report

The use of irradiation for the preservation of cultural heritage

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iia

About this Document

This document provides an overview of the use of irradiation by several organisations in different countries in support of the preservation of cultural heritage. It aims to provide a high-level introduction to the topic and highlight how this beneficial irradiation application is utilised.

It is a result of collaboration between the International Irradiation Association (iia) and organisations that research and use irradiation for the preservation of cultural heritage. The iia would like to thank the following individuals and organisations that have contributed by providing content for this publication:

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The International Irradiation Association is a not-for-profit organisation that supports the global irradiation industry and scientific community. A core objective of the Association is to support its members in advancing the safe and beneficial uses of irradiation.

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Introduction

Our heritage gives us a connection with the past and teaches us about our ancestors and their beliefs, cultures and achievements. Preservation helps to ensure that this connection is not lost and that future generations can benefit and learn from our past.

Many artefacts and cultural heritage objects, particularly those made from organic material, are threatened by biological attacks. Some items serve as food for insects and microorganisms, wooden artifacts are often infested with woodworm or wood-boring beetles, and manuscripts and paper can be damaged by fungi. These attacks may be triggered by events such as floods but more often they are the result of inadequate long-term storage conditions in religious buildings, museums or libraries. Today, climate change is also a consideration, and it is increasingly important to mitigate against its direct and indirect impact on artefacts and items of historical importance.

Research into the use of irradiation to treat artefacts started in the 1960s and it has now developed into a valuable tool for the preservation of our cultural heritage. Today, irradiation technologies (gamma and electron-beam) are used to provide fast and effective treatment to prevent the deterioration of many materials and objects. Irradiation is an environmentally friendly alternative to the use of fumigation and liquid chemicals.

The following chapters summarise the activities and experience of leading organisations in the field from several countries.

Copyright ©ARC-Nucléart / CEA-Langlois Irradiation of an Egyptian mummy in its coffin, Grenoble Museum, France.

Brazil

An overview of disinfection and consolidation of cultural heritage materials by ionizing radiation at IPEN-Brazil

Introduction

Brazil's predominantly humid tropical climate significantly accelerates the biodeterioration of organic cultural heritage materials, favouring infestations by xylophagous insects and fungal colonization. In addition, recurrent flooding and other environmental incidents have compromised numerous collections across the country. In this context, gamma radiation has emerged as an effective alternative to conventional chemical and atmospheric treatments for the disinfection and consolidation of cultural heritage artifacts.

Over the past decades, the Nuclear and Energy Research Institute (IPEN), through its Multipurpose Gamma Irradiation Facility located at the University of São Paulo (USP), has established a structured collaboration program with museums, archives, libraries, and conservation professionals. To date, more than 50,000 cultural objects, including paintings, sculptures, manuscripts, archival documents, ethnographic and archaeological artifacts, musical instruments, and natural history collections, have been treated for disinfection purposes.

Gamma irradiation offers significant advantages over traditional methods: it leaves no toxic residues, allows immediate handling after treatment, ensures deep penetration and homogeneous dose distribution, and enables reliable dosimetric control. These characteristics make it particularly suitable for large-scale and complex objects. The International Atomic Energy Agency (IAEA) has supported regional initiatives reinforcing the role of nuclear techniques in safeguarding cultural heritage as a legacy to be transmitted to future generations.

Disinfection of Cultural Heritage Materials

Modern Art on Canvas

Modern paintings (late 19th to mid-20th century) typically consist of heterogeneous material systems combining canvases, ground layers, adhesives, pigments, and varnishes. These materials are highly susceptible to biodeterioration under inadequate storage and exhibition conditions, particularly when cracks, cavities, and accumulated dust create favourable microenvironments for biological growth.

Traditional chemical fumigation methods may compromise varnishes and sensitive pigments, while large-format canvases pose logistical challenges for homogeneous treatment. Ionizing radiation provides an effective solution, as it penetrates complex structures without requiring direct chemical contact.

At IPEN, large paintings, including works from public institutions such as the Pinacoteca de São Paulo, have been successfully disinfected. Doses between 6–10 kGy are typically applied for fungal contamination, while 2–3 kGy are sufficient for insect eradication. After irradiation, artworks undergo mechanical cleaning and conservation procedures under professional supervision.

FIG. 1. Paintings on canvas disinfected with ionizing radiation at the IPEN. Government Palaces Collection.

FIG. 2. An example of a large artwork treated at the IPEN/CNEN.

Preservation of Traditional African Wooden Artifacts

In 2021, approximately 1,700 African wooden artifacts donated to the Museu Oscar Niemeyer (MON) were found to be infested by termites and woodborers. Chemical pesticide treatment was discarded due to risks of color alteration, fiber embrittlement, toxicity, and health hazards to staff.

Around 1,500 contaminated wooden objects were selected, documented, packaged in rigid containers, and transported to IPEN following established protocols. The irradiation process lasted 15 days. An absorbed dose of 2–3 kGy ensured elimination of active infestations, with dosimetric values recorded in final reports. After treatment, the objects underwent mechanical cleaning and restoration.

It is important to emphasize that irradiated objects do not become radioactive. However, preventive conservation measures, particularly environmental and pest control, remain essential to avoid reinfestation.

FIG. 3. Item to be treated with gamma radiation.

FIG. 4. Receipt of boxed items at the IPEN's radiator facility.

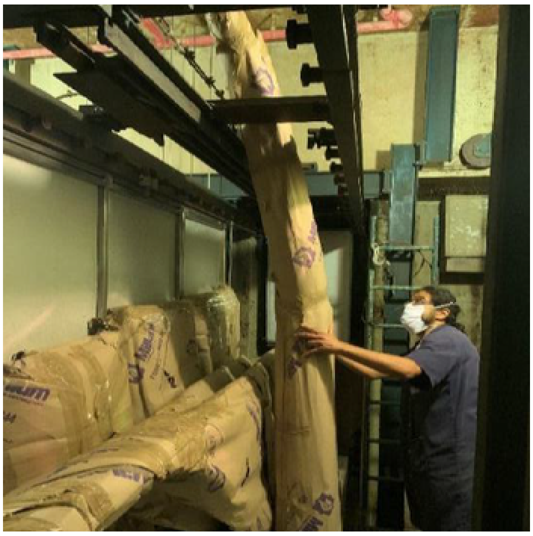

FIG. 5 and 6. Items of various sizes from the collection inside the irradiation chamber.

FIG. 7. Exhibition of African artworks at the museum.

Mass Decontamination of Archival and Library Collections

Mass biodeterioration can occur due to floods, inadequate storage, or uncontrolled environmental parameters. Under Brazil's climatic conditions, insect and fungal outbreaks can rapidly compromise entire collections.

IPEN has disinfected more than 1,000 m^3 of archival and library materials. For cellulose-based materials affected by insects, doses around 1 kGy are typically applied; for fungal contamination, 6–10 kGy are recommended.

Case Studies

- **FAU/USP Architectural Collection** – More than 2,000 original architectural drawings from the School of Architecture and Urbanism of USP were treated following severe biodeterioration

- **Cia City Historical Archive** – Over 200 m^3 of historical documents were processed after flooding incidents, preventing future microbial contamination.

- **Institute of Chemistry Library (USP)** – Approximately 12,000 volumes and 3,000 journal issues infested by Anobiidae (book borers) underwent staged irradiation (4 m^3 per week), followed by cleaning to prevent reinfestation.

These cases demonstrate the efficiency, scalability, and safety of gamma irradiation for emergency and large-volume intervention.

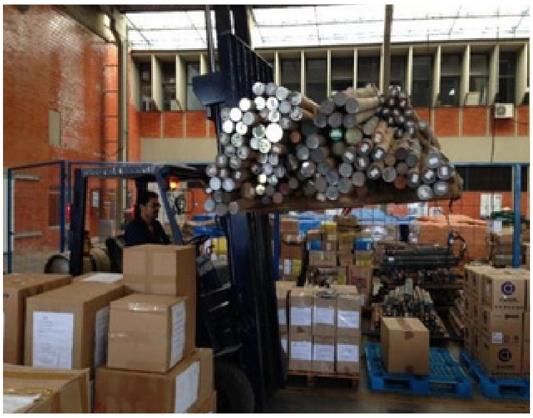

FIG. 8 and 9. Architectural drawings from School of Architecture and Urbanism treated at the IPEN.

FIG. 10. Cia City historic documents at the IPEN.

FIG. 11. Cleaning of books after gamma radiation treatment.

Oversized and Dense Objects

Large and dense objects represent a major challenge for conventional treatments due to limited gas penetration and logistical constraints. Gamma radiation, by contrast, ensures homogeneous treatment in a single application due to its high penetration power.

Oversized works from institutions such as the Museu de Arqueologia e Etnologia da USP (MAEUSP) and private collections have been successfully processed. In such cases, dosimeters are strategically positioned throughout the object's geometry to verify dose uniformity, with measurement uncertainties maintained between 2% and 2.5%.

One notable example involved a one-ton sculpture from the Pinacoteca collection treated using a calibrated PMMA dosimetry system traceable to the IAEA's International Dose Assurance Service (IDAS). After irradiation, the sculpture proceeded to restoration and public display.

FIG. 12. Positioning the box inside the irradiator chamber was difficult due to the weight of the object.

FIG. 13. Modern art radiation processing at the IPEN.

FIG. 14. To ensure that the oversized canvas is handled properly, conservators are monitoring the arriving of the artwork at the IPEN.

