

Preserving the Past with Gamma Rays: Real Case Studies from the Montecassino Abbey Collection

D'Orsi Beatrice¹, Rocco Carcione¹, Iliaria Di Sarcina¹, Jessica Scifo¹, Teresa Rinaldi², Nicola Tangari³ and Alessia Cemmi¹

¹ ENEA, Nuclear Department, Via Anguillarese 301, 00123 Rome, beatrice.dorsi@enea.it, rocco.carcione@enea.it, iliana.disarcina@enea.it, jessica.scifo@enea.it, alessia.cemmi@enea.it

² Sapienza University of Rome, Department of Biology and Biotechnologies, Piazzale Aldo Moro 5, 00185 Rome, teresa.rinaldi@uniroma1.it

³ University of Cassino and Southern Lazio, Department of Letters and Philosophy, Viale dell'Università, 03043 Cassino (FR), nicola.tangari@unicas.it

Abstract – This study explores gamma irradiation as a non-invasive and residue-free method for the conservation of historical documents, focusing on two case studies from the Montecassino Abbey collection. Gamma rays from cobalt-60 source effectively eliminate biodeteriogens such as fungi, molds, and insects, without inducing radioactivity. This approach leaves no harmful residues, and is fully compatible with restoration practices, offering a faster, safer alternative to conventional chemical treatments. In this work, fragments of parchment and paper were irradiated at 8 kGy and analyzed before and after gamma exposure by coupling Raman spectroscopy, FTIR/ATR, and colorimetric techniques. FTIR/ATR and Raman spectroscopy results confirmed the structural stability of collagen and cellulose, with no remarkable molecular alterations. Colorimetric data showed minimal changes ($\Delta E_{00} < 1.8$), indicating no significant impact on visual perception. These findings demonstrate the potential of gamma radiation as a reliable and efficient conservation tool for safeguarding Cultural Heritage.

Keywords: Cobalt-60, gamma radiation, CH conservation, Montecassino Abbey

I. INTRODUCTION

The preservation of archival, literary, and documentary materials is essential for the protection of national Cultural Heritage (CH). Within the broader field of CH conservation, this task becomes particularly complex when dealing with delicate organic materials, such as paper and parchment, which are highly vulnerable to biological degradation. Traditional restoration practices often involve chemical agents and manual interventions that can pose risks to both the treated materials and the professionals executing the procedures. Moreover, the time-consuming nature and often invasive character of these methods make them less suitable for large-scale

preservation efforts.

In addition, many cultural institutions, including libraries, archives, and monasteries, face inadequate storage conditions. Specifically, high humidity, poor ventilation, and uncontrolled environments promote the proliferation of fungi, bacteria, and insects, which in turn contribute to the accelerated deterioration of priceless historical collections.

In response to these issues, gamma irradiation has become a widely used method in international conservation laboratories and institutions for the decontamination and stabilization of biodeteriorated archival materials. While this approach has been extensively implemented abroad [1–4], it is only now starting to be adopted in Italy as a promising alternative treatment for CH. The ability of gamma radiation to penetrate deep into objects and eliminate microbial threats without leaving chemical residues or requiring elevated temperatures makes it particularly effective. This method can sterilize both the surface and bulk of artifacts uniformly, making it especially appealing for large-scale conservation of paper and parchment-based collections.

The International Atomic Energy Agency (IAEA) has developed specific guidelines for the application of ionizing radiation in the CH field. According to these guidelines, a gamma dose of 8 ± 2 kGy [5,6] is considered both effective and safe for the treatment of paper and parchment, ensuring microbial decontamination while minimizing the risk of significant structural or chemical alterations to the treated materials.

