ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN
2019 International Nuclear Atlantic Conference - INAC 2019
Santos, SP, Brazil, October 21-25, 2019

Agência Brasileira do ISBN
ISBN 978-85-99141-08-3

IRRADIATION PROTOCOL FOR CULTURAL HERITAGE CONSERVATION TREATMENT

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ABSTRACT

Ionizing radiation supplied by cobalt-60 is an excellent alternative tool to the traditional process of decontamination of cultural and historical materials, mainly because of its biocidal action. Analyzing the occurrence of requests for treatment materials from cultural institutions with ionizing radiation for fungal decontamination in the Multipurpose Gamma Irradiation Facility of the Nuclear and Energy Research Institute - CTR/IPEN, there was a need to establish a protocol for the care of institutions and individuals carrying cultural and historical collections. The objective of the present study was the establishment of an efficient and reproducible model of an irradiation protocol for the treatment of cultural heritage materials in industrial irradiators. One of the main conditions of effective decontamination, resulting in the least possible deterioration of the materials due to the treatment, is the homogeneity of the mass of the materials to be treated. In this sense, it is important to establish and follow a protocol for the effective processing of ionizing radiation and to respect the ethical principles of conservation and restoration activities. The proposed protocol can also be applied to other types of files and collections. The decision to treat ionizing radiation should be conducted by professionals of conservation of cultural goods in agrément with professionals of the area of application of ionizing radiation. The objective of the protocol is to be a practical guide, from the detection of the problem to the final cleaning, so that conservatives and professionals of the irradiation can act in a collaborative and objective way to reach the objective of the treatment.

1. INTRODUCTION

In the last decades, mainly due to the biocidal characteristics of the ionizing radiation, irradiation processing has been used in several sectors of economic importance. Medical-disposable and hospital-use materials have traditionally been irradiated for the eradication of various microorganisms, mainly bacteria, viruses and fungi. Applications of ionizing radiation for polymer crosslinking and food disinfestation are well-established procedures in the industry. Irradiation of pharmaceuticals, human tissues for transplantation and medicinal herbs [1] has also been highlighted. The curing of resins by radiation, such as paints and varnishes, favors the reduction of the amount of volatile components that would be emitted during the painting and coating process. The irradiation of rubbers for vulcanization discards the use of sulfur [2] and produces beneficial results for health, toxicology and environmental issues. The application of ionizing radiation to the treatment of effluents and chemical pollutants [3]–[5] presented results to minimize contamination of soil and water resources.

Preferably, isotopic sources emitting gamma radiation, such as cobalt-60, and electron accelerators were chosen. There are approximately 200 gamma irradiators operating in the world in 55 countries and 120 of these facilities are located in Europe and North America. Industrial scale radiation processing has grown as a result of nuclear reactors, which have begun to produce radioisotopes with useful properties, such as cesium-137 (^{137}Cs) and cobalt-60 (^{60}Co) [6]. Sealed ^{60}Co sources are obtained from the ^{59}Co neutron bombardment. In addition to its energy and penetration characteristics, the ^{60}Co radioisotope, in cases of encapsulation breakdown, is not water soluble, unlike the ^{137}Cs, making it very popular and safe in medical and industrial applications. In recent years there has been an increase of installations of industrial accelerators of electrons. Currently there are more than 1400 electron accelerators in operation in the world [3], [4], mainly for applications of polymer processing, semiconductors, surface curing, sterilization of medical and food products, being 24 in activity in Latin America and the Caribbean.

The use of fumigants for the control of biodeterioration in cultural heritage collections such as methyl bromide and ethylene oxide [7], [8] was common practice in cultural institutions mainly in the mass treatment of contaminated materials. However, the toxic effects of these fumigants on health and the environment made it impossible to apply them in the treatment of cultural collections and ionizing radiation for disinfestation and disinfection became a safe alternative. The most important regulation that disseminated and encouraged the use of irradiation in several countries was the ban on the use of ethylene oxide (EtO) as a transmitter of highly contaminating pollutants and with carcinogenic properties. The use of methyl bromide has been phased out under the Montreal Protocol, which regulates the use of compounds harmful to the ozone layer.

