2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

IAEA fosters the development and applications of accelerator-based analytical techniques for Heritage Science

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

[1] *Division of Physical and Chemical Sciences, International Atomic Energy Agency, Vienna International Centre, Wagramer Strasse 5, PO Box 100, 1400 Vienna, Austria, L.Bassel@iaea.org, Aliz.Simon@iaea.org*

[2] *Nuclear and Instrumentation Laboratory, International Atomic Energy Agency Laboratories, A-2444, Seibersdorf, Austria, A.Migliori@iaea.org, R.Padilla-Alvarez@iaea.org*

***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 XRF spectrometers and other analytical techniques is provided at the Nuclear Spectrometry and Instrumentation Laboratory, and access to ion beam accelerators and synchrotrons is facilitated thanks to collaborations with Ruđer Bošković Institute (RBI) in Croatia and the Elettra Sincrotrone facility in Italy. Member States are also supported on their Research and Development programs, 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.**

I. INTRODUCTION

The IAEA Physics Section is pursuing efforts on utilizing accelerator-based analytical techniques including ion beam analysis, accelerator mass spectrometry and synchrotron-based techniques, to support fundamental and applied research, as well as provide capacity building and training world-wide in the field of Heritage Science.

This paper intends to provide insight into the IAEA activities on the characterization of cultural heritage objects, with some emphasis on how the involvement and collaborations with the IAEA could be enhanced.

There are various tools and mechanisms to foster nuclear science and technology for characterization, dating, authentication, and provenance determination of cultural and natural heritage, such as capacity building, knowledge transfer, and providing support to the IAEA technical cooperation projects; they will be described in the first part of this paper.

Aligned to the same objectives, the activities carried out at the Nuclear Spectrometry and Instrumentation Laboratory (NSIL) in Seibersdorf, part of the Physic Section, will be presented in the second part.

II. IAEA TOOLS AND ACTIVITIES

A. Capacity building

a) Key topics and Coordinated Research Projects

The Physics Section is strongly engaged in coordinating research on characterization, technological and methodological development for improved elemental sensitivity, as well as imaging in a multi-analytical approach. Working towards safe analysis of heritage objects and materials is one of the priority areas. With improved beam power and reduced beam size the deposited beam dose during the analysis - especially if long runs are expected for imaging – can result in irradiation side effects which should be considered when designing the analysis. It is especially crucial that such aspects are discussed and agreed with the curator. The IAEA coordinated a round robin exercise to compare analytical results on damage formation from various techniques. The results contributed to the development of best practices for scientists and curators when it comes to the investigation of objects with ionizing radiations [1]. A recent review article confirms that these efforts and technological developments over the past 10 years sufficiently spread and were adopted [2].

In parallel, fighting illicit trafficking in cultural property is key to preserving our heritage and hence understand our own identity, history, and culture. Improving the understanding and use of nuclear techniques to support authentication and provenance of cultural property is crucial and IAEA Physics Section is contributing globally to raise awareness, apply nuclear and complementary

techniques and foster collaborations in the field.

The IAEA supports research by bringing together research institutions from its developing and developed Member States on common projects conceived from assessment of their needs and demands.

In the area of cultural heritage, the coordinated research project (CRP) "Enhancing Nuclear Analytical Techniques to Meet the Needs of Forensic Science" (2017-2021), in cooperation with 14 Member States (MSs), had a dedicated work package on the authentication of art objects. Neutron Activation Analysis (NAA) and Particle-Induced X-ray Emission (PIXE) analysis were, for instance, performed on fake and genuine coins, with the objective to identify the original ones. Painting authenticity and tracking restorations were also assessed using accelerator-based analytical techniques, and the scientific articles published as a result of these works made a tangible contribution to research [3-5].

In addition, the Nuclear Spectrometry and Instrumentation Laboratory coordinated the CRP "Experiments with Synchrotron Radiation for Modern Environmental and Industrial Applications" involving 18 MSs, 3 of which submitted proposals for applications in the field of cultural heritage, representing 10 % of the total beamtime allocated during this project [6]. Two CRPs are currently in planning phase covering methodological development and best practice to detect looted artifacts, and the safe analysis of heritage objects and materials.

b) Collaborating Centres

In support of these programmatic activities, the IAEA has established a Collaborating Centre with University Paris-Saclay, France and the Australian Nuclear Science Technology Organisation (ANSTO), Australia with the aim to cooperate in the field of cultural heritage. These partnerships are intended to enhance the use of nuclear technology in the field of characterization and preservation of cultural and natural heritage, and they play an important role in boosting activities related to heritage science.

