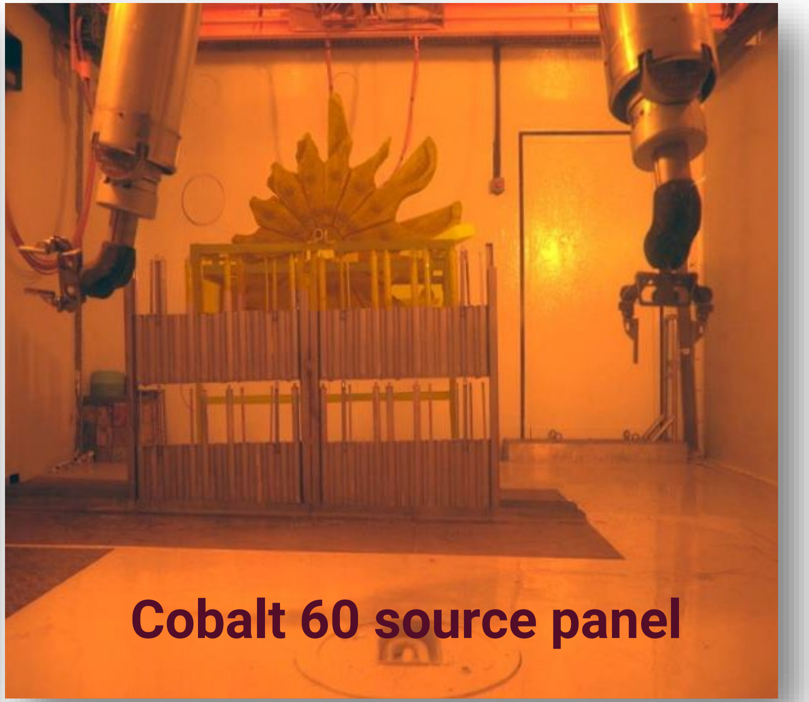

Fungi attack

Natural disasters

Consolidation of porous artefacts

Wood Consolidation by densification in two steps

1) Liquid Resin Impregnation   2) Gamma Radiation-curing of the resin

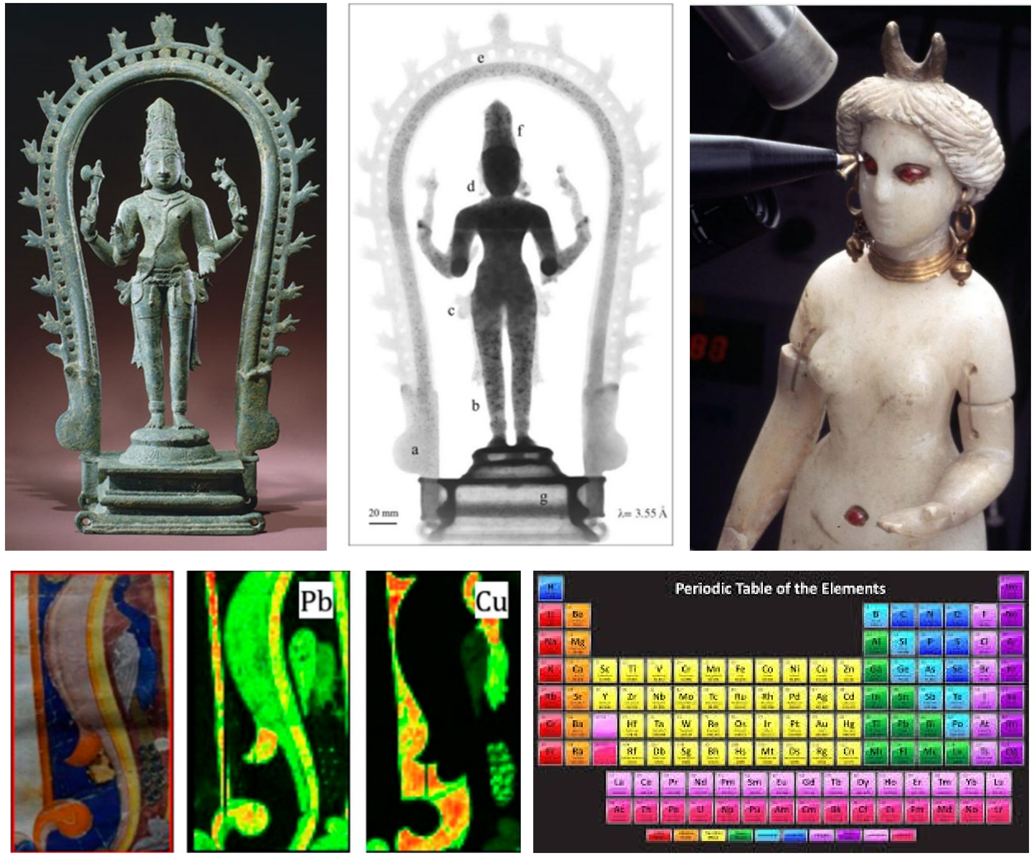


ARC-nucleART
Atelier de Recherche et de Conservation

Courtesy of BumSoo HAN, IAEA Section of Radioisotope Products and Radiation Technology

