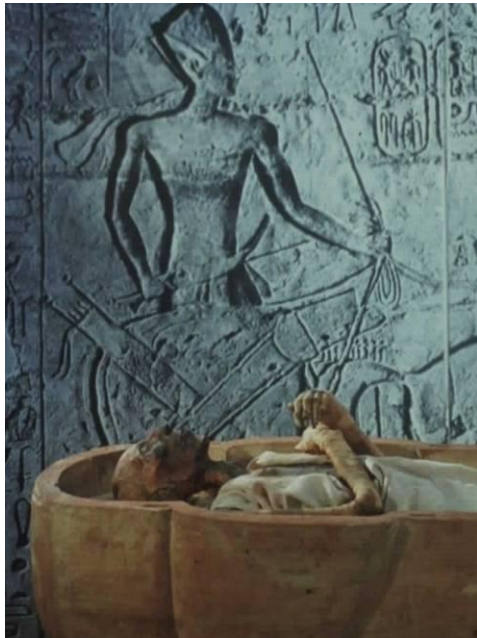
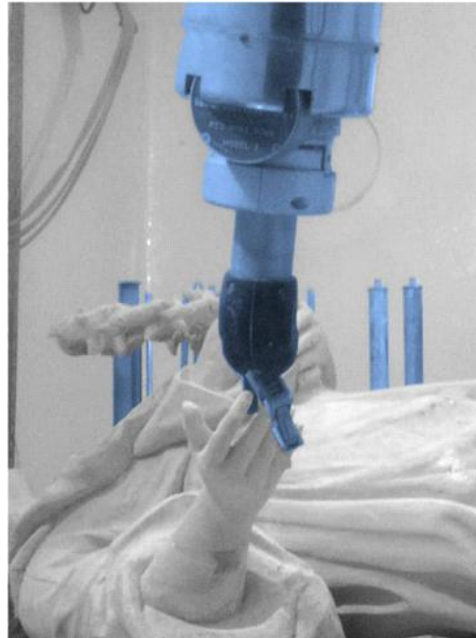


Gamma irradiation for the conservation of cultural heritage artifacts from the 70's to nowadays in France



Ramses II mummy in Musée de l'Homme, Paris
1977



Sculpture in the irradiation chamber, 2000



Frozen baby mammoth Siberia, 2010

INAC 2013

11th Meeting on Nuclear Applications – XI ENAN

Recife, PE, Brazil, November 24-29, 2013



ARC-nucleART

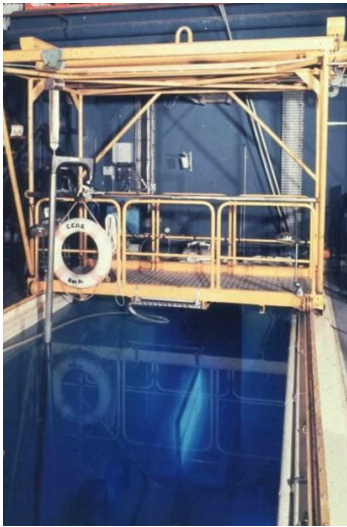
Khôi TRAN, PhD

Summary:

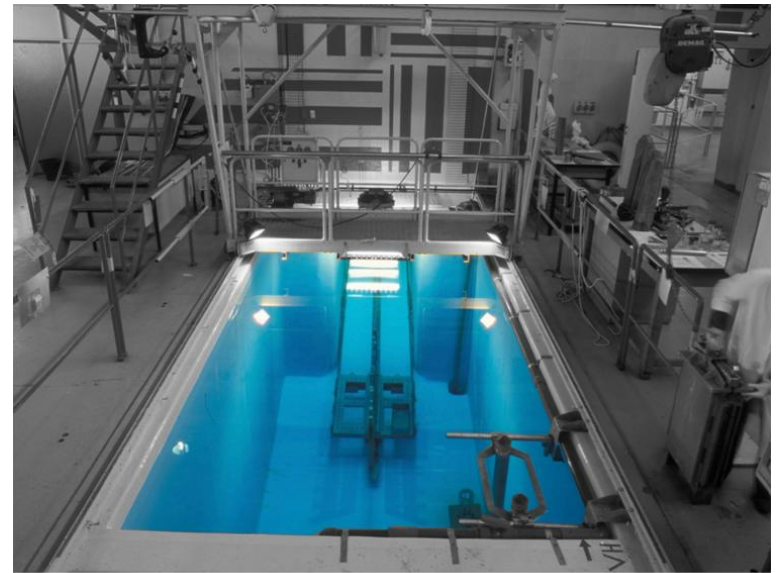
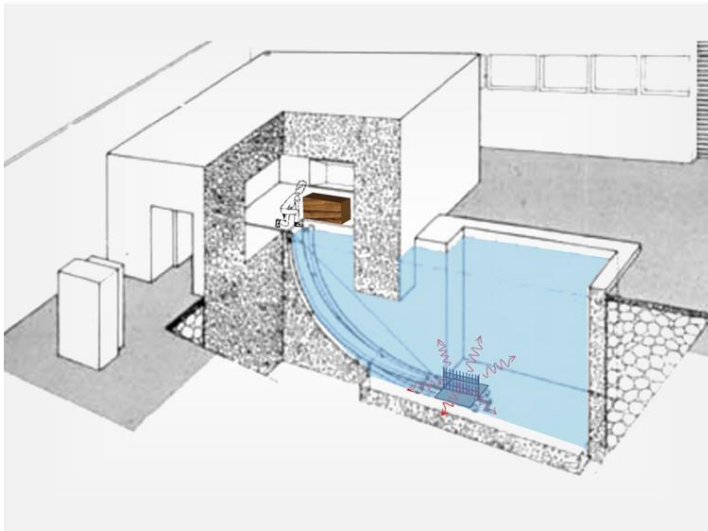
- ⚙ Historical applications of nuclear techniques to the preservation of cultural heritage at ARC-Nucléart: **1970 - 1980**
 - Ancient city hall of Grenoble , parquet of the wedding room : **1970**
 - 11st century archaeological site, lake Paladru near Grenoble
 - **Ramses II mummy : 1977**
 - Other pioneers.
- ⚙ ARC-Nucléart today.
- ⚙ Some insect eradications of museum collections and church wooden items, in Grenoble and in the world.
- ⚙ Some dry wood Nucléart consolidation and waterlogged wood Nucléart treatments, and other treatments worldwide.
- ⚙ Khroma, the baby mammoth / **2010**
- ⚙ The roman period Arles shipwreck : **2013**

Historical Activities

70's



- ⚙ Initially, the irradiator built in **1964**, was involved in applied research for industrial sector, including the aim to improve the properties of wood, such as its hardness and resistance to compression, with radiation-curing resin.
- ⚙ In **1970**, at the instigation of Louis de Nadaillac, an engineer working for this research, these techniques were applied to save an historical parquet of the ancient city hall of Grenoble.



The gamma facility today

Hôtel Lesdiguière Parquet



An 18th c. historical marquetry parquet of 155 m², probably due to famous cabinet maker family Hache, used as the wedding room of Grenoble ancient city hall.

- *Its consolidation in 1970 was the first application of conservation of cultural heritage item using gamma irradiation in France.*



The parquet consolidation

The floor was completely removed. Each panel was impregnated with monomers methyl methacrylate and then irradiated to cure the resin. The panels were then reinstalled one to one.

⚙️ The building was afterwards used as the Musée Stendhal for 30 years.



The parquet today in 2013,
43 years later !

The pioneers

After this success, a test program was started, looking about consolidation of dry and waterlogged wood, stone, ethnographic materials ...

- ⚙ A first wooden statue was consolidated in **1971** with **new polyester-styrene resin**.



Vierge à l'Enfant, 14th c., Flavigny, Burgundy

From **1973**, new technicians and engineers are employed.

The “*projet Nucléart*” is born

The pioneers, second.

- ⚙️ During this beginning of 70's, new consolidation of wood sculptures and polychromed wood sculptures, furniture, were carried out using polyester-styrene resin.



L'Homme Sauvage, 16th c., Musée Dauphinois, Grenoble



Vierge à l'Enfant au baldaquin, Noiron-sur-Seine, Burgundy



Shelf element, decor assigned to the family of cabinetmakers Hache, Musée Dauphinois, Grenoble

“Paysans Chevaliers de l’an Mil –Paladru Lake”



In 1972, started the systematic excavation of a medieval site in Paladru Lake. It has been occupied for approximately thirty years, between 1008-1010 and 1040 and then preserved underwater after it has been abandoned.

- As immersion allows the preservation of organic remnants, thousands of objects in wood, leather, baskets, etc. are dated back.
- ⚙ As soon as 1972, the archaeologist Michel Colardelle sought to preserve these remains and asked the team of Louis de Nadaillac to find a way to save objects in waterlogged wood from the collapse which they are promised by drying.



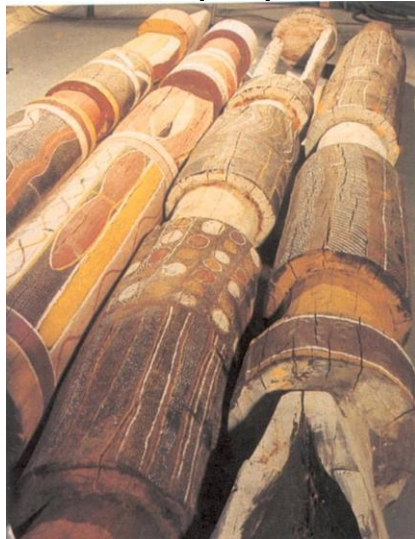
Thousands of waterlogged wooden artifacts (11st century site Paladru lake) saved by the “Nucléart” process since 1972



The pioneers, third.



But since the beginning, the interest of gamma irradiation was not only on consolidation, but also on disinfection, and mainly on xylophagous insects



Australian Totems, Musée des arts océaniques et africains, Paris



Furniture from the area of Grenoble



A modern wooden sculpture of Zadkine: "Fauve", Musée de Grenoble



Pietà, 15th c.,
Saint-Aupre, near Grenoble

The pioneers, fourth.

- ⚙ In 1975, the interest of insect eradication mass treatment by gamma irradiation was shown, with the treatment of several hundred m³ of items from the “Musée Dauphinois” storage rooms.



Other mass treatment will follow as soon as 1978, with the “musée Paul Dupuy”, Toulouse.



