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A survey of the possibilities of various radiographic techniques for the non destructive examination of cultural heritage artefacts

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With a large contribution of the image libraries of my former colleagues & friends
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Bernard Rattoni (CEA) & Elisabeth Ravaud (C2RMF)

International Conference on Applications of Radiation Science & Technology (ICARST 2017)

IAEA - Vienna - April 24-28th 2017

Content of the presentation

1 - Specific situation of cultural heritage examination and analysis

2 – Physical basis of the different radiographic techniques

3 – Interest of radiographic examination for the study of a cultural heritage artefact

4 - Some examples of application of radiographic techniques

5 - Conclusion

1 - Specific situation of cultural heritage examination & analysis

- For the examination, characterisation & analysis of cultural heritage artefacts or art objects & their component materials, the conservation scientist needs a palette of non-destructive techniques:
  - to improve understanding of their manufacture, their evolution and/or degradation during time
  - to give a rational basis for the restoration and/or the conservation of the objects

- For non-destructive testing (NDT), the existing scope of methods includes photography, endoscopy, **radiography**, holography, liquid penetrant testing, magnetic testing, Eddy current, thermography, acoustic emission, ultrasonic testing…

- These methods are widely used in industrial control & generally as complementary ones.

- We will discuss on the different techniques which covers the general term **radiography** & see what they can provide to the study of cultural heritage artefacts

Uses of ionising radiation techniques for the examination & analysis of cultural heritage artefacts & their component materials

- **X-ray radiography**

- **Gamma radiography (^{192}Ir & ^{60}Co) of large metal (mainly bronze) & stone statues**

- **Accelerator radiography**

- **Beta radiography (^{14}C) or secondary electron radiography of paper, manuscripts, drawings, prints… to underscore watermarks, paper manufacturing processes…**

- **Neutron radiography & neutron induced autoradiography**

- **Computed assisted tomography**

- **X-ray fluorescence analysis: pigments in easel paintings, mural or parietal paintings, ceramics, enamels, glass…, metals in coins, medals, statues, ethnographic artefacts, jewellery…, minerals in gemstones, various archaeological findings… (in laboratories or in situ: museums, restoration workshops, excavations, on historical building scaffoldings…)**

- **X-ray diffraction**

- **Neutron diffraction**

- **Activation analysis (neutron & particle induced)**

- **Prompt gamma neutron analysis (PGNA)**

- **Ion beam analysis (IBA): PIXE, RBS, ERDA…**

- **Synchrotron radiation based analytical methods**

- **Thermoluminescence dating**

- **Carbon 14 accelerator mass spectroscopy (AMS) dating or liquid scintillation dating**

*Uses of ionising radiation techniques for the conservation/restoration of cultural heritage artefacts **

- **Desinfestation or sterilisation by irradiation (^{60}Co or accelerator)**

- **Resin impregnation & in core polymerisation by irradiation (^{60}Co)**

** Topics that have been treated in session A09*

Table I - LabS TECH - FREQUENCY OF THE DIFFERENT TECHNIQUES (26/02/2009) N.B. : 114 different techniques are indicated by the 151 participating institutions		
RANK	TECHNIQUE	FREQUENCY
1	Reflection Light Microscopy	107
2	Transmission Light Microscopy	99
3	Classical Visible Light Digital Photography	91
4	Scanning Electron Microscopy (SEM)	89
5	Classical Visible Light Silver Emulsion Photography	73
6	Infrared Spectrometry	73
7	Visible & Ultraviolet Spectrometry	60
8	Diffractometry	57
9	Standard Colorimetry	57
10	Ultraviolet Fluorescence Photography	57
11	Powder Diffractometry	56
12	Low HV (<150 kV) X-ray Radiography	53
13	Environmental Weathering Tests (Chambers)	52
14	Infrared Spectrometry Microscopy	52
15	Digitisation & Image Archiving	49
16	Gas Chromatography (GC)	43
17	High Performance Liquid Chromatography (HPLC)	42
18	Gas Chromatography - Mass Spectrometry (GC-MS)	41
19	Infrared Silver Emulsion Photography	41
20	Differential Thermal Analysis (DTA / TG / DTG)	40
21	X-ray Fluorescence Analysis - X-ray Tube - Laboratory Fixed Instrument	39
22	Universal Mechanical Testing	39
23	Low Angled Photography	39
24	Infrared Reflectography Electronic Camera	39
25	Spectro-Photo-Colorimetry	38

Table I - LabS TECH - FREQUENCY OF THE DIFFERENT TECHNIQUES (26/02/2009)
N.B. : 114 different techniques are indicated by the 151 participating institutions

RANK	TECHNIQUE	FREQUENCY
26	Accurate Colour High Resolution Digital Photography	36
27	High voltage (150 < HV < 450 kV) X-ray Radiography	33
28	Ion Chromatography	32
29	Raman Spectrometry	32
30	X-ray Fluorescence Analysis - X-ray Tube - Portable	30
31	Thin Layer Chromatography (TLC)	29
32	Atomic Emission spectrometry (ICP-AES)	28
33	Electron Microprobe	27
34	Atomic Absorption Analysis (AAA)	26
35	Environmental Natural Weathering Tests (Outdoor)	26
36	Pyrolysis Gas Chromatography (Py-GC)	22
37	Mercury Porosimetry	22
38	Particle Induced X-ray Emission (PIXE)	21
39	Pyrolysis Gas Chromatography - Mass Spectroscopy (Py-GC-MS)	18
40	Environmental Scanning Electron Microscopy (ESEM)	18
41	Synchrotron Radiation Examination	18
42	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	18
43	Ultraviolet Fluorescence Microscopy	18
44	Fluorescence Spectrophotometry	17
45	Electron Impact Mass Spectrometry (EI-MS)	16
46	Ultra-Sound Testing	16
47	Rutherford Backscattering Spectrometry (RBS)	16
48	Specific Surface Area Measurement (BET)	15
49	Transmission Electron Microscopy (TEM)	15
50	Contact Angle measurement	15

Table I - LabS TECH - FREQUENCY OF THE DIFFERENT TECHNIQUES (26/02/2009) N.B. : 114 different techniques are indicated by the 151 participating institutions		
RANK	TECHNIQUE	FREQUENCY
51	AFM Microscopy	15
52	Scanning Infrared Reflectometry	15
53	X-Ray Induced Photoelectron Spectrometry (XPS)	14
54	Particle size analysis	13
55	Nuclear Reactions (PIGE - PIGME)	13
56	Envirormental monotoring	13
57	Laser Ablation Mass Spectrometry	13
58	Thermoluminescence Dating (TL)	12
59	Liquid Chromatography - Electospray Ionisation (LC-ESI-MS-MS)	11
60	Microbiological analysis	11
61	Surface corrosion rate measurement	11
62	Materials hydric behaviour measurement	11
63	Mössbauer Spectrometry	10
64	Chemical Ionisation Chromatography (CI-MS)	10
65	Neutron Activation analysis	10
66	Carbon 14 Accelerator Mass Spectroscopy (AMS) Dating	10

A survey of the results of three successive research projects (2000-2015) funded by the European Commission (LabS TECH, EU-ARTECH & CHARISMA) has been recently published:

Une Europe de la recherche en sciences du patrimoine

(A European research in cultural heritage science)

Techné, n° 43 (2016) - ISBN 978-2-7118-6338-9

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Integrated Platform for the European Research Infrastructure ON Cultural Heritage

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3D Imaging in Cultural Heritage

Thursday 9 th – Friday 10 th November 2017 BP Lecture Theatre, The British Museum London ...
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Kick-off meeting “European Research Infrastructure for Heritage Science – Preparatory Phase” (E-RIHS PP)

March 30-31, 2017 Auditorium, Fondazione Cassa di Risparmio di Firenze Via Bufalini 6, Florence, Italy ...
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E-RIHS – European Research Infrastructure for Heritage Science - International Workshop “Towards a European Research Infrastructure for Heritage Science”

March 29, 2017 Sala Capitolare, ex Convento del Maglio Via Venezia 5, Florence, Italy Heritage...
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IMaTTe 2017 - International conference on the values of tangible heritage

LNEC Congress center Lisbon, Portugal May 29-30, 2017 Intangibility Matters , the IPERION...

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Calls for Trans-National Access

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Doctoral schools

1st Iperion Ch Doctoral Summer School - Advanced Characterization Techniques, Diagnostic Tools & Evaluation Methods in Heritage Science

Training Camps

1st IPERION CH TRAINING CAMP - HERITAGE SCIENCE IN PRACTICE

2 – Physical basis of the different radiographic techniques

The various radiographic techniques

- Microradiography (focal spot: some µm – some kV to 100 kV)

- Classical X-ray radiography (from some kV up to 450 kV) – Various detectors : classical silver halide industrial radiographic films, storage phosphor imaging plates, solid state digital detectors, fluoroscopy…

- Gamma radiography (^{192}Ir & ^{60}Co)

- Accelerator radiography (2 MV up to 30 MV)

- Beta radiography (^{14}C) or secondary electron radiography of paper, manuscripts, drawings, prints… to underscore watermarks, paper texture & manufacturing process…

- Secondary electron radiography (as a substitute of beta radiography)