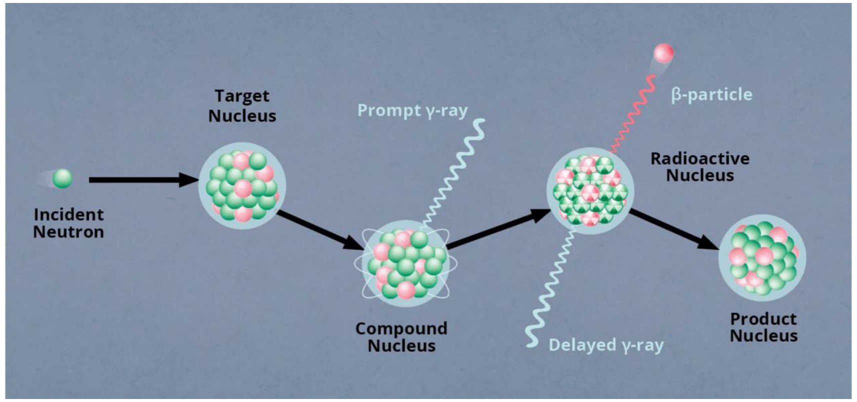
Characterization, dating and imaging (2D and 3D)

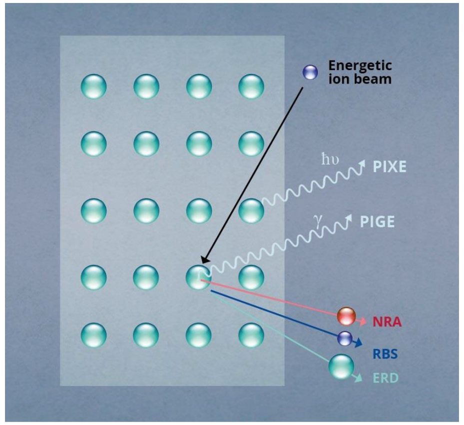
- Identify the material(s) used to make an object
- Identify the age / chronology
- Identify 2D/3D structure
- Identify the technologies, e.g.
  - soldering methods
  - pigments
  - surface coating
  - ink and paint recipes
- Identify the source of materials
  - provenance studies
  - trading routes
- Understand the history of individual objects
  - Corrosion
  - modification and previous conservation

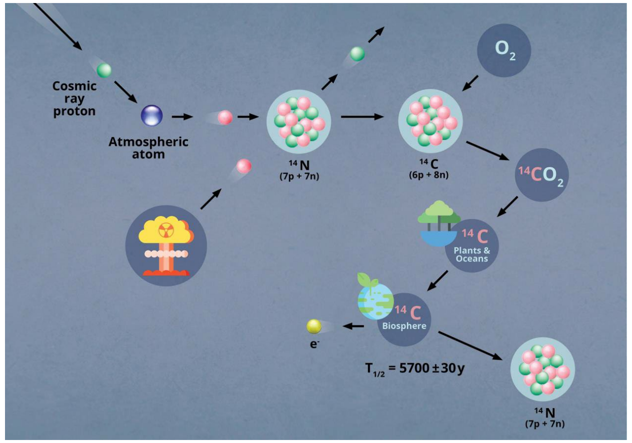


Sottili et al., 2022. https://doi.org/10.3390/app12136585

Aliz.Simon@iaea.org







NAA

IBA

AMS

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Addressing forensic science challenges with nuclear analytical techniques – A review

A. Simon [a,*], N. Pessoa Barradas [a], C. Jeynes [b], F.S. Romolo [c]

Table 2. Summary of characteristics of selected analytical techniques.

The values are indicative only of typical performance that may be achieved.