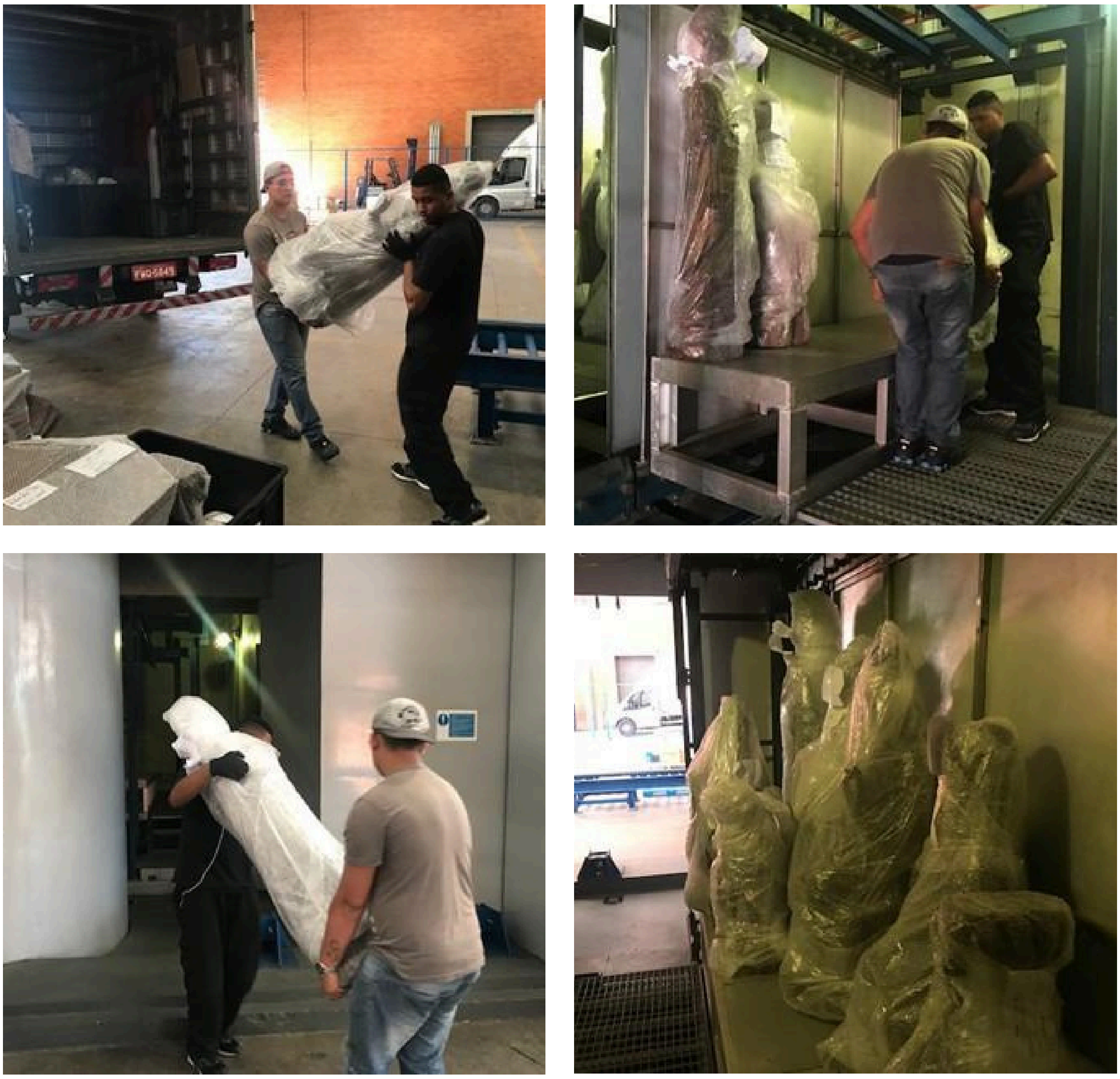

FIG. 15. Irradiation of CIJY large artifacts at the IPEN.

Consolidation by Radiation-Curable Resins

Rationale

Consolidation is a remedial conservation treatment intended to restore mechanical integrity to degraded porous materials. Traditional consolidants are applied by brushing, injection, or immersion; however, factors such as viscosity, compatibility, aging behavior, reversibility, and toxicity must be carefully evaluated.

Ionizing radiation offers a distinct advantage: it induces polymerization without chemical initiators or significant temperature increase. Radiation curing produces a three-dimensional crosslinked polymer network, improving mechanical strength and chemical stability while minimizing thermal stress. However, as the process is irreversible, it should be considered only when conventional methods are insufficient.

Radiation Polymerization Mechanism

When gamma radiation interacts with matter, it generates free radicals, ionic species, and solvated electrons. Polymerization occurs in three stages:

1. **Initiation** – formation of reactive radicals;
2. **Propagation** – growth and crosslinking of polymer chains;
3. **Termination** – formation of a stable three-dimensional network.

Unsaturated polyester resins containing reactive double bonds are particularly suitable for this process, forming infusible and mechanically stable polymers after irradiation.

Case Study: Consolidation of a Wooden Sculpture of Saint Jerome

A 19th-century polychrome wooden sculpture of Saint Jerome from the Palácio dos Bandeirantes collection exhibited severe structural degradation due to xylophagous insect attack. The object was extremely fragile, requiring structural reinforcement prior to exhibition.

Pre-Treatment Assessment

Computed tomography and radiography were performed to document internal damage and evaluate porosity. These non-destructive techniques guided the impregnation strategy.

Impregnation Procedure

An unsaturated isophthalic polyester resin (Resapol® LP 8847) diluted with styrene monomer was used. The sculpture was placed in a stainless-steel reactor vessel. Air was removed under vacuum (20 mmHg), followed by nitrogen pressurization (5 atm) to prevent oxygen inhibition. Resin impregnation proceeded for 24 hours to ensure deep penetration into insect-generated cavities.

Irradiation

After drainage of excess resin, the sculpture was wrapped in cotton fabric and irradiated at the cobalt-60 facility. Dosimetric studies determined the optimal geometry and dose rate. A total dose of 50 kGy at 1 kGy/h was applied to achieve complete polymerization. At 10 kGy, the wrapping textile was removed to prevent surface gloss formation.

FIG. 16. Sculpture positioned for irradiation.

Post-Treatment Evaluation

Tomographic analysis confirmed homogeneous internal polymerization and improved structural integrity. The sculpture was ventilated for several weeks to eliminate residual styrene, followed by detailed conservation treatment. The object was subsequently restored for safe exhibition. This case represents the first successful consolidation of a polychrome wooden sculpture in Brazil using ionizing radiation and demonstrates the feasibility of combining advanced diagnostic techniques with radiation curing technology.

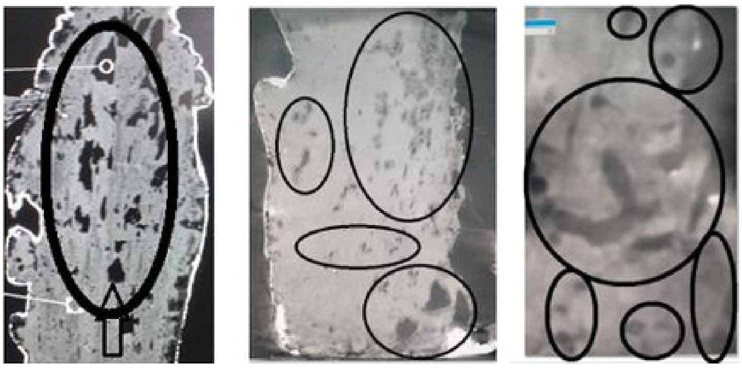

FIG. 17. Tomography images before and after after resin impregnation.

FIG. 18. The cleaning process was performed by conservator.

Conclusion

Ionizing radiation has proven to be a reliable, scalable, and environmentally safe technology for both disinfection and consolidation of cultural heritage materials in Brazil. Its high penetration capacity, absence of toxic residues, and precise dosimetric control make it particularly suitable for:

- Mass decontamination of archives and libraries;
- Treatment of oversized or dense artifacts;
- Emergency response following floods or infestations;
- Structural consolidation of severely degraded wooden objects.

The long-standing collaboration between IPEN and cultural institutions demonstrates the successful integration of nuclear technology into conservation practice. While preventive conservation remains essential to ensure long-term preservation, gamma irradiation provides an effective remedial intervention when biodeterioration threatens the integrity of cultural heritage collections.

About the IPEN Multipurpose Gamma Irradiation Facility

The consolidation treatments were conducted at IPEN's Category IV panoramic wet-storage irradiator. The facility employs cobalt-60 sources encapsulated in stainless steel pencils arranged in source racks. The installed activity in 2024 is approximately 11.1 PBq (300 kCi). The system ensures controlled human access and high dosimetric reliability, allowing treatment of objects of various sizes, including oversized artifacts.

Website: https://www.gov.br/ipen/pt-br

FIG. 16. Sculpture positioned for irradiation.