Ramses II mummy disinfection

- ⚙️ **1977** : the most emblematic operation that launches definitively the laboratory Nucléart.



mummy



Ramses II.



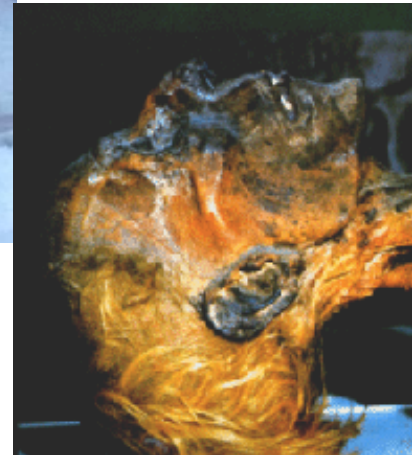
Ramses II arrival on Paris



Ramses II arrival on Paris



Ramses II mummy studies



Formation of a consortium of Museums and Research laboratories for the operation of Ramses II Mummy Disinfection



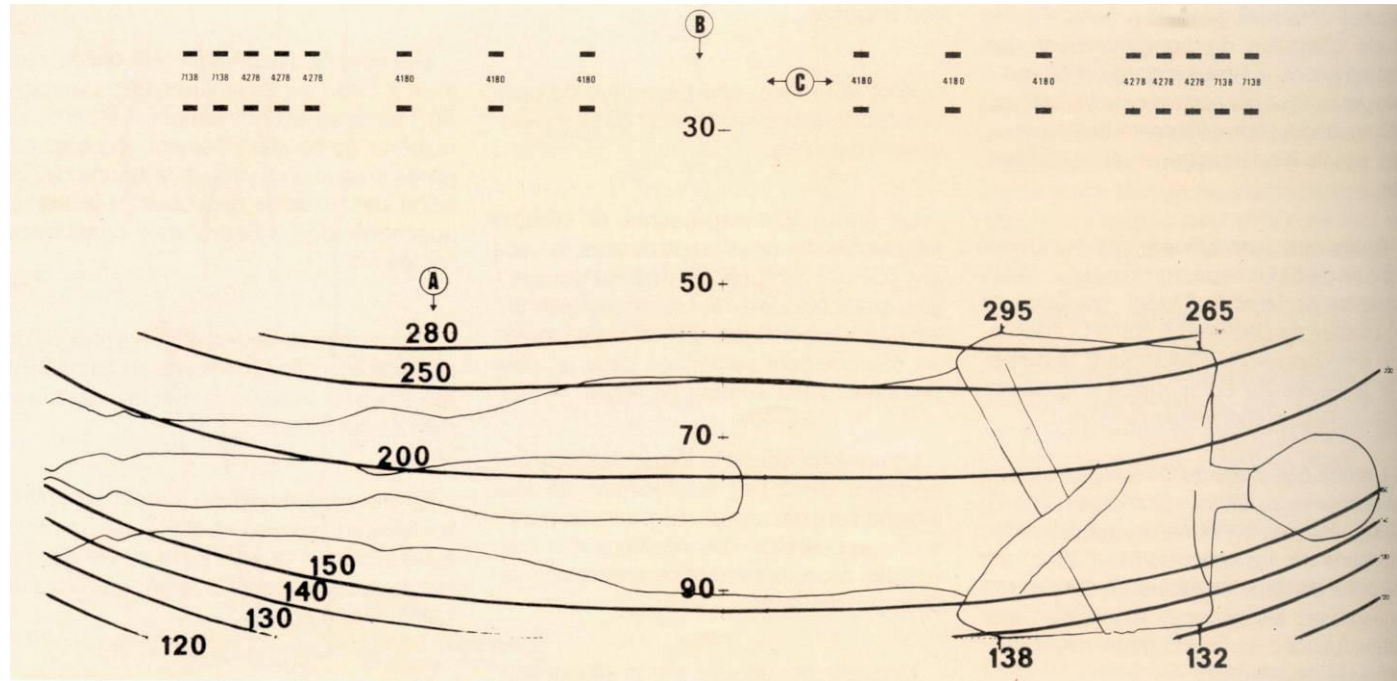
Study of Behavior of Mummy Constituents under Irradiation

- ⚙️ A less famous mummy, from the “cabinet de curiosité” of the “musée des beaux arts de Grenoble” was tested under irradiation.



- ⚙️ Other studies included irradiation of hair, teeth, linen textile, bone, etc.

Ramses II Mummy Disinfection Modelisation

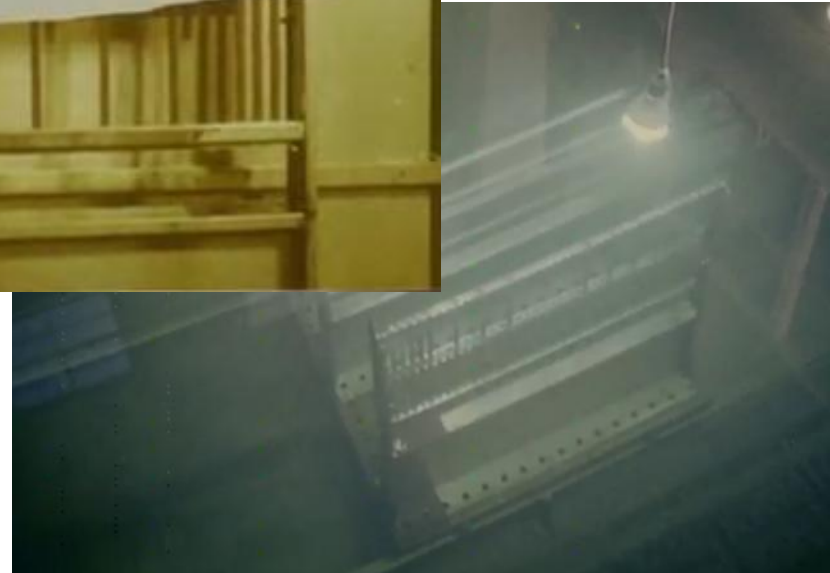
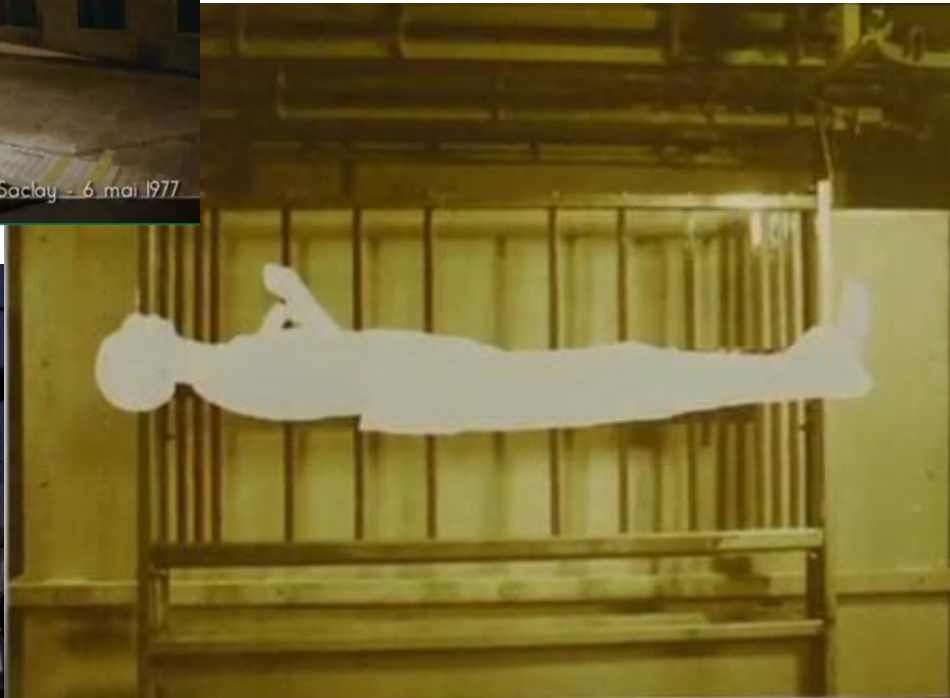


Ramses II Mummy Preparation



Ramses II Mummy Irradiation

Minimum dose of 18 kGy during 12h40 mn
ratio max/min : 1.33



Co60 activity : 160 kCi

Ramses II Departure from Paris

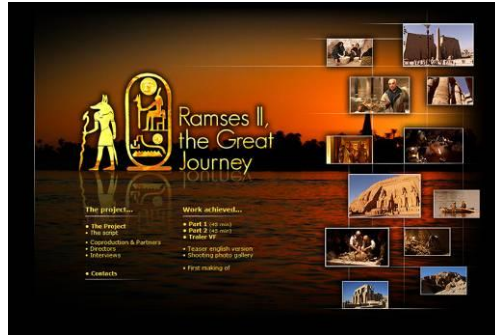




And Arrival to the Cairo Museum



An operation that still make talk about it



TV5MONDE

Broadcasting in
Latin America:
23/01/12

Chapter 5
RAMESSES IN PARIS

In 1975, during a complex period of international relations, the French President Valéry Giscard d'Estaing and Christiane Desroches-Noblecourt, curator of Egyptian Antiquities at the Louvre, collaborate to save the mummy.

In 1976, after long diplomatic negotiations, Ramsesses the Second boards a military plane, crosses the Mediterranean and arrives in Paris to a welcome fit for a head of state.