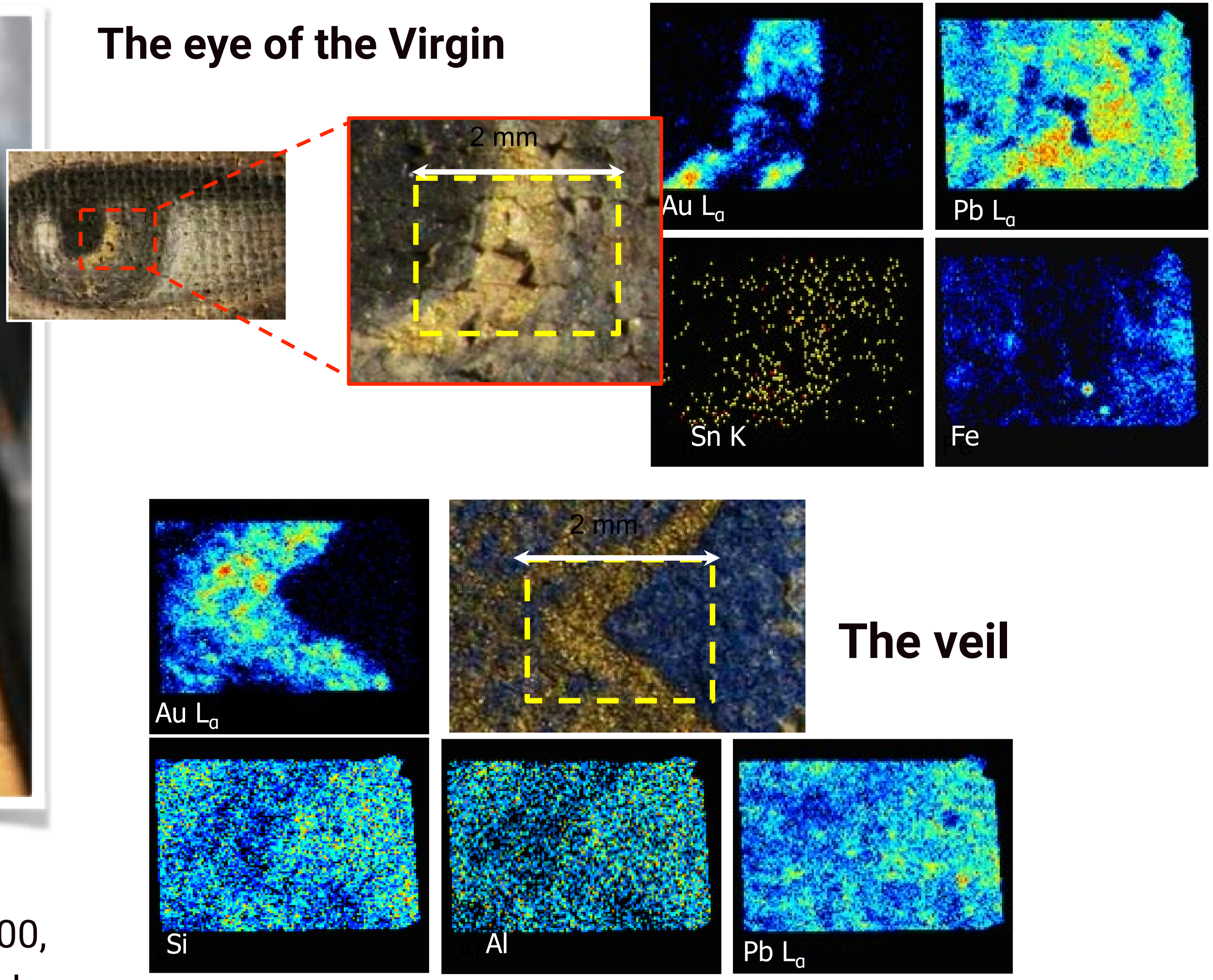
Technique [1]	Measures	Sensitivity [2]	Test portion may be returned [9]	Depth profiling	Quantitative [3]	Information depth [2]	Imaging	Depth resolution [2]
NAA	up to 70 elements	10^{-6}	Yes [10]	No	Reference [5]	bulk	No [8]	-
NDP	light isotopes	10^{-3}	Yes	Yes	Standards [6]	10 mm	No	20 nm
N-imaging	structure	10^{-2}	Yes	Radiography	No [7]	bulk	Yes	10 µm
NR	structure	10^{-3}	Yes	Interference	Reference	10 mm	No	5 nm
N-scattering	structure	10^{-2}	Yes	Interference	Reference	bulk	No	5 nm
EBS	all elements	10^{-3}	Yes	Yes	Total-IBA [6]	10 mm	Yes	5 nm
ERD	all elements	10^{-3}	Yes	Yes	Total-IBA [6]	500 nm	Yes	5 nm
HI-ERD	all elements	10^{-3}	No [4]	Yes	Standards	100 nm	No	2 nm
HR-PIXE	all elements	10^{-6}	Yes	Model	Total-IBA [6]	20 mm	Yes	50 nm
NRA,PIGE	light isotopes	10^{-4}	Yes	Yes	Total-IBA [6]	500 nm	Yes	5 nm
PIXE	all elements	10^{-6}	Yes	Model	Total-IBA [6]	20 mm	Yes	50 nm
RBS	all elements	10^{-3}	Yes	Yes	Reference	10 mm	Yes	2 nm
HE-SIMS	molecules	10^{-5}	No	No	No	100 nm	Yes	1 µm
Total-IBA	all elements	10^{-6}	Yes	Yes	Total-IBA [6]	10 mm	Yes	2 nm
AMS	^{14}C and other isotopes		No	No	Relative isotope ratios	N/A	Rare	N/A
GI-XRF	structure	10^{-3}	Yes	Interference	Reference	50 mm	Yes	2 nm
XRR	structure	10^{-1}	Yes	Interference	Reference	1 mm	No	2 nm
AES	all elements	10^{-3}	Yes	Sputter	Standards	50 nm	No	2 nm
EPMA	all elements	10^{-4}	Yes	Model	Standards	2 mm	Yes	20 nm
GD-OES	all elements	10^{-7}	No	Yes	Reference	50 mm	No	50 nm
LA-ICP-MS	all elements	10^{-7}	No	Yes	Reference	10 mm	Yes	50 nm
SAM	all elements	10^{-3}	Yes	Sputter	Standards	50 nm	Yes	2 nm
SE	structure	10^{-3}	Yes	Model	Reference	10 mm	No	1 nm
SEM	topography	10^{-3}	Yes	Model	Standards	2 mm	Yes	100 nm
SIMS	elements, molecules	10^{-7}	No	Sputter	Standards	100 nm	Yes	2 nm
XPS	all elements	10^{-3}	Yes	Sputter	Standards	50 nm	No	0.5 nm
XTEM	all elements	10^{-2}	No	Xsection	Standards	500 nm	Yes	0.1 nm