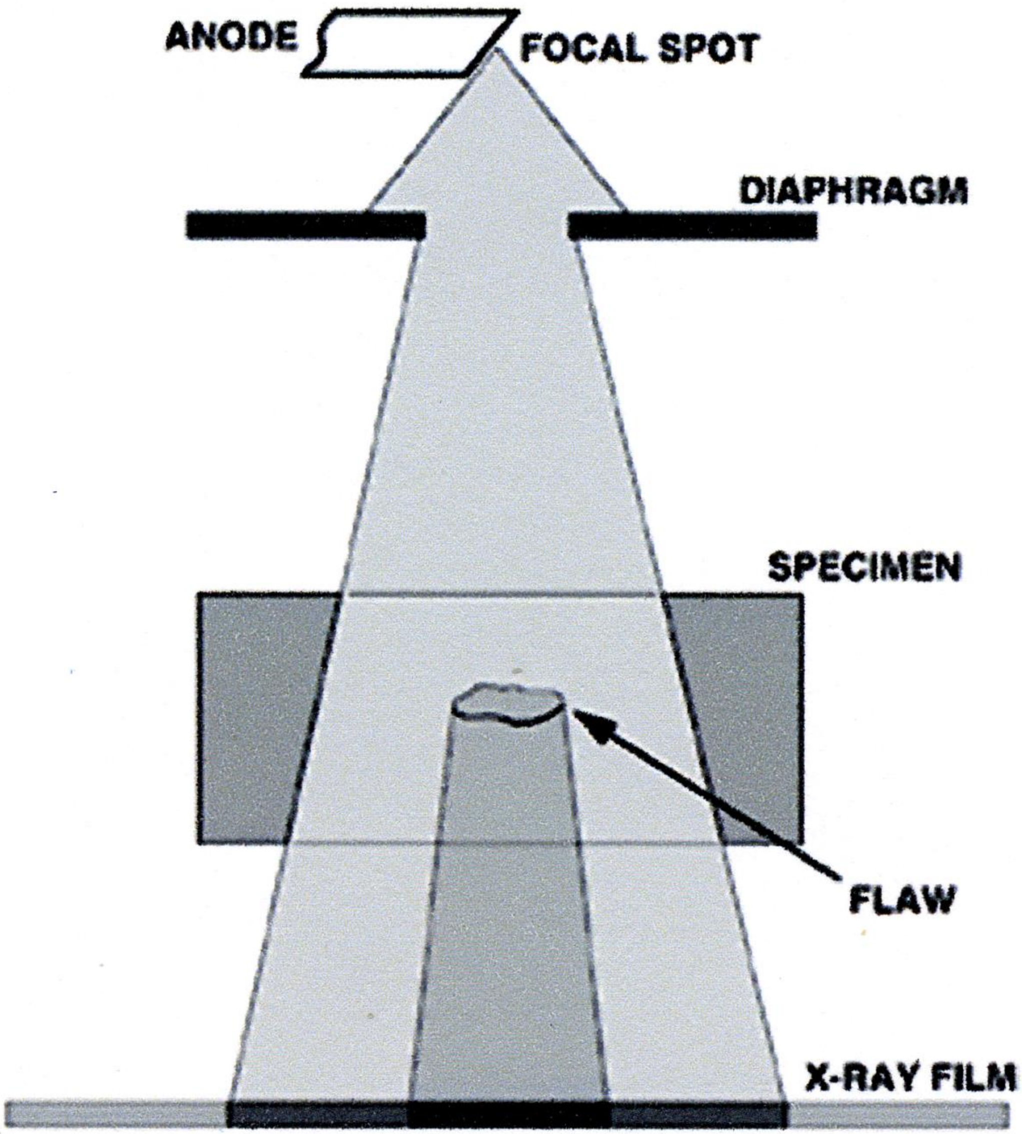
- Neutron radiography

- Electron emission radiography

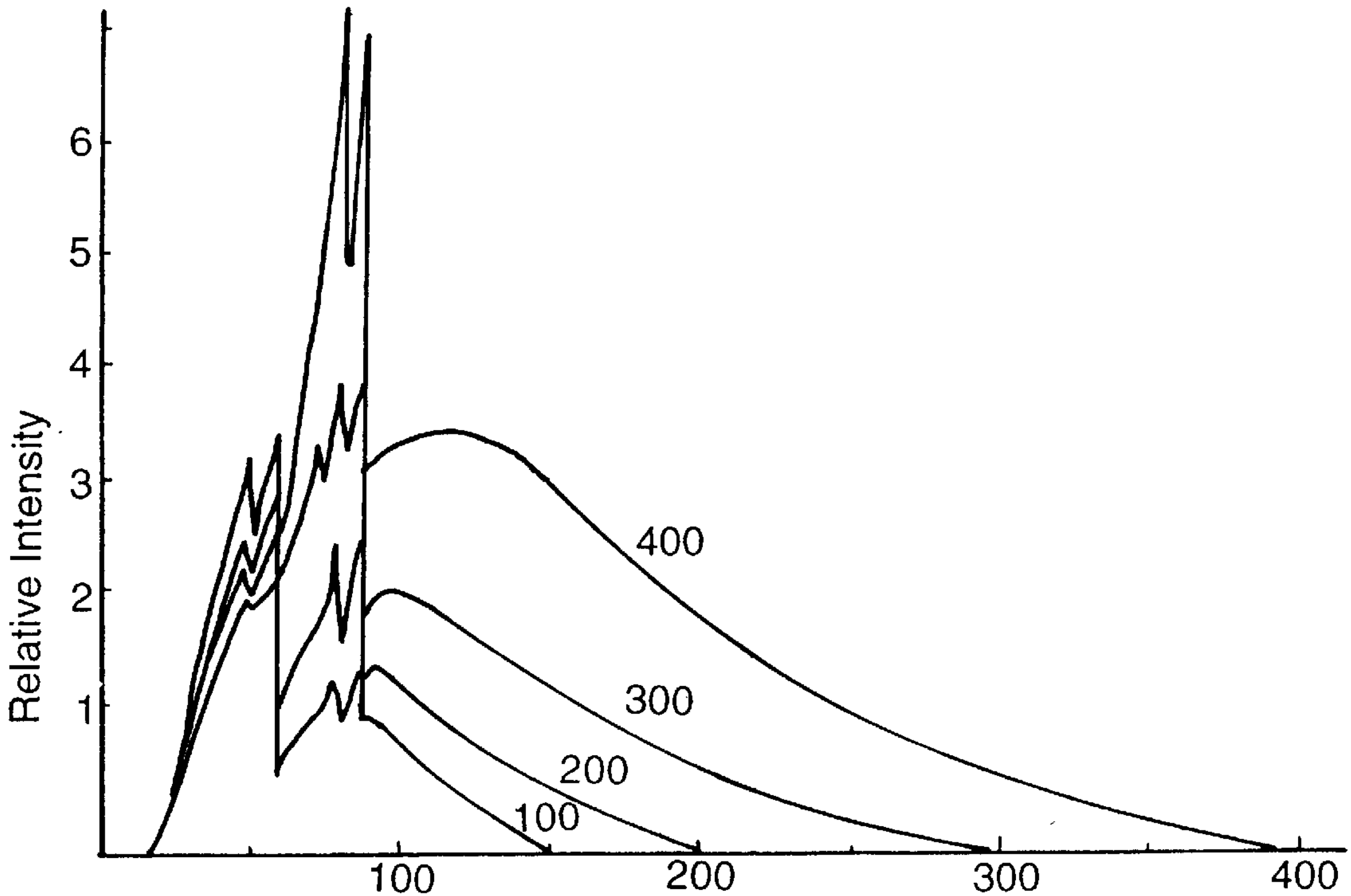
- Neutron induced autoradiography

- Computed assisted tomography

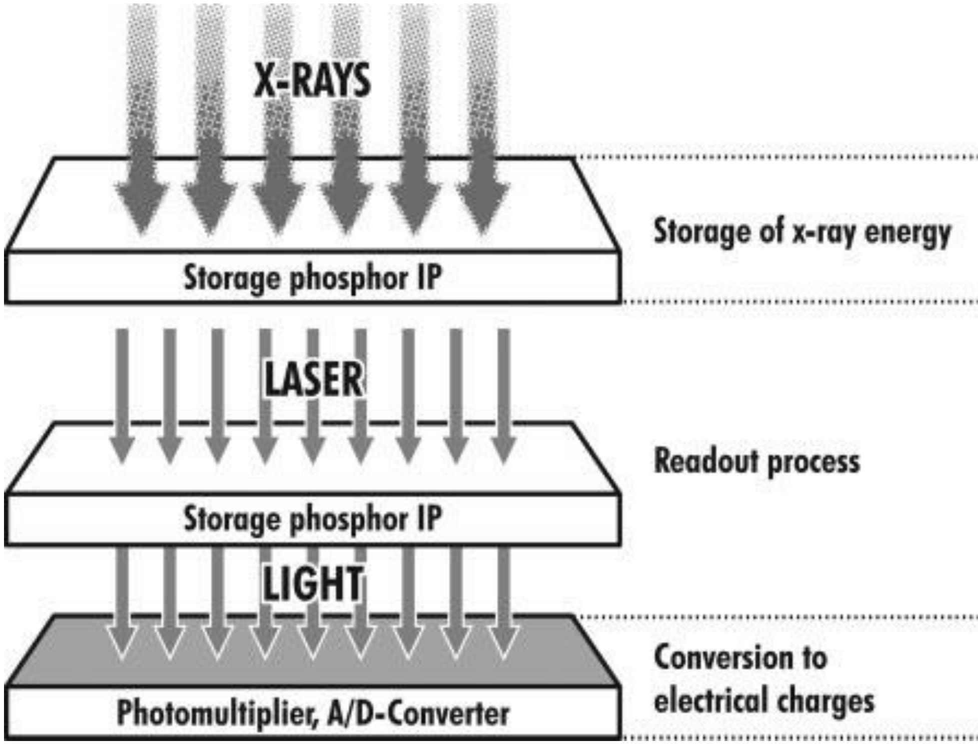
- Synchrotron radiation based radiographic or tomographic methods