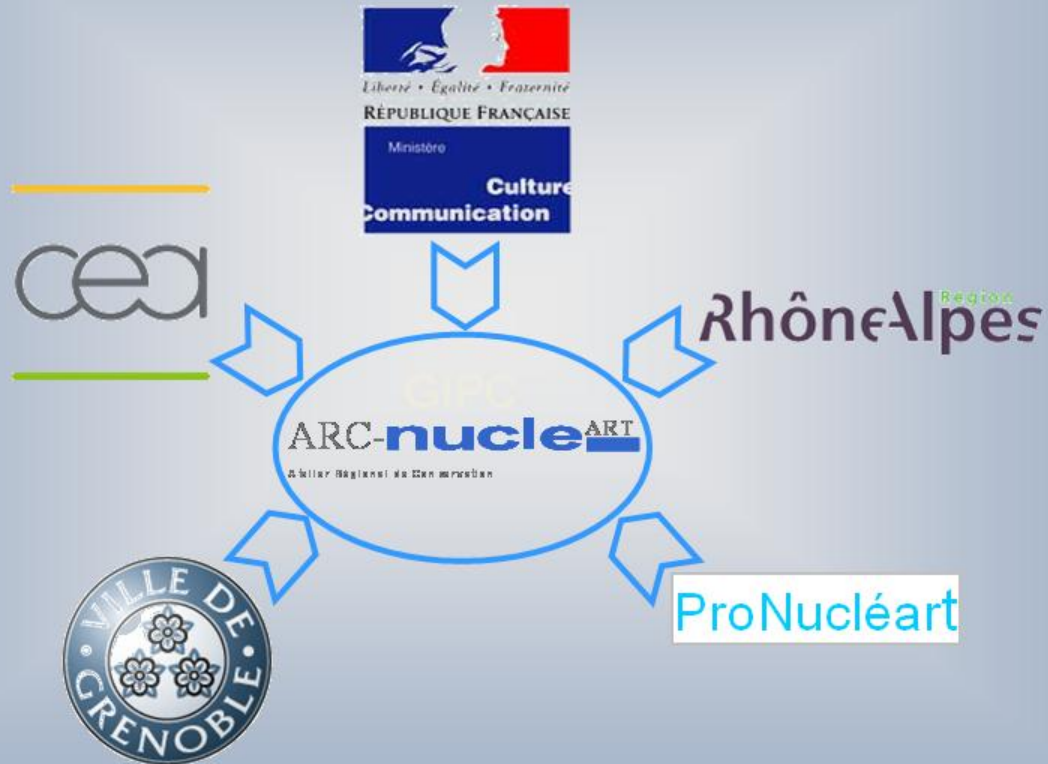
No less that 105 researchers and technicians undertake the task of analysis and treatment, under tight security.

The analyses carried out on the pharaoh give precious information concerning his physical particularities, his state of health at the time of his death, and the techniques employed in his mummification.

ARC-Nucléart today

A partnership with 5 partners

GIPC: Groupement d'intérêt public culturel



ARC-Nucléart today

A conservation center and a research-development laboratory

- A conservation center offering services of conservation and / or restoration.
- A laboratory, for the development of new process.

A mission:

**To implement the best technologies
for the conservation of cultural heritage artifacts**

Conservation of organic materials :

- Historic (dry)
- Archaeological (waterlogged)



Insect Eradication

The most popular application of gamma rays

Many thousands of cubic meters of wooden objects disinfected since the 70's (about 100 m³ per year):

- ⚙ Furniture
- ⚙ Statues
- ⚙ Ethnologic objects
- ⚙ Music instruments
- ⚙ ...



*Desk, 18th c.,
Hache Cabinetmaker*



*Saint Louis, 16th c.,
L'Ambergement-de-Varey*



*Cosmographic Apparatus, 18th c.,
La Côte-Saint-André*



*Alto, 18th c.,
Mirecourt*

Dose of 0.5- 1 kGy for Church Sculptures **insect eradication**



Angels and apostles, 17th c., Le Pègue

Church Sculpture Insect Eradication



*Child Jesus, 18th c.,
Bonifacio*



*Saint John, 18th c.,
Cluses*



*Saint James of Compostela, 17th c.,
Salviac*

Church Sculpture Insect Eradication

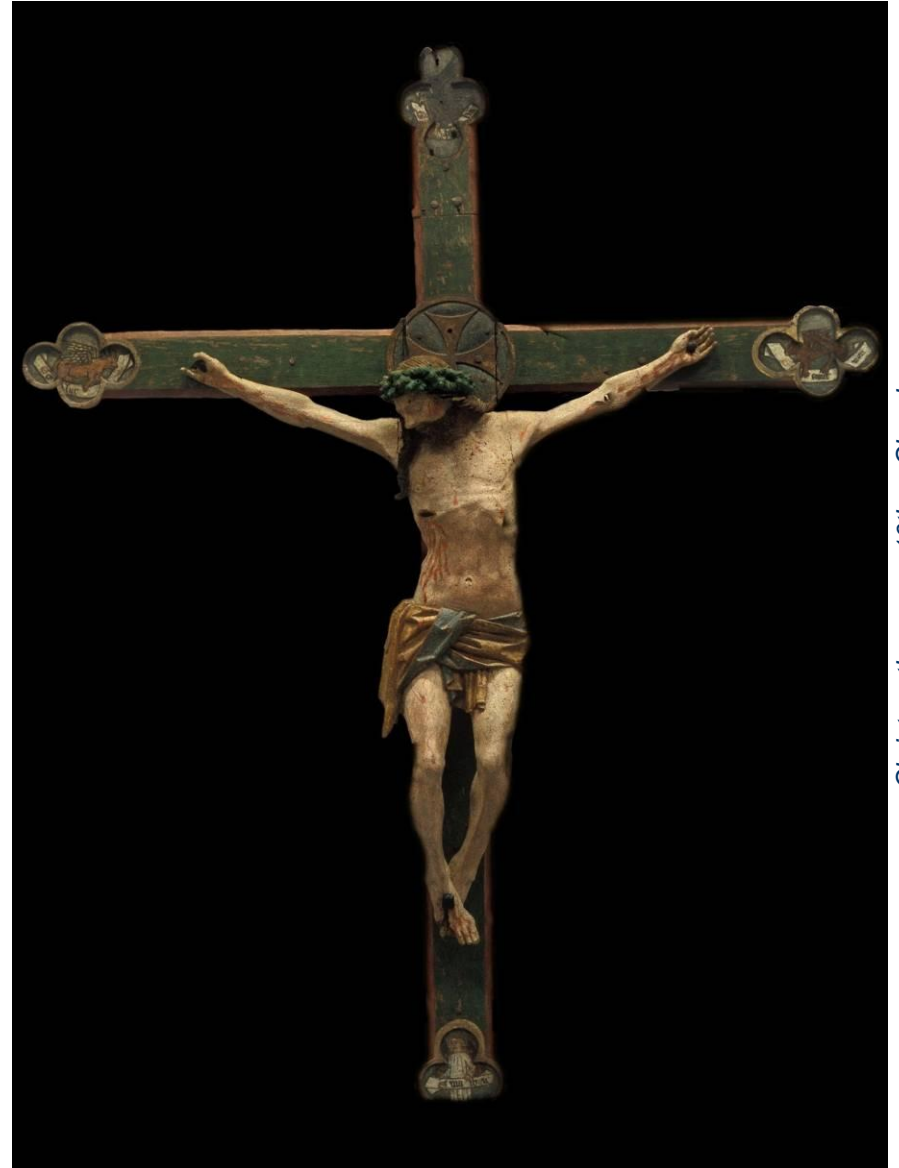
First step
before classic
restoration



Christ on the cross, cartapesta, 17th c., Espalio

Church Sculpture Insect Eradication

First step before restoration
(release of polychromy)



Christ on the cross, 16th c., Chambors

Church Sculpture Insect Eradication

First step
before
restoration

(release of
polychromy)



*Pietà, 14th c.,
Yenne*



*Marie-Madeliene, 18th c.,
Yenne*

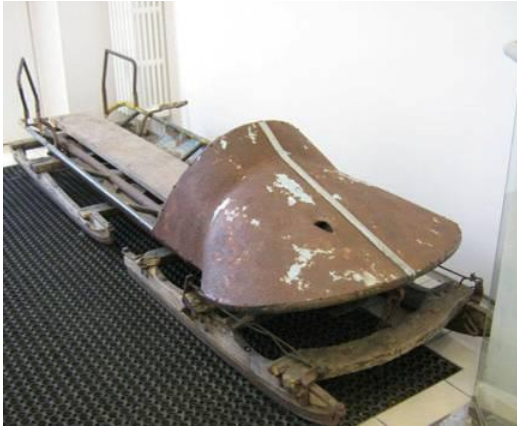
Museum Artefact Insect Eradication



*Ethnographic object,
Collection Lacroix, 20th c.,
Museum of Fessy*

Museum Artefact Insect Eradication

Bobsleigh, 20th c., Museum of Villard-de-Lans
(insect eradication before restoration)



Museum Artefacts Insects Eradication

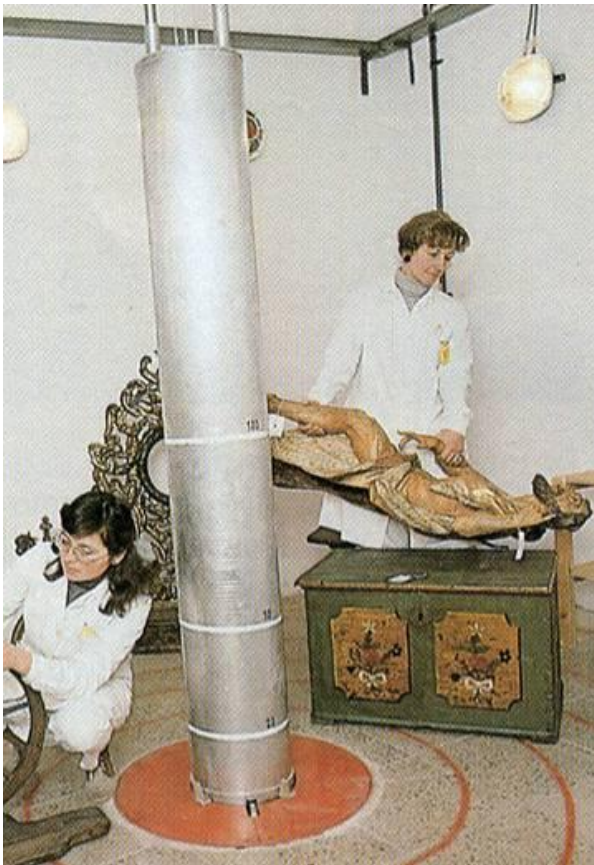
Sedan chair, 1752, Pauk Pastre Museum, Marsillargue
(Insect eradication before restoration)



Gamma Disinfection in Czech Republic

The only gamma irradiator in a museum

☼ the Museum of Central Bohemia in Rožtoky



Konzervační ozařovací pracoviště
Přijím zakázek, vždy po předchozí domluvě: Po-pá 8.00–12.00 12.30–15.30
u větší zakázky lze dohodnout jiný termín. tel.: +420 233 029 046, +420 233
029 011 fax: +420 233 029 033 e-mail: ozarovna@muzcum-roztoky.cz