In this context, the PERGAMO Project, which originated from an agreement between the Department of Letters and Philosophy of the University of Cassino and Southern Lazio, Sapienza University of Rome and the Nuclear Department of ENEA, launched an experimental campaign in collaboration with the Library of the National Monument of Montecassino, a historical institution that preserves one of the most important monastic collections

in Europe. Despite the wartime destruction of the Abbey's monumental architecture during World War II, a substantial portion of its documentary heritage, comprising approximately 1150 manuscripts and a vast corpus of parchment fragments, has survived. These include rare codices in Beneventan, Caroline, and Gothic scripts, as well as early printed books and liturgical manuscripts [7–9], many of which remain under-catalogued and insufficiently studied.

For this study, two representative fragments from the Montecassino collection, one paper and one parchment, were selected for irradiation and subsequent analysis. The documents were irradiated at 8 kGy, in accordance with IAEA suggestions, to assess not only the microbiological efficacy of the treatment but also its chemical, structural, and chromatic impact on the different material substrates. To this aim, the materials were characterized before and after exposure using non-destructive and non-invasive experimental techniques, including Raman spectroscopy, Fourier Transform Infrared spectroscopy in Attenuated Total Reflectance (FTIR/ATR) mode and colorimetric analysis. In particular, Raman spectroscopy was used to investigate possible molecular changes, while FTIR/ATR spectroscopy provided information on structural modifications in the functional groups of the materials. Additionally, colorimetric analysis was performed to detect variations in surface color and overall visual appearance, key indicators in conservation diagnostics. On the bases of the collected results, this work confirms that gamma irradiation is a safe, non-invasive technique suitable for use on original artifacts and effective for the preservation of paper and parchment CH-based materials. Furthermore, the study highlights the usefulness of a multidisciplinary approach, which combines expertise from the fields of microbiology, physics, and chemistry. This integration of diverse methodologies not only enhances the reliability of the results but also allows for a more comprehensive understanding of the effects of gamma irradiation on cultural heritage materials. The collaboration between CH operators, such as library curators, and researchers proves essential in addressing complex conservation challenges, and serves as a model for future research in the field.

II. MATERIALS AND METHODS

A. Materials

As part of the PERGAMO project, two historical documents from the private collection of the Abbey of Montecassino were selected for experimental testing. The first sample is a parchment document dated Sulmona, July 31, 1448, measuring 570 by 227 mm (Figure 1a). The document is in a compromised state of preservation: the left margin is almost entirely missing, and the final portion of the membrane is damaged, with only half of it surviving.

The second sample consists of detached paper leaves, numbered 185 to 192, measuring 418 by 285 mm (Figure 1b). These pages are part of a printed edition of *Digestum vetus interpretationes*, published in Lyon in 1552 by the legal scholar Franciscus Curtius Iunior. The paper is fragile, torn, and visibly affected by humidity exposure. Both materials show evident surface degradation, including staining and darkened areas due to water damage and natural ageing processes.



Fig. 1. Photo showing fragments of a) the parchment document and b) the paper document.

B. Calliope gamma irradiation facility

The gamma irradiation was conducted at the Calliope facility, located at the ENEA Casaccia Research Centre near Rome [10]. This facility is specifically designed for controlled gamma exposure using a cobalt-60 (^{60}Co) source housed in a water-shielded pool. The facility can deliver dose rates of up to approximately 5 kGy/h (May 2025), with a licensed maximum activity of 3.7×10^{15} Bq (100 kCi). For this study, the irradiation dose was set at 8 kGy, in line with IAEA guidelines. This absorbed dose value is considered sufficient to neutralize microbial agents while avoiding alterations to the physical or chemical structure of the treated objects. In the last years, at the Calliope facility several research studies in the field of cultural heritage conservation through ionizing radiation were conducted [11–17].

C. Experimental techniques

Raman spectra of samples were collected with a micro-Raman spectrometer (Horiba XploRA Plus) under a 785 nm laser excitation, a 50 mW laser power and a diffraction grating of 1200 gr/mm at the objective magnification of 100X. Before the analysis, Raman spectra were background subtracted and smoothed. Raman spectra of paper samples were deconvolved by using several lorentzian line functions to derive position, area and amplitude peaks parameters.