Aliz.Simon@iaea.org

IAEA

Elemental mapping with micro-PIXE

Andrea Mantegna, “Madonna col Bambino”, oil on canvas,1490-1500, Accademia Carrara, Bergamo, Italy

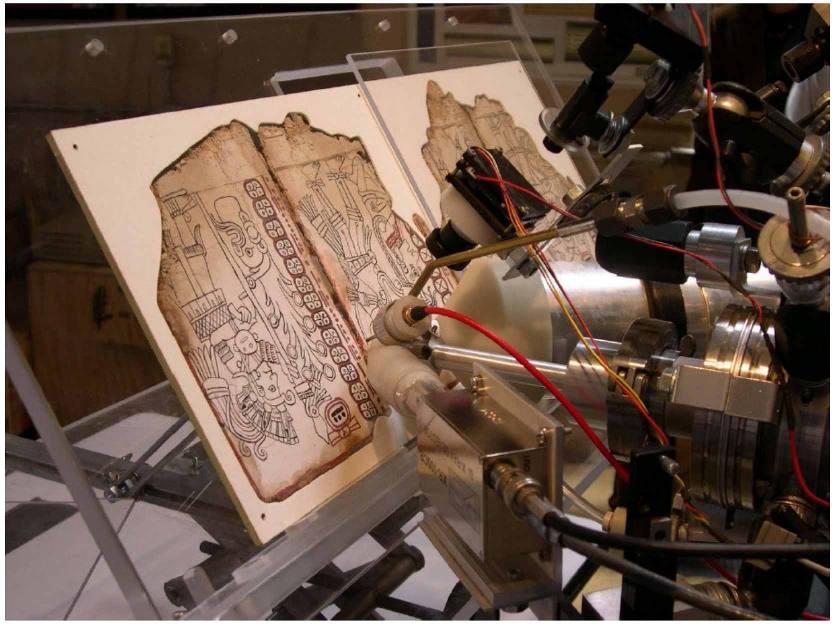


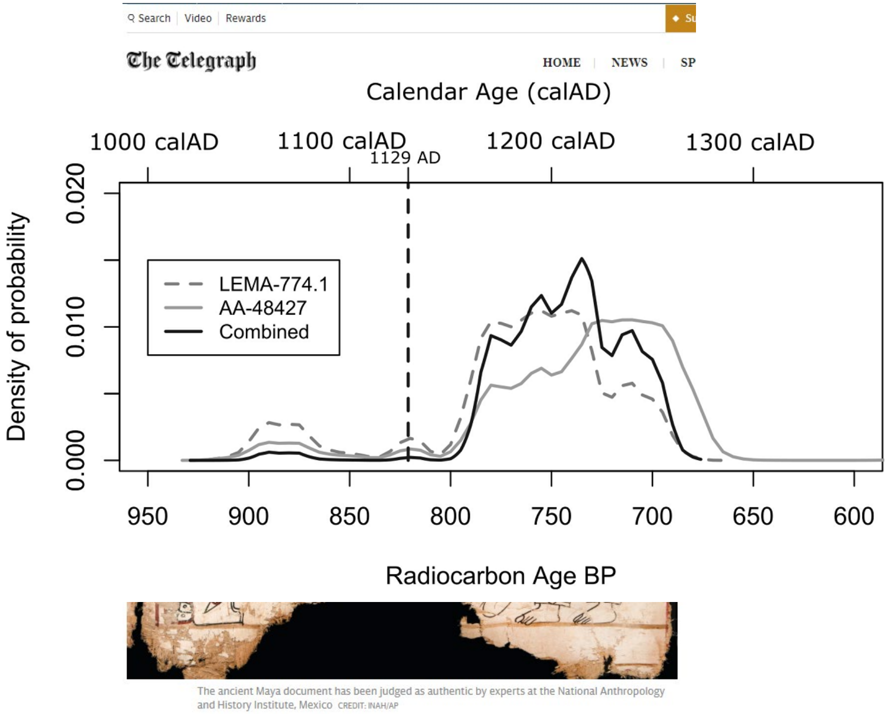
Aliz.Simon@iaea.org

Courtesy of Massimo Chiari, INFN-LABEC, Italy

Authentication of the Maya Codex of Mexico (ex Grolier Codex)