CENÍK RADIČNÍHO OŠETŘENÍ platný od 1. 1. 2012

TYP ZÁSAHU	OŠETROVANÝ PŘEDMĚT	CENA ZA JEDNOTKU OBJEMU
Hubení hmyzu <i>dezinfekční dávka</i> D = 500 Gy	Nábytek:	
	Skřepné a duté předměty	1 dm ³ -2,10 Kč
	Skřepový se zásuvkami	1 dm ³ -2,90 Kč
	Stůl (celkový uspojovací prostor)	1 dm ³ -2,10 Kč
	Zidle	230 Kč
Hubení hmyzu <i>dezinfekční dávka</i> D = 500 Gy	Křeslo	330 Kč
	Postel (lžec, matrace)	570 Kč
	Hodiny (stolní, závěsné)	230 Kč
	Calouněný nábytek	1 dm ³ -3,20 Kč
	Obrazy:	
Hubení hmyzu <i>dezinfekční dávka</i> D = 500 Gy	Deskové	1 dm ³ -4,00 Kč
	Plátro včetně rámu	1 dm ³ -2,90 Kč
	Prázdný rám	1 dm ³ -2,10 Kč
	Varhany, krabice (stůl dřev. předmět)	1 dm ³ -3,20 Kč
	Pině dřevo	1 dm ³ -6,50 Kč
Plastika	1 dm ³ -4,00 Kč ☉	
	1 dm ³ -6,50 Kč ☉	
Tónovní skla	Tabulové sklo	1 dm ³ -4,00 Kč
	Masivní plastiky	1 dm ³ -35 Kč
Hubení plísní a hub <i>dezinfekční dávka</i> D = 18 kGy	Malé předměty	1 dm ³ -30 Kč
	Cena za rozměrné předměty se stanoví dle doby ozařování	
Sterilizace	Biologický materiál,	1 dm ³ -70 Kč
	tech. pomůcky	Dřevomorka je na upřesnění.

Ceny v tomto ceníku jsou bezesrotační, cena celkové zahrnuje práci na objektu, dopravu předmětů vhodnou a vstříplou kabinou (včetně přepravy materiálů v plastových přepravních sáčkách). Nejmenší účinná dávka pro všechny druhy je 120 kGy. Upozornění: Sklo může po ozařování trpět tvorbou bílých nářezů. Při ozařování dřevnatých částí dřevotřískových desek může nastat změna v jejich vlastnostech. 1 kGy = 100 kJ/kg, a 1 kGy = 10 kJ/kg.



KONZERVAČNÍ OZAŘOVACÍ PRACOVIŠTĚ
VE STŘEDOČESKÉM MUZEU
V ROZTOKÁCH U PRAHY

PŘÍSPĚVKOVÁ ORGANIZACE
Zámek č. p. 1, 252 63 Rožtoky u Prahy
tel.: 233 029 046, 233 029 011 fax: 233 029 033
e-mail: ozarovna@muzcum-roztoky.cz
www.muzcum-roztoky.cz



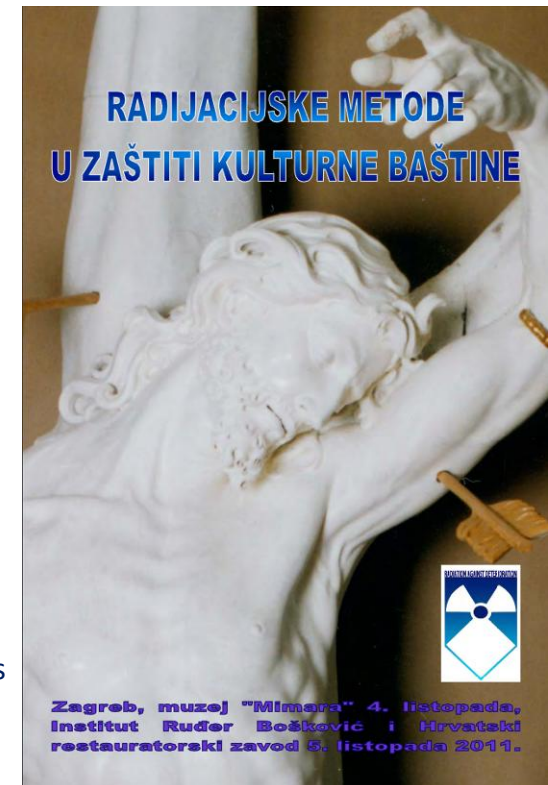
Gamma disinfection in Croatia

- ⚙ Use of ^{60}Co gamma irradiation source in the dry panoramic irradiation facility for treatment for the protection and conservation of cultural heritage artefacts,
- ⚙ More than 5000 wooden sculptures, parts of altars, furniture, tools, musical instruments, other wooden, paper, straw, textile, leather items, etc., treated from 20 years



Polychromic sculptures – Mary Petrinja - 10 years buried in the crypt of a church destroyed during the war in Croatia

(1991 – 1995)



Large used of **electron beam** instead of gamma ray

⚙ **Insect eradication of wooden sculptures and furniture**

⚙ Disinfection of sixty thousands shoes looted from prisoners of the Nazi concentration camp in Lublin, popularly called Majdanek and the victims of "Action Reinhardt" (State Museum at Majdanek)



⚙ Archives from Main Library on Technical University of God and Library of Warsaw University



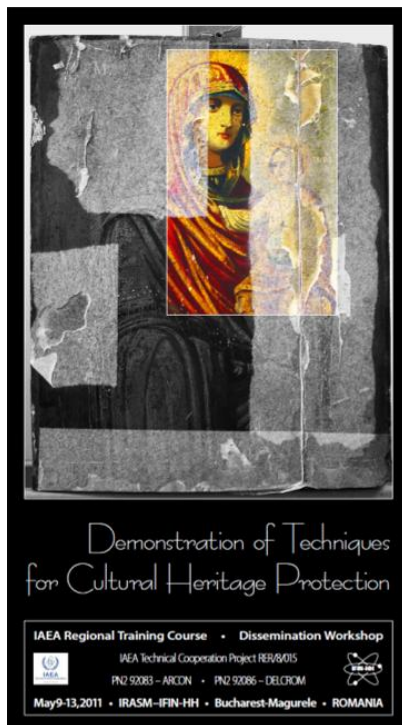
Gamma Disinfection in Romania

A multi purpose irradiator near Bucharest:

⚙️ the IRASM Radiation Processing Centre

Many disinfestations of archives, wooden sculptures, Romanian icons, etc.

Studies on effect of gamma irradiation on paper and on polychromy



A popular practice in many countries

Researches and services are carried worldwide



☼ Brazil, Portugal, Netherlands, Korea, United Kingdom, Germany, Italy, United States ...



IAEA technical cooperation project 2013-2014

Consultant's Meeting at IAEA Headquarters, Vienna

28 October to 1 November 2013

“Preparation of Guidelines on the use of radiation techniques for preservation of artifacts and cultural objects”

Participants at the meeting :

- **Brazil : IPEN Sao Paulo**
- **Romania : IRASM Bucharest**
- **Netherlands : TNO Delft**
- **France : Mr J.L Boutaine and ARC-Nucléart Grenoble**

Other countries to be involved for the Guidelines edition : Croatia, Italy, Portugal, Poland

Objective : IAEA Edition of the Book-Guidelines in October 2014

Side-effects of irradiation on materials of cultural heritage artifacts

A question of irradiation dose :

- Standard dose for medical sterilisation : 25 kGy
- Insect eradication dose : 0.5 kGy
- Bacteria, fungi disinfection dose : 10 kGy

Interaction of gamma rays with the atoms :

→ **Ionization** : only a minor part of the deposited energy is consumed in ionization

$$1 \text{ kGy} \Leftrightarrow 6 \cdot 10^{21} \text{ eV/kg}$$

⇒ $2 \cdot 10^{20}$ ionizations/kg (*~30 eV per ionization*)

⇒ 1 ionization every 3000 molecules (*for a macromolecule of molecular weight 1000*)

- Ionization

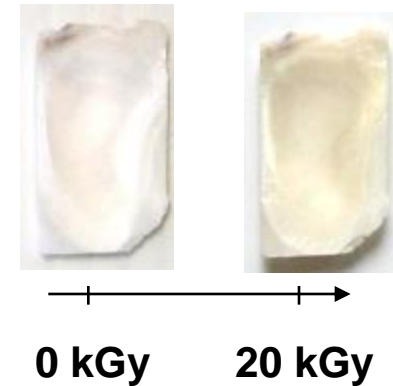
- Radiolysis

⇒ *Oxidation* ⇒ *yellowing*

⇒ *Free radical creation*

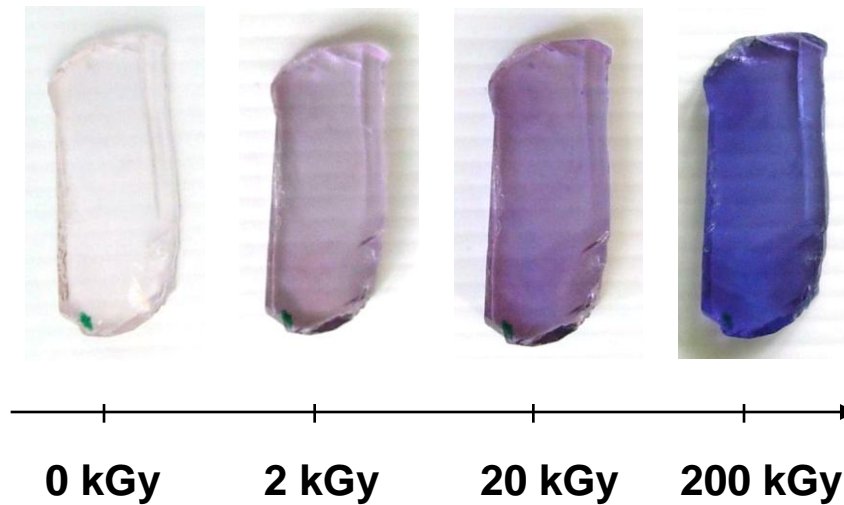
- Transformations of the connections in the polymer chains : chain scission and/or cross-linking

