IAEA
International Atomic Energy Agency
Atoms For Peace

REPORT

Consultancy Meeting on

"Standard Operating Procedure for Preservation of Cultural Heritage"

01-04 July 2019

IAEA Headquarters Vienna, AUSTRIA
(Meeting Room – M0E70, VIC)

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BACKGROUND

The preservation of Cultural Heritage (CH) has emerged as a key issue for maintaining national identity and understanding the influences or exchanges among civilizations throughout history. Cultural heritage artefacts are made up of materials varying from simple mono-components to complex structures integrating inorganic and organic materials. Degradation by insects and microorganisms such as fungi and bacteria constitute a major threat against the long-term preservation of CH. The success and consolidation of the application of ionizing radiation for inactivation of microbes presents a powerful technique for the disinfection of paper, textiles and wood based CH artefacts. In recent years, collaboration of radiation processing facilities with cultural heritage institutions such as museums and libraries has opened new perspective for the use of this technology for treating large quantities of deteriorated products that required emergency intervention or had a complex structure that limited the use of conventional techniques. The radiation processing shows several and indisputable advantages over classical preservation procedures and represents the most reliable and effective method to be applied in case of harmful natural calamities (such as floods and earthquakes) occurrence.
To increase the diffusion and the acceptability of ionizing radiation processing in CH field, the issuing of well-defined and shared guidelines is extremely desirable. The purpose of the event is to exchange expertise and experiences and develop standardized integrated guidelines for the application of radiation as a tool for the preservation and consolidation of cultural heritage objects.

SUMMARY OF PRESENTATIONS

BRAZIL

Preparation protocols for decontamination of cultural heritage objects and archived materials using ionizing radiation

Decontamination of cultural heritage objects and archived materials by ionizing radiation has been successfully applied in recent years. Radiation processing used for cultural heritage disinfection has several advantages when compared with conventional methods mainly related to the safety, efficiency, reliability, capacity, process time and safe for environment. Due to the increasing frequency of requests for this treatment in the Multipurpose Gamma Irradiation Facility at the Nuclear and Energy Research Institute, several protocols were developed for attending the conservation institutions. The decision to process with ionizing radiation must be carried out by the professionals of the conservation of cultural artefacts in conjunction with professionals in the field of ionizing radiation applications. In order to obtain a correct decision about ionizing radiation treatment, it is essential to carry out a diagnosis of the status of the collection including signs and symptoms, state of conservation, environment guard, associated pathologies, contamination examination, previous irradiation, problem classification, presence of insects only, presence of insects and fungi, bacteria, etc. The choice of treatment for ionizing radiation should include different stages as separation of the materials by type of contamination, use of multi-barrier packaging, scheduling of the irradiation and arrangement for special transportation for cultural goods. Contaminated materials need to be exposed towards an ionizing radiation source at a dedicated absorbed dose that should be established in advance. After irradiation, materials should be stored in an environment protected from heat, light radiation and high relative humidity. Mechanical cleaning is

recommended to remove dust and residues from insects and microorganisms. Some archived materials can be digitalized to ensure that digital information of continuing value remains accessible and usable. Also important is to maintain reports with all details of the decontaminated materials and the documentation related to the applied absorbed doses.

CROATIA

Status and Recent Issues on the Preservation of Cultural Heritage by Ionizing Radiation in Croatia