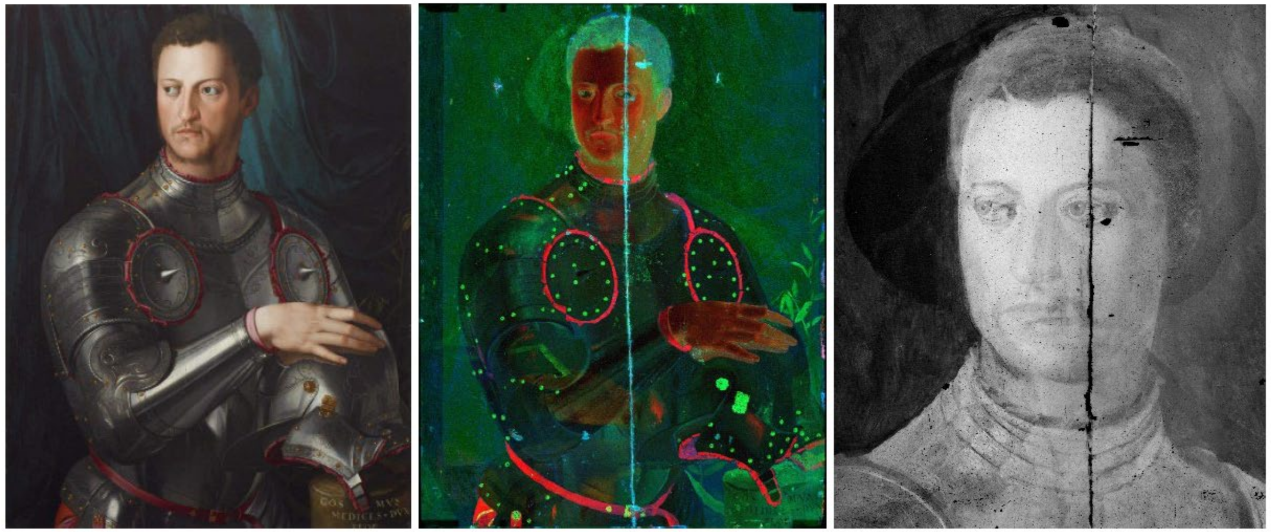
11th-12th century





elemental analysis and age determination

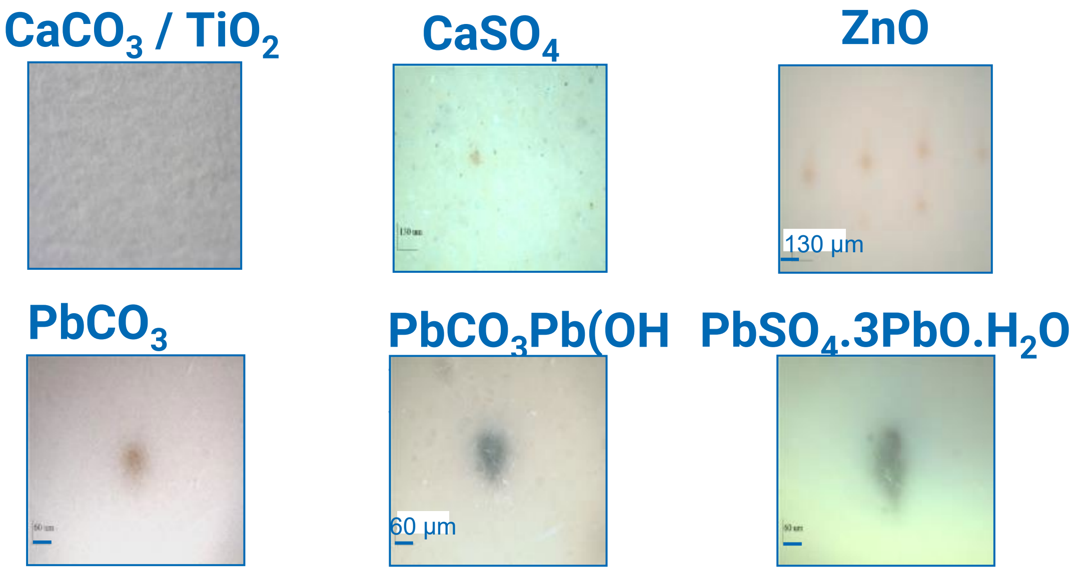
Aliz.Simon@iaea.org Universidad Nacional Autónoma de México, Mexico City, Distrito Federal, Mexico



Australian synchrotron high-definition X-ray fluorescence microscopy based image of a 16th-century Bronzino painting of Duke Cosimo de' Medici (left) has revealed an underlying portrait as well as allowed detecting and mapping metals in paint pigments non-invasively (right).