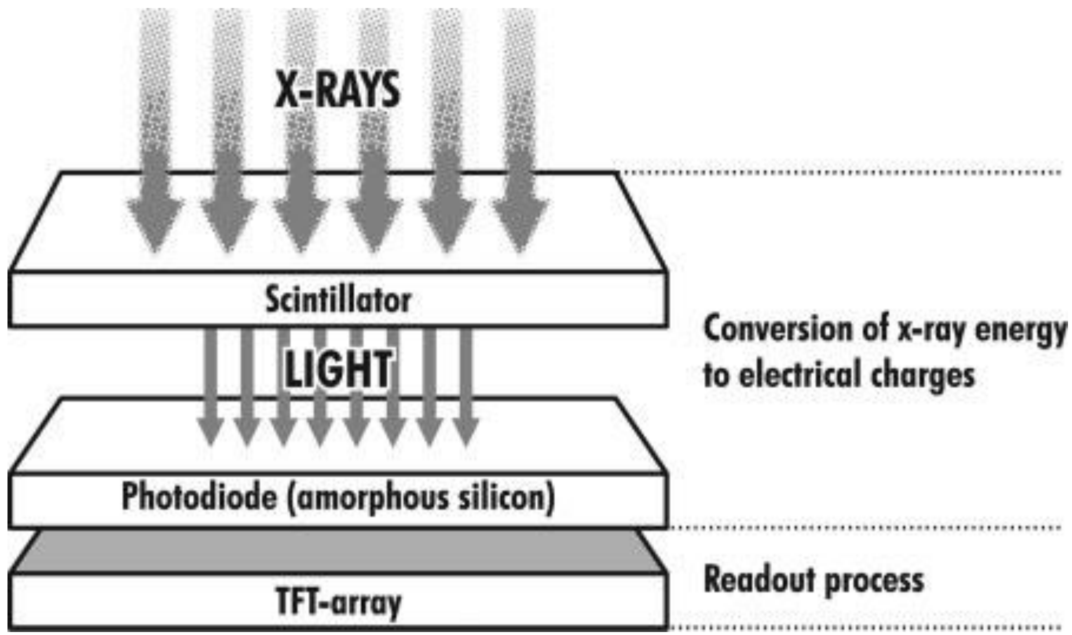
Schematic diagram of a radiographic exposure.
The darker region of the film represents the more penetrable part of the object; the lighter region, the more opaque



Experimental relative intensity vs. energy (keV) distribution for 100, 200, 300 & 400 kV X-rays generators with tungsten anticathode



Schematic drawing of a storage-phosphor imaging plate.
The image generation is separated into two steps. First, the image plate *(IP)* is exposed to the X-ray energy, part of which is stored within the detective layer of the plate. Second, the imaging plate is scanned with a laser beam, so that the stored energy is set free and light is emitted. An array of photomultipliers collects the light, which is converted into electrical charges by an analog-to-digital *(A/D)* converter



Schematic drawing of an amorphous silicon–based digital radiography detector.
The X-ray energy is converted into visible light in a scintillator layer.
The emitted light is then converted into electrical charges by an array of silicon-based photodiodes and read out by a TFT array

3 - Questions to be solved by radiography. Some examples

For certain categories of objects and/or materials, one has to solve different problems.

A - PAPER, SUPPORT OF DRAWING OR TEXT

Visualisation of the texture of the paper, of local variation of mass per unit area, of the watermarks, whatever can be the drawings or the texts, manuscript or printed, on it.
Solution: beta radiography or radiography with secondary electrons.

B – EASEL PAINTINGS

The classical structure of an easel painting is a multilayer one:
- plane support : canvas (linen, hemp, cotton), wood (panel of different species, cut according to different manners), metal (copper), stone (obsidian)
- preparation layer (chalk, gypsum (or gesso), lead white)
- animal glue
- eventually underdrawing (carbon black)
- paint layer : adjacent and/or superimposed spots of organic or mineral pigments suspended in organic media
- varnish.

One wants to put in evidence the texture of the backing and of the paint layer, the characteristic "touche" of the author, the eventual existence of an underlying painting, the pentimenti, the alterations, the restorations, the modifications of frame, the linings, the transpositions...
Solution: low energy X-ray radiography and/or electron emission radiography

C – ENAMELS

Glassy layer loaded with mineral pigments, on a metallic backing (generally copper alloy). One wants to determine contrasts in the composition in the enamel layer, its alterations…
Solution: X-ray radiography, sometimes at different energy (selective filtration), and electron emission radiography
.

D - WOOD

The goal is to visualise the characteristic texture of the wood species, the assembly techniques, the alterations (flaws, brittleness areas), the infestations, the restorations, the eventual metallic inserts…
Solution: X-ray radiography
.

E – STONE

One wants to determine the texture of the stone material, its homogeneity, the eventual cleavage planes, the eventual repairs or previous restorations and eventual metallic inserts…
Solution: high energy X-ray radiography or gamma radiography.

F – FOUNDRY (METAL)

- Determination of the internal structure of the object : hollow / fill, thickness & steadiness of the walls, homogeneity / heterogeneity of the constitutive materials, presence of structural defects (porosities, shrink holes, inclusions, cracks, slag, bubbles, voids, delaminations, corroded or altered zones…)
- assembling features, nails, screws, welding, brazing, armatures, core pins…
- repairs : inserts, secondary casting, screws…
- presence of eventual previous restorations.

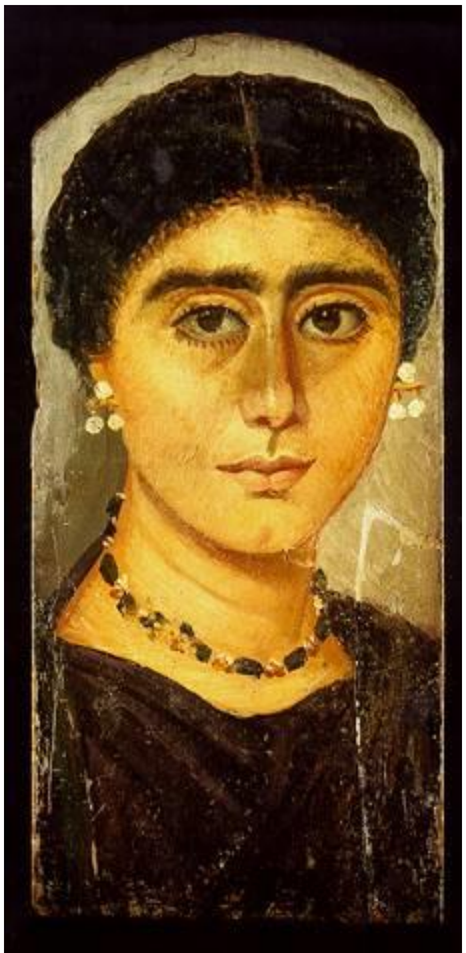
Solution: high energy X-ray radiography, gamma radiography or radiography with an accelerator.

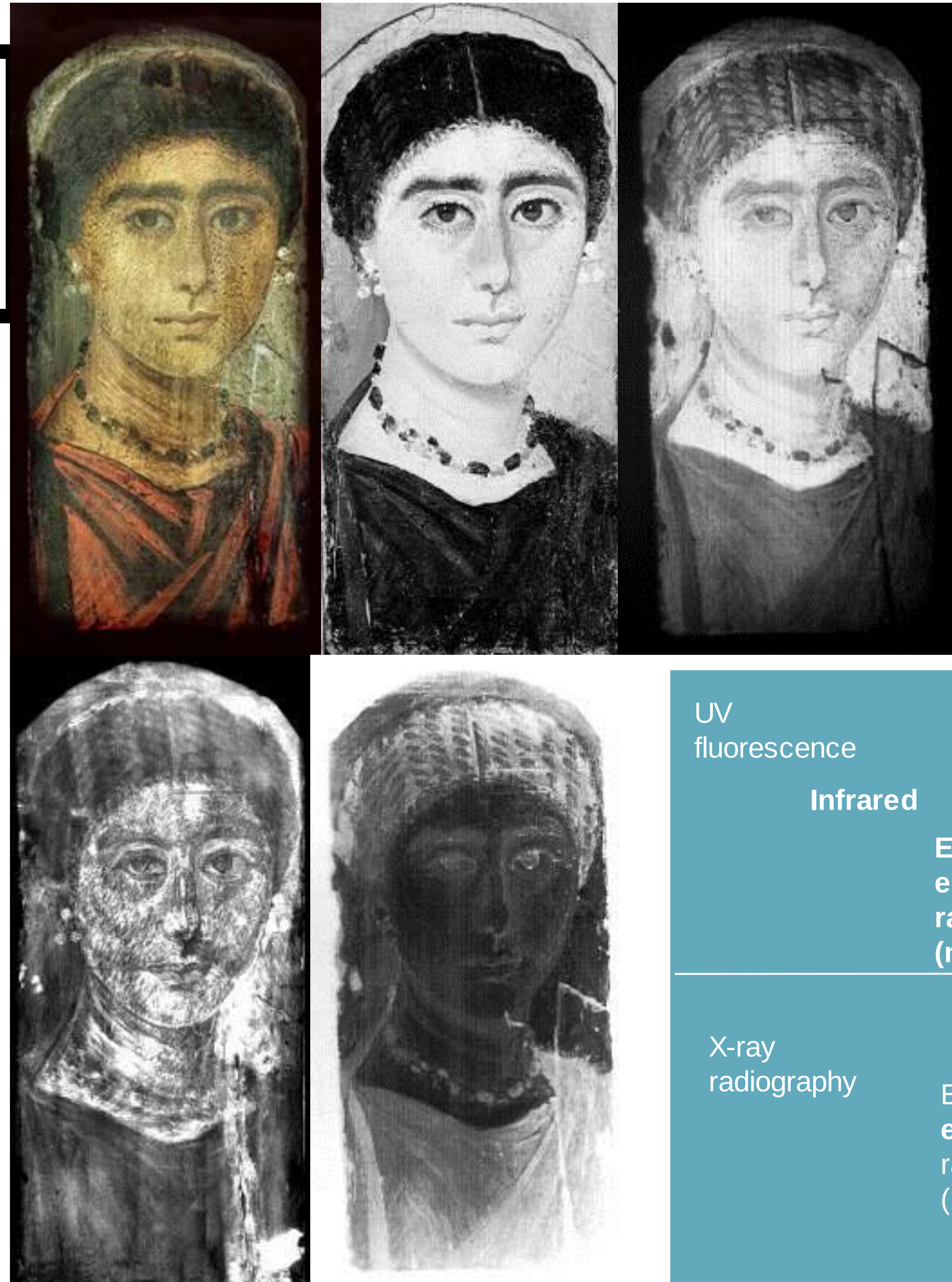
FOR ANY TYPE OF ARTEFACTS AND/OR ANY MATERIALS

This may also give pertinent information regarding the conservation state & arguments for eventual consolidation and / restoration procedures.