The study of physico-chemical effects of ionizing radiations in matter forms the subject of basic and applied research of the Radiation Chemistry and Dosimetry Laboratory (RCDL) at the Ruđer Bošković Institute (RBI) in Zagreb covering research in radiation chemistry, radiation protection and radiation dosimetry and radiation processing. The main equipment is a panoramic-type dry storage gamma irradiator (activity about 65 kCi) which has been initially designed by the RCDL staff for experimental work only. With its periodical upgrading having been assisted by the IAEA it has grown to a batch multipurpose radiation facility as only facility of its kind in Croatia and the region. After the first significant upgrade of the 60Co source to the pilot plant level in 1983. it became possible to perform both the irradiations with a scientific objective, as well as those aimed to the sterilization, decontamination and disinfestation of larger quantity of various materials. This included irradiation treatments of cultural heritage objects, which were performed for preventive and curative purposes for desinsection (2 – 5 kGy for wooden objects, textiles, paper, parchment) and for decontamination (5 – 15 kGy for wooden objects, paper, leather). The capacity of the irradiator chamber is 4 - 6 m^3 of material per batch. The demand for radiation treatment of cultural heritage objects of some significance has become particularly acute during the war in Croatia (1991 – 1995) when the cooperation with the Croatian Conservation Institute (CrCI) in that field grew in time and it lasts until today. The larger part of all cultural heritage objects (more than 8000 wooden sculptures, parts of altars, furniture, tools, other wooden, paper, straw, textile, leather items, etc.) treated over the past 30 years at the gamma irradiation facility of the RBI, were in cooperation with the CrCI. Besides the CrCI the RCDL cooperates also with the Academy of Fine Arts, the Museum of Contemporary Art; the Croatian State Archives, the National Academy Library, 10 museums and numerous private restaurateurs. Presently, about 20 m3 heritage objects are treated annually.

The RCDL has several ongoing scientific projects on the research of irradiation-induced changes of the cultural heritage objects basic materials, with special consideration given to the gathering a database of materials of organic origin, as well as of microorganisms that are most commonly found on objects of cultural heritage made by paper and textile, as well as to the prevention from corrosion of metal surfaces of cultural heritage objects using gamma irradiation. Among several recent examples of radiation treatments performed at the RCDL a particular example should be mentioned: assisting the experts of the CrCI, who were carrying out the renovation and restauration, the scientists of the RCDL contributed their expertise by providing disinsection by irradiation of the wooden chapel of St. Martin in Stari Brod as a rare example of a traditional folk Baroque architecture with a completely preserved painted interior. This renovation project of CrCI deserved the European Award for Conservation Works in 2017.

FRANCE

Protocole for consolidation of wooden artefacts by impregnation with radiation-curing resins and R&D of new formulations without styrene monomer and reversible

Since the seventies, ARC-Nucléart has been using a styrene unsaturated polyester resin for the consolidation of degraded dry wooden artefacts in a process called "Nucléart", involving resin impregnation under vacuum/pressure, followed by in-situ polymerization of the resin under gamma irradiation. Waterlogged archaeological artefacts are first dried by freeze-drying, then impregnated as a dry artefact. However, this method is irreversible due to the cross-linked solid state resin which is insoluble to any solvent. Moreover, the consolidation of wood by 100 % reactive resin fills almost completely the wooden pore structure, creating in fact a wood-plastic composite whose density is more or less equivalent to that of the waterlogged wood.

These features constitute limitations of this method vis-à-vis two well-known criteria for the conservation of artefacts, i.e. the reversibility of the treatment and minimalizing the procedure in order to avoid the denaturation of the original object.

Furthermore, even though this technique has proved during many decades its effectiveness in saving from destruction numerous highly degraded artefacts, other drawbacks of the current process are the toxicity and the relatively high vapour pressure of the styrene monomer. Moreover, because of increasingly stringent safety regulations, our research has been focused on the improvement of the "Nucléart" method by two distinct means: the use of already available styrene-free resins and the development of methacrylate monomers, whose polymers are in principle reversible. This R&D programme started in late 2015 with its final phase in 2018-2019.

Methacrylic monomers such as alkyl-methacrylates, hydroxy-propyl methacrylate's and available styrene-free resins were tested for the consolidation of non-degraded wooden samples, as well as degraded samples taken from ancient artefacts. Partial consolidation of the wood was realized by formulating the monomer in various solvents at different concentrations; such formulations may avoid the inhibition of oxygen on the polymerization of acrylic compounds which are particularly sensitive to this effect. Besides spectroscopic analysis of the radiation-cured polymers (FTIR, NMR), dimensional changes, mechanical testing, colorimetry and SEM observations were carried out to characterize the wood-polymer composites. Very promising results were obtained showing that the styrene-free resin tested could be an alternative to the current styrene-unsaturated polyester resin, and the formulations based on the methacrylate monomers mixed with acrylic polymer Paraloid® B72 give interesting results in terms of surface appearance, mechanical improvement, dimensional stabilization and reversibility of the treatment.