In this context, ionizing radiation processing of cultural heritage assets has proven to be a viable alternative for many materials in cultural institutions, but much research has yet to be done to ensure the application of this technology and to increase its dissemination.

Analyzing the occurrence of requests for the treatment of cultural heritage materials with ionizing radiation for fungus decontamination in the CTR / IPEN Cobalt-60 Multipurpose Irradiator, it was verified the need to institute a protocol for attending the institutions and persons holding photographic and cinematographic collections. The proposed protocol, derived from the present work, can also be applied to other types of archives and collections. The decision to treat ionizing radiation should be conducted by professionals of the conservation of cultural goods in agreement with the professionals of the area of application of the ionizing radiation.

2. PROCESSING BY IONIZING RADIATION IN CULTURAL HERITAGE OBJECTS

2.1. History of ionizing radiation processing of cultural heritage objects

At the end of the 1950s, the first experiments related to the effects of ionizing radiation on the fight against biological agents in the degradation of cultural goods were carried out. BLETCHLY [9]–[11] irradiated gamma rays with wood chips contaminated with xylophagous insects and achieved disinfestation at a dose of 0.5 kGy, suggesting that their biocidal effect could be used to stabilize biodegradation in cultural heritage objects . Therefore, the first studies regarding the use of this technique in the treatment of fungus-infected documents were published in Russia by BELYAKOVA [12] and a minimum dose of 6.5 kGy for disinfection was suggested. In Europe, since 1970, the ARC-Nucléart program in France [13] started to develop works in cooperation with various cultural institutions in Europe and resulted in a great acceptance by the community when transferring the technology of irradiated with cobalt-60 source.

Many successful cases have been published in the United States, France, the Netherlands and Italy, but only in the last five years has the use of ionizing radiation been highlighted as a unique tool that enables mass treatment of materials. The first research carried out in Brazil was carried out in 1994 and demonstrated the applicability of gamma radiation to treat documents infected by fungi [14]. Because it is a relatively new technique in the field of conservation of cultural material goods, and is in the process of dissemination, especially among Latin American cultural institutions, many professionals are still afraid to choose irradiation as a safe treatment method, the importance of expanding the dissemination of the analysis of treatment results through the research. The use of ionizing radiation in culturally valuable materials is based on the fundamental principles of justification, optimization and limitation of absorbed dose, while respecting the ethical principles of conservation of cultural heritage, keeping the object as close as possible to its original conditions by the greatest time.

The choice of the use of ionizing radiation as a treatment method for the disinfection and disinfection of collections, when compared to other traditional methods used in the area (Table 1), allows a relative ease of application and immediate effectiveness, leaves no chemical residues, no it activates the nuclei of the materials and the processed products do not require quarantine [15]–[18]. Another advantage is related to the possibility of eradicating insects and fungi definitively, since the radiation acts at any stage of their life cycle [12], [19], which guarantees reliability in the treatment of biodeterioration.

Table 1: Comparison between traditional methods of disinfestation and disinfection of cultural heritage

Method	**Effectiveness**
Alcohol 70%	It eliminates the fungus, but it does not have an effect on the spores.
Fumigation (ethylene oxide, methyl bromide)	Effective, but carcinogenic. Discontinued use.
Anoxia	Does not guarantee penetrability in the material and does not eliminate fungi and other anaerobic organisms.
Freezing	Removes the fungus, but the spores remain dormant.
Dry sanitization	Remove the fungus superficially, the mycelium remains branched in the material.

Several studies have demonstrated that the possible side effects that ionizing radiation can induce in the materials are not significant when compared to their natural aging process (Butler et al., 2002; D'Almeida et al. And in the absence of a high degree of polymerization, even in low doses [7], [20], [21].