4 - Some examples of classical X-ray radiography taken among various collections : easel paintings, manuscripts, bronze statues, stones statues, cult objects, archaeological objects, industrial heritage…

Complete set of examination of a wax painting – Ptolemaic Egypt (320 – 30 BC) - Louvre Museum (C2RMF)





UV fluorescence

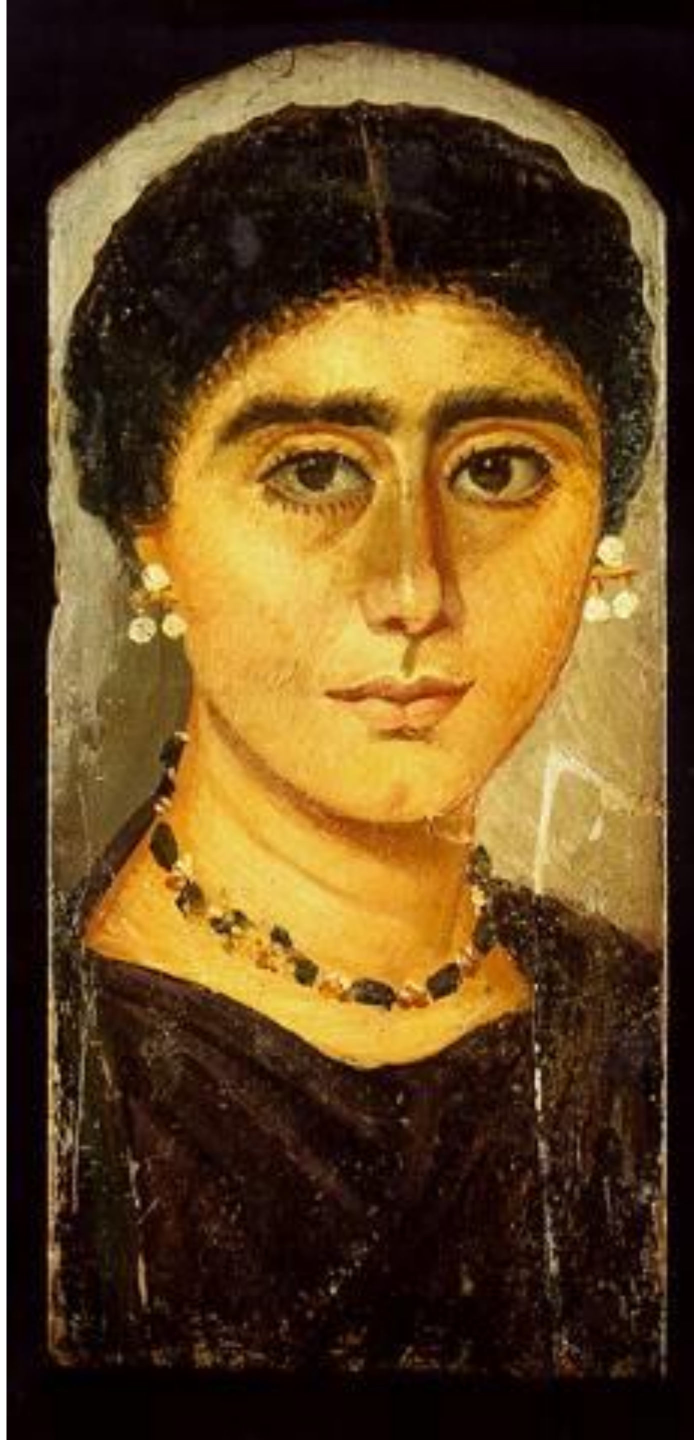
Infrared

Electron emission radiography (negative)

X-ray radiography

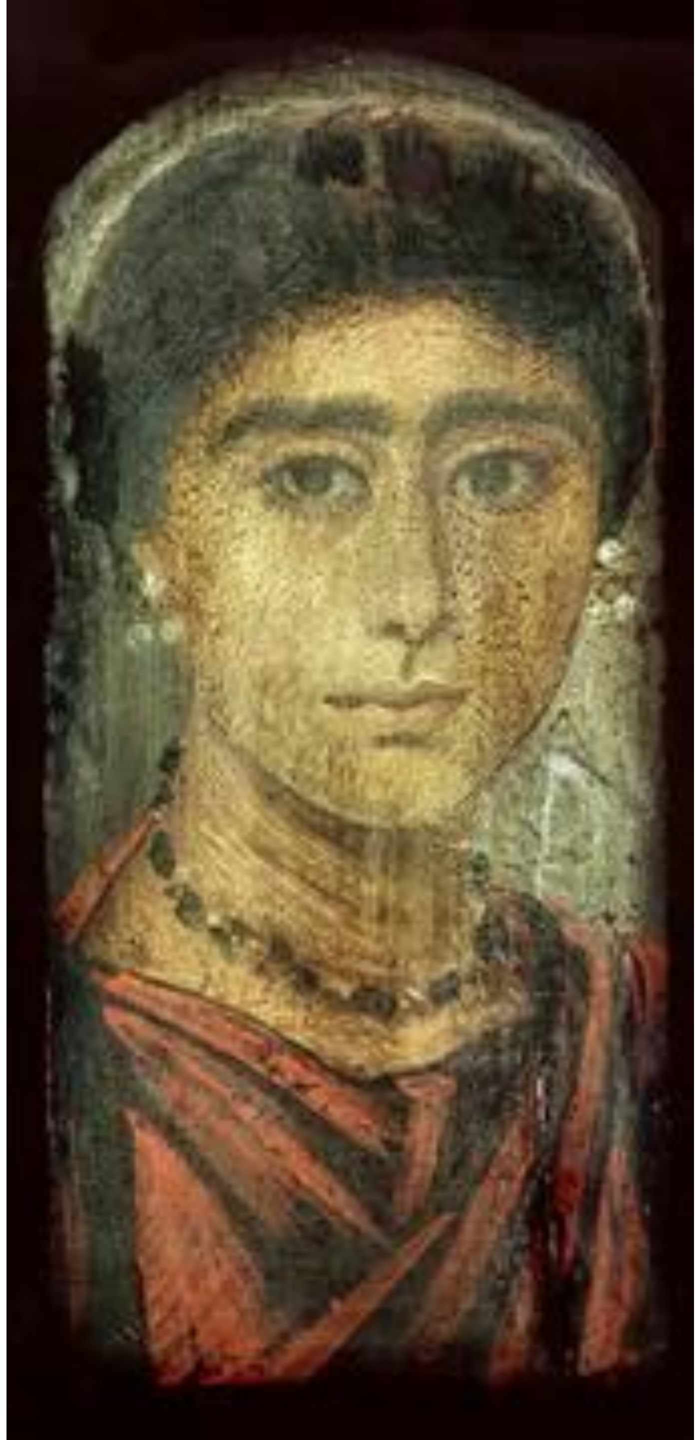
Electron **emission** radiography (regular)