Croatia

The preservation of Croatia’s cultural artefacts and museum collections using irradiation

The Ruđer Bošković Institute (RBI) Radiation Chemistry and Dosimetry Laboratory (RCDL) irradiation facility plays a significant role in cultural heritage (CH) preservation and has, over the past 40 years, successfully carried out the activities in the protection and conservation of various cultural heritage objects. During this period more than 10,000 CH objects have been treated for preventive and curative purposes at RCDL’s gamma irradiation facility, mostly wooden objects like sculptures, altars, furniture, tools, musical instruments, but also books, clothing, leather items etc. The facility continuously collaborates with museums, galleries, and cultural institutions to provide scientific expertise in conserving and preserving cultural artefacts. This partnership enhances the understanding of the best practices in cultural heritage conservation. One of the first and longstanding cooperation was established with Croatian Conservation Institute (CCI) which was essential for the successful application of irradiation treatment to objects of cultural heritage and enhances the understanding of the best practices in cultural heritage conservation. Also, RBI successfully cooperates with Croatian State Archives, National and University Library in Zagreb, Academy of Fine Arts, a number of museums and galleries (Museum of Arts and Crafts, Museum of Contemporary Art, Ethnographic Museum, Croatian History Museum, Mimara Museum, Sisak Municipal Museum, etc.) In addition, strong cooperation has been established with religious institutions and private restaurateurs who recognize irradiation as a valid method for the treatment of cultural artefacts. All these activities would not be possible without the continuous support through various projects and activities with International Atomic Energy Agency (IAEA).

In irradiation treatments, the most important parameter is the absorbed dose. For cultural artefacts, special attention must be given to the materials from which the objects are made, as they may consist of sensitive natural polymers such as paper, textiles, and leather. Additionally, the type and level of infestation are crucial factors. Another important parameter is the dimensions of the CH object, which pose challenges for achieving uniform dose distribution across the entire object. If necessary, dose distribution is calculated using Monte Carlo (MC) simulations and checked before irradiation. Taking all these factors into account, the target dose and irradiation setup are established. The doses typically applied for irradiation treatments at the RCDL align with those generally accepted in professional literature: 0.5 to 2.0 kGy for insect eradication, 5 to 10 kGy for the control of fungi and spores, and 5 to 20 kGy for bacterial control. However, if objects are highly contaminated with fungi and spores, a higher dose may apply in agreement with restorers and conservators, or manual removal of the infestation may be performed prior to irradiation.

Over many years of activity with numerous cases, two particularly significant and successful large-scale cultural heritage preservation initiatives in Croatia can be distinguished: the protection of cultural heritage endangered during the aggression against Croatia (1991–1995) and the large-scale preservation of museum collections damaged by the Petrinja earthquake in 2020.

Successful cases of the preservation of cultural heritage during the War in Croatia

During the Croatian War of Independence (1991–1995), extensive rescue operations were carried out to protect cultural heritage objects from areas directly affected by armed conflict.

Museum Documentation Centre evidenced 3178 destroyed objects and 2283 damaged objects. In cooperation with CCI numerous artefacts were evacuated and treated at RBI (RCDL) for disinsection or, if necessary, disinfection. Following treatment, the objects were stored in controlled depot conditions under the supervision of the CCI until the end of the war.

A representative example of this intervention is the Church of the Blessed Virgin Mary of the Snows in Kamensko (15th century) (Figure 1). The Pauline monastery near Karlovac was destroyed in 1991; however, 29 sculptures and paintings had been evacuated in advance and placed in temporary shelters. Parts of the altars remained in the church and suffered severe deterioration following the roof collapse and prolonged exposure to adverse environmental conditions. By 1995, extensive microflora growth was observed, particularly on objects hidden in the crypt. During the recovery phase, altar fragments were collected and conserved on site, and gamma irradiation was applied according to the infestation severity: 2 kGy for insect eradication, 5 kGy for disinfection, and up to 20 kGy for heavily infested materials. The previously evacuated sculptures were also irradiated prior to reintegration, enabling the complete reconstruction of the Holy Cross Altar (1685), which was reinstalled in the restored church in 2008 (Figure 1). (Ref 4,5)

FIG. 1. Remaining parts of the altar choked with microflora in the Church of the Blessed Mary of the Snows (left and middle picture) and the Holy Cross Altar after conservation and restoration (on the right). (Ref 4,5)

In the post-war period, many cultural heritage objects that had not been evacuated were recovered from the ruins of destroyed or damaged churches, museums, and galleries. These artefacts were frequently found to be heavily infested with insects and microorganisms and were subsequently treated at RCDL to eradicate both insect and fungal contamination.

This example of using radiation methods to rescue cultural heritage endangered by the war in Croatia has been recognized by international experts as a particularly successful application of this technique. It continues to be presented as an illustration of the effectiveness of this unique method in times of crisis.

Massive preservation of large museum collection damaged during Petrinja Earthquake

On December 29, 2020, a significant earthquake with a magnitude of 6.2 struck near Petrinja, Croatia. The intensity at the epicentre was reported to be between VIII and IX on the European Macroseismic Scale (EMS), indicating severe effects, including considerable damage to buildings and infrastructure. Shortly after the earthquake, the Minister of Culture and Media initiated actions to secure and document the damage to museum exhibits, archives, library collections, religious collections and other cultural heritage objects.

A central depot for the temporary storage of damaged CH objects was established in the Sisak Municipal Museum. During preparations for the movement of these objects, it was observed that not all objects were stored in suitable and controlled environmental conditions, which could lead to cross-contamination between objects from different collections. In collaboration with the Sisak City Museum all infested or suspected objects were transported to the Radiation Chemistry and Dosimetry Laboratory for radiation treatment. Preventive radiation disinsection or disinfestation was performed with a radiation dose of 2 kGy, while in some cases a dose of 5-7 kGy was used to eliminate fungi found on certain objects due to inadequate storage conditions. After treatment, the objects were stored in the temporary storage facility in Sisak.

The first collection treated, which included books, paintings, furniture, and other personal belongings, was infested with insects as well as mould and fungi (Figure 2). Afterwards, the collection of textile and ethnographic objects from the Sisak City Museum storage was also sent for radiation treatment. (Ref 6)

FIG. 2. Radiation disinfection of rescued cultural heritage objects at the panoramic 60Co gamma irradiation facility at the Radiation Chemistry and Dosimetry Laboratory of the Ruđer Bošković Institute. (Ref 6)

Over the past 40 years, RCDL has treated numerous wooden sculptures, altar components, musical instruments, and other objects made of leather, paper, and textiles for both preventive and curative purposes. The integration of gamma irradiation into comprehensive conservation strategies is further illustrated by multiple case studies, with some of the most notable examples shown in Figure 3-6 (Ref 4,6). In each case, irradiation provided a crucial intervention to halt biological deterioration. Successful outcomes, however, depended on a combination of measures, including pre-irradiation stabilization, controlled transport, appropriate packaging, and post-treatment storage and restoration. These projects demonstrate that, while gamma irradiation is a powerful tool for disinfection and disinsection, its effectiveness is maximized when applied within a structured conservation workflow that considers the material, environmental, and logistical requirements of each object.

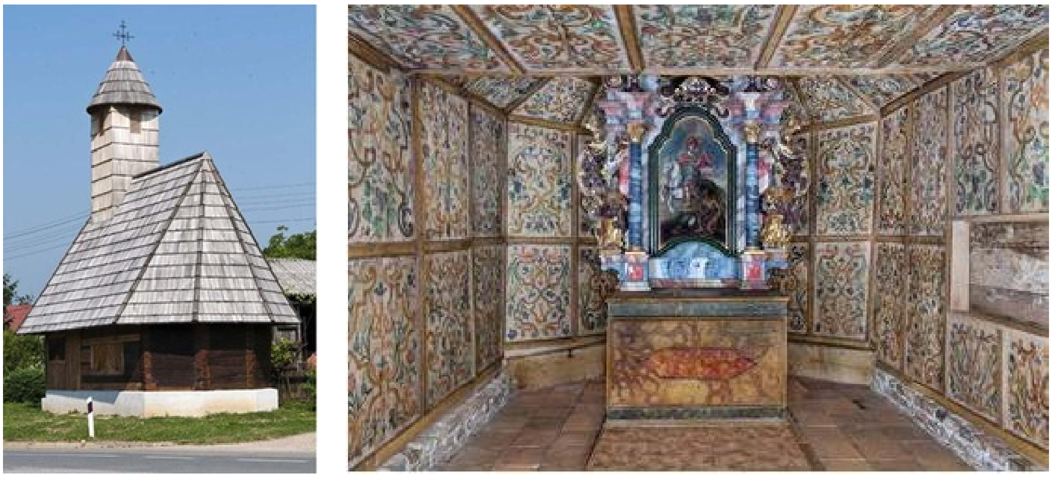

FIG. 3. Interior of the chapel of St. Martin in Stari Brod (Croatian Conservation Institute). The successful outcome of this project was recognized with an international award for conservation excellence (European Heritage Europa Nostra Awards 2017).

FIG. 4. The Altar of our Lady of Loreto, St Jurja (Plešivica) – before (left) and after conservation (right) – the applied dose was 2 kGy (Croatian Conservation Institute).

FIG. 5. Garments of the Alka Collection (A) – the collection belongs to the Society of Tilters of Sinj (18-19 century), the garments were treated with a dose of 1 kGy for disinsection.

A B C

FIG. 6. Some of the many interesting examples of cultural heritage artefacts treated at RBI facility:

A: Leather and wood Cover; of The Book of Statutes of the town of Dubrovnik from 1272 (Dubrovnik State Archives). The Book is written on parchment with wood/leather cover, partially heavily damaged by insects, moulds and mechanical stresses, (treated with 5 kGy).