⇒ *modification of the mechanical characteristics of polymers - embrittlement*

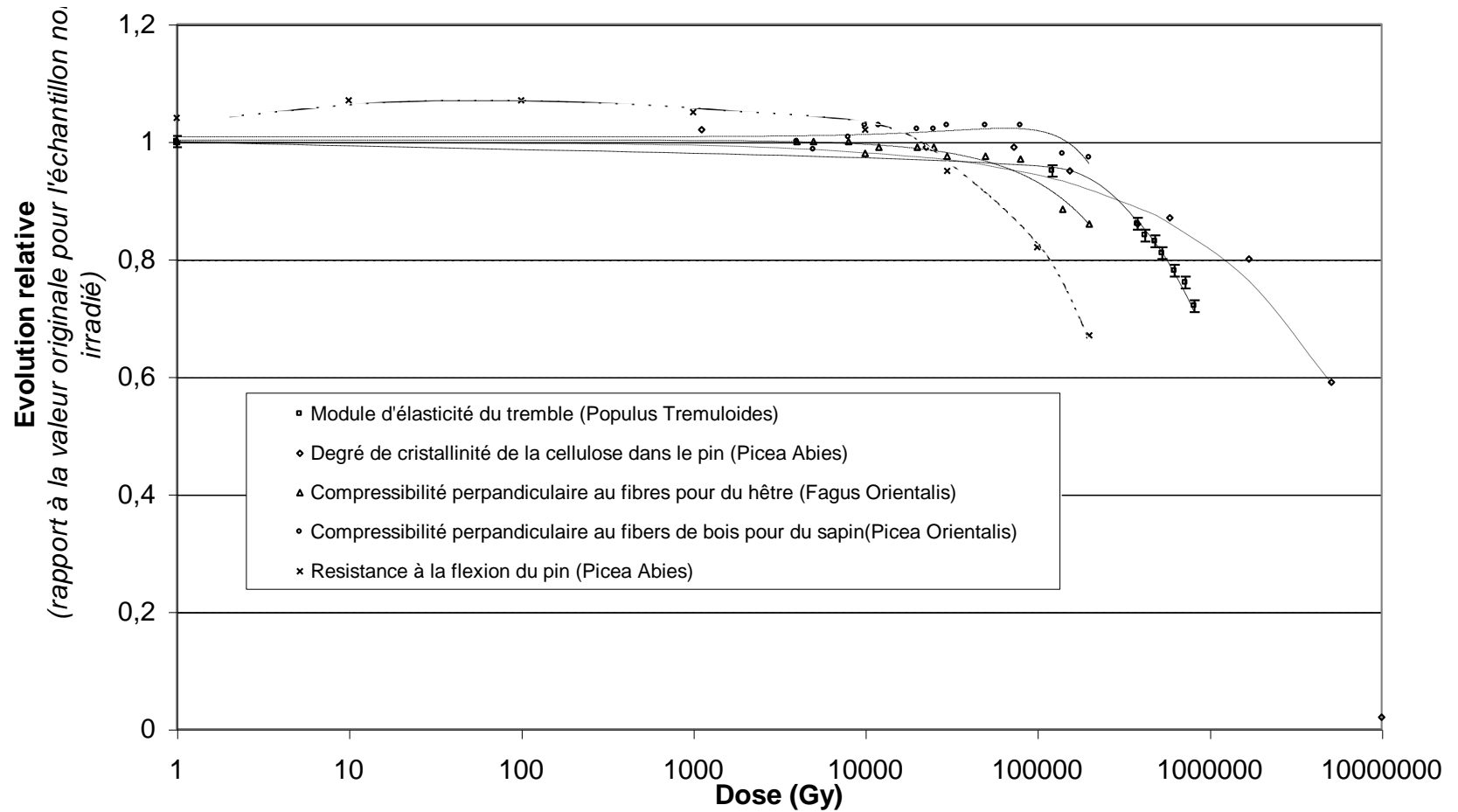


→Electronic Excitation

- The major part of the deposited energy is consumed in electronic excitation of the medium
- Modification of the optical characteristics of materials :
⇒ *Opacification and/or coloration of transparent materials*



Mechanical properties changes of **wood** after irradiation

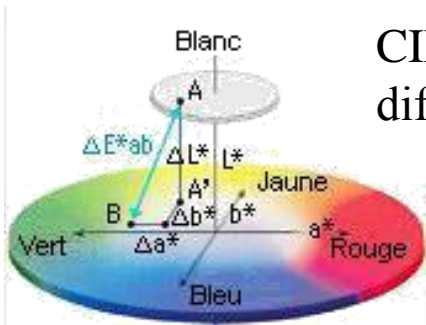


Pigments under irradiation

- No noteworthy change even after 200 kGy

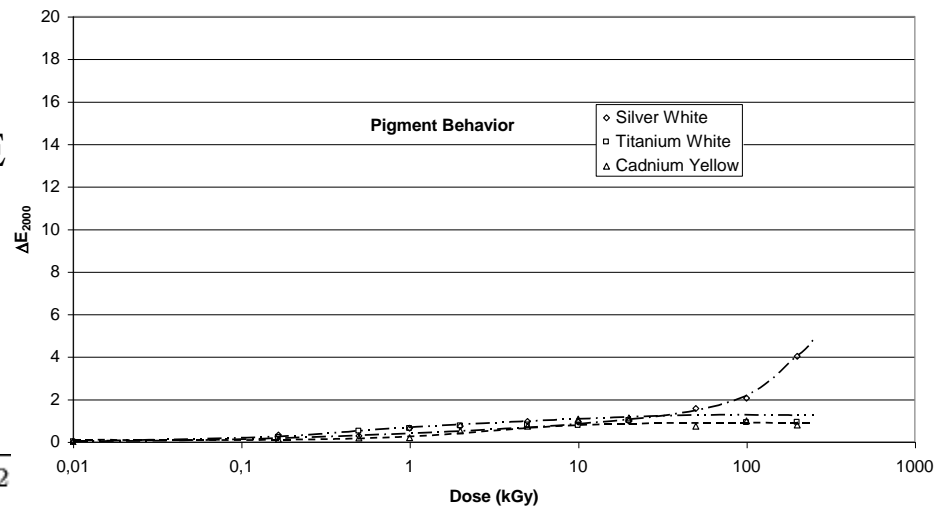


Only silver white presents ΔE_{2000} significantly higher than 2



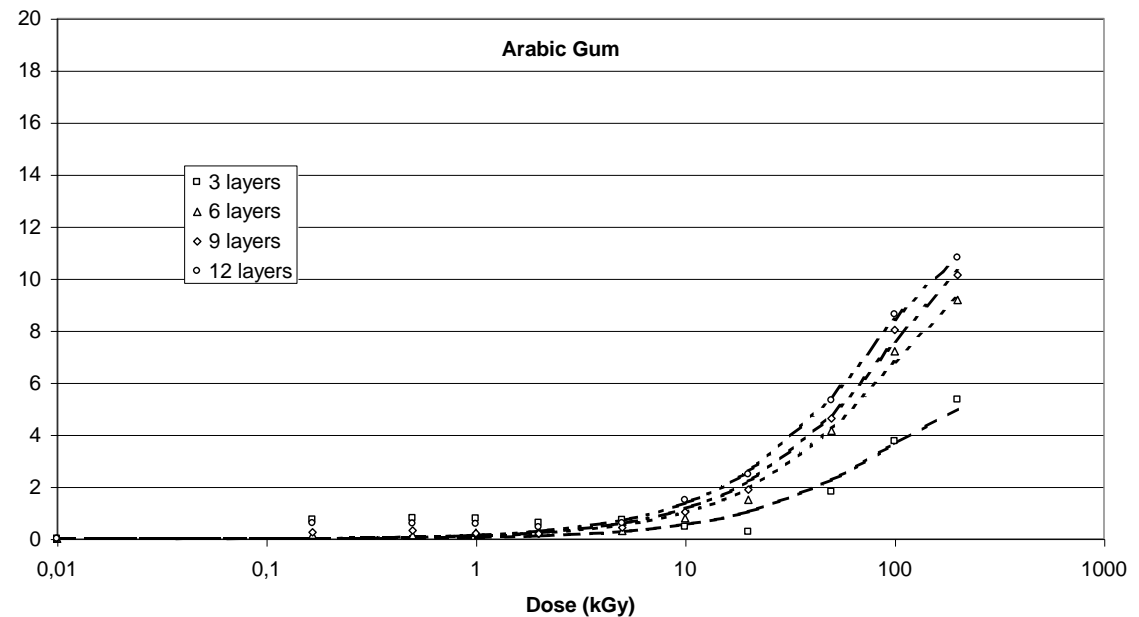
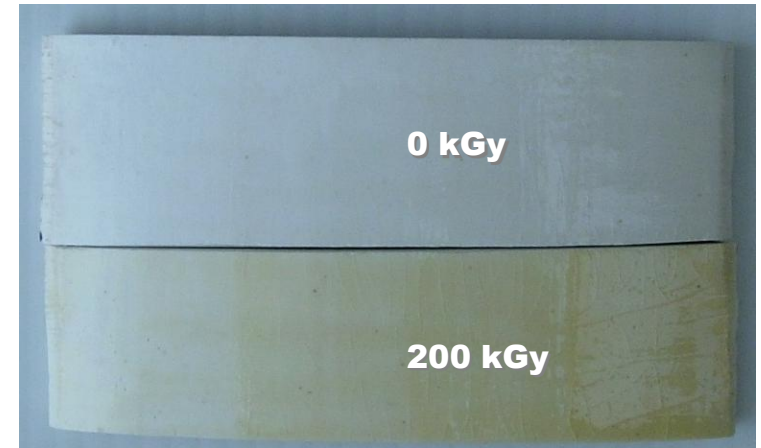
CIEL ab color
difference measurement ΔE