Other authors [22], [23] presented controversies regarding the treatment with irradiation in collections, but it is necessary to consider that, if a stock attacked by fungi does not receive appropriate conservation or intervention treatment in the short term, there is a high probability of intense depolymerisation of the materials and of complete deterioration, both in the matter of the support and the information. Although the relative depolymerization attributed to the treatment with ionizing radiation is considered, the macro properties of the materials are not affected [8], [24]–[27]. For disinfestation processes due to attacks of various species of insects, studies by CANEVA et al [28], NITTERUS [29], ADAMO et al. [19] and MAGAUDDA [30] demonstrated that doses of radiation absorbed between 1 and 3 kGy were sufficient to promote the eradication of these pests. The effectiveness of ionizing radiation for the elimination of common fungal species found in the collection environment, such as Acremonium, Aspergillus, Cladosporium, Eurotium, Fusarium, Penicillium and Trichosporon has been demonstrated in studies by TOMAZELLO [14], MITRAN et al. [31], ADAMO et al. [19], DA SILVA et al. [15] and found that the recommended disinfection dose should be applied between 6 kGy and 10 kGy.

2.2. Differences between the application of ionizing radiation between gamma rays and electron beam

The main difference in the application of gamma rays and electron beam is the ability to penetrate the material exposed to radiation and processing time. Gamma rays have a long penetration range, which favors their application in materials of large and varied dimensions. The penetration capacity of the electron beam depends on the energy of the electron accelerators and its application is limited to materials of thin thickness. For a material with a density similar to that of water of 1 g / cm3, the electron beam with energy of 10 MeV can penetrate up to 5 cm, while the gamma rays, with average energy of 1,25 MeV, reach up to 50 cm depth [32]. However, for the electron beam the required dose can be applied in seconds [33], whereas for the same dose of gamma radiation several hours of application are required. Agility in electron beam processing occurs because of the dose rate that is higher than gamma ray irradiation. Some polymer crosslinking processes are only feasible at high dose rates [34] and electron beam radiation becomes the only feasible option. Therefore, the choice of electron beam or gamma ray radiation should consider factors such as: material type, geometry, thickness, irradiation target, processing time and cost.

Faced with the applicability series, several sectors of the economy and society, such as: medical-pharmaceutical, agribusiness, automobile, electronics, energy, wastewater treatment and cultural heritage, have found benefits with the use of nuclear technology. The use of ionizing radiation with industrial irradiators has developed improvements in manufacturing processes, conservation, quality and environmental benefits, being considered a safe alternative and with significant advantages over conventional processing methods.

The option for ionizing radiation processing of cultural goods offers advantages as described below.

a) sterilization by ionizing radiation, using radiative installations using gamma rays and electron beam, is a well-established and safe technology for various materials;

b) unlike other sterilization processes, irradiation allows to treat the materials without the need to remove them from the final package, thus, it does not require quarantine after the sterilization process;

c) the process is controlled by a simple parameter, the measurement of the absorbed dose of radiation in the product or dosimetry, which defines the amount of dose applied according to the type of decontamination treatment;

d) the treatment does not associate any risk to the conservator, restorer, curator, visitor or environment; nor for the operator of the facility who generally performs its activities in a control room;

e) treated artifacts do not become radioactive (they do not become activated and do not emit radiation) and no toxic residue remains on the irradiated object;

f) the process is highly efficient due to the penetration characteristics of the ionizing radiation. When a gas is used to sterilize (such as the anoxic atmosphere treatment) the efficiency of this treatment is limited by its diffusion in the material, this being a parameter of difficult measurement;

g) the reliability of the irradiation process is high due to the fact that the irradiation parameters are stable all the time;

h) irradiation acts simultaneously on all biological contaminants;

(i) large objects can be treated simultaneously in the case of gamma radiation;

(j) treatment in industrial plants is carried out at short intervals (days or hours);

k) when irradiation is properly applied for decontamination, there are no modifications of the basic properties of wood, paper, leather, parchment, silk, cotton, wool and other products such as textiles and furniture;

l) artifacts made with composites (plastic derivatives) can be treated without precautions;

m) raw materials used for restoration (glues, resins, paints and varnishes) can be irradiated;

n) the treatment is performed at room temperature;

o) the objects are treated in their original packaging, without the need to manipulate the contents.