ITALY

Gamma radiation processing for Cultural Heritage preservation in Italy

Despite ionizing radiation treatments for preservation of artefacts present several and indisputable advantages over classical procedures, strong resistance to their application is shown by the Italian Cultural Heritage experts at official level. The reason for this mistrust, is often due to the incorrect knowledge of the physical-chemical modifications (side-effects) induced by ionizing radiation on treated materials.

In the last years, several activities were performed at the Calliope gamma irradiation facility (ENEA Casaccia R.C., Rome, Italy) with the aim to investigate the gamma irradiation side-

effects on cellulose-based substrates by means of different analyses and to have an indication about the most significant parameters to take into account for the evaluation and the measure of the degradation phenomena and about the most correct experimental techniques to be used. The experimental results acquired, can contribute to achieve a irradiation conditions standardization (in term of irradiation dose and dose rate, environmental atmosphere, pre-treatment of the cultural heritage object) and treatment procedures codification, guaranteeing the safeguard of the artefacts and a reliable diffusion of this technology.
Furthermore, the problem of the permanence of irradiated cellulose over time is an issue of great interest for CH operators. Although several authors faced this problem, it is very difficult to obtain agreed outcomes and shared conclusions, since the high variability of the starting materials in term of macroscopic and microscopic features (DP, oxydation state, acidity, humidity) and storage conditions, do not allow to extend the obtained results in full and certain way to each irradiated material. For these reason, ongoing activities aim to the definition of a "reference" starting material.
The paper permanence it is not only interesting when preservation treatments (e.g. irradiation) were performed, but it is influenced also by the natural ageing of the cellulose or by the storage conditions. The prediction of the permanence of paper by accelerated ageing test and Arrhenius plot was proposed, due to the reaction rate increase with the temperature. The method described could also allow to know and define the «lifetime» of the considered material before it reaches a threshold value (e. g. DP > 300, to avoid mechanical problems) at specific environmental and storage conditions (T, R.H.).

ROMANIA

Status and prospects of gamma irradiation for cultural preservation in Romania
Early experiments on the use of ionization to preserve cultural heritage began in the late 1970s in Romania. In the 1990s, at IFIN-HH, experiments were resumed using a pilot gamma irradiator (10kCi of Co-60). Afterwards, with the strong support of research and development projects, IRASM Center of IFIN-HH began to develop large-scale treatment of cultural heritage objects with the multipurpose industrial gamma irradiator (maximum 2MCi Co-60, wet storage, box).
Acceptance of radiation treatment among end users/stakeholders has not been rapid: apart from the fear of "radiation" (which is easily overcome by explaining the nature of ionizing radiation), there are always concerns about changes induced in complex, aged and already degraded materials. Following the example of other countries (France, Italy), IFIN-HH IRASM has conducted large-scale research projects in collaboration with other R&D organizations, specialized in materials of interest (wood, paper, leather / textiles) and stakeholders (Work Safety) . IRASM has continuously supported the dissemination to end-users of scientific results obtained in Romania and around the world regarding the effects of radiation treatment. The main advantages of irradiation (high penetration and certainty of biocidal effect) are generally accepted, and there is often a need for rapid, large-scale intervention.
Acceptance and demands for radiation treatments have gradually increased and nowadays IRASM processes more than 250 tons of paper (archives, library and religious books) and thousands of articles of wood, textiles and leather each year. Recent examples of radiation treatments performed at the IRASM facility include: large iconostasis (6 x 4 meters) and wood-painted icons collections, the entire inventory of Th. Aman Museum (Romanian

painter and sculptor), the "Royal Patent" Collection (State Office for Inventions and Trademarks), the "Official Journal" collection (Archive of Romanian Parliament), the complex Museum collection of the Bucharest National Theatre and collections of the old religious books from the Orthodox Church and Monasteries.
Many industrial irradiators can perform irradiation for cultural heritage but due to the nature of the CH items (irregular shape, size and weight) the standardization of the irradiation process is much difficult compared to the processing of the manufactured items (medical devices, food, etc).