Colour, visible light



Infrared

False colour,
ultraviolet
fluorescence



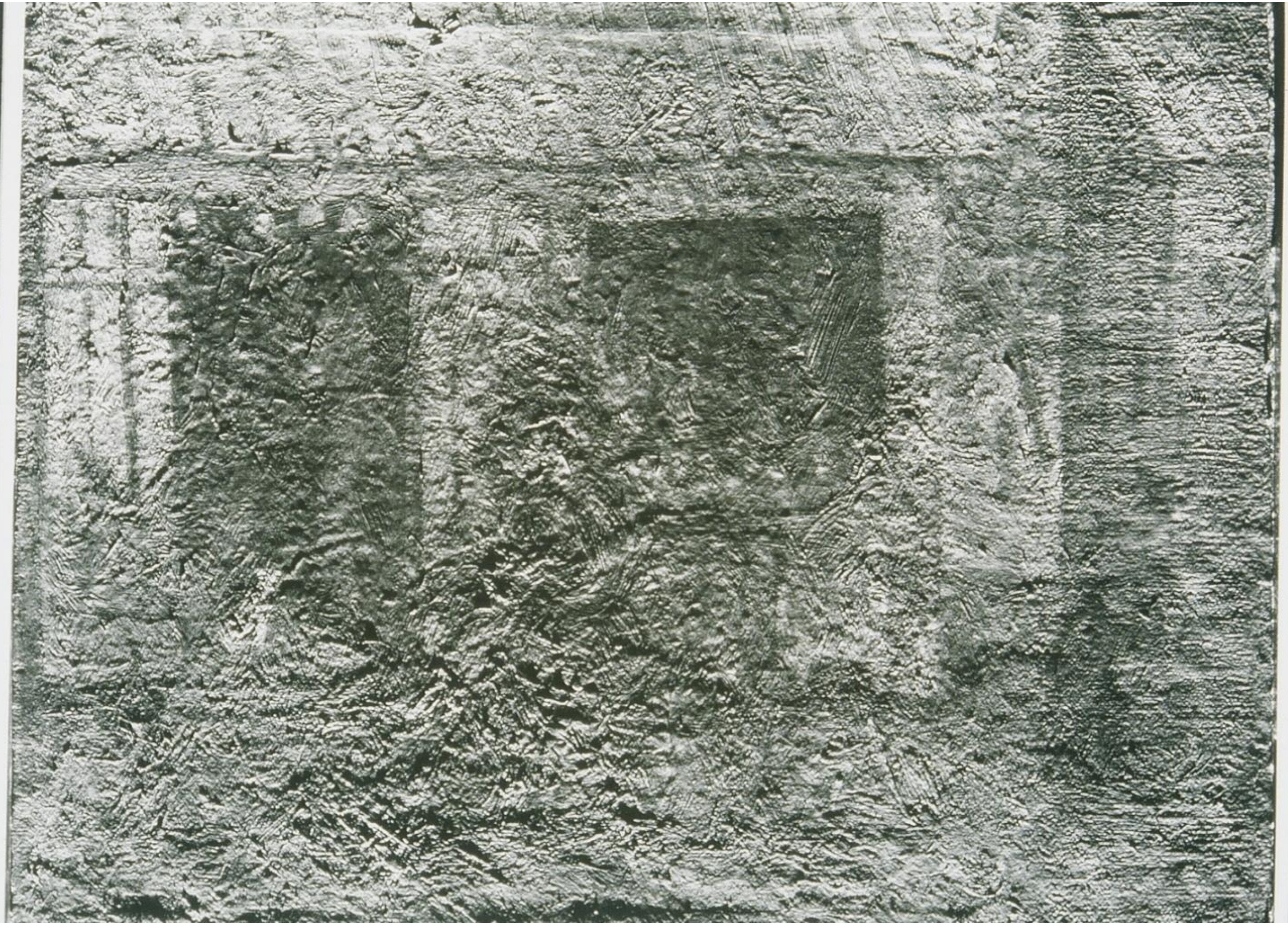
X-ray radiography

Electron emission radiography, left positive, right negative

La Belle Ferronnière, Léonard de Vinci, Musée du Louvre

Mikhail Larionov, *Small Jewish shop at the Vitebsk market*, Centre Georges Pompidou (Paris), colour visible light photography, colour ultraviolet fluorescence, raking light photography, X-ray radiography (C2RMF)

NB: one of the first example of the use of agglomerate wood panel as a substrate for easel painting



***Jupiter* from Vieil-Evreux,** bronze sculpture, H = 92 cm, Gallo-Roman, sanctuary of Vieil-Evreux, 2nd half of 1st Cent. AD, lead bronze (primary castings: [Sn] = 5,3 %, [Pb] = 20,8 % / secondary castings: [Sn] = 4,1 %, [Pb] = 17,7 %) + inlays (silver for the eyes, non alloyed copper for the lips & the teats), Evreux Museum

The radiograph discloses the join between the head & the trunk. It is constituted of a welding bead punctuated by a sequence of basins shaping a necklace.

***APOXYOMENOS*, bronze statue, 2nd-1st Cent. BC- Losinj (Croatia), copy of an original Greek marble statue (4th Cent. BC). Found in 1996 in the Adriatic Sea.**
Restored by the Croatian Institute of Restoration (HRZHR) – Zagreb –
Radiography E. Lambert (C2RMF) at the occasion of the Louvre Museum exhibit (2012)

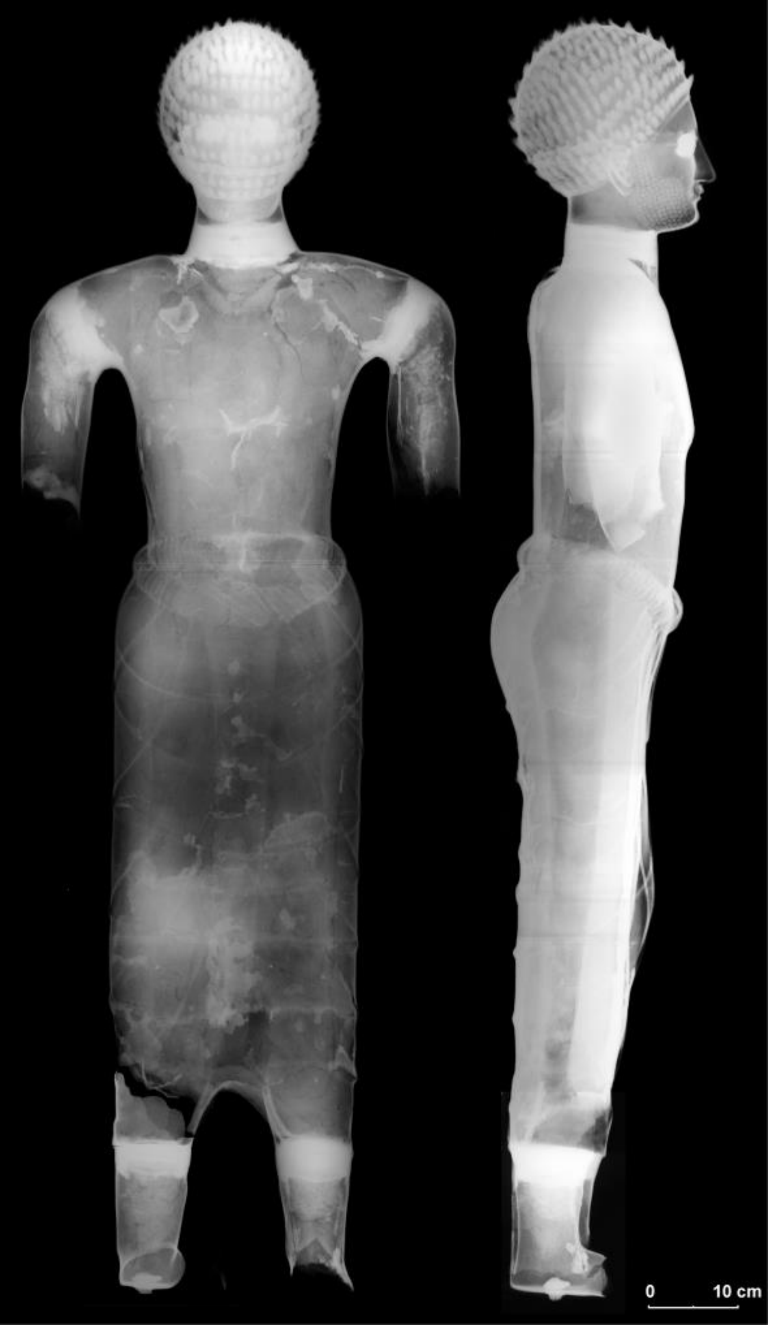


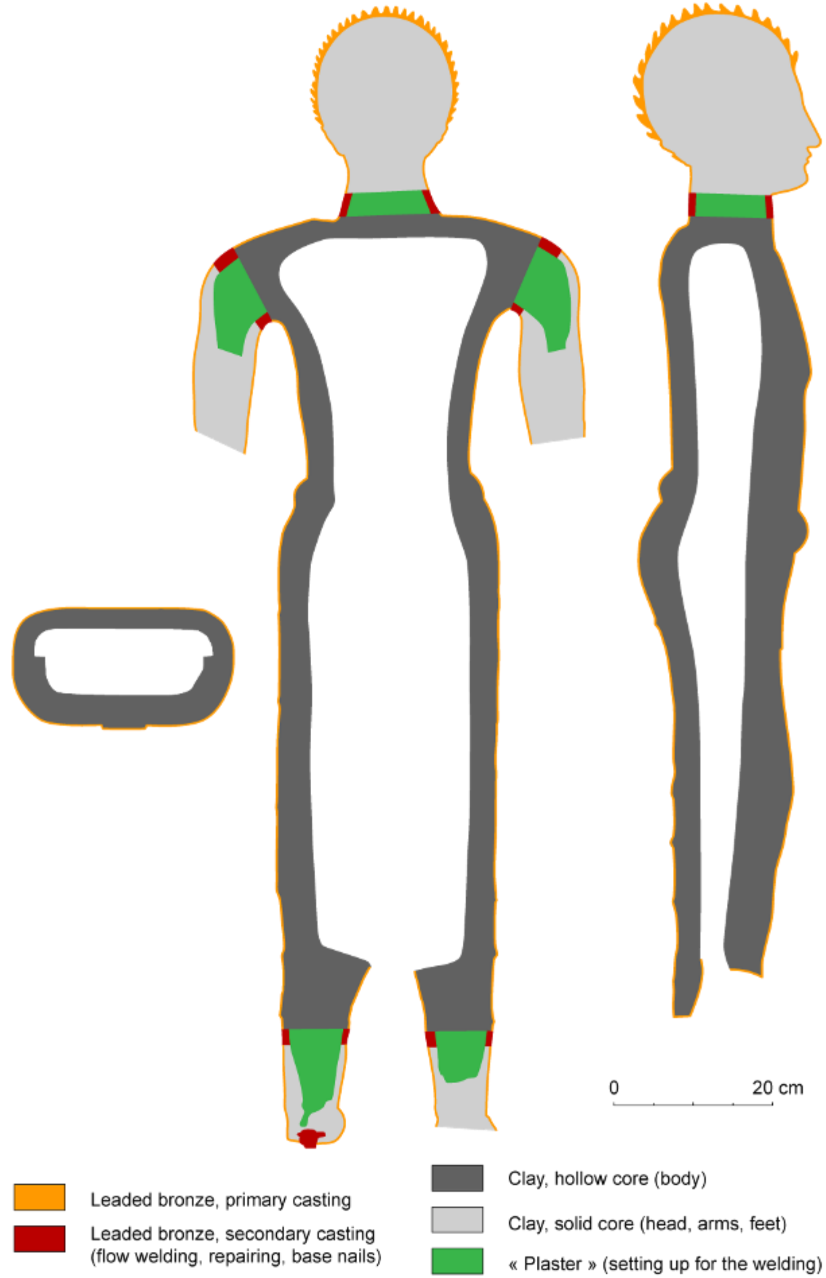
Dimension H = 192 cm

X-ray radiography 420 kV
High definition radiographic film
+ copper filtration
+ lead anti backscattering
protection