$$\Delta E^*_{ab} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

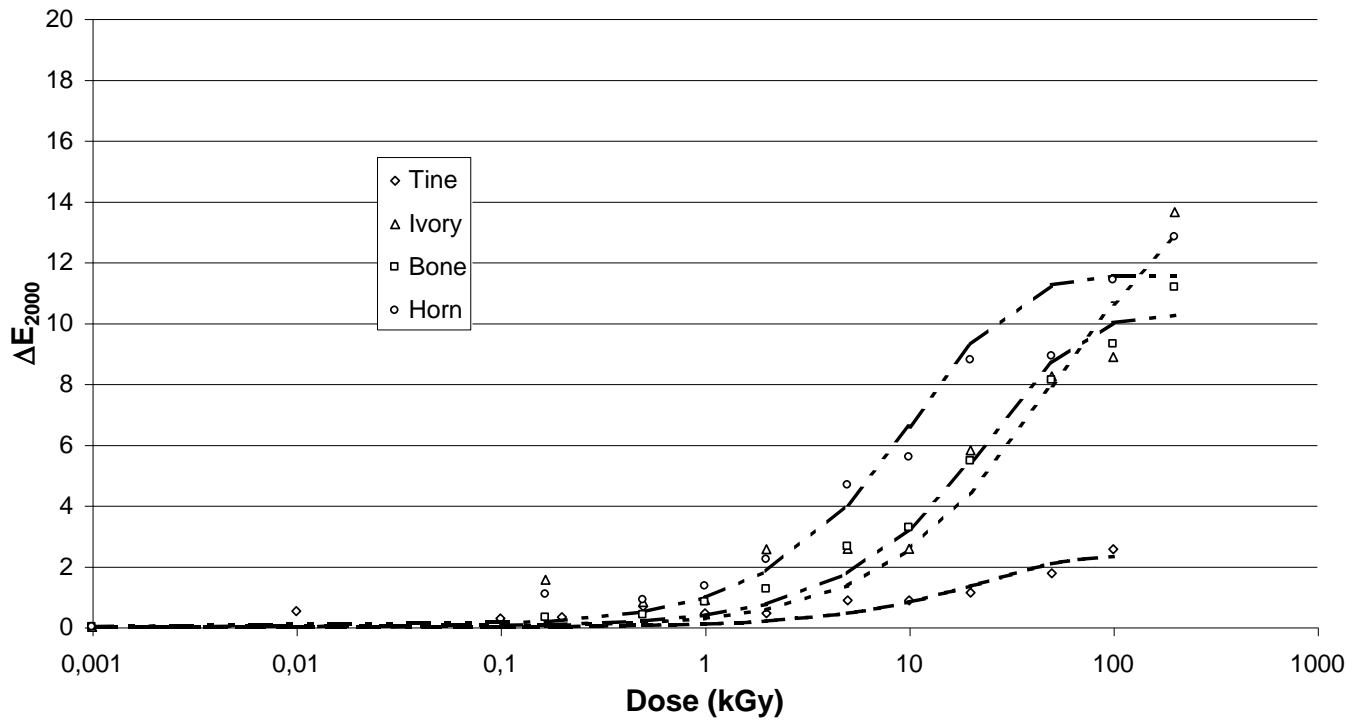
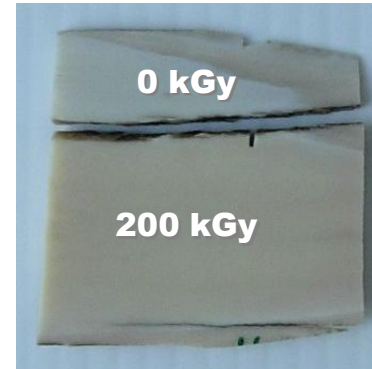


Binder **Arabic GUM** under irradiation

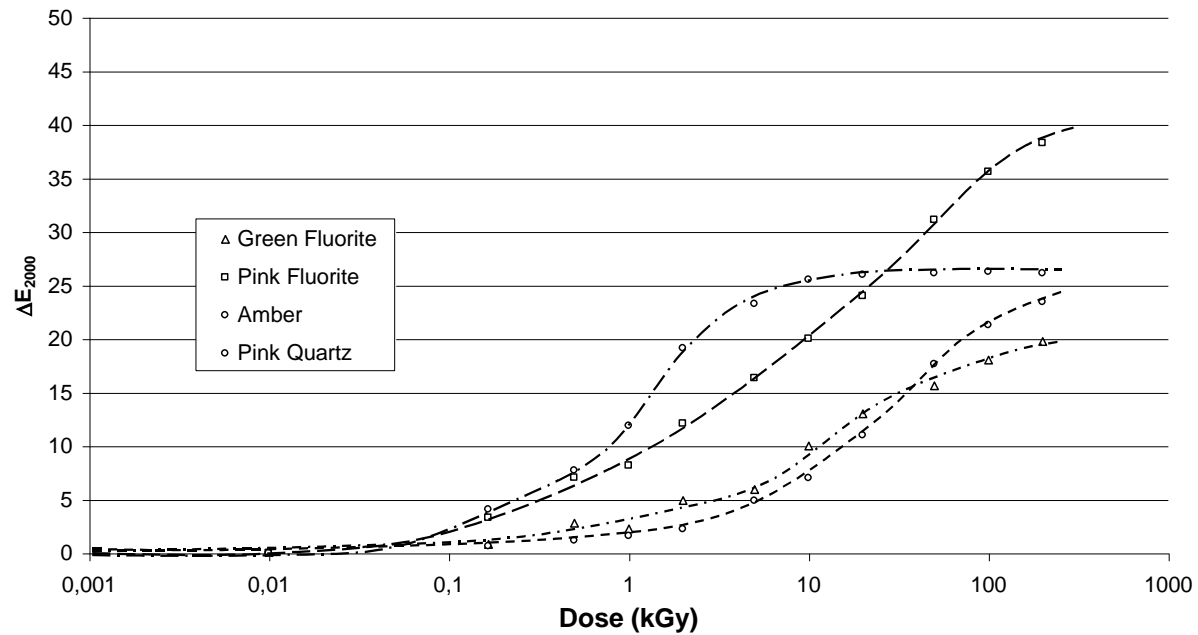
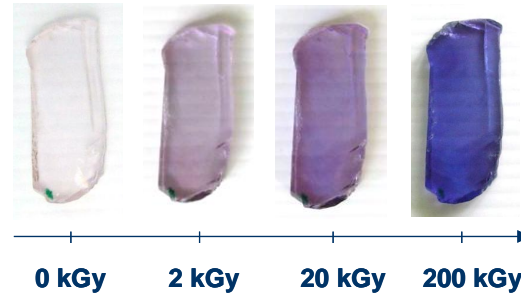
nom	nbr couches	ΔE_{2000}	
		20kGy	200kGy
colle de peau	3 couches	0,81	2,35
	6couches	2,07	4,11
	9 couches	1,93	3,82
	12 couches	1,98	3,78
paraloid B72	3 couches	1,11	0,93
	6couches	0,76	0,68
	9 couches	1,21	1,01
	12 couches	1,52	1,98
gomme laque	3 couches	0,35	0,96
	6couches	0,57	0,95
	9 couches	0,73	1,01
	12 couches	0,53	0,73
blanc d'œuf	3 couches	0,64	1,42
	6couches	0,67	1,76
	9 couches	0,49	1,83
	12 couches	0,59	1,67
gomme arabique	3 couches	0,26	5,35
	6couches	1,5	9,17
	9 couches	1,89	10,13
	12 couches	2,48	10,81
huile d'oeillette	3 couches	0,99	1,2
	6couches	1,17	1,02
	9 couches	0,9	1,71
	12 couches	0,5	1,27
huile de lin	3 couches	0,85	0,88
	6couches	0,73	0,57
	9 couches	0,84	0,91
	12 couches	0,8	0,61
blanc de Meudon	4 couches	0,7	0,41
gomme damar	3 couches	1,19	3,37
	6couches	1,28	3,63
	9 couches	1,09	3,66
	12 couches	0,96	3,32



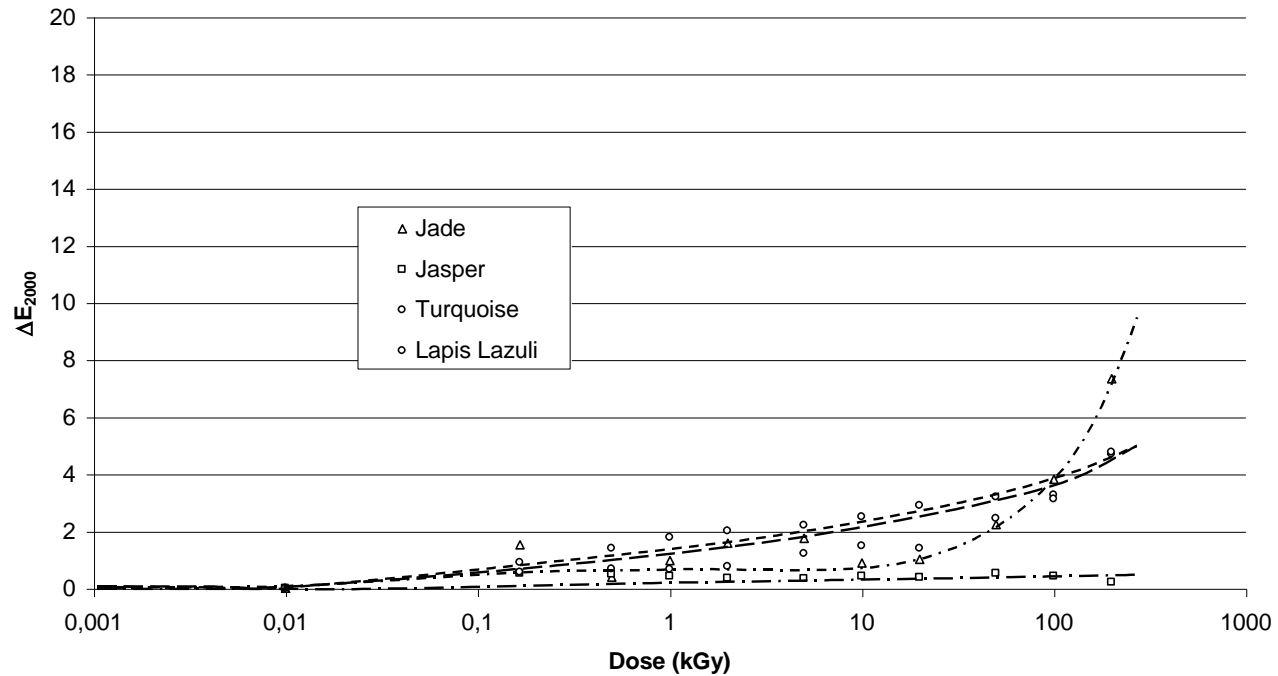
Tine, ivory, bone and horn under irradiation