B. Knowledge transfer and networking

To exchange ideas and knowledge, share best practice on the application of nuclear analytical techniques for cultural heritage, a multi-disciplinary approach is applied and closely involves also expert from humanities. Their contribution is crucial to the enhancement of scientific-technological knowledge. To this purpose, the IAEA regularly organizes events and develops both outreach materials and e-resources.

a) Events

Training courses, Workshops and Conferences are meetings organized either online, hybrid or in-person only, whose main objective is to provide a forum for all personnel involved in the field of Heritage Science. Such events are organized in strongly involving humanities as well; thus bringing together physicists, material scientists, chemists, archaeologists, conservators, curators, and heritage science stakeholders.

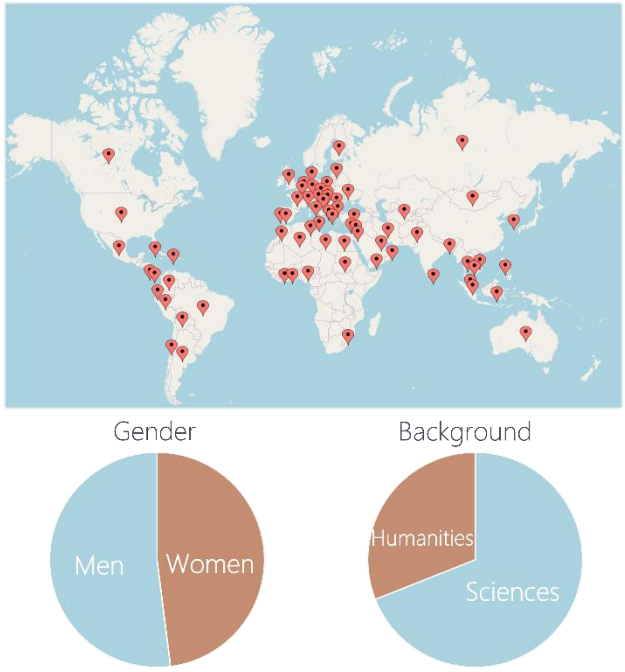

Fig.1. Member states, gender and background distribution for the total number of participants attending events related to Cultural Heritage in 2022.

The IAEA is particularly committed to engage both scientific community and heritage science stakeholders. Such approach allows to further enhance the nexus between Art and Science; a key aspect to work towards the World Heritage Convention adopted in 1972 which states our obligation, to promote the identification, protection, conservation, preservation, and transmission to future generations of the world's cultural and natural heritage.

For the year 2022, four Training courses, two International Conference, one Workshop and four Consultancy meetings gathered about 322 participants originating from IAEA 80 Member States.

During these events, the most recent research works, and their results are presented, as well as innovative technological developments, while international collaborations could be initiated or fostered. A milestone was reached in June 2022 with the IAEA Workshop on Innovative Approaches of Accelerator Science and Technology for Sustainable Heritage Management with 125 participants from 55 Member States, where 54 oral presentations and 20 poster presentations were delivered.

b) Publications and outreach materials

The Physics Section maintains a thematic portal for accelerators, including databases on accelerators facilities worldwide -324 linear ion beam accelerators from 56

Members States and 60 synchrotron light sources from 26 Member States registered so far- as well as one database on X-Ray Fluorescence laboratories (1274 in 119 countries), offering a broad overview about the availability of such facilities in MSs. A specific page on this IAEA Accelerator Knowledge Portal was designed to serve the scientific community highlighting the use of accelerator-based techniques for cultural and natural heritage [7].

The IAEA Bulletin on Accelerators published in May 2022 includes two articles on cultural heritage applications [8]. For a wider audience, and intended for a more general public, regular contributions are provided for articles and web stories published by the IAEA Office of Public Information and Communication, highlighting specific activities or significant achievements [9].