FTIR/ATR spectra were recorded in the range 4000–700 cm^{-1} using a Spectrum 100 Perkin-Elmer FT-IR spectrometer (8 scans for each measurement with a scan resolution of 1 cm^{-1}). The ATR accessory was equipped with a zinc sulfide (ZnS) crystal plate measuring approximately 7 cm \times 1.5 cm.

Colorimetric measurements were performed before and after irradiation tests using a PCE-CSM 8 to investigate the possible samples color changes (yellowing or even browning) due to oxidation processes. The color evaluation method is based on the CIE 2000 system of colorimetry that allows for the definition of the parameter ΔE_{00} , which provides information about color differences [18,19]. Specifically, a value of ΔE_{00} below 1.8 indicates no perceptible color difference to the human eyes [20,21].

III. RESULTS AND DISCUSSION

Raman spectra collected from ink-free areas of the documents before and after irradiation at 8 kGy are shown in Figure 2. Independently on the typology of CH artifact, the Raman spectra showed no significant changes after irradiation at 8 kGy, indicating no remarkable variations in the molecular signatures of either material. In the Raman spectra of parchment document, no signals ascribable to collagen phase can be noted. On the other hand, the presence of calcite signals before irradiation disclose a starting degradation level for this CH artifact. The maintenance of the calcite bands after irradiation suggests that the exposure to gamma rays did not induce additional degradation (Figure 2a).

The Raman spectra acquired on paper document in Figure 2b exhibit signals assigned to cellulose and hemicellulose chains. The deconvolution procedure disclosed that the cellulose fingerprint area remained unchanged before and after irradiation, indicating the maintenance of structural integrity of the polysaccharide backbone (Figure 2b).

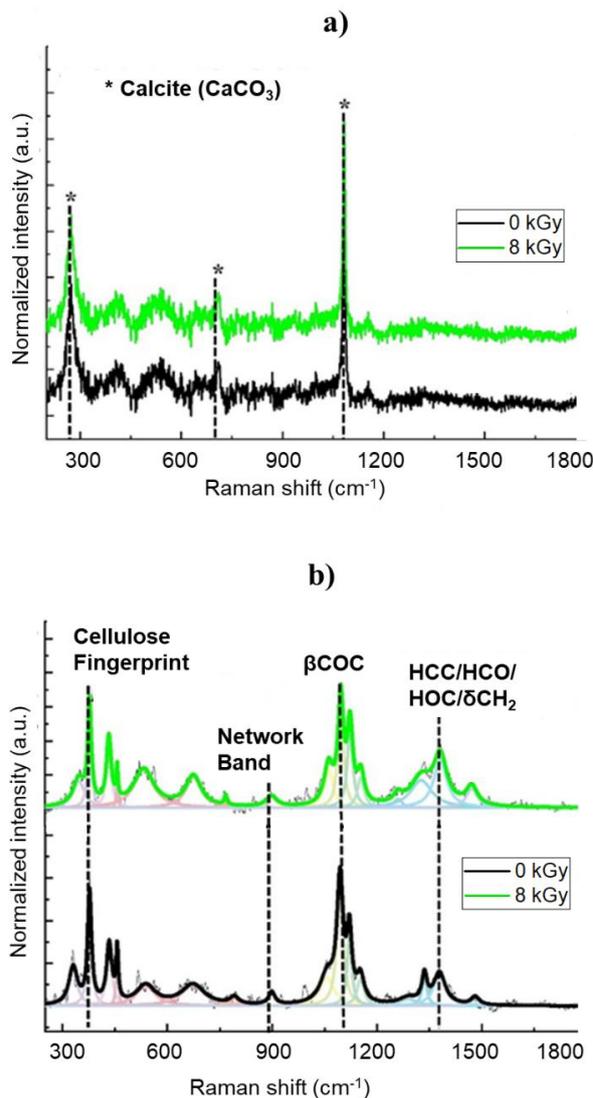


Fig. 2. Representative Raman spectra of a) parchment document and b) representative deconvolved Raman spectra of paper document at 0 and at 8 kGy.

