Concerns over Radiation-Induced Side Effects in Cultural Heritage

A Common Issue for Scientific Communities Using Radiation for Characterization or Preservation of Cultural Heritage

Laurent CORTELLA, ARC-Nucléart[1], France
Loïc BERTRAND, Université Paris-Saclay, France
Maartje STOLS-WITLOX, University of Amsterdam, The Netherlands
Branka MIHALJEVIC, Institut Rudjer Boskovic, Croatia
Luis M. FERREIRA, C2TN/IST/UL, Portugal
M. Helena CASIMIRO, C2TN/IST/UL, Portugal
Victoria CORREGIDOR, C2TN/IST/UL, Portugal
Ineke JOOSTEN, Cultural Heritage Agency of The Netherlands, The Netherlands
Pablo A. VASQUEZ S., Instituto de Pesquisas Energéticas e Nucleares and University of São Paulo, Brasil
Katarina MARUSIC, Institut Rudjer Boskovic, Croatia
Luís C. ALVES, C2TN/ IST/UL, Portugal
Aliz SIMON, IAEA, Austria
Bumsoo HAN, IAEA, Austria
Celina I. HORAK, IAEA, Austria

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Introduction

Electrons, X-rays, neutrons, ions and gamma rays are radiations commonly used in imaging and spectroscopy to provide information about materials in archaeological, paleontological, historic or artistic objects, as illustrated in Figure 1 (a,b) (IAEA, 2011). Gamma and electron irradiation is also widely used for biocide treatments of organic artefacts (see Figure 2 (a)), and in the consolidation of weakened objects with radio-curable resins (IAEA, 2017).

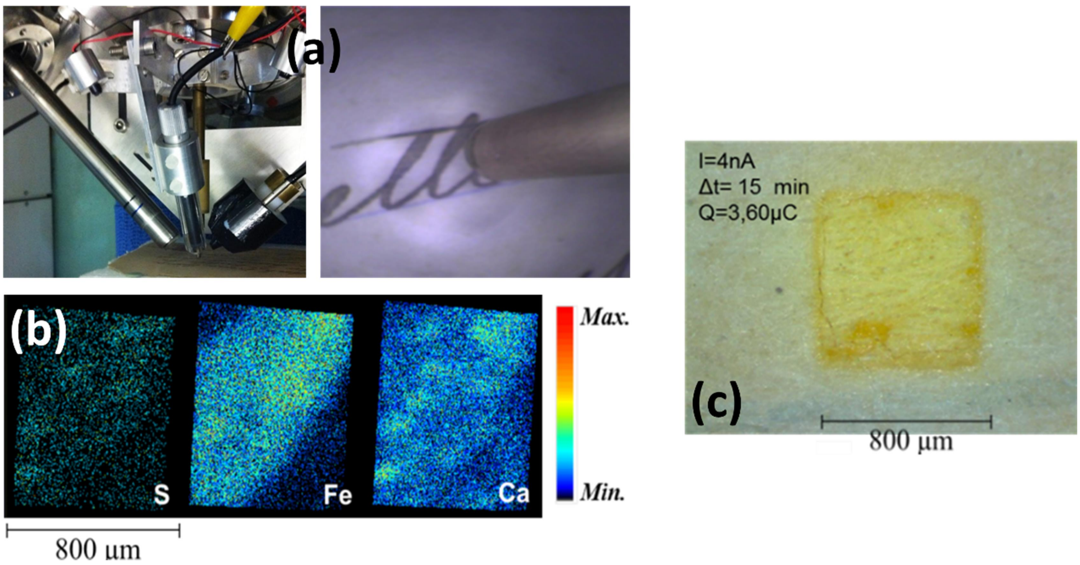

Fig. 1. External ion beam set-up at C2TN. 2MeV proton beam is used to measure iron gall ink in an ancient manuscript (a). The beam can raster the surface and 2D elemental maps from PIXE spectra can be obtained (b). Irreversible damage (degradation of cellulose chains and oxidation processes) induced by proton beam on a white paper sample using a very high intensity beam; in extreme cases the paper will completely collapse structurally (c).