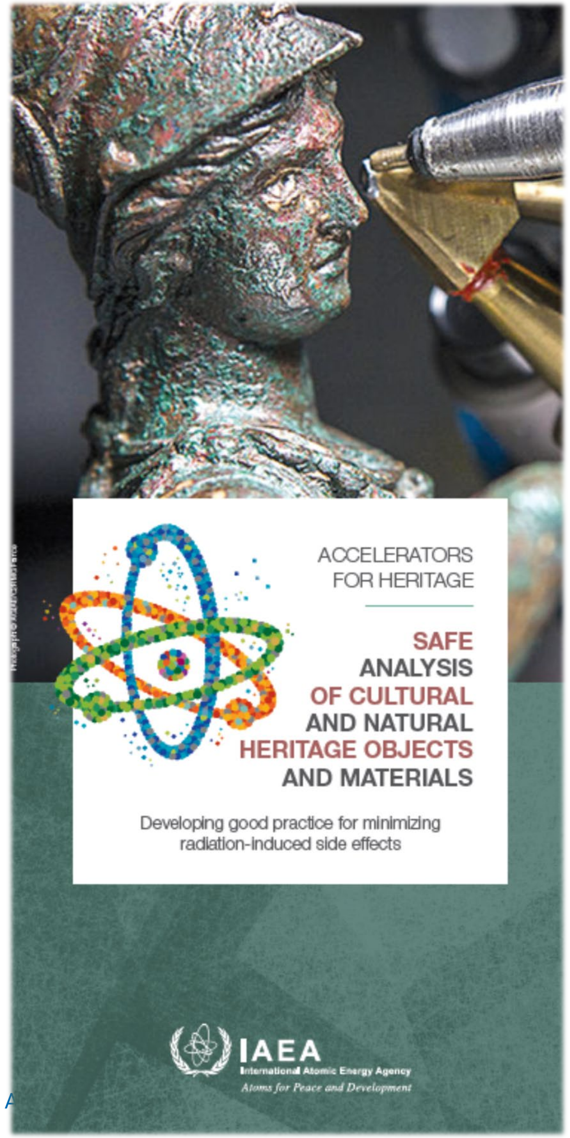
Source: Art Gallery of New South Wales (left), Australian Nuclear Science and Technology Organisation (centre and right)

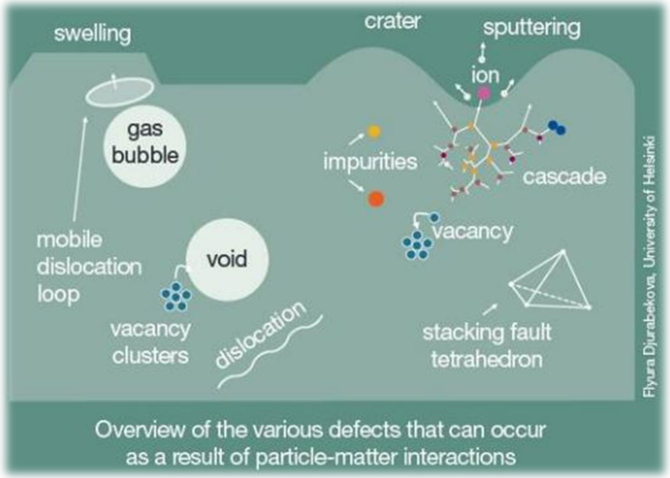
Courtesy of Daryl Howard
The Australian Synchrotron (ANSTO) Melbourne
Australia

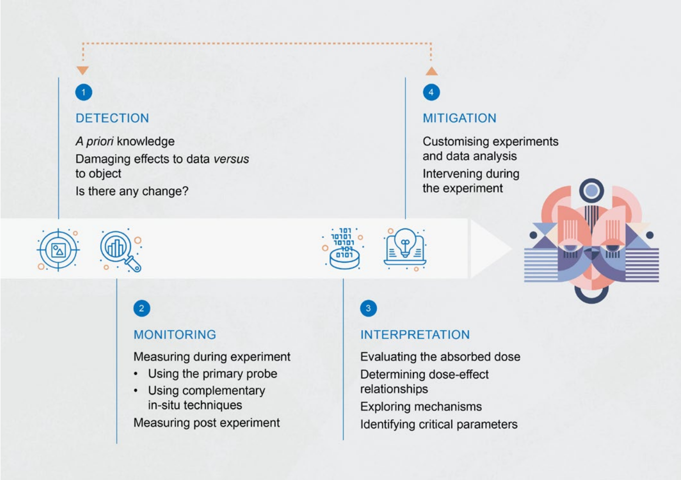


Courtesy of Lucile Beck
Université Paris-Saclay, France

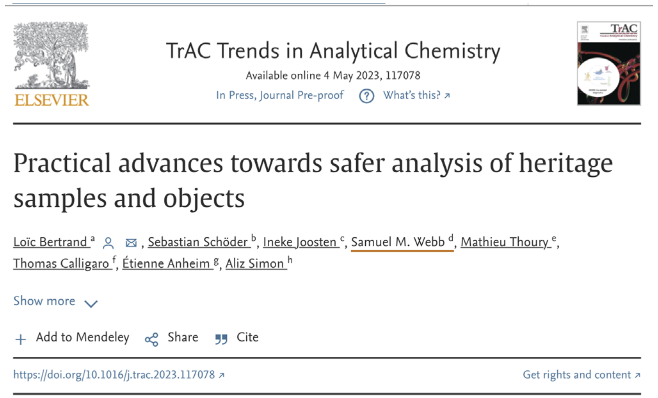
Understanding and Minimizing radiation damage







10.1016/j.trac.2023.117078



TrAC Trends in Analytical Chemistry

Available online 4 May 2023, 117078

In Press, Journal Pre-proof What's this?