58 exposures
DSD = 3 m

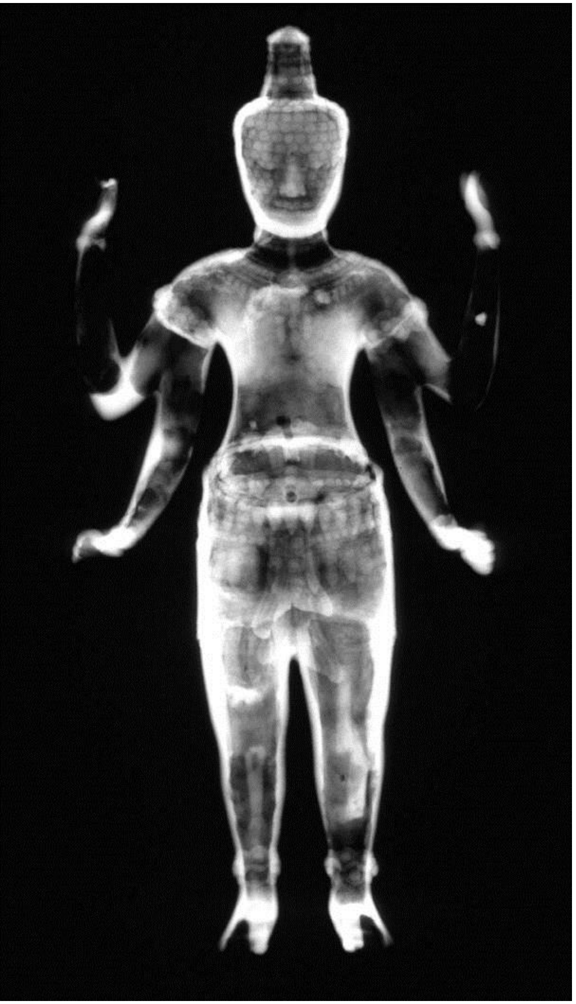
***Hawtar'athat*,** bronze sculpture, H = 140 cm, South Arabian period, Nashqum (presently Al-Bayda), Yemen, end of VIIth-VIth Cent. BC, lead bronze (primary castings: [Sn] = 6 to 12 %, [Pb] = 7 to 17 % / secondary castings : [Sn] = 7 % , [Pb] = 12 %) + lead (eyes), Sanaa National Museum

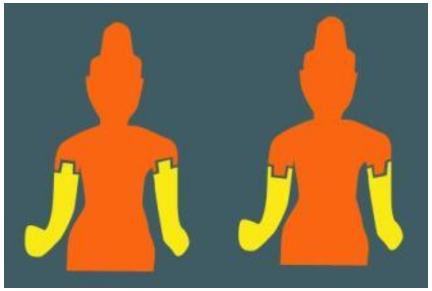

0
10 cm


0
20 cm
Leaded bronze, primary casting
Leaded bronze, secondary casting
(flow welding, repairing, base nails)
Clay, hollow core (body)
Clay, solid core (head, arms, feet)
« Plaster » (setting up for the welding)

Joining techniques - large variety

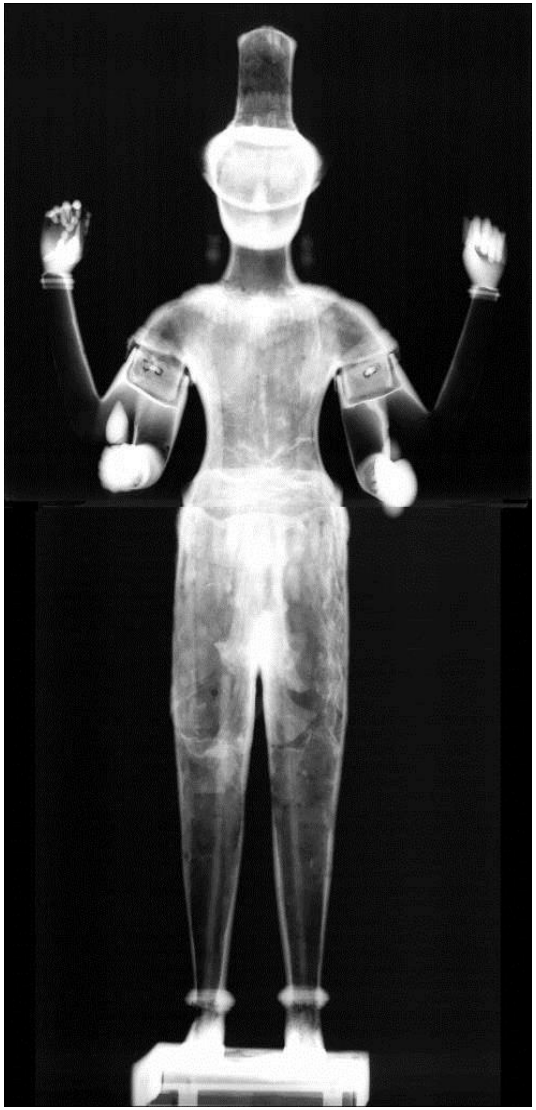
Examples: Khmer techniques – Musée Guimet (Paris)