2.3. Requirements for the treatment of cultural objects by ionizing radiation

In order to arrive at a decision on ionizing radiation treatment, a prior diagnosis of the status of the collection is essential, including:

a) signs and symptoms;
a) state of conservation;
b) environment guard;
c) associated pathologies;
d) contamination examination
e) antecedent irradiation;
f) classification problem;
g) presence of insects only;
h) presence of insects and fungi;
i) bacteria;
j) quantity.

The choice of treatment for ionizing radiation should include the following steps:

a) separate the lots by type of contamination;
b) pack seven barriers into plastic wrappings and then into cardboard or polyester cartons;
c) schedule the irradiation and arrange for special transportation for cultural goods.

After irradiation, materials should be stored in an environment protected from heat, light radiation and high relative humidity. Mechanical hygiene is recommended to remove residues from microorganisms and digitization in preservation parameters. In the case of photographic and cinematographic collections, consideration should be given to storage in cold rooms.

Figure 1 shows the flowchart of the work process for the application of ionizing radiation in cultural heritage materials.

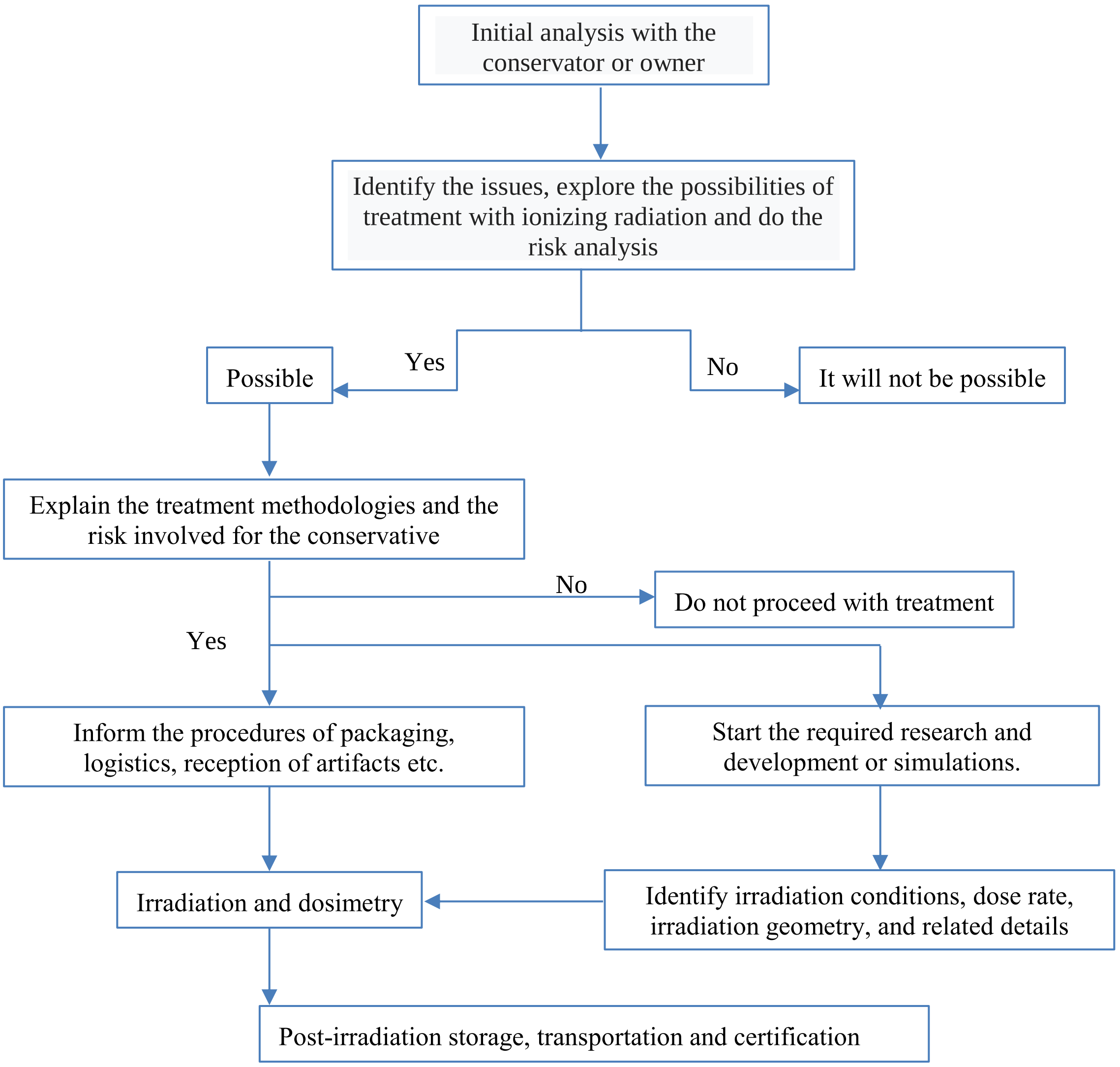

Figure 1: Flowchart of the process of irradiation of cultural goods

2.4. Protocol for the decontamination of cultural goods using ionizing radiation - a description of the process, procedures and records.

2.4.1. 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. Gamma irradiation, which must come from the Cobalt-60 isotope, is characteristic of 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 is produced from an electrical source and is quick to apply.

Once treated, materials may be safely returned to the contamination free repository after safe removal of surface contamination (ie dust, dead fungus, waste, etc.).

2.4.2. Subject and area of application

This protocol describes the quality of how to deliver and treat contaminated materials using gamma radiation. The decontamination process will be applied to materials placed on pallets.

2.4.3. Conditions

One of the main conditions of effective decontamination, resulting in the least possible deterioration of the materials due to the treatment, is the homogeneity of the mass of the materials to be treated. This is because the research in practice has proved that the dose received differed by type of object present on a pallet and that an undesired effect was found of volume density (mass per volume distribution). An inadequate construction pallet may result in an inhomogeneous dose of the objects.