B: Bible in Czech from 1667 – private collection, treated with 2 kGy for disinsection.

C: Harp infected by insects, treated with dose 1 kGy (no noticeable changes in tone quality). Private collection.

Conclusion

The RCDL has documented numerous success stories in the application of irradiation techniques for the preservation of cultural heritage both in crises situation and in regular practice. Many of these activities are acknowledged at exhibitions of restored CH objects. These stories highlight the effectiveness of gamma irradiation in treating various artefacts. The success of these interventions depends on careful planning, accurate dosimetry, appropriate dose and dose rate selection, and integration into comprehensive conservation workflows. By combining traditional restoration techniques with advanced radiation technology, conservators can effectively address biological threats, stabilize materials, and safeguard cultural heritage for future generations.

About the Ruđer Bošković Institute, Radiation Chemistry and Dosimetry Laboratory

Croatia has one Co-60 gamma irradiation facility located at the Ruđer Bošković Institute (RBI), Radiation Chemistry and Dosimetry Laboratory (RCDL) in Zagreb, Croatia. It is a semi-industrial, panoramic, cylindrical source rack, dry-storage type irradiator designed and built at RBI. Its maximum capacity is 150 kCi, while current (January 2026) activity is 25 kCi, and the maximum dose rate is 3.0 Gy/s. By adjusting the height or increasing the distance from the source, the dose rate decreases, allowing for a wide range of possible dose rates (three orders of magnitude or more when using attenuators) and doses (from Gy to MGy). This extensive dose range makes the RCDL irradiation facility suitable for a broad spectrum of scientific investigations and applications, including sterilization, microbiological decontamination, and the preservation of cultural heritage objects. The facility has implemented the EN ISO 13485:2016 standard (1) and has been certified since 2021. Dose mapping of the facility is performed with ionisation chamber measurements and Monte Carlo (MC) simulations while for routine dosimetry, ethanolchlorobenzene (10% ECB) system developed by Igor Dvornik in 1966 (ISO/ASTM 51538:2017) is used and oscillometric read-out is performed. ECB dosimeters are calibrated in-plant and traceable to the reference laboratory Risø High Dose Reference Laboratory. MC model and dose mapping of the facility have been made and validated using two MC codes (PHITS and Geant4). (2,3).

Website: https://www.irb.hr/eng/Divisions/Division-of-Materials-Chemistry/RadiationChemistry-and-Dosimetry-Laboratory

France

Gamma radiation processing for cultural heritage preservation: France’s many years of experience

According to International Council of Museum – Committee for Conservation, remedial conservation is defined as “all actions directly applied to an item or a group of items aimed at arresting current damaging processes or reinforcing their structure” (ICOM-CC, 2008). From 1970, application of gamma radiation processing in such a way of remedial conservation of cultural heritage artefacts has been developed at the CEA Grenoble pool irradiator, giving rise to the workshop ARC-Nucléart. Biocidal treatments, arresting biodeterioration due to pests, and consolidation thanks to radio-curable resin, reinforcing the more weakened artefacts, are the main two ways gamma irradiation is used for such purpose.

Insects and fungi, including moulds and rots, are extremely dangerous pests for artefacts made of organic materials. Some of them are for instance able to destroy wooden objects in just a few years. Thanks to its strong penetrating power, gamma irradiation treatment is perfectly suited to fight against these pests when they infest movable cultural goods. Insect eradication and fungicidal treatments are indeed the most common uses of gamma radiation for remedial conservation. 500 Gy is the threshold required to ensure deterministic death of any kind of insect, whatever its stage of development. By increasing the dose up to 2 kGy, the insect's survival time is generally reduced from two or three weeks to just a few days. For fungicidal purposes, doses between 3 and 10 kGy drastically reduce, in a probabilistic way, the worst contamination down to an acceptable level, such as that found in a museum or a "clean/healthy" storage room (total sterilization is not relevant because small quantities of fungal spores are always present in the air, even in those “healthy” local).

While the minimum dose is set with respects to the expected biological goal, the death of the pests, the maximum dose, i.e. the one that should not be exceeded, must be determined after analyses of the potential side effects. This point, of course, always requires careful attention. Fortunately, apart from a few rare contraindications such as transparent materials, experience shows that the technique applies safely at least until 10 kGy to a very large range of materials (Ponta et al, 2017).

Dosimetry can be managed easily and very reliably through both calculations and measurements. The spatial and temporal stability of gamma radiation from 60Co allows for very precise mastering of the process. This characteristic gives the technique not only excellent efficiency but also unparalleled reliability.

Treatments need typically few hours for insects’ eradication, until one or two tens of hours for fungicidal doses.

This technique is suitable for the treatment of a very large diversity of collections, from individual treatment of the smallest object to mass treatment of the larger collections, from one single material item to multicomponent ones, from the humblest artefact to the most prestigious.

Furniture, wooden sculpture, painting, ethnological artefact, musical instrument, natural history specimen, books and archives, as well as modern and contemporary arts are among the collections commonly treated. Egyptian mummies, not only the one of Ramesses II treated by ARC-Nucléart pioneers, have also undergone this kind of treatments. Within this wide diversity of collections, one can mention more unusual bactericidal treatments applied to archaeological human remains or to the baby mammoth "Khroma," exhumed at the frozen state from the permafrost of Yakutia, thus combining sanitary and conservation objectives. Interesting enough, a recent treatment was applied to two central panels of the relief map of the city of Douai, north of France, commissioned by Louis XIV and completed in 1710. Measuring approximately 3.7 m x 1.65 m and weighing roughly 170 kg each, these two panels set a record, being the largest objects treated to date at the Grenoble irradiator.

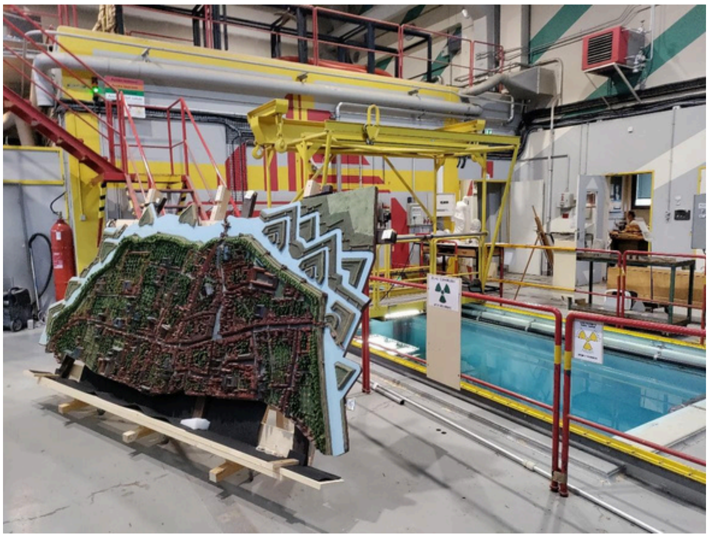

FIG. 1. Copyright ©ARC-Nucléart Relief map of the city of Douai, early 18th century, in front of the ARC-Nucléart irradiator pool.

Some of the treatments carried out in Grenoble are detailed in the recent IAEA book "Best Practices in the Disinfection of Cultural Heritage Artefacts and Archives Using Ionizing Radiation" (Cortella et al, 2025-a, b, and c).

The second application of gamma irradiation for heritage conservation exploits the radiochemical effects of ionizing radiation to consolidate the most fragile objects. It was named the "Nucléart" method by its pioneers, who first implemented it in the 1970s in Grenoble. This consolidation method involves the mass densification of porous materials using a radiopolymerizable resins after impregnation under usual vacuum/pressure processes.

Today, an unsaturated styrene/polyester resin is used, the hardening of which is ensured by cross-linking, triggered and driven by the irradiation. This gives operators, among other advantages, the possibility of carefully wiping away excess resin before starting the resin curing process. Unlike conventional techniques for consolidating porous heritage materials, all the resin that fills the object's microporosity and is retained by capillarity, is transformed from liquid to solid, without loss through evaporation. The amount of consolidant is therefore maximized, making this technique particularly effective.

Efficiency and stability are the two added values of this method compared to traditional methods. However, it is invasive, it typically doubles the weight of the artifacts, and above all it is irreversible, which is contrary to the ethics of heritage conservation. This is the reason why this practice is deliberately limited to fully justified cases for which the conservation issue cannot be met with less interventionist and more reversible means. It can be for instance the “last chance” treatment of much degraded wooden artefacts, or when functional mechanical strength is required to maintain their use. Thanks to its high chemical stability, it is also used for treatment of waterlogged archaeological wood, especially in presence of inseparable metallic parts that would be subject to corrosion with conventional method.

FIG. 2. © Rémi Banali/MDAA Gallo-Roman barge from the Arles Antique Departmental Museum, France. The shipwreck was first treated with conventional methods, but the treatment has been completed with radiocurable resin for the prow and for the mast to improve the chemical and mechanical stability of these elements.

The first application was the consolidation in 1970 of a historic 17th -century marquetry parquet floor which was in a critical state, for which the treatment allowed it to continue to be walked on ever since (Cortella, 2024). Painted wooden sculptures, for instance from church, for which it is not uncommon that the wood has been completely worm eaten under the polychrome layers, are regularly treated to save them from complete destruction. A last example is the treatment of the prow and the mast of a Gallo-roman barge from 1st century discovered in the Rhone River in the city of Arles. While all the elements of the 31 m long shipwreck were preserved using conventional polyethylene impregnation and freeze drying, the treatment of those two elements was completed with the so-called Nucléart method, in order to avoid corrosion of iron plates that was present on the prow and to maintain the mast in vertical position by itself (Bernard-Maugiron and Courboulès, 2018).