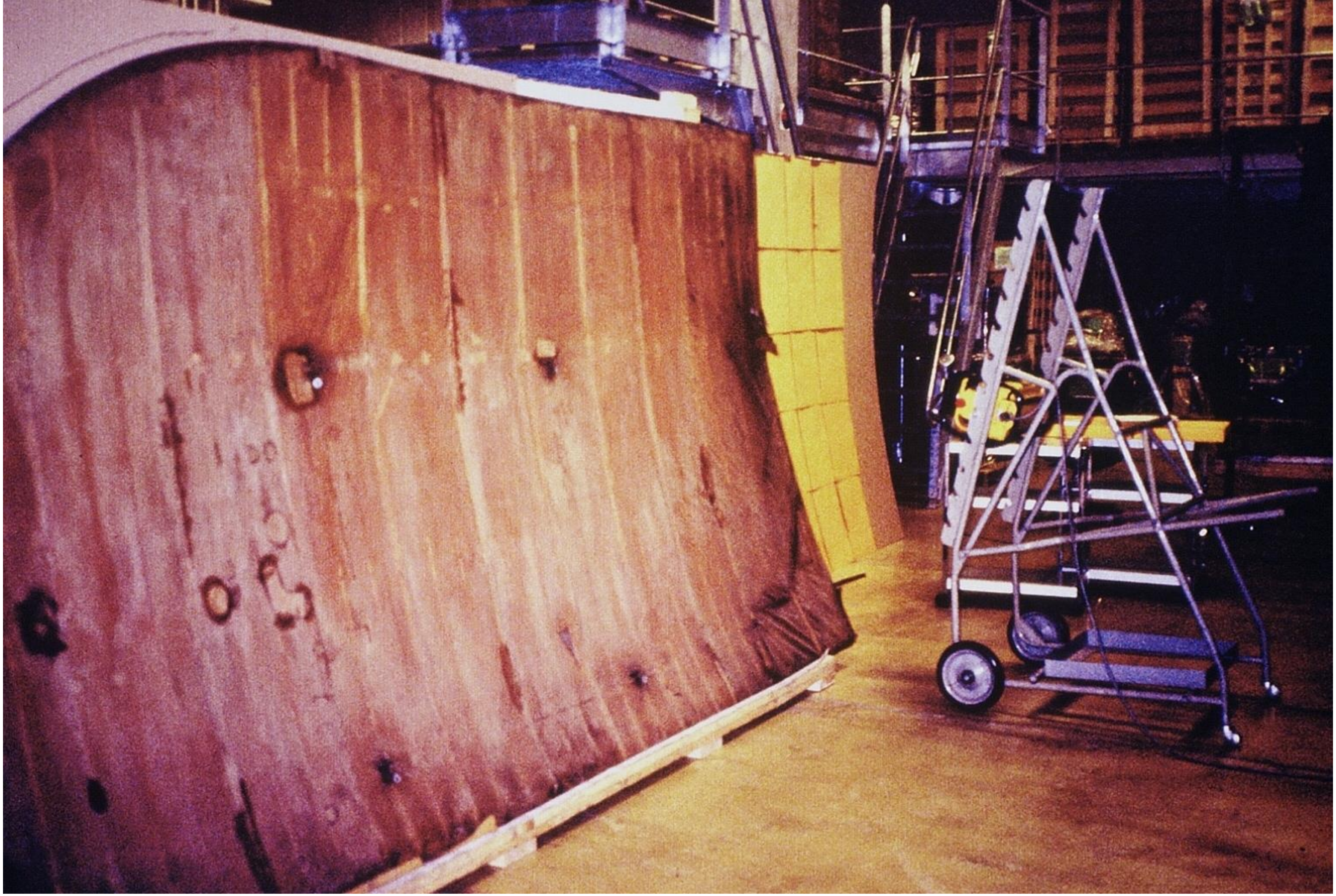


Lokesvara, Bayon, 42 cm

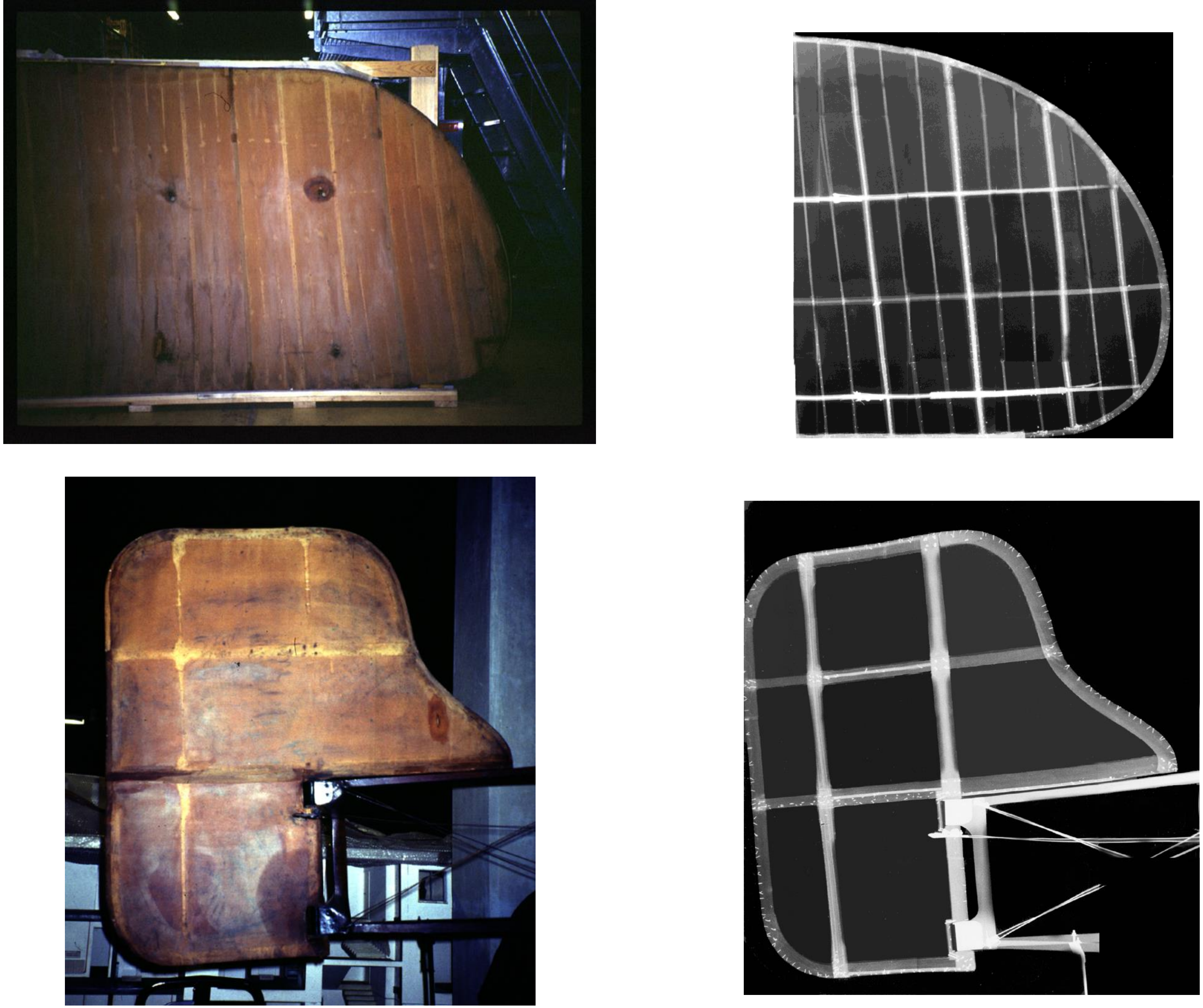
Ganesa, Bayon, 26 cm



Male Divinity, Angkor Vat, 63 cm

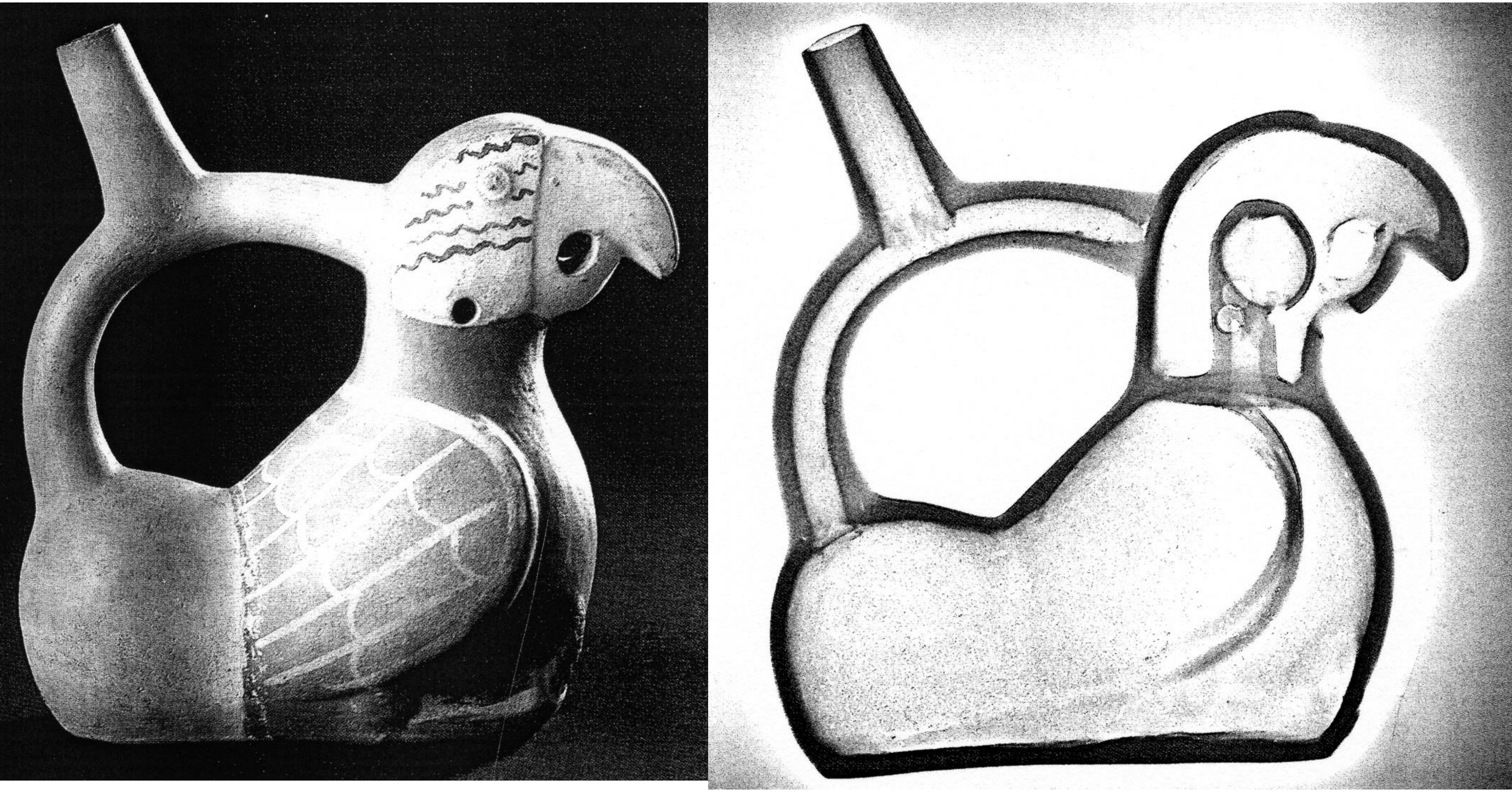


X-ray radiography (before restoration) of the Blériot XI which made the first flight across the Channel in 1909 Musée des Arts & Métiers - Paris



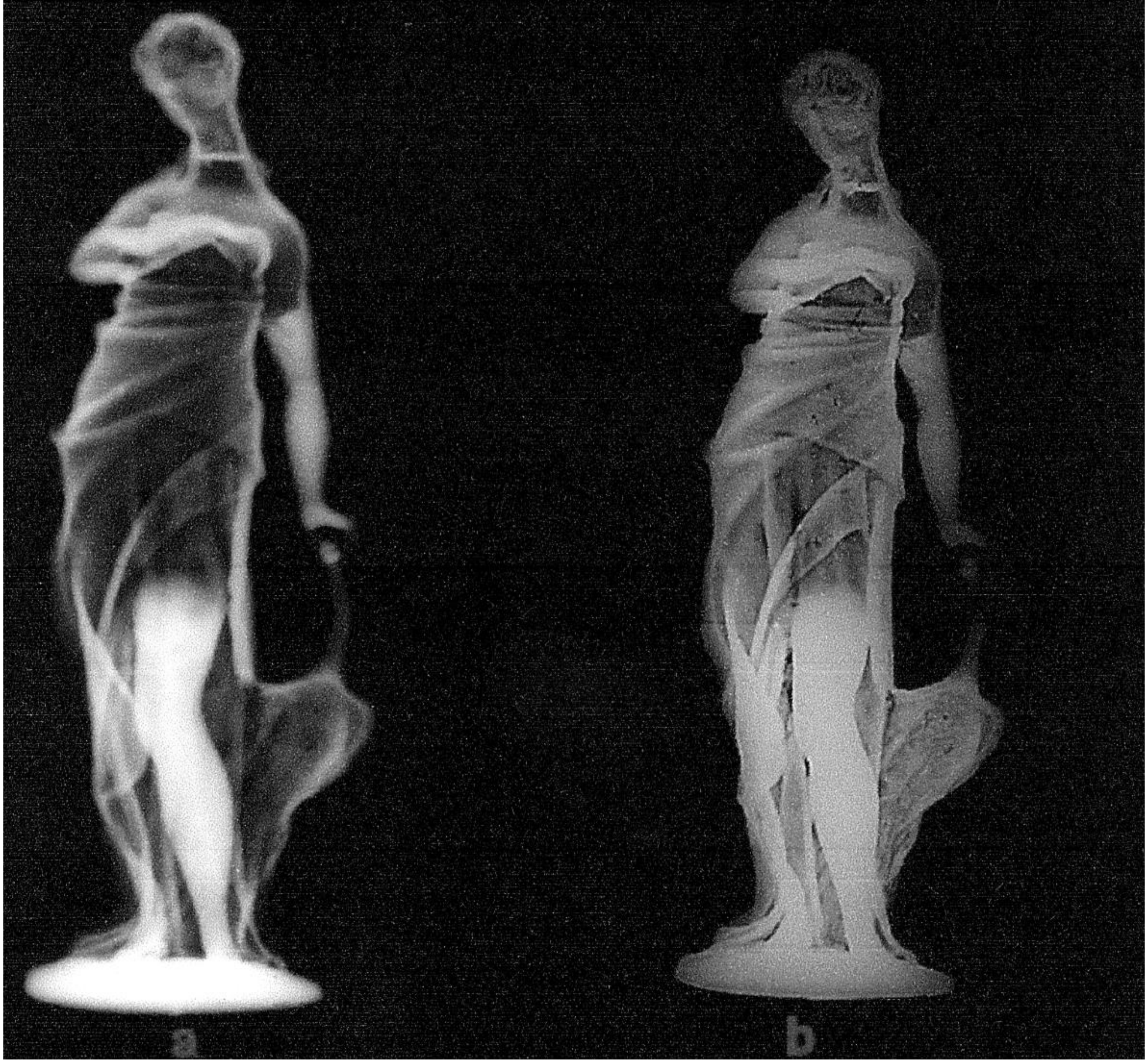
X-ray radiography of the wing & the fin of the Blériot XI
T. Borel (C2RMF)