Finally, promoting the safe, reliable, and effective use of accelerator-based techniques for the study and preservation of cultural heritage through its global networks and partners is a key priority for the IAEA. General Conference's side events intend to raise awareness of this important and rich topic.

c) Electronic resources

The IAEA learning platform provides e-learning courses in various fields free of charge [10]. Recently, a course on accelerator mass spectrometry radiocarbon dating for heritage and forensic science was released including six modules. Additional e-learning courses in the field of cultural heritage include Portable X-ray techniques for characterization of valuable archaeological and art objects, Neutron imaging and the course on forensic science. In overall, more than 900 scientists were reached through these e-learnings.

Moreover, the Nuclear Spectrometry and Instrumentation Laboratory is highly involved in the development of electronic resources and released dedicated lectures as well as XRF-related practical demonstrations covering topics like the preparation of solid samples for XRF analysis or assessing the elemental distribution using micro and confocal XRF [11]. Videos introducing two Elettra Sincrotrone beamlines (and related analytical techniques) or IBA methods practical demonstrations about PIXE, RBS, NRA, PIGE techniques and microprobe experiments are also available for students, laboratory staff and users of these facilities [12].

C. Technical cooperation projects

Technical cooperation mechanism is devoted to the transfer of nuclear technology to developing Member States to address specific priorities defined by the country or region. With this mechanism, projects are thus originating from Member States, and can be at a national, regional, or interregional level. For the period of 2018-2023, 10 TC projects are related to cultural heritage involving MSs from Latin America and the Caribbean, Asia-Pacific, ARASIA regional collaboration and Europe. These collaborations allow activities with regional aspects to be conducted e.g. manufacturing technology, trading routes or provenance of materials. In addition, there is an emphasis to share best practice and provide not only trainings but analytical services also within the regions.

III. NUCLEAR SPECTROMETRY AND INSTRUMENTATION LABORATORY

A. Mission

The Nuclear Spectrometry and Instrumentation Laboratory located in Seibersdorf, Austria, contributes to the Physics Section's activities by assisting MSs in strengthening their capabilities, introducing, and extending the use of nuclear instrumentation for, among other fields of application, cultural and natural heritage [13].

To this purpose, NSIL provides training and analytical services and conducts research aimed to improve analytical performance and extend applicability.

In addition, NSIL facilitates access to ion beam accelerators and synchrotrons thanks to specific collaborations with the Ruđer Bošković Institute (RBI) in Croatia and the Elettra Sincrotrone facility in Italy. An increasing number of requests from MSs involve cultural heritage projects.

B. Access to analytical facilities

The laboratory is equipped with a wide variety of instruments for in-situ inspection of valuable objects and for determining the elemental concentration and spatial distribution in samples of diverse origin. Different XRF spectrometers are available in NSIL since more than 20 years, which is considered a leading training hub on topic related to XRF, hosting several techniques like energy dispersive XRF, a micro XRF and a confocal XRF setup, Full-Field XRF, a handheld XRF, as well as other variants of XRF technique and other analytical techniques such as SEM-EDS and XRD. Recent work involved the characterization of black deposits inside the ornate Palaeolithic Ebbou cave (Ardèche, France) showing the presence pf phosphorus, iron and manganese and thus contributing to the discussion on the different assumptions regarding the origin of the coatings.

A virtual tour of the laboratory allows to have a look at the instruments and find out more information and is available at https://my.matterport.com/show/?m=27SbAzwypzW.