For more than 50 years, gamma irradiation has been continuously used in ARC-Nucléart for cultural heritage preservation (Cortella et al, 2020). Tens of thousands of artefacts have been treated by gamma irradiation for biocidal treatments, arresting biodeterioration due to pests, or to consolidate them thanks to radio-curable resin, reinforcing the more weakened artefacts. Both those techniques still offer relevant solutions to the conservation issues some of our cultural heritage artefacts face in France and abroad, sometime being the only solution to save them from destruction.

FIG. 3. ©ARC-Nucléart Installation of archives in the irradiation chamber for fungicidal treatment.

About ARC-Nucléart

It was the treatment of the mummy of Ramesses II by gamma irradiation in 1977 by ARC-Nucléart pioneers to definitively launch the activity of "using nuclear techniques for the conservation of cultural heritage," which had begun to develop 7 years earlier around the gamma irradiator at the CEA* in Grenoble.

Today, ARC-Nucléart is both a conservation-restoration workshop, providing conservation and restoration services, and a research laboratory, recognized for its expertise in the development of conservation techniques.

Located inside the research centre of the CEA in Grenoble, it acquired the special status of "Groupement d'Intérêt Public" in 1997, which is a kind of consortium whose members are the CEA, the Ministry of Culture, the City of Grenoble, and the support association ProNucléart.

Thanks to appropriate facilities and a reduced multidisciplinary team of 18 permanents peoples including physicists, chemists, biologists, technical staff, as well as conservators and a curator, it offers a unique expertise for the conservation of cultural heritage objects in organic materials. Alongside gamma irradiation treatments, ARC-Nucléart has two specialties: the conservation/restoration of polychrome wooden sculptures and the conservation/restoration of waterlogged archaeological wood. However, it is the fact that it operates an irradiator dedicated to heritage that gives ARC-Nucléart a unique position among workshops of conservation and has led to its designation as a collaborative centre of the IAEA.

(*) The French Alternative Energies and Atomic Energy Commission (CEA) is a key player in research, development and innovation in four main areas: defence and security, low carbon energies (nuclear and renewable energies), technological research for industry, fundamental research in the physical sciences and life sciences.

Website: https://www.arc-nucleart.fr/

Italy

The use of irradiation for the preservation of cultural heritage in Italy

The Calliope gamma irradiation facility of ENEA [1] carries out a wide range of research activities, including key studies on the use of ionizing radiation technologies for the conservation and preservation of Cultural Heritage (CH). The facility employs gamma radiation from a Cobalt-60 source, which decays by emitting two photons in coincidence with a mean energy of 1.25 MeV. Calliope allows irradiation tests to be conducted at different dose rates, atmospheric and temperature conditions, and is also equipped with a characterization and dosimetric laboratory. It is a unique facility in Italy since the source is housed in a very large volume shielded cell (7x6x3.9 m^3) (Fig. 1) which allows the simultaneous treatment of different samples.

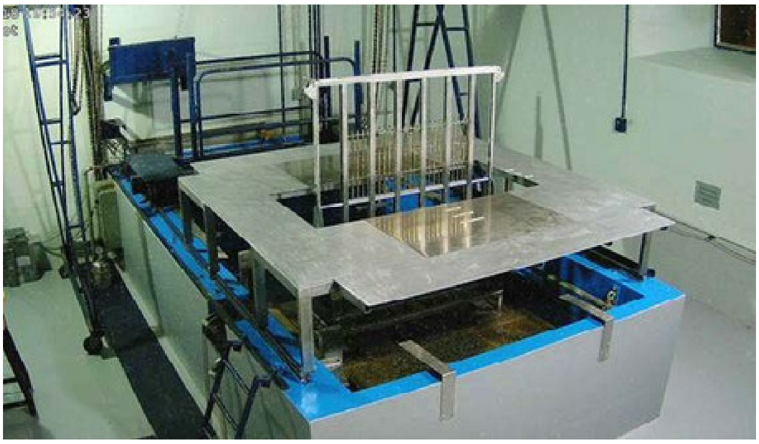

FIG. 1. Calliope irradiation cell during irradiation.

Over the past fifteen years, the Calliope facility has been involved in numerous national and international projects focused on cultural heritage conservation [2–6]. Gamma irradiation has proven to be a highly effective treatment technique, offering several advantages over conventional conservation methods, which are often time-consuming and typically involve the use of chemical substances that may be harmful to both restorers and artworks. Thanks to its high penetration capability, gamma radiation allows the simultaneous treatment of multimaterial and complex-shaped objects, ensuring a rapid and homogeneous process. Moreover, the technique does not require chemical agents and does not leave harmful residues on treated artifacts, making it particularly suitable for delicate and valuable cultural heritage objects. Despite these advantages, CH operators in Italy still show a certain resistance to the use of radiation-based conservation treatments. In this context, the activities of Calliope also aim to disseminate data and expand knowledge of the effects induced by radiation on treated materials, in order to promote the use of these techniques within the CH community.

Initial research activities at the Calliope facility in this field primarily focused on the optimization of irradiation parameters, namely absorbed dose and dose rate, in order to minimize radiationinduced effects on treated materials, commonly referred to as secondary effects. These studies were conducted within the dose range recommended by the International Atomic Energy Agency (IAEA) for cultural heritage applications, namely 8 ± 2 kGy [7,8]. The research approach combined material characterization studies and microbiological investigations. In the first phase, reference materials such as Whatman paper and pure cellulose were irradiated and extensively characterized to verify the absence of significant radiation-induced modifications at both structural and visual levels. To investigate secondary effects induced at different irradiation doses and dose rates, a wide range of optical and spectroscopic techniques was employed, including Fourier Transform Infrared (FTIR), Electron Paramagnetic Resonance (EPR), and microRaman spectroscopy, as well as viscosimetric and colorimetric analyses. These experimental techniques allow the assessment of radiation-induced modifications at both microscopic and macroscopic levels, such as changes in chemical structure, oxidation state (e.g., formation of C=O bonds), free radical formation and optical appearance. Extensive characterization has been carried out on paper-based materials [9], parchments, and more recently on innovative substrates such as Kombucha-derived nanocellulose [10], which is gaining increasing interest for conservation and restoration applications. Pictures of some of the materials studied are shown in Figure 2 as examples.

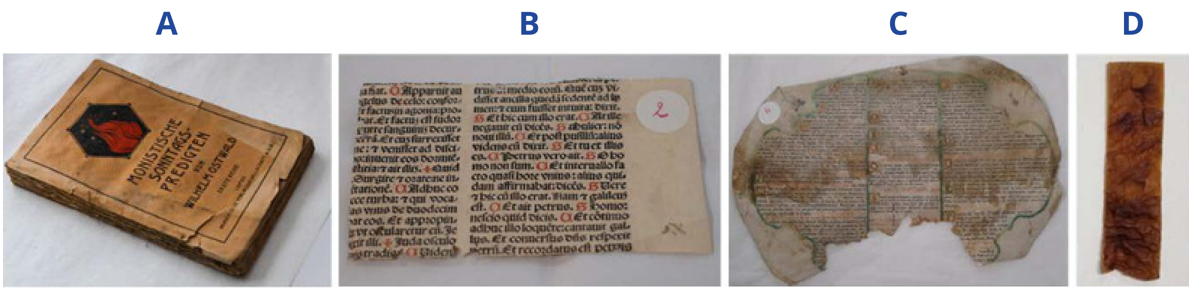

FIG. 2. A) old book (case study) and real materials investigated at the Calliope facility, including B) ancient paper, C) parchment and D) innovative cellulose-based substrates used in cultural heritage conservation studies.

In addition to the study of bulk materials, specific research activities have been dedicated to the investigation of the effects of gamma irradiation on inks applied to different substrates [11]. In the case of real artifacts and specific case studies, microbiological analyses were carried out to identify the type and concentration of microorganisms present (Figure 3a-b). Microbiological sampling was followed by replication of isolated microorganisms colonies on culture plates, which were irradiated at increasing absorbed doses. After irradiation, re-streaking onto fresh plates was performed; the absence of microbial regrowth after incubation was used to identify the minimum dose ensuring complete decontamination.

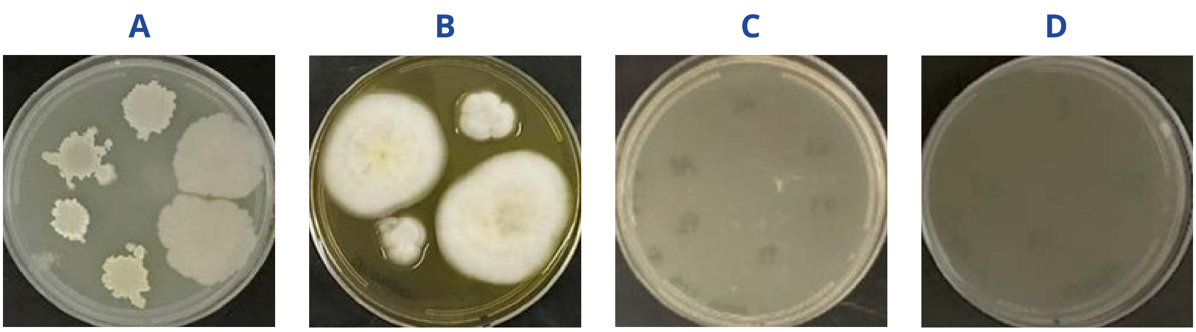

FIG. 3. Example of bacterial (in A) and fungal (in B) species cultured from archival materials affected by biodeterioration. After gamma radiation at 10 kGy of the plates showed in A) and B), the strains were cultured in new plates, (C and D). No growth of bacteria and fungi was observed after a week of incubation, indicating that the irradiation has inactivated the biodeteriogenic.