SUMMARY OF DISCUSSIONS

The participants invited as the experts in this field by IAEA, discussed in general about acceptance of radiation technologies in CH conservation and preservation and necessity of the wider use of this technique. The Meeting aimed to formulate the way forward to develop harmonized guidance to be adopted based on the shared experience of Member States to ensure safe CH irradiation practices on a larger scale. Through presentations of their experience and scientific knowledge in radiation conservation of CH artefacts (including research of case studies) participants have evidenced several advantages of this method in comparison with other conventional method, and in some cases, e.g in massive bio-deterioration of CH objects, it's use is only possible one.
We discussed about the frame of a protocol for end-users who intend to apply ionizing radiation in this field. As result we gave some recommendations for standard operating procedure for preservation of cultural heritage artefacts and archives using ionizing radiation.

CONCLUSIONS

1. A protocol for radiation treatment of cultural heritage objects and archival materials containing recommendations and procedure descriptions has been proposed to assist establishment and optimization of the use of radiation technology for their conservation and protection.
2. The purpose of the protocol is to be a practical guide, from the detection of the problem to the final disinfection of cultural heritage objects, so that conservatives and professionals of the irradiation can act in a collaborative and objective way to reach the purpose of the treatment.
3. The publication from IAEA Radiation Technology Series No. 6: *Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation*, was very valuable and base for this protocol proposal.

RECOMMENDATIONS TO THE IAEA

1. The IAEA should support activities and collaborations among member states in CH preservation by ionizing radiation technology to improve the knowledge on capabilities and limitations of this technology.
2. The IAEA should organize international workshops, symposiums and training programs for dissemination of the results of applicability of radiation treatment of CH objects, and continuous development of future directions.
3. The IAEA should support the education of potential end-user as curators, conservators and restorers, including e-learning platform.
4. The IAEA should support a new publication: *Standard Operating Procedure for Preservation of Cultural Heritage*, in continuation following the first publication No. 6: *Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation*, to update and extend the existing knowledge to stakeholders.
5. The IAEA should support continuous cooperation between the technologists working on the CH preservation by ionizing radiation technology and on characterisation of CH objects with nuclear techniques.

ANNEX I

Recommendations for SOP for the disinfection of cultural heritage artefacts and archives using ionizing radiation

Content:

1. Introduction

Decontamination (disinfection) of large quantities of fungus-infected materials can be done using ionizing radiation. For this, the contaminated materials will be exposed towards a source of irradiation with a determined dose, which must be established in advance. The most common source is gamma irradiation of the most common Cobalt-60 isotope, producing characteristic electromagnetic radiation (such as radio waves occur in microwaves), which are able to completely pass through the materials and leave no (radioactive) residue in the material treated. The electron beam and x-ray are produced from an electrical source.

Once treated, materials must be returned to a contamination free repository and is recommended to remove dust.

2. Scope

This document describes how to treat biological contaminated cultural artefacts using ionizing radiation.

3. Conditions

Radiation treatment of CH artefacts should be applied only if there is a real need. Materials which are not appropriate for irradiation at the required doses should be removed from objects before irradiation. The size of individual items should be adequate with the physical limitations of irradiator and dose uniformity requirements. A good homogeneity of the mass of the materials dose uniformity is improved, resulting in the least possible deterioration of the materials due to the treatment and in increased effectiveness of the treatment.

4. Terminology and definitions

(this section contains a list with terminology and definitions, (Ref. IAEA Book) and etc.)

Biological decontamination, disinfection, disinfestation

Disinfection: eradication of microorganisms

Cobalt-60 source: Cobalt is a metal that can be found in nature as stable (non-radioactive) and non-stable (radioactive). The best known and used radioactive isotope is cobalt-60.

Gamma Rays: Invisible electromagnetic ionizing waves with a higher energy level than UV light, for example.

ionizing radiation emitted by unstable isotopes

Homogeneity: comparable, of equal composition

Volume by mass: mass of an object divided by its volume

Stretch sheet: polymer sheet specially developed for pallet packaging and provides protection against dirt and dust.