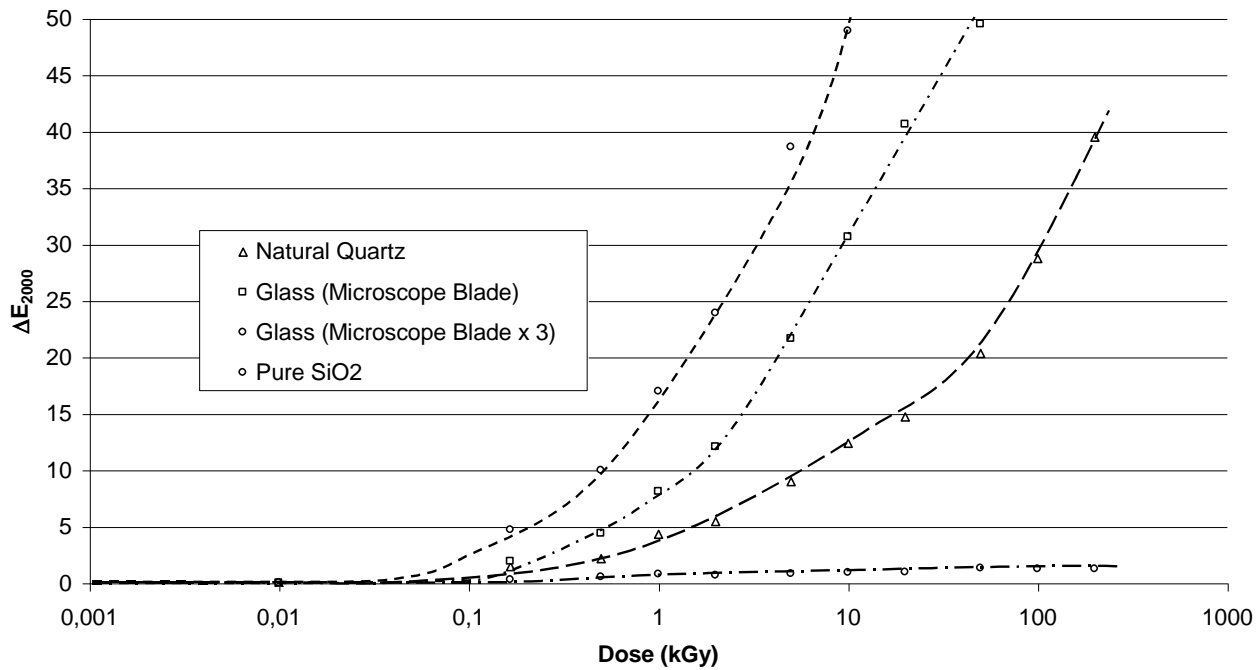
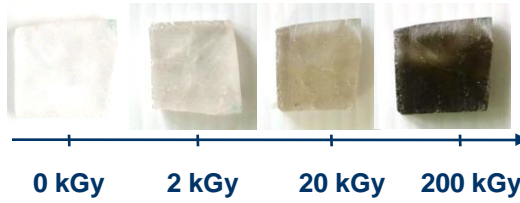
Transparent gems under irradiation



Opaque gems under irradiation



Silica under irradiation



Current studies on archive disinfection : dose limits following different countries



- **Changes of cellulosic materials** after a dose of 8 ± 2 kGy
 - No significant changes by coloured objects observed
 - No significant changes in selected mechanical properties observed
 - Effect of mould is more severe than gamma radiation
 - Slight effect in change in the degree of polymerisation observed
- First we observe a chemical change on micro level, but this will not affect the performance on macro level

Ref: Results from Dr J. Havermans, TNO research center Netherlands

- **Emission of volatiles**
 - Slight decrease of volatiles emission due to the treatment
 - However: acetic acid emission increases

Gamma Services GmbH, Dresden, Germany : 10-12 kGy

ENEA , Roma, Italy : 3-8 kGy

France : insect eradication : YES

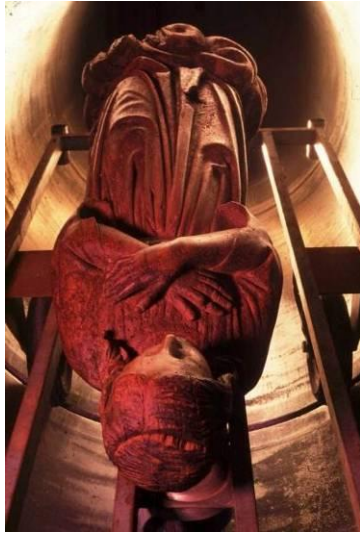
fungi disinfection : NO

Nucléart Consolidation of ancient parquet



Former diocese
of Viviers (Ardeche - France)

Church Sculpture Nucléart Consolidation

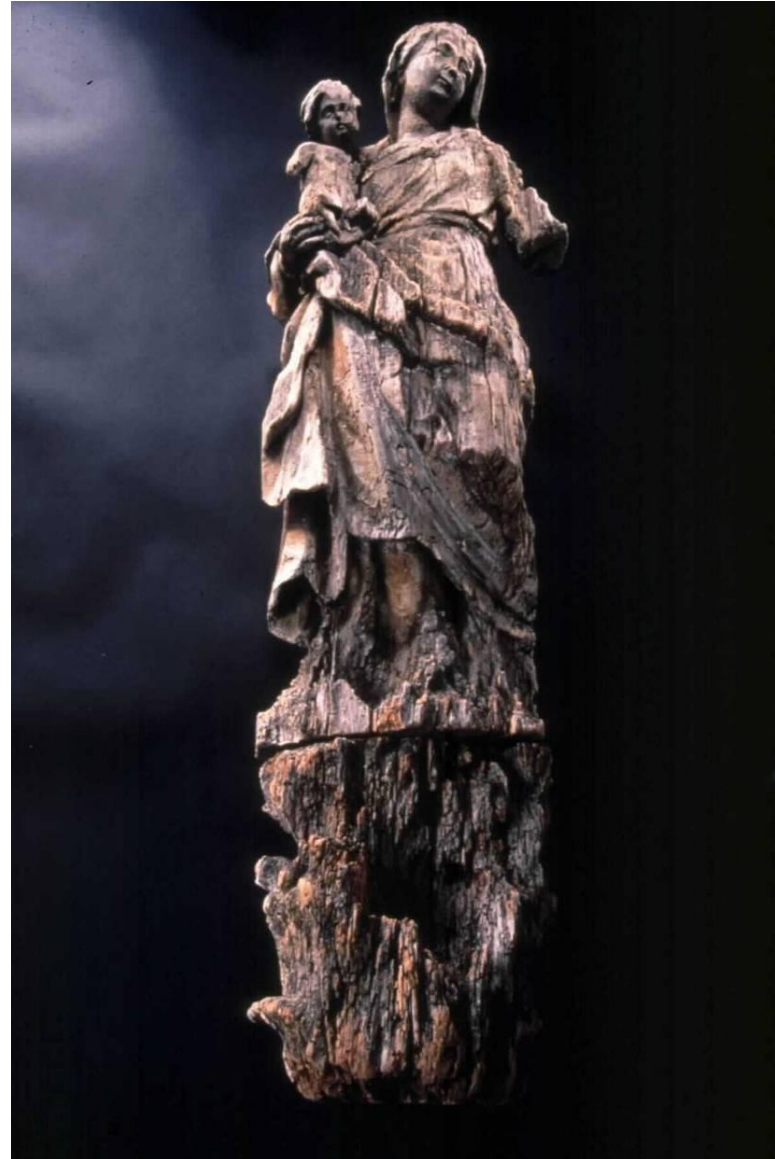


Cherubs, 18th c., Beauvallon

Church Sculpture Nucléart Consolidation

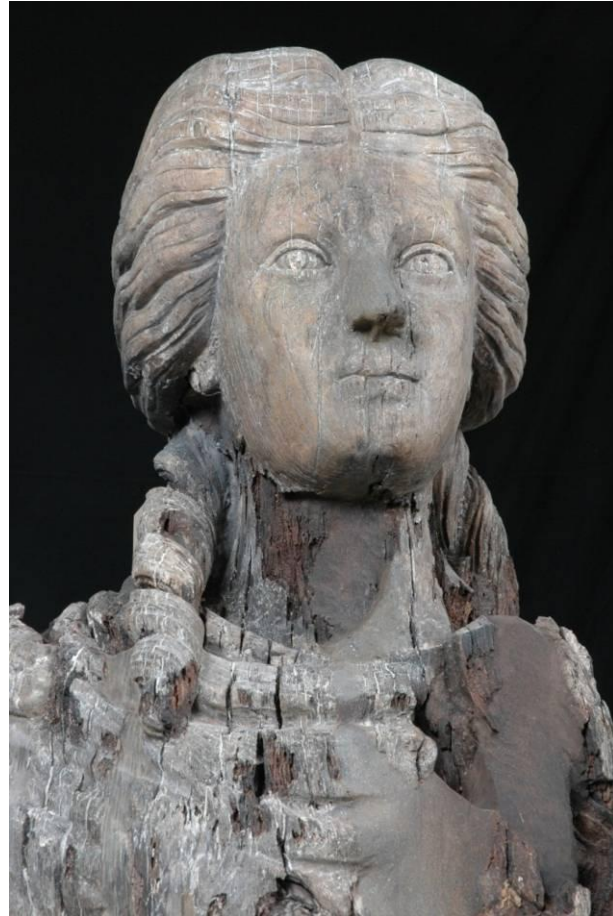


*Virgin and Child, 17th c.,
Auberive-en-Royans*



The Marta “Nucléart” consolidation

- ⚙️ A figurehead of a schooner of the end of the 19th century.



An hydraulic wheel “Nucléart” Consolidation



Waterlogged Wood “Nucléart” Conservation

*Gallic bucket, 1st c. bc,
Vieille-Toulouse*



Gallo-Roman anchor, Arles



« Tirez les premiers, messieurs les anglais ! »*

* *“Shoot first, English gentlemen!”*

Gun carriage from the wreck of the
HMS Stirling Castle, XVIIth c.



French canon, XVIth c., Le Havre

French response



The Nucléart Technique implemented in Mexico



Consolidation of a Maya Pre-Columbian wooden sculpture (irradiation carried out at National Institute of Nuclear Research, near Mexico City).