Practical advances towards safer analysis of heritage samples and objects

Loïc Bertrand [a], Sebastian Schöder [b], Ineke Joosten [c], Samuel M. Webb [d], Mathieu Thoury [e], Thomas Calligaro [f], Étienne Anheim [g], Aliz Simon [h]

Show more

Add to Mendeley Share Cite

https://doi.org/10.1016/j.trac.2023.117078

Get rights and content

ACTA IMEKO
ISSN: 2221-870X
September 2024, Volume 13, Number 3, 1 - 8

IAEA fostering of the development and applications of nuclear analytical techniques for Heritage Science

Léna Bassel[1], Alessandro Migliori[2], Roman Padilla-Alvarez[2], Aliz Simon[1]

[1] *Physics Section, Division of Physical and Chemical Sciences, International Atomic Energy Agency, Vienna International Centre, Wagramer Strasse 5, PO Box 100, 1400 Vienna, Austria*
[2] *Nuclear Science and Instrumentation Laboratory, International Atomic Energy Agency Laboratories, A-2444, Seibersdorf, Austria*

ABSTRACT
The IAEA Physics Section is strongly involved in the development and utilization of accelerator-based analytical techniques, which are powerful tools for the characterization of cultural and natural heritage objects and materials. Various activities are carried out with the purpose to build capacity, strengthen capabilities, transfer knowledge and foster networking in the field of heritage science. In addition, access to different X-ray fluorescence spectrometers and other analytical techniques is provided at the Nuclear Science and Instrumentation Laboratory (part of the IAEA Physics Section), and access to ion beam accelerators and synchrotron light is facilitated thanks to collaborations with Ruđer Bošković Institute (RBI) in Croatia and the Elettra Sincrotrone facility in Italy, respectively. Member States are also supported on their Research and Development programmes, as well as through the technical cooperation projects. This paper aims to provide a broad overview about how the IAEA Physics Section is engaged in the field of heritage science, promoting the safe, reliable, and effective use of ion beam, X-ray and neutron-based techniques for the characterization and preservation of cultural and natural heritage through its global networks and partners.

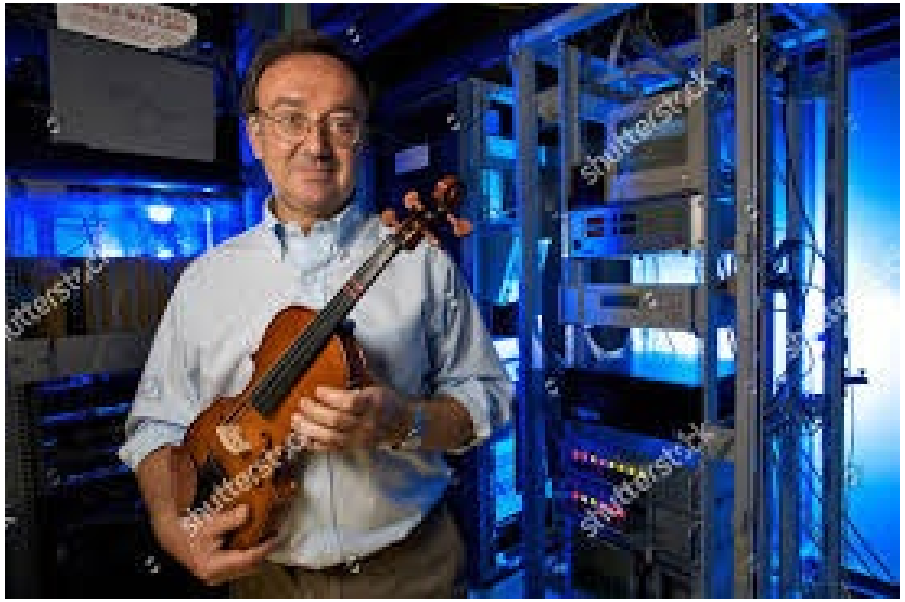
Medical imaging - CT scan

Gibson, AP . Medical imaging applied to heritage .
The British Journal of Radiology 96, No 1152 (2023) . https://doi .org/10 .1259/bjr .20230611