5. Pre-treatment of materials to be decontaminated

5.1. Isolation of the collection – quarantine

Contaminated collections should be isolated from any uncontaminated collection. This can be done through a quarantine area in the same or another building.
Climate, relative humidity
Storage duration recommendation treatment ASAP

5.2. Packaging and delivery

Recommendation for the most economic packing appropriate to transport conditions and the size/weight limitations of the irradiation facility. Packaging should be performed by the end-user.

ANEX I-1: Examples according to the facility type

If needed, the pre-packaging (consolidation, wrapping, etc) or re-packaging of the materials should be performed by the responsible, such as the restorer or conservator.
If a direct packing is required, the collection should preferably be delivered in boxes (archive box, polyethylene or wood transport box, stacking resistance etc.).
The contents should be as homogeneous as possible in bulk.

If the materials to be treated are already packed in a transport resistant manner (containers, bags), re-packaging is not necessary.

ANNEX I-2 Examples according to type of CH:
Recommendation: for books, archived materials, wooden items, etc.
Recommendation for pre-sorting depending on the facility type

Materials of exceptional size and mass must have packed according to the size limitations of the irradiation facility.
(Recommendation depending on the facility type?)

5.3. Registration

Registration form – refers to the registration of collections at the end-users.

6. Transportation of cultural heritage materials

Infested/infected cultural heritage materials should be transported using a closed, dry and clean vehicle. By the case, a specialized transport company may be required.

Treated materials should be transported in an closed, dry and clean vehicle and not mixed with the infested/infected ones.

Materials should be properly wrapped protecting them from external biological contaminants.

7. Disinfection treatment

7.1 Reception and storage of materials to be decontaminated

Registration of receiving of CH by the treatment company (supplier) with all needed data.
The registration must include at least:

- name of the person responsible (owner or owner representative),
- transport company,
- reception date,
- quantity of CH materials received (artefacts, paletts/box, etc)
- damage of the packages found on reception.

Storage until processing – description depending on the facility conditions.

7.2. Irradiation

7.2.1. Preparation of the treatment

Description of placement of the boxes/treatment boxes/paletts depending on the facility type
Description of the placement of the dosimeters.

7.2.2 Recommended dose

The irradiation dose range (minimum and maximum) should be established by literature data, previous experience or preliminary tests (microbiological, physical and chemical).

ANNEX … - Examples of doses

1) Reduction or elimination of fungi and spores: mean (8 ± 2) kGy
2) Reduction or eradication of insects and pests: average of 2 kGy
3) Reduction or disinfection ≥ 10 kGy
3) Another dose is possible and should be determined together with user.

7.2.3 Verification of radiation treatment

Description of the verification procedure by dosimetry (dosimeter type, physical-chemical property in function of absorbed dose, measuring, traceability)
Interpretation results using a calibration curve, uncertainty.
Results: minimum, maximum and average dose.
Note: Usually the existing dosimetry procedures of the irradiation facilities (for medical sterilization, food irradiation, etc) can be used for verification of the radiation treatment.
ANNEX … - Examples of diametric system

7.2.4 After irradiation

The storage conditions after irradiation should be specified. Irradiated and non-irradiated materials must be physically separated.

8. Documentation

The irradiation facility should maintain documented information on:

- Reception of the CH materials
- Irradiation of the CH materials
- Dosimetry measurements of the CH materials
- Delivery of the CH materials

9. Report

The result of the radiation treatment should be reported to the end-user.
The report shall include at least:

- The request for the treatment
- Identification of the CH materials treated (according to reception)
- Dosimetry results
- Reference number of the treatment
- Date of irradiation.