Within this research framework, the Calliope facility has been actively involved in several international projects promoted by the IAEA. In the context of these projects, detailed case studies were carried out on two historical books from the National and University Library of Croatia, combining microbiological investigations and pre- and post-irradiation material characterization. These studies contributed to expanding the understanding of the effects of absorbed dose and dose rate on paper materials with different compositions, including the presence of additives and lignin, as well as on materials exhibiting different ageing states. The results supported the validation of safe irradiation procedures in line with international recommendations and reinforced the reliability of gamma irradiation as an effective and noninvasive tool for cultural heritage conservation.

At the national level, a major milestone was represented by the PERGAMO project, funded by the Lazio Region. This project was the first in Italy to explicitly include the use of ionizing radiation for the treatment of CH objects. The project focused on paper documents and parchments from the archive of the Abbey of Montecassino, a highly significant European institution, affected by microbiological contamination. The project activities began with a detailed study of the microorganisms present on the artifacts, including fungi, moulds and bacteria, carried out in collaboration with Sapienza University of Rome. Based on microbiological analyses, the optimal irradiation dose ensuring almost complete decontamination was identified. Subsequently, the CH documents were treated at the Calliope gamma irradiation facility. Comprehensive characterization, including only non-destructive and non-invasive techniques, of the artifacts was performed both before and after irradiation in order to verify the absence of significant alterations induced by the treatment. Structural, chemical and visual properties were carefully evaluated, confirming that the irradiation process effectively eliminated biological contamination without causing substantial modifications to the materials. The PERGAMO project therefore represented a crucial step toward the practical application of gamma irradiation as a safe and effective conservation tool for archival and documentary heritage in Italy.

Overall, the long-term research carried out at the Calliope facility demonstrates that gamma irradiation represents a mature, safe and versatile technology for the conservation of cultural heritage, when applied within well-defined and internationally recommended irradiation parameters.

About ENEA

ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) is a public research body operating in the fields of energy, environment and sustainable economic development. The Agency carries out research activities, technological innovation and provides advanced services to enterprises, public administrations and citizens. ENEA relies on highly qualified personnel, state-of-the-art laboratories, experimental facilities and advanced instrumentation for the implementation of projects, studies, testing, analyses, assessments and training activities, with a strong focus on product and process innovation and the valorization of research results to enhance the competitiveness of the national economic system. Since its foundation in the 1960s, ENEA has been particularly committed to applied research, technology transfer and technical-scientific support to public and private stakeholders. Its main areas of activity include renewable energy, energy efficiency, nuclear fusion and safety, climate change, circular economy, resource efficiency, cultural heritage technologies and environmental protection, supported by extensive national and international collaborations.

Website: https://www.enea.it/en/enea-agency.html

Romania

Gamma irradiation for cultural heritage preservation in Romania

The need

The idea of using gamma radiation to "sterilize" museum objects or library books attacked by mould or insects arose shortly after the beginning of industrial radiation sterilization. The problem is real and sometimes overwhelming: collections of hundreds of wooden objects and thousands or tens of thousands of books or other paper documents, highly damaged by the biological attack.

Radiation treatment has not been easily accepted in the world of conservators and restorers. In addition to the initial fear of "nuclear" technology (as in food irradiation), reasonable concerns have been expressed about the radiation stability of the materials that compose cultural artifacts.

The evolution

In Romania, industrial radiation sterilization was delayed compared to other countries. Some specificities of the communist regime and the problems of the transition to a market economy led to the fact that until 2000 there was no large irradiation facility in the country. This means that experimental studies for the irradiation of cultural heritage also started late.

The situation changed rapidly, however, after the establishment of the IRASM multi-purpose irradiation facility at IFIN-HH. With great interest from the scientific and cultural heritage community and substantial financial support from the state (> 1 million euros), IFIN-HH led several R&D projects in partnership with museums and other specialized institutes. The aim was to find adequate answers to all concerns related to the effects of radiation on basic materials: wood, paper, leather, textiles and on any additives: pigments, dyes, varnishes, etc. Recent similar research conducted in other countries, such as Italy, France, Brazil, Croatia, Argentina, was of great help.

In this way, from a few objects irradiated per year just after the year 2000, currently in Romania, radiation treatment for cultural heritage has become a routine option taken into consideration in the conservation and restoration panels from museums, libraries or archives. To date, over 2800 wooden objects, over 800 textile pieces, 3500 films, as well as over 170,000 books and 180 tons of archives have been treated by irradiation in Romania.

The technology

Books, archives and other small objects are packed in cardboard boxes or in bags, like any other industrial products, and are irradiated in the automatic mode of the irradiator conveyor. The multi-purpose attribute of the IRASM gamma irradiator is supported by the relative ease of changing the dose, from the sterilization range (minimum 25 or 15 kGy) to lower doses (below 10 kGy). Large objects are irradiated by manually placing them in the irradiation room. For better dose distribution, the tote-boxes can be partially filled, and large objects can be rotated (manually) halfway through the irradiation time.

Dose limits, according to the purpose of the treatment (insect or mould disinfection) and the materials involved can be found in IAEA STI/PUB/1747. Examples on packaging cultural items and irradiation geometry can be found in IAEA STI/PUB/2115.

Wooden icons and iconostasis

Painted wood is a characteristic of the Orthodox Church. In addition to individual icons, Orthodox churches must also have them assembled into a massive wooden panel, which completely covers the altar (iconostasis). Woodworms are the main pest of wood in temperate zones, and even when large collections are kept in good storage conditions (in dry and dark places), they actually favour the spread of woodworm attack. The same can happen inside a church, when the iconostasis and the entire wooden inventory can be completely destroyed.

FIG. 1. The first iconostasis treated with gamma rays at IRASM, in 2002 [1]: detail of the decay attack; dismantled, in the IRASM warehouse; in the church, after complete restoration.

FIG. 2. Icons from the Art collection of Romanian Patriarchate: icons with a large diversity of shapes and sizes shown in the IRASM warehouse and irradiation room. The Patriarchate Conservation Laboratory carried out an extensive renovation of its warehouses and sent them to IRASM for radiation treatment in the period 2020-2022: wooden icons, iconostasis fragments, church furniture and other objects (1011 pcs), old religious books (50 pcs), paintings, lithographs (168 pcs) and textiles (191 pcs) [2].

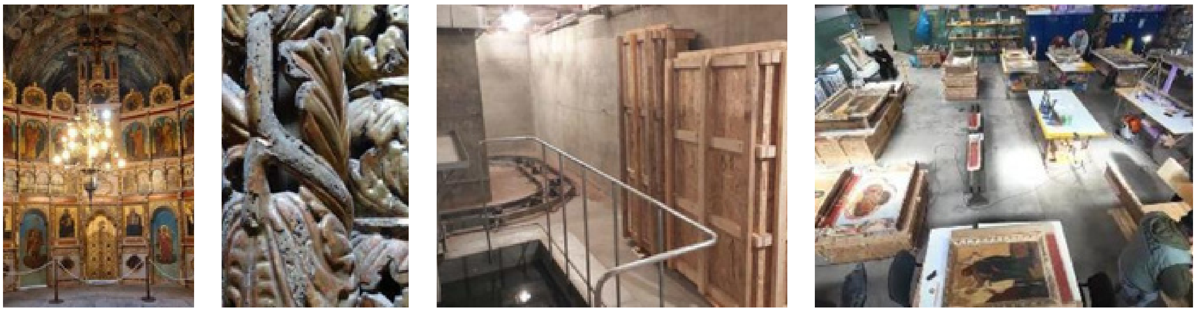

FIG. 3. Iconostasis of the church from Arbore Monastery – UNESCO heritage (2025): in the church; detail of woodworm attack; in the irradiation room; during the restoration process after the radiation treatment.

Archives and books

Paper is the most susceptible material to radiation degradation. It is well known that the degree of polymerization of cellulose is drastically reduced even at low doses of gamma radiation. Early findings also showed that other properties of paper (such as mechanical strength) remain unchanged or even improve within a certain dose range. More recent research has explained this by the increase in the number of hydrogen bonds in cellulose fibrils, as some covalent (betaglycosidic) bonds are lost.

Furthermore, there are situations where no other physical or chemical decontamination method can be effectively applied to huge quantities of paper articles massively attacked by mould in years or decades after flood accidents or unfavourable storage conditions.

Radiation treatment can be applied quickly, immediately after the flood accident, in combination with other damage mitigation actions (cleaning, freezing, drying).

FIG. 4. Documents from the Sahia Film Archive (2016). IRASM irradiated 825 boxes ~ 13 tons of documents under strong fungal attack, at the direct request of the Romanian Ministry of Culture [4].