[1] Author adress: ARC-Nucleart, CEA Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France – laurent.cortella@cea.fr

Because of the unique value of cultural heritage objects and the risk of loss of critical analytical information, any investigation or treatment must mitigate side effects induced by radiation. Therefore, knowledge about potential side effects and underlying physico-chemical mechanisms is key.

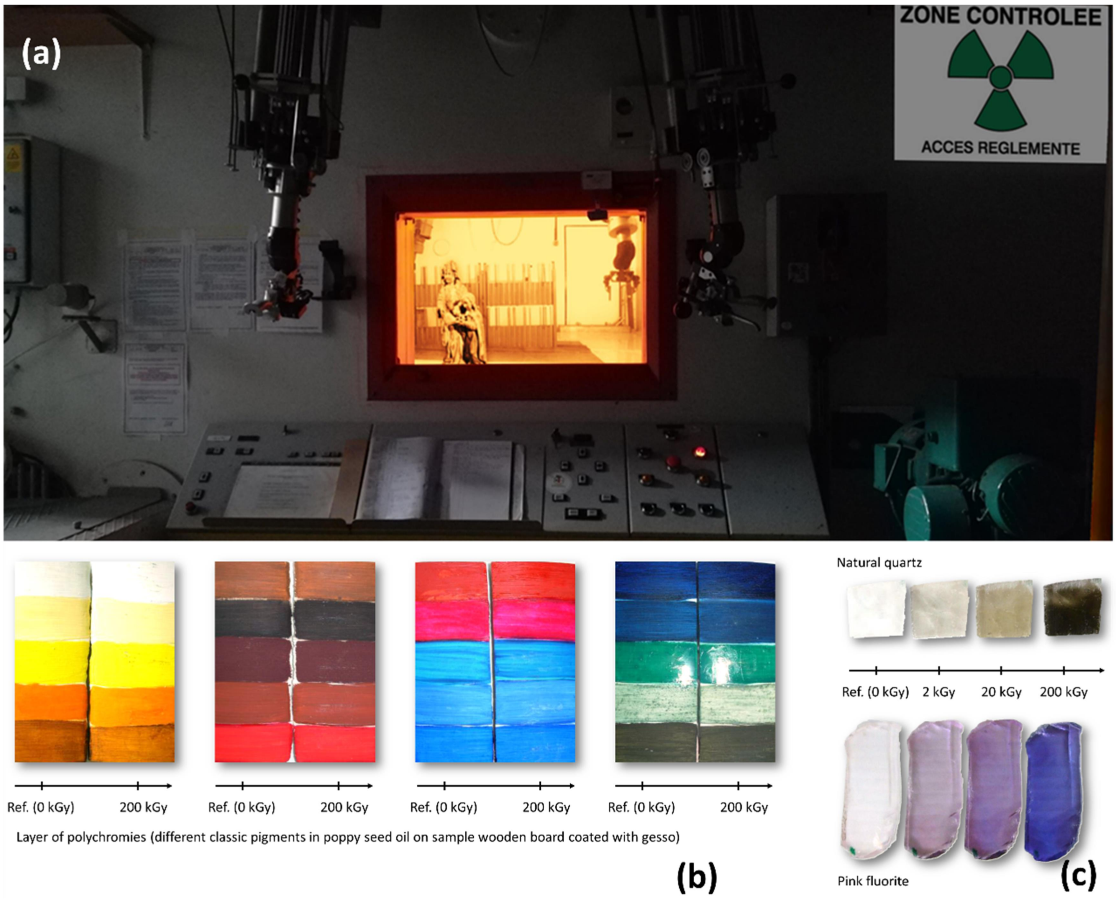

Fig. 2. Insect eradication in ARC-Nucléart of a polychrome wooden sculpture ("Education of the Virgin", 17th c., Chateau-Chalon, France) (a). 500 Gy is the minimum gamma irradiation dose. Possible changes of color is one the main issues to be taken into account but classical polychrome layer are generally very stable with irradiation (b), in contrast to some transparent materials that can be used as ornament in artwork (c).