Speakers of this session

Sebastian Schöder
Synchrotron SOLEIL, France

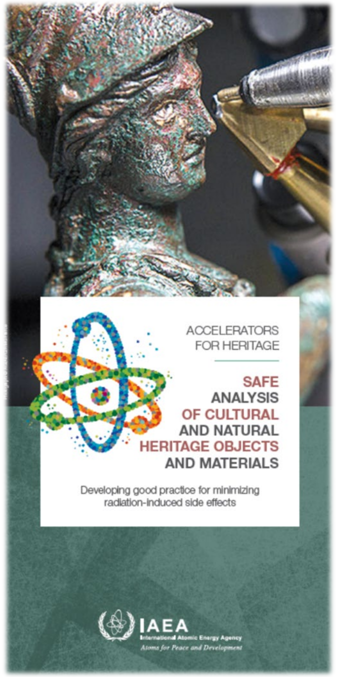
Franco Zanini
Elettra Sincrotrone, Trieste, Italy



Aliz.Simon@iaea.org

Development of e-learning tools

Available at: **elearning.iaea.org**



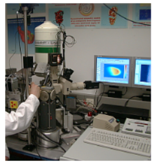
A new e-learning module is expected to be launched in Q2 2025.

Course categories:

Nuclear Technology & Applications / Sciences and Applications / Nuclear Techniques

Search courses: Go

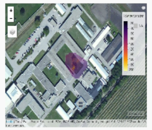
Introduction to X-Ray Emission Spectrometry



X-ray spectrometry techniques are nowadays widely used in many analytical applications. The different interactions of x-rays with matter have served to provide useful information for comprehensive characterization of materials, including: Elemental composition (x-ray characteristic emission); Mineral composition (x-ray diffraction); Chemical speciation (x-ray absorption near edge spectroscopy); Density (x-ray attenuation and phase contrast tomography); Spatial distribution of elements (micro and confocal x-ray fluorescence, x-ray selective absorption tomography); and Characterization of layered structures (x-ray reflectometry, grazing incidence x-ray emission).

This course aims at introducing the reader to fundamentals of several x-ray spectroscopy techniques: Due to the common need for elemental composition analysis, emphasis is made on Energy Dispersive x-ray Fluorescence, which constitutes an affordable option for IAEA Member States laboratories. This course is addressed to specialists and managers of laboratory facilities willing to incorporate x-ray spectroscopy techniques into their research and services. Managers will benefit from general knowledge on the capabilities, advantages and limitations of the techniques. The infrastructure required for the implementation can be identified, as well as the needs for specialized training and capacity building. Specialists working in applied research and analytical services will learn on the capabilities of the techniques for different applications and analytical tasks.

Introduction to in-situ techniques for radiological characterization of sites

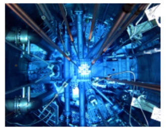


The use of in-situ techniques in environmental monitoring has increased during the last years. However, there is an uneven level of experience and access to such techniques in the IAEA Members States. The IAEA has a vision that its Member States will eventually have in place a proper infrastructure and technologies for radiological characterization of the sites in a timely, safe and cost-effective manner. Aligned with this vision the INSITU Working Group was created within the IAEA Network of Environmental Management and Remediation (ENVIRONET), to produce a variety of products and services aimed at facilitating and increasing the exchange of information and experiences in the specific field of in-situ methods for characterization of sites. The ultimate goal of this group is to build capacity in the different IAEA Member States and to facilitate the full implementation of remediation projects.

This course is addressed to different stakeholders involved in environmental impact assessment and remediation: Public or stakeholder groups, educational institutions, junior professionals and graduate level, environmental monitoring laboratory specialists, managers, regulators, environmental remediation companies professionals, and emergency responders.

For additional information please contact: nsil@iaea.org

Neutron Activation Analysis



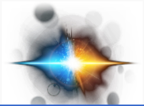
The objective of the course is to increase human capacity building in Neutron Activation Analysis (NAA), as well as to contribute to the overall sustainability of the technique. The e-learning tool is directed at young specialists or beginners without sufficient experience of conducting NAA independently, and it covers all aspects of NAA.

The course can also be used by experienced practitioners who want to implement or use another variety of NAA, professional technicians and analysts, users of NAA and other stakeholders who wish to understand the techniques better, professors teaching nuclear sciences and applications & nuclear analytical techniques, undergraduate and graduate students interested in nuclear sciences and applications & nuclear analytical techniques, and facility managers or supervisors who have to make decisions for an NAA system at their neutron source.

Product of TCAP. The development of this e-learning was supported by the IAEA Technical Cooperation Department through projects RAS0075, RAF1005, RER1016 and RLA1012

To enrol in this course, send an email to RRAppl.Contact-Point@iaea.org - please mention the IAEA NAA elearning.

Nuclear Analytical Techniques for Forensic Science



Neutron and ion beam nuclear analytical techniques have provided unique information in many fields due to their multi-elemental sensitivity, low limits of detection, ability to provide spatially resolved and/or quantitative profiling of trace elements, and, very often, traceability of results.

Although these analytical techniques are readily available and routinely applied in research, there is still a considerable gap when it comes to routine forensics applications.

The purpose of this e-learning tool is to help to bridge the gap between the practitioners of nuclear analytical

Thank you!

Aliz Simon

Physics Section
Department of Nuclear Sciences and Applications
International Atomic Energy Agency

Aliz.Simon@iaea.org