FIG. 5. Books and periodicals from the "destructured collections" of the National Library of Romania [5], estimated at 4,430,000 bibliographic units: volunteers in the "destructured" warehouses (14 warehouses - 4,482 m2 in total). IRASM has treated by irradiation 378 boxes of periodicals and 7,775 boxes of books (~ 88 tons) during the period 2023-2025. The radiation treatment (ongoing) is mainly done for the protection of the staff who must pick up each book or magazine, for cleaning (dusting) and registration before placing them on the shelves.

Textiles, leather and complex collections

FIG. 6. The complete inventory of the Theodor Aman Museum including furniture, decorations, musical instruments, painting and sculpture tools (46 pcs.), wallpaper (115 m2), doors, door frames (25 pcs.) and panelling (135 m2) were treated by IRASM between 2006-2010; the Official Gazette of Romania collection, bound in luxury leather covers, belonging to the Romanian Parliament, 1,313 boxes weighing ~ 6.5 tons were treated by IRASM in 2015; and woollen carpets from Brasov Ethnography Museum, 84 boxes containing 284 pieces were treated at IRASM in 2018.

About Horia Hulubei Institute

Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) is the largest R&D organization in Romania. With roots in the 1950s, the institute has gradually developed with state-of-the-art equipment, today covering both fundamental research, applied research, scientific education and national reference expertise for nuclear physics.

Addressing the specific needs of society, in 2000, a multi-purpose high-dose gamma ray irradiator (IRASM) went into operation at IFIN-HH. It is the first and still the only industrial gamma irradiator in the country (tote-box conveyor, max. 2 MCi) and irradiate a wide range of products: disposable medical devices, pharmaceutical primary packaging, veterinary drugs, peat soil, various raw materials, but also cultural heritage artifacts.

Website https://www.nipne.ro/

Serbia

Preservation of Cultural Heritage in Serbia using Gamma Irradiation

Cultural heritage represents one of the most valuable resources for preserving historical continuity, collective memory, and cultural identity of societies. Museum, archival, and library collections comprise objects originating from diverse historical periods and thematic contexts, produced from a wide range of materials—including paper, textiles, leather, wood, metals, ceramics, and complex composite structures. The material heterogeneity of these collections, combined with the predominantly organic nature of many artifacts, makes cultural heritage particularly vulnerable to environmental changes and biodeterioration processes.

In recent decades, climate change, frequent flooding events, increased ambient humidity, and insufficiently controlled storage conditions have significantly intensified the problem of biological contamination of cultural heritage objects. Organic materials such as paper, textiles, leather, and wood are highly susceptible to colonization by fungi, moulds, bacteria, and insects that metabolize cellulose, proteins, and other organic constituents. These processes result in progressive mechanical weakening, chromatic alterations, embrittlement, and ultimately irreversible loss of cultural, historical, and informational value.

In response to these challenges, the proposed project aims to further develop and implement gamma irradiation as a safe, effective, and non-invasive method for the conservation and biodecontamination of cultural heritage materials. Gamma irradiation based on Co60 sources has proven to be a highly reliable disinfection technique due to its exceptional penetration depth and ability to inactivate biological agents at all life stages, without direct contact, chemical additives, or the generation of toxic or radioactive residues.

The project adopts a comprehensive material-oriented approach, targeting cultural heritage objects made of various organic materials, including paper-based archival and library collections, leather, textiles, and wood. These materials constitute the most biologically vulnerable segment of museum, archival, and library holdings. The methodological framework is designed to be flexible and adaptable, allowing the irradiation parameters to be individually optimized according to material type, manufacturing techniques, conservation state, and prior treatment history. The central objective is to determine irradiation doses that ensure effective disinfection and disinfestation while remaining below thresholds that could induce physical, chemical, or aesthetic degradation of the treated materials.

All irradiation procedures will be carried out at the Radiation Unit of the Vinča Institute of Nuclear Sciences, under strictly controlled conditions and continuous dosimetric supervision. Absorbed doses will be measured for each treated object using ethanol–chlorobenzene dosimeters, ensuring full traceability and reproducibility of the process. Following irradiation, materials will be subjected to detailed mechanical, chemical, optical, and structural analyses, providing a scientifically robust assessment of treatment safety and long-term material stability.

Previous Results of the Team

A major strength of the proposed project lies in the extensive prior experience and documented results achieved by the research team at the Radiation Unit of the Vinča Institute in the field of cultural heritage preservation using gamma irradiation.

One of the most representative case studies involved the treatment of severely contaminated leather gloves from the Nikola Tesla Museum. Due to extensive fungal colonization, the objects posed a risk not only to their own integrity but also to surrounding collections. Gamma irradiation at an average dose of 5 kGy resulted in complete elimination of mould contamination, as confirmed by microbiological analyses, without any detectable changes in the leather's visual appearance, texture, or mechanical properties. Following treatment, the objects were safely returned to museum storage and exhibition (Figure 1.).

FIG. 1. Samples of Nikola Tesla leather gloves before and after the performed treatment. Gloves are decontaminated, preserved from further deterioration, and are now displayed in the museum.

Another significant and highly sensitive intervention was the conservation of a medieval leather shoe from the collection of the National Museum in Belgrade. Based on prior microbiological assessment, the object was irradiated at an average dose of 5 kGy in the Vinča Radiation Unit. Post-treatment analyses demonstrated total eradication of fungal contamination, while visual, tactile, and structural inspections confirmed preservation of the material's integrity. This case provided strong evidence of the suitability of gamma irradiation for unique, irreplaceable, and fragile heritage objects (Figure 2.).

FIG. 2. Conservation of a medieval leather shoe.

In addition to applied conservation cases, the team has conducted systematic experimental studies on the effects of gamma irradiation on a wide range of heritage-relevant materials. These include textiles made of wool, linen, cotton, and silk, as well as historic leather samples treated with commonly used conservation preservatives. The results consistently indicate that within internationally recommended dose ranges for cultural heritage applications (typically up to 8–10 kGy), gamma irradiation does not induce changes that would compromise the functional, structural, or aesthetic properties of the materials, while providing a high level of biological stabilization (Figure 3.).

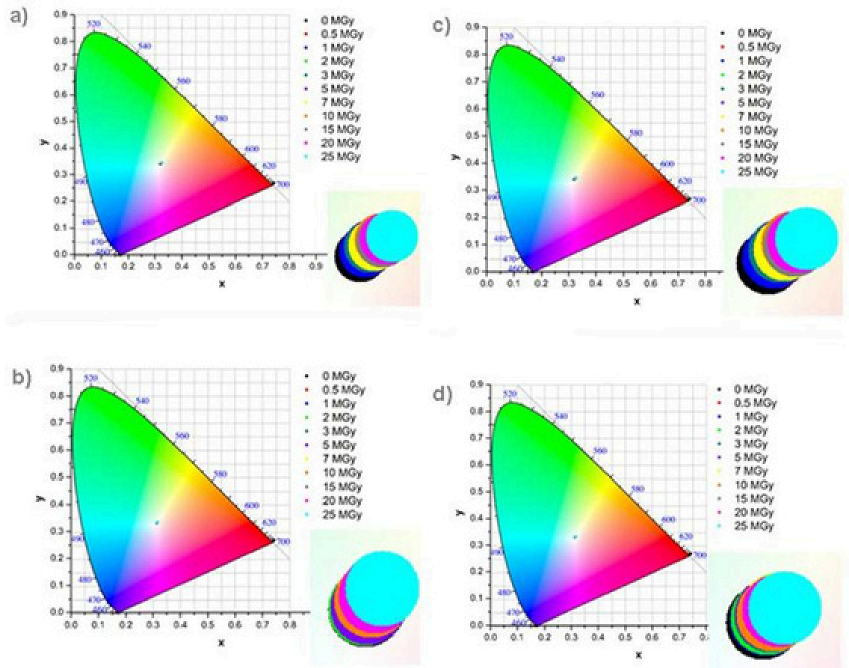

FIG. 3. The CIE chromaticity diagram of undyed samples of (a) wool, (b) linen, (c) cotton and (d) silk fabrics irradiated with different doses of gamma rays.

Previous research activities conducted by the project team have demonstrated the effectiveness and material compatibility of gamma irradiation for the conservation of organic cultural heritage. Systematic studies were performed on historically relevant, traditionally vegetable-tanned calf, bovine, goat, and sheep leathers, irradiated at controlled dose ranges and subsequently monitored under museum-like conditions for a period of six years. Comprehensive analyses using FTIR spectroscopy, electron paramagnetic resonance (EPR), colorimetry, and mechanical testing confirmed that, at conservation-relevant doses (5–10 kGy), gamma irradiation does not induce irreversible changes in collagen structure, mechanical performance, or visual appearance, while ensuring effective suppression of biological activity (Figure 4.).

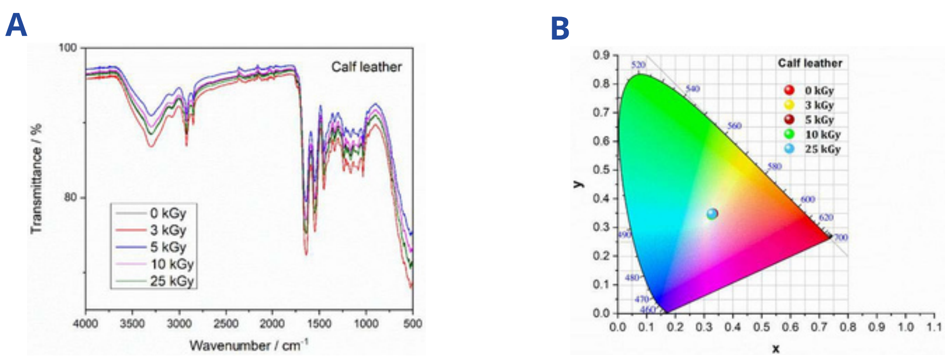

FIG. 4. A) Fourier Transform Infrared (FTIR) spectroscopy of calf leather; B) Colour stability of calf leather.