ICOM Committee for Conservation, 2008 (vol II, pp. 724-730)



Conservation of Chinese Terra Cotta



☼ by E-beam curing (40 kGy)
The polymerization takes place mainly in the upper layer of the terracotta, where the electrons are absorbed, and it does not cause any side reactions with the pigments



Terracotta army of the Chinese emperor Qin Shihuangdi, 91 BC (Ref: Angew.Chem.Int. Ed. 2003,42, 5676-5681)



☼ Preservation of the polychromic layer by hydroxyethyl methacrylate (HEMA)



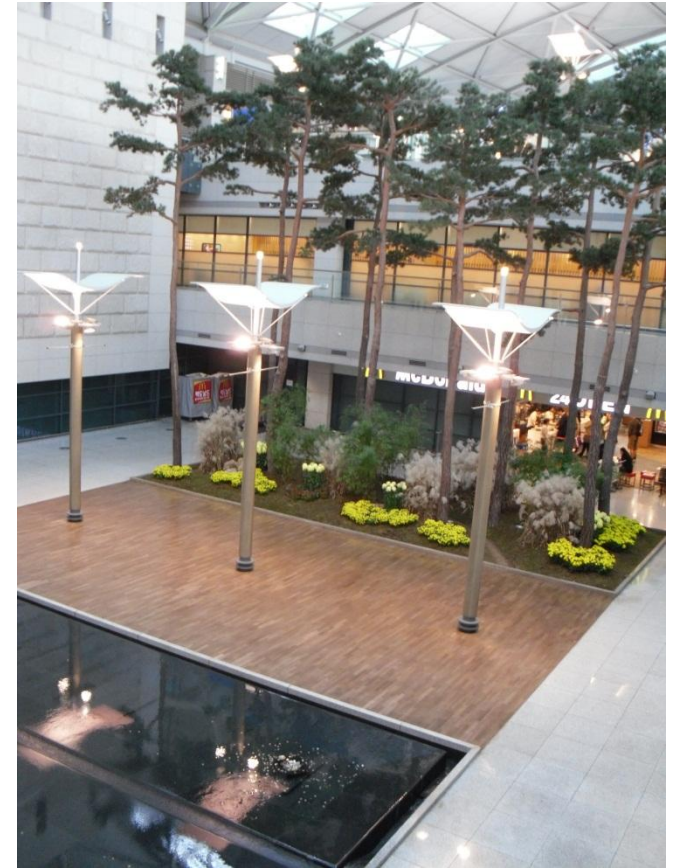
Industrial applications from conservation techniques

“Wood Plastic composite”

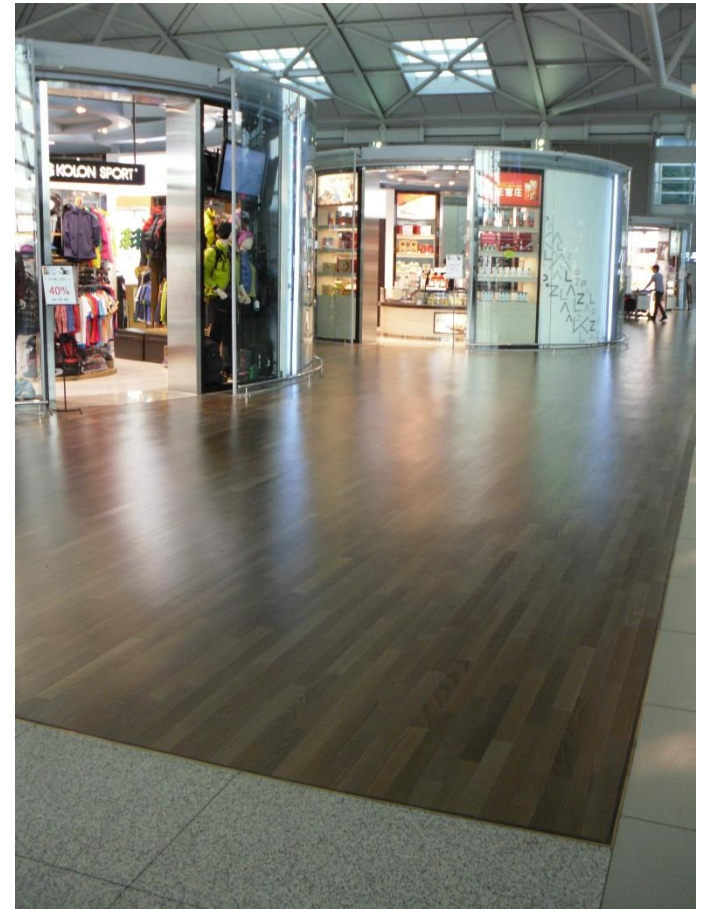


Parquet at the Natural History Museum
Paris

Incheon International Airport SEOUL densified parquet flooring



Radiation-curing parquet at Seoul Incheon International Airport



2010

Khroma, the Baby Woolly Mammoth

- Khroma, a frozen specimen of baby mammoth death at least 50,000 years ago and discovered by a Hunter on the banks of river Khroma, was dug out in 2009 from the Yakutia permafrost in Siberia.
- The ice-encased body had been partially eaten by foxes which devoured the trunk and the top of its head.
- It is both the oldest and the best-preserved baby mammoth ever found, with regards to its flesh.



Khroma, the Baby Woolly Mammoth

- Loaned by the Academy of Sciences of the Republic of Sakha (Yakutia) for the exhibition "Mammoth & Co." at the Museum Crozatier, Puy-en-Velay, at the initiative of the International Mammoth Committee, it should also be a program of study in the same city on the occasion of the 5th International Conference on Mammoths and their families.
- He needed treatment to inactivate traces of bacteria or other potentially pathogenic germs he was carrying...

- ⊗ Gamma irradiation has quickly been retained as the only technique for cold and nondestructive biocide treatment of the entire volume of the specimen.
- ⊗ It was also expected that it could help to preserve the flesh from the decomposition during the thawing.



Khroma, the Baby Woolly Mammoth

- ⚙️ The dose was set to 20 kGy, with references to *Bacillus anthracis* that may be present in soil and on the remains of dead animals, especially herbivores.
- ⚙️ For dose calculations, the simple analytical model conventionally implemented at ARC-Nucléart was completed with a Monte Carlo model, and the results were compared with values of dosimeters plotted on the specimen.



Khroma, the Baby Woolly Mammoth



After its irradiation at ARC-Nucléart for 50 hours from 13 to 15 July 2010, Khroma joined the museum Crozatier in Le Puy-en-Velay, where he was displayed in a showcase at -18°C .



2013



Display of the roman period 30 meter long boat
at Arles Antic Museum , Friday 4 October 2013

The section of the prow, the stem of the boat
just after lifting from the Rhône river :
waterlogged state

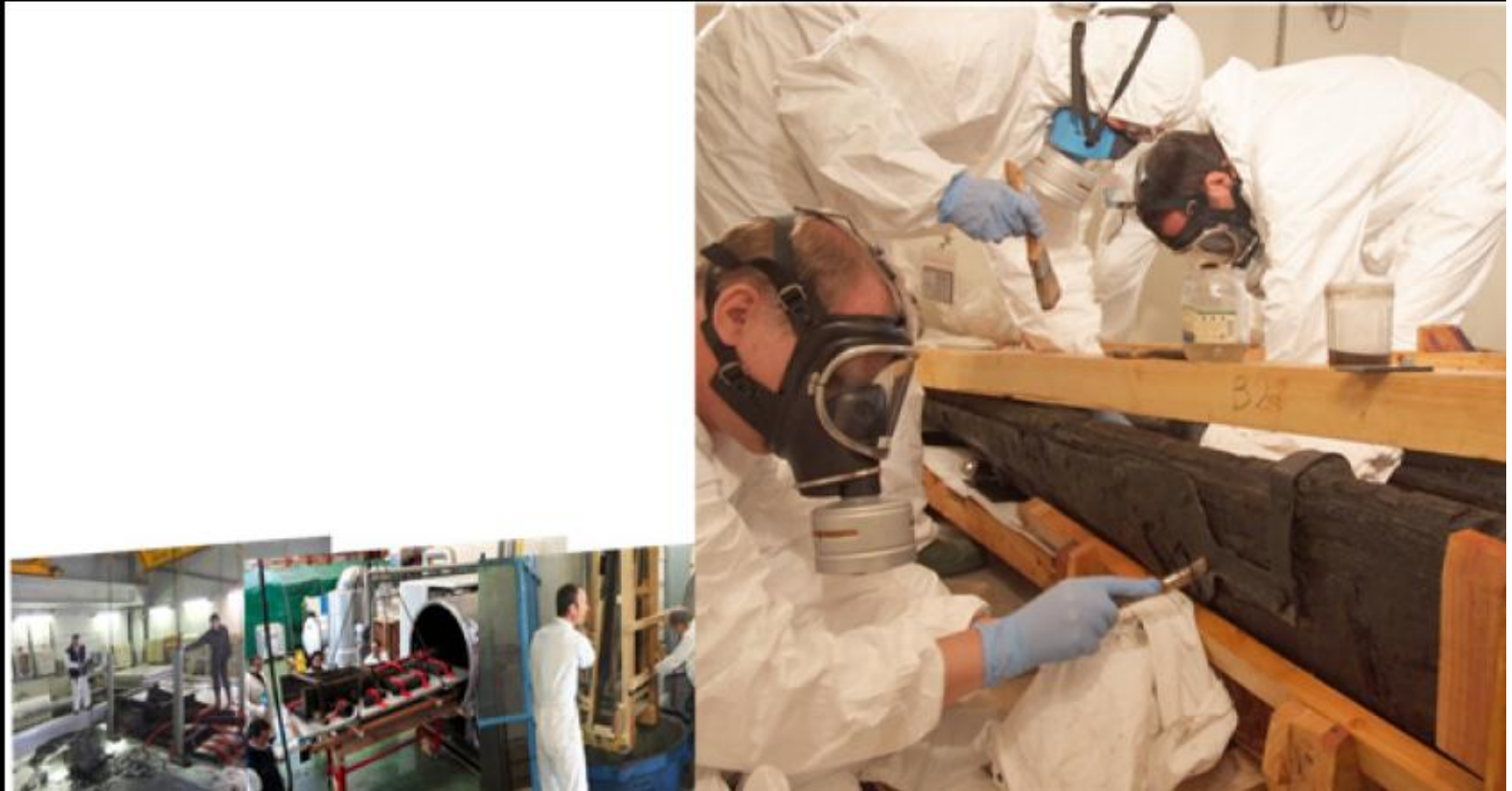




Freeze-drying after PEG impregnation



After drying, radiation-curing resin impregnation (vacuum and under nitrogen pressure)



Cleaning during the irradiation phase

The artefact under gamma irradiation





Final result at the Museum



Muito obrigado pela sua atenção