FTIR/ATR spectra supported these findings by showing no noticeable shifts or loss of functional group signals typically associated with collagen and cellulose. Both substrates retained their characteristic absorption bands, indicating the absence of radiation-induced breakdown or chemical transformation (Figure 3a and Figure 3b).

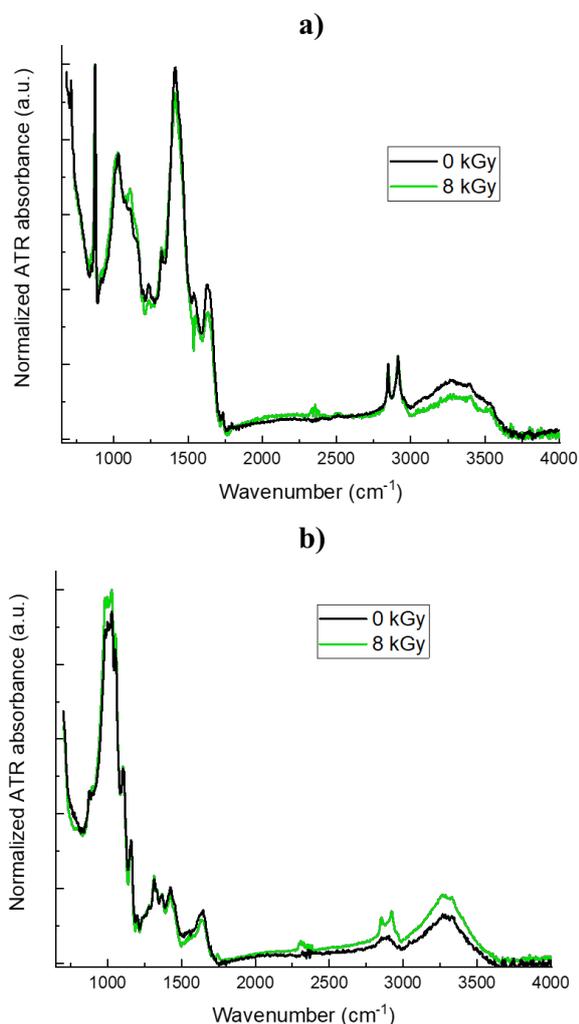


Fig. 3. FTIR/ATR spectra of a) parchment document and of b) paper document at 0 and at 8 kGy.

The colorimetric analysis allowed to obtain the ΔE_{00} values of the documents after exposure to 8 kGy absorbed dose, compared to their initial, not irradiated states. Specifically, values of 0.940 and 0.522 were obtained for the parchment and paper document, respectively. These measurements revealed minimal variations in color ($\Delta E_{00} < 1.8$), well below the perceptibility threshold for the human eye, indicating that gamma irradiation does not induce visible yellowing or browning. This confirms that the visual appearance of the documents is preserved, which is a critical aspect of their conservation.

Overall, the combined results demonstrate that gamma irradiation at the tested doses does not compromise the molecular, structural, or aesthetic properties of the examined materials, validating its potential for safe, non-invasive decontamination of documentary heritage.

IV. CONCLUSION

The experimental investigation confirms the chemical and visual stability of parchment and paper documents subjected to gamma irradiation at 8 kGy, as suggested by IAEA for CH conservation purposes. Raman and FTIR/ATR spectroscopies showed no significant alterations in the chemical and molecular structure of collagen or cellulose, while colorimetric data indicated no perceptible color change of the documents surface. These findings demonstrate the compatibility of gamma treatment with the conservation requirements of delicate historical materials, supporting its application in real-world archival contexts. The case studies from the Montecassino Abbey collection highlight the feasibility and effectiveness of this method for large-scale, non-invasive preservation of documentary heritage.

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