2.4.4. Terminology and definitions

(this section contains a list with terminology and definitions, and can be expanded, etc.)

Decontamination: disinfection

Disinfection: death 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.

Radioactive waves: 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.

2.4.5. Pre-treatment of materials to be decontaminated

a) Isolation of the collection

Contaminated collections should be isolated from any uncontaminated collection. This can be done through a quarantine area in the same or another building.

b) Packaging and delivery

As the treatment costs are usually calculated per pallet, this pallet should be constructed as economically as possible. The pallet should be packed with polymeric foil (eg 17 μm stretch film) and the top should be packed with a top sheet.

The materials to be decontaminated must be identified and delivered on a pallet (100 x 120 cm) or, preferably, a standard pallet (80 x 120 cm). The maximum height of the materials to be decontaminated must be 180 cm.

Care should be taken with the homogeneity of the mass of the materials present on the pallet. The maximum mass volume should be (300 ± 30) kg / m3. The mass volume is measured at the supplier's location. The maximum (gross) weight of a pallet is 1000 kg.

Example: Suppose a standard archive box is approximately 4.5 to 5 kg and a standard book meter is approx. 40-50 kg. Thus, a full standard pallet may contain approximately 112 archival boxes.

2.4.5.1 In case of need of prepacking

The prepackaging 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 cardboard boxes (archive box, transport box, etc.). Polyethylene boxes may also be used. The mass and size of these boxes must be compatible in size and the contents should be as homogeneous as possible in bulk.

2.4.5.2. The materials are already packaged and packaged

If the materials to be treated are already packaged and packed carefully in boxes (archive boxes, gearboxes), packaging is not necessary. The boxes must be placed by the applicant on a pallet so that the mass distribution is as homogeneous as possible. It is preferred that each has a maximum mass deviation of approximately 20%.

recommendation: It is important to have compatible objects / artifacts on a pallet. So, just books, or loose archived materials, well packaged. Semi filled or empty boxes should be avoided.

recommendation: If pre-sorting is not possible, heavier boxes should be evenly distributed at the lower end of the pallet. This is necessary to avoid material damage due to weight.