These combined applied and experimental results demonstrate the team's capability to bridge laboratory research and real-world conservation practice, offering a solid scientific foundation for the proposed project and its further expansion at national and international levels.

Impact and Relevance

By implementing an optimized, scientifically validated, and ethically acceptable irradiation protocol, the proposed project will enable systematic preservation of large volumes of cultural heritage objects, significantly extending their lifespan and improving storage safety. Preserved artifacts and archival records represent not only irreplaceable historical evidence and cultural identity markers but also assets of considerable educational, social, and economic importance. Through interdisciplinary collaboration between conservators, material scientists, radiation physicists, and microbiologists, this project contributes to the advancement of international conservation standards and promotes gamma irradiation as a sustainable and reliable technology for long-term protection of cultural heritage across Europe and the wider region.

About Vinča Institute of Nuclear Sciences

Established in 1948 by Professor Pavle Savić, a distinguished physicist, the Vinča Institute of Nuclear Sciences is Serbia's premier multidisciplinary research organisation. Originally founded to spearhead the national nuclear research program, the Institute has evolved into a global centre for scientific innovation. Today, it comprises over twenty specialised departments and centres, where more than 500 researchers and PhD candidates engage in diverse fields, ranging from particle physics and chemistry to molecular biology, power engineering, and nanoscience. As a prominent member of the University of Belgrade, Vinča serves as a vital educational hub, fostering the next generation of scientific elite through hundreds of international projects and collaborations.

A cornerstone of the Institute's technical infrastructure is its gamma irradiation facility, which has been operational since 1978. While the facility serves a critical role in the industrial sterilisation of medical devices and food preservation, it maintains a highly specialised and prestigious mission in cultural heritage preservation. This facility allows the Institute to apply its extensive expertise in radiation physics to the delicate requirements of conservation science.

Utilising Co-60 gamma radiation, the process achieves deep-penetration biocidal effects, effectively eradicating fungi and xylophagous insects in organic substrates—such as wood, paper, and textiles—without leaving toxic residues or inducing mechanical stress. By integrating rigorous dosimetry with multidisciplinary research, the Vinča Institute ensures that irreplaceable historical artefacts are preserved with scientific precision, successfully bridging the gap between high-capacity radiation processing and the meticulous standards of heritage science.

Website: https://www.vin.bg.ac.rs/en/industry/radijaciona-jedinica

Türkiye

Preserving Cultural Heritage through Nuclear Technology: Turkish Experiences

Türkiye is a country of universal richness and diversity in terms of cultural heritage. Its favourable geographical location has allowed various civilizations to settle in these lands throughout history, leaving behind a wide variety of cultural artifacts. This cultural richness imposes an international responsibility on Türkiye. The cultural heritage it holds must be meticulously preserved, not only for its artistic and scientific value but also because it is the 'common heritage of humanity'.

In Türkiye, activities regarding the conservation, restoration, and preservation of tangible cultural heritage, such as paper, wood, and textile artifacts found in museums and state archives, are primarily carried out by the Directorate General of Cultural Heritage and Museums under the Ministry of Culture and Tourism. Meanwhile, the Turkish Energy, Nuclear and Mineral Research Agency (TENMAK), in official cooperation with the General Directorate of Cultural Heritage and Museums, has been significantly contributing to the preservation of cultural heritage through the use of radiation technology for over 20 years. The irradiation of cultural heritage artifacts is performed using a box-type irradiation facility sourced with a ^{60}Co gamma source (SVST-1 category IV) installed at the Nuclear Energy Research Institute. In addition, the institute houses an electron accelerator facility with ICT-type 500 keV and 20 mA specifications. This facility is utilized for the irradiation of thin objects, such as paper, and offers services for the surface decontamination of artifacts.

In the applications for the preservation of cultural heritage using radiation technology, the initial step is to identify the existing pests and mould species on the artifacts. Subsequently, the appropriate irradiation dose needed for the elimination of these species is determined. Prior to irradiation, the physical and chemical characterization of the artifact is performed using nondestructive nuclear and analytical techniques to examine whether the dose to be applied will have any adverse effects on the artifact's structure. Once potential short- and long-term changes are evaluated and it is confirmed that the artifact can be safely irradiated, the irradiation process is conducted. Nevertheless, microbiological and non-destructive chemical tests are performed again following the irradiation to verify the effectiveness of the application.

To date, radiation treatments conducted at TENMAK have ensured the survival of diverse historical objects, ranging from wooden objects to old manuscripts. Wooden artifacts that are not stored under appropriate conditions are vulnerable to a range of wood-destroying pests. Particularly, the larvae of wood insects feed on the internal tissues of wood and create tunnels and galleries inside the objects, which weakens the structure and leads to significant damage. This type of damage can be observed in wooden artifacts represented in Figure 1.

FIG. 1. Insect attack on wood artifacts; wooden items from Kastamonu Ottoman Mansion (on the left) and a wooden chest from the Seljuk period (on the right).

FIG. 2. The throne belonged to Ghiyath al-Din Kaykhusraw I

The Ottoman Mansion, a distinguished example of civil architecture in Kastamonu province, is among the earliest and most artistically valuable buildings in the city. Dating from the late 18th and early 19th centuries, this mansion is renowned for its magnificent woodwork and interior decorations. However, the wooden objects have been infested with insects over time, and this magnificent piece has suffered critical damage (Fig. 1, on the left). Similarly, a wooden chest dating from the Seljuk period has suffered the same fate (Fig. 1, on the right). Notable for its rich ornamentation, the chest is thought to have been used for storing valuables, jewellery, or important documents. The extent of the damage and the types of insects present were determined by the preliminary examinations of these artifacts. Furthermore, analyses of the ornaments on the chest were conducted. The results indicated that the wooden objects of the mansion could be irradiated with a dose of 3 kGy. However, the decorations on the chest were identified as aragonite (seashell). Therefore, the chest was irradiated at 1.5 kGy, thereby minimizing the pest load while preserving the colour and integrity of the decorations. Even though lethality was not achieved at this dose, sterility was induced.

Beyond being produced to meet people's practical needs, textiles act as silent narrators of history. Every stitch, colour choice, and pattern order serve as a cultural representative, weaving together the story of traditional life and the emotions of the people who created them. To develop effective conservation strategies, studies are being conducted on the decontamination of textile artifacts using radiation technology. A crucial aspect of these studies is to ensure that the natural fibres and dyes used in these textiles are not damaged by the radiation dose applied. Therefore, the types of fibres and dyes are always determined prior to irradiation of the textile artifact. One of the most important examples related to these studies is the 13th-century throne carpet and coverings (Figure 2) known to have belonged to Ghiyath al-Din Kaykhusraw I, the Seljuk ruler who reigned in Anatolia. Following the pre-analysis of the textile artifacts, gamma irradiation at a dose of 3 kGy has been applied.

TENMAK also conducted research on the preservation of archival papers using radiation technology. A project was underway at the Ottoman State Archives, which houses over 100 million documents, to remove biological contaminants from these documents. This project aimed to preserve the integrity of these documents for many years and allow their transmission to future generations. As a result of biological, entomological, physical, and chemical analyses performed in this archive, irradiation processes have been conducted on relatively young documents (150 years old). Efforts are ongoing to establish an electron accelerator facility in the vicinity of the archive building for the decontamination of such a rich collection.

As demonstrated by experiences in Türkiye, radiation technology can be employed to decontaminate diverse artifacts through processes tailored to material sensitivities. Integrating this technology with other conservation methods offers a sustainable, large-scale approach to safeguarding the cultural heritage of humanity against the unavoidable impacts of biological deterioration.

About TENMAK

The Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) operates in the fields of energy, mining, ionizing radiation, particle accelerators, and nuclear technology. The aim is to strengthen scientific infrastructure, guide technological advancements, and develop new products and processes. TENMAK engages in joint projects and cooperative activities conducted under national and international agreements. The Nuclear Energy Research Institute under TENMAK is equipped with a gamma irradiation facility, electron and proton accelerators, and an open-pool-type research reactor. The research, such as radiation technology applications, radiation detector development, dosimetry, food and agriculture, materials research and development, radionuclide metrology, accelerator and fusion technologies, radioisotopes and radiopharmaceuticals, nuclear physics and microelectronics, and nuclear reactor safety and design, is conducted to promote the peaceful use of nuclear energy and radiation technology. In addition to long-standing research in the preservation of cultural heritage through ionizing radiation, the Institute has played a vital role in generating 'identity cards' for artifacts and in the repatriation of various smuggled items to Türkiye.

Website: https://www.tenmak.gov.tr/

Further Reading

1. IAEA Best Practices in the Disinfection of Cultural Heritage Artefacts and Archives Using Ionizing Radiation
   https://www.iaea.org/publications/15831/best-practices-in-the-disinfection-of-cultural-heritage-artefacts-and-archives-using-ionizing-radiation

2. IAEA Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation
   https://www.iaea.org/publications/10937/uses-of-ionizing-radiation-for-tangible-cultural-heritage-conservation

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France

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