Radiography with other detectors than films



Moche style whistling ceramic pot in the form of a parrot, Northern Peru, between 100 BC & AD 700, British Museum London. Xeroradiograph revealing details of construction, including the hollow whistling mechanism located within the head of the bird

Example of radiography with imaging plate: *Satyr with Urn* (Walters Art Museum, Baltimore - MD). Italian sculpture, 16th century. Photography & radiography with imaging plate GE-CR50P. The X-ray image reveals wax drippings and circular metal plugs

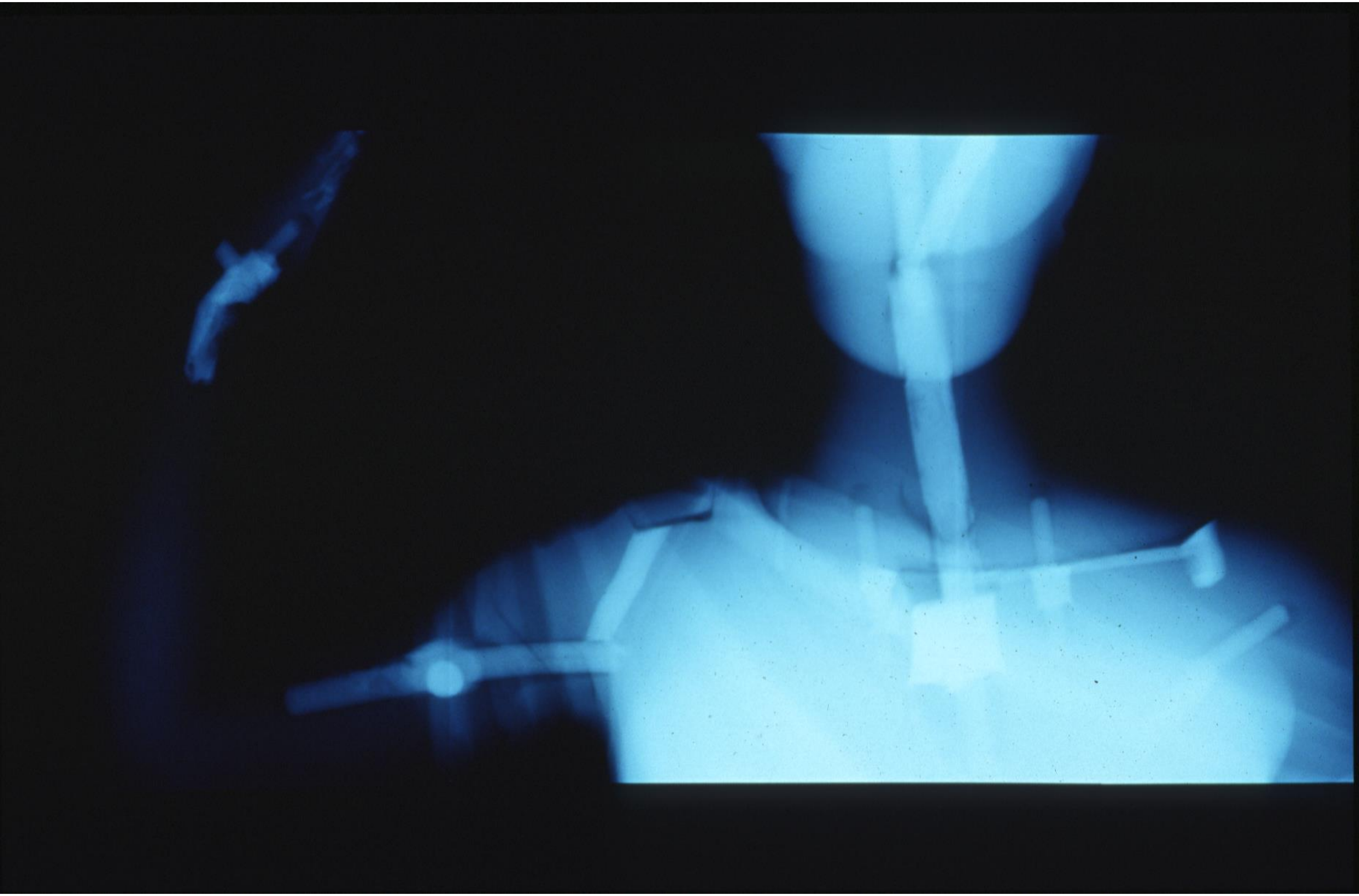


Example of radiography of a bronze statue (Metropolitan Museum New-York) with (a) film – 320 kV, (b) with a-Si Vidisco digital detector, 230 kV

Some examples of gamma radiography

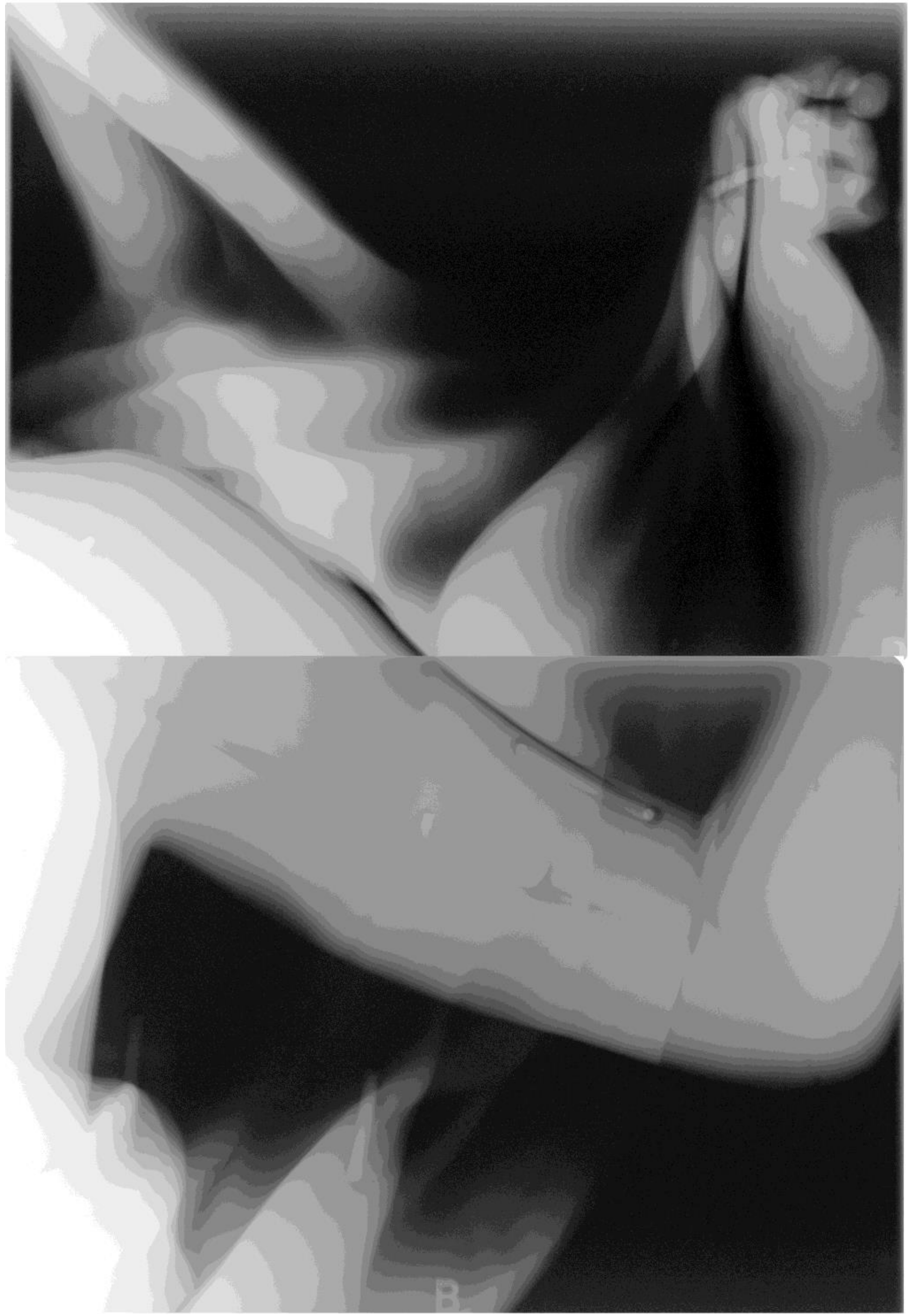
Gamma radiography (iridium 192 - Kodak Définix film) of the *Gold mask of Toutankhamon*, at the occasion of the exhibition «Toutankhamon et son temps» - Petit Palais Paris