2.4.5.3. exceptional dimensions and masses

Materials of exceptional size and mass must be delivered to the supplier immediately upon contact.

In a volume of greater mass (300 ± 30) kg / m3, a pallet can be changed. Per to empty the middle area (such as a chimney).

2.4.6 Registration

Registration form as collection information, suggested application rate.

2.4.7. Transportation of contaminated materials

2.4.7.1. For the supplier

Contaminated cultural heritage materials should be transported using a closed, dry and clean vehicle. Materials should be packaged and stably distributed on the pallet.

2.4.7.2. From the supplier

Treated materials should be transported in an enclosed, dry and clean vehicle. Materials should be wrapped in plastic film, stably placed on the pallet and ensure that no external contaminant can enter the treated materials.

2.4.8. Decontamination

2.4.8.1. Reception and storage of materials to be decontaminated

Contaminated materials must be registered on receipt by the treatment company (supplier). Each pallet should be weighed and measured individually. Based on these data, the dose (radiation time) should be established.

Note: In case there is a need to repackage or repackage the materials to be decontaminated, the responsible for the materials must be contacted and subsequently the work must be performed.

Materials delivered to the supplier must be stored safely in the supplier's repository until processing. Usually this is the area for untreated materials.

The registration of materials must include at least:

- name of the person responsible,
- conveyor,
- receipt of the date,
- number of pallets,
- damage found on receipt.

In close contact with the caretaker, storage until treatment should be up to 72 hours. In case of an exception, the responsible person should be contacted immediately.

2.4.9. Radiation

2.4.9.1. pre-treatment

The materials, delivered on pallets, must be placed in so-called inboxes (metal treatment boxes). The dosimeters should be placed in different places (timely verification dosimetry). These are polymeric, wherein the discoloration is due to irradiation and the level of discoloration will correspond to the amount of the dose.

By means of a transport system (eg. monorail), the cages or inboxes will be conducted through the radiation source. All pallets will receive the required dose during a treatment.

2.4.9.2. recommended dose

To ensure a good removal of biological contaminants, the following dose is applied:

1) Removal of fungi and spores: mean (8 ± 2) kGy
2) Removal of insects and pests: average of 2 kGy
3) Another dose is possible and should be made in contact between the commissioner and the seller.

2.4.9.3. verification of radiation treatment

The dose given to the materials and decontaminated must be done with dosimeters. By means of a spectrophotometer, the absorption of light from the dosimeters will be measured. In addition, the thickness of the dosimeters is measured. Interpretation should be made using a calibration curve, including uncertainty. This will result in dose data applied in the amount (minimum, maximum and average dose).

2.4.9.4. After irradiation

After irradiation, the pallets are placed in the area of the "treated materials" of the repository. If necessary, the pallets will be labeled before shipping.

2.4.10. Report

The report of the decontaminated materials shall include at least:

- Name of the company responsible for decontamination.
- Name of the company that performed the decontamination.
- Name of the transport company.
- Date of packaging and repackaging.
- Description of how the pallet was constructed.
- Bulk volume of treated pallet.
- Pallet dimensions.
- Contents of the pallet.

2.4.11. Documentation

Upon request, a certificate of treatment may be issued. This certificate shall include at least:

- The requested dose.
- Reference number of the treatment.
- Date of irradiation.
- The average dose during treatment.

3. CONCLUSIONS

A protocol of preparation for ionizing radiation treatment of cultural heritage objects and archival materials containing procedures and guidelines for packaging and sanitizing after ionizing radiation processing has been proposed to optimize processing by industrial irradiators. The purpose of the protocol is to be a practical guide, from the detection of the problem to the final hygiene, so that conservatives and professionals of the irradiation can act in a collaborative and objective way to reach the purpose of the treatment.

ACKNOWLEDGMENTS

The authors are grateful for research support from the Nuclear and Energy Research Institute - IPEN.

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