Knowledge of Side Effects

While there is good general understanding of the effects of irradiation on materials in other fields (e.g. food industry, nuclear or medical industries), targeted studies to explore the fundamentals of irradiation side effects on cultural heritage materials and objects are still needed (Bertrand et al, 2015). The diversity of materials encountered in cultural heritage is vast and objects are often of heterogeneous composition on several scales, always requiring more applied and fundamental research. The main physico-chemical changes observed in the below examples show the importance of such research:

- Radiation easily tints transparent materials, in some cases even at doses below 1 kGy, due to trapping of electrons in the vicinity of impurities (figure 2 c). Such behaviour often does not affect visually opaque materials, such as polychrome layers (figure 2 b).
- At higher doses, broken bonds, cross-linking and temperature-induced effects can modify important material properties and affect mechanical integrity (see Figure 1c). With heavy or very energetic particles, atoms may be knocked out, giving rise to vacancies and molecular defects.
- Radiation-induced radicals can trigger undesirable chemical change, such as oxidation. It can lead to colour changes or surface erosion, and induce long-term autocatalytic degradation mechanisms.

Risk Analysis

The consequence of side effects may not only affect the characteristics and behaviour of the heritage material or object; but there is a risk that they distort immediate or future analyses. Therefore, researchers and conservators must together weigh the expected benefits of exposure against possible drawbacks before any treatment or investigation of a cultural heritage artefact is carried out. For example, considering the radiation-based treatment of objects, the range of irradiation dose used for fungicidal treatments (typically 5 to 10 kGy) entails the possibility of generating minimal effects in somewhat sensitive materials like paper. Notwithstanding this slight risk, the reliability and ease of implementation of these methods – if equipment is available - make their application a viable option. The question “is the radiation treatment better or worse than alternatives, including doing nothing?” must always be asked.

Mitigation and optimization.

To avoid over-exposure, optimization and careful control of all parameters is crucially important. An ALARA (As Low As Reasonably Achievable) approach has been proposed regarding the minimum dose, dose rate and the time of exposure (IAEA, 2018). Good practices include dosimetry (simulations and measurements) and should take into account the radiation interaction parameters of the target materials or surrounding media. If a large object is exposed, or if important gradients of dose are expected, mapping may provide more precision. For sensitive materials, when possible, real-time monitoring of relevant changes during experiments allows stopping experiments at the first sign of concern.

Controlling the environmental parameters and atmosphere (inert gas, vacuum, low temperature, etc.) can effectively mitigate some adverse effects like oxidation. Humidity control can be beneficial, for instance to avoid secondary reactions linked to water radiolysis. Experimentalists training and increasing awareness is of paramount importance and has been supported by IAEA (Bertrrand et al, 2015), which dedicated Technical Meetings in Paris (2015), Amsterdam (2017) and Zagreb (2018).

Documentation.

Documentation is a crucial pillar of the whole cultural heritage field. It must include documenting condition of exposure to radiation. Dosimetry data can be supplemented by experimental parameter monitoring. Detectable change should be better investigated, quantified and documented. A digital exposure passport reporting the main radiation parameters experienced by an object or a research sample is currently under development.

Conclusion.

Scientists involved in cultural heritage research and conservation need radiation techniques for a variety of applications. Special care is vital in order to avoid radiation-induced side effects that may affect the material characteristics and (future) behaviour of cultural heritage objects. Understanding such effects is a prerequisite both for specialists working on material analysis and for those involved in the treatment of cultural heritage, and risk analysis must be undertaken before exposure. This can only be supported by dedicated research programs.

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