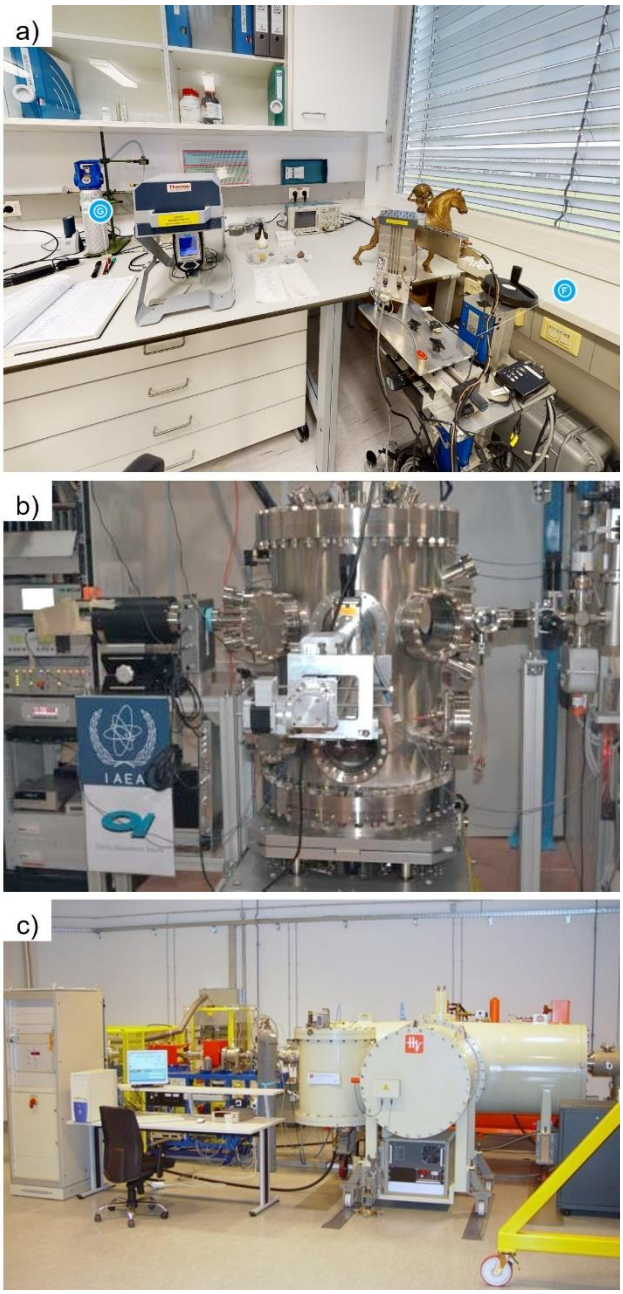

Fig.2. Instrumentation overview. a) Handheld XRF device and transportable XRF system available in NSIL; b)The IAEAXspe end station at the XRF beamline of the Elettra Sincrotrone Trieste, Italy; c) 1.0 MV Tandetron accelerator at Ruđer Bošković Institute, Croatia.

a) Cooperation with Elettra Sincrotrone, Italy

NSIL has a cooperation agreement with Elettra Sincrotrone Trieste (EST), Italy, since 2013 which became an IAEA Collaborating Centre in 2020. This long-standing agreement involves mainly the XRF beamline of EST that offers several complementary X-ray techniques, and for which the IAEA designed and developed the end-station, installed in Autumn 2013, and provides a dedicated beamtime access to interested parties on a competitive basis [14]. A very recent study involved the combined use of XRF mapping and XANES measurements at the Fe K-edge on gold coins from the Roman Empire. Elemental concentration was obtained for the metallic alloy, and presence of hematite and magnetite in the dirt accumulated on the coin surface was identified, providing important information for historians working on this ancient civilization [15].

NSIL is organizing a training in Elettra Sincrotrone every year for young scientists with limited experience with synchrotron light sources and techniques that includes guidance for proposal writing, and hands-on training on three different beamlines. In addition, regarding the XRF beamline, users from developing countries can benefit from NSIL's technical support for the writing of the proposal, or data acquisition and analysis once beamtime is allocated.

b) Cooperation with Ruđer Bošković Institute, Croatia

A long collaboration with Ruđer Bošković Institute Accelerator Facility in Zagreb, Croatia, also facilitates the access of IAEA collaborating partners to different ion beam analysis methods. Twenty days of beamtime are available every year for research groups from developing countries. Similarly, two hands-on training courses are organized every year, the last one being held in November 2022 on "Advances in Ion Beam techniques and their applications" including cultural heritage case studies. NSIL has initiated a five-year CRP "Facilitating Experiments with Ion Beam Accelerators" in 2018, involving 11 ion beam facilities worldwide to provide beamtime and expertise to scientists without access to accelerator facilities to conduct experiments. More than 14 experiments were conducted in total, and one project dealing with archaeology was proposed by a group from Tunisia. A comparative study using PIXE technique was performed for the characterization of archaeological pottery and raw material, looking for information about the provenance (unpublished work).