ANNEX II

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IAEA Consultancy Meeting on "Standard Operating Procedure for Preservation of Cultural Heritage"

01-04 July 2019, Vienna IAEA HQ (M0E70)

MEETING AGENDA

Monday, 01 July 2019

08:00 - 09:00	**Registration at the Gate 1, IAEA headquarters, VIC**	
Session I:	**Introductory Session**	
09.00 - 09.30	**Opening of the meeting by:** - **Ms Melissa Denecke, Director NAPC (IAEA)** - **Mr Joao Alberto Osso Junior, Section Head of RPRT (IAEA)** - **Mr Bumsoo Han, Scientific Secretary, RPRT (IAEA)** - **Ms Dinara Abbasova, RPRT (IAEA)** **Scope and Objectives of the Meeting, Adoption of the agenda** Election of the chairperson of the meeting, introduction of participant	
Session II:	**Participants' Presentations**	
09:30 – 10:20	Mr Pablo Vaques (**Brazil**)	Radiation Processing Protocols for Preservation of Cultural Heritage
10:20 – 10:50		*Coffee Break*
10:50 – 11:40	Ms Branka Mihaljevic (**Croatia**)	Status and Recent Issues on the Preservation of Cultural Heritage by Ionizing Radiation in Croatia
11:40 – 12:30	Mr Quoc-Khoi Tran (**France**)	Consolidation of wooden artefacts by radiation-curing resins, its protocol and R&D for alternative formulations
12:30 – 14:00		*Lunch Break*
14:00 – 14:50	Ms Alessia Cemmi (**Italy**)	Gamma radiation processing for Cultural Heritage preservation in Italy

14:50 – 15:40	Discussion on Current Status and Recent Issues on the Preservation of Cultural Heritage by Ionizing Radiation in Member States
15:40 – 16:10	*Coffee Break*
16:10 – 17:00	Discussion on Current Status and Recent Issues on the Preservation of Cultural Heritage by Ionizing Radiation in Member States

Tuesday, 02 July 2019

Session III & IV:	**Standard Operating Procedure for Preservation of Cultural Heritage**	
09:00 – 10:30	Mr Valentine Moise (**Romania**)	Status and prospects of gamma irradiation for cultural preservation in Romania
10:30 – 11:00	*Coffee Break*	
11:00 – 12:30	Discussion on development of IAEA Publication on "Standard Operating Procedure for Preservation of Cultural Heritage"	
12:40 – 14:00	*Lunch Break*	
14:00 – 15:30	Discussion on development of IAEA Publication on "Standard Operating Procedure for Preservation of Cultural Heritage"	
15:30 – 16:00	*Coffee Break*	
16:00 – 17:30	Discussion on development of IAEA Publication on "Standard Operating Procedure for Preservation of Cultural Heritage"	
17:30 – 18:00	Drafting of the Publication Skeleton (scope/contents/structure/conclusions/recommendations)	

Wednesday, 03 July 2019

Session V & VI:	**E-Learning Module on Application of Ionizing Radiation for Cultural Heritage**	
09:00 – 10:30	Ms Dinara Abbasova (**IAEA**)	Presentation of E-learning Module on Application of Ionizing Radiation for Cultural Heritage Preservation
10:30 – 11:00	*Coffee Break*	

11:00 – 12:30	Revision and Discussion of E-learning Module of Application of Ionizing Radiation for CH
12:40 – 14:00	Lunch Break
14:00 – 15:30	Revision and Discussion of E-learning Module of Application of Ionizing Radiation for CH
15:30 – 16:00	*Coffee Break*
16:00 – 17:30	Finalizing the E-learning Module of Application of Ionizing Radiation for CH and confirmation for uploading to CLP4NET
17:30 – 18:00	*Finalize and document the discussion*

Thursday, 04 July 2019

Session X:	**Final Review and Acceptance of Meeting Report**
09:00 – 10:30	Drafting of the meeting report (scope/contents/structure/conclusions/recommendations)
10:30 – 11:00	*Coffee Break*
11:00 – 12:30	Review and acceptance of the meeting report
12:40 – 14:00	*Lunch Break*
14:00 – 16:00	Final remarks *Closing of the Meeting*

ANNEX III

F2-CS-1804864
Consultancy Meeting on a Standard Operating Procedure for the Preservation of Cultural Heritage
Vienna, Austria
1 to 4 July 2019

List of Participants

(as of 2019-06-19)

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