IV. CONCLUSION

Characterization of cultural and natural heritage for their conservation is among the key priority areas of accelerator applications at the IAEA. This paper has shown the various activities and diverse mechanisms implemented at the IAEA Physics Section to promote the utilization of accelerator-based techniques, which are a powerful tool to gain better insight into cultural and natural heritage objects and materials.

REFERENCES

[1] Bertrand, L., Schöeder, S., Anglos, D., Breese, M. B., Janssens, K., Moini, M., & Simon, A. (2015). Mitigation strategies for radiation damage in the analysis of ancient materials. TrAC Trends in

Analytical Chemistry, 66, 128-145. https://doi.org/10.1016/j.trac.2014.10.005

[2] Bertrand, L., Schöder, S., Joosten, I., Webb, S. M., Thoury, M., Calligaro, T., ... & Simon, A. (2023). Practical advances towards safer analysis of heritage samples and objects. TrAC Trends in Analytical Chemistry, 164, 117078. https://doi.org/10.1016/j.trac.2023.117078

[3] Calligaro, T., Banas, A., Banas, K., Radović, I. B., Brajković, M., Chiari, M., ... & Simon, A. (2022). Emerging nuclear methods for historical painting authentication: AMS-14C dating, MeV-SIMS and O-PTIR imaging, global IBA, differential-PIXE and full-field PIXE mapping. Forensic Science International, 336, 111327. https://doi.org/10.1016/j.forsciint.2022.111327

[4] Hajdas, I., Calcagnile, L., Molnár, M., Varga, T., & Quarta, G. (2022). The potential of radiocarbon analysis for the detection of art forgeries. Forensic Science International, 335, 111292. https://doi.org/10.1016/j.forsciint.2022.111292

[5] Quarta, G., Molnár, M., Hajdas, I., Calcagnile, L., Major, I., & Jull, A. J. T. (2021). 14C intercomparison exercise on bones and ivory samples: implications for forensics. Radiocarbon, 63(2), 533-544. https://doi.org/10.1017/RDC.2020.142

[6] Karydas, A. G., Czyzycki, M., Leani, J. J., Migliori, A., Osan, J., Bogovac, M., ... & Kaiser, R. B. (2018). An IAEA multi-technique X-ray spectrometry endstation at Elettra Sincrotrone Trieste: benchmarking results and interdisciplinary applications. Journal of Synchrotron Radiation, 25(1), 189-203. https://doi.org/10.1107/S1600577517016332

[7] https://nucleus.iaea.org/sites/accelerators/Pages/Accelerators4Heritage.aspx

[8] https://www.iaea.org/bulletin/63-2

[9] https://www.iaea.org/newscenter/news/studying-and-preserving-cultural-heritage-using-nuclear-science-and-technology

[10] https://elearning.iaea.org/m2/

[11] https://nucleus.iaea.org/sites/nuclear-instrumentation/Pages/XRF-Practical-demonstrations.aspx

[12] https://nucleus.iaea.org/sites/accelerators/Pages/IBA-video-demonstrations.aspx

[13] Foulon, F., Abdelouahed, H. B., Bogovac, M., Charisopoulos, S., Matos, M., Migliori, A., ... & Swainson, I. (2020). IAEA nuclear science and instrumentation laboratory: support to IAEA member states and recent developments. In EPJ Web of Conferences (Vol. 225, p. 10005). EDP Sciences. https://doi.org/10.1051/epjconf/202022510005

[14] https://www.elettra.eu/lightsources/elettra/elettra-beamlines/microfluorescence/x-ray-fluorescence.html

[15] Carlomagno, I., Zeller, P., Amati, M., Aquilanti, G., Prenesti, E., Marussi, G., ... & Adami, G. (2022). Combining synchrotron radiation techniques for the analysis of gold coins from the Roman Empire. Scientific Reports, 12(1), 15919. https://doi.org/10.1038/s41598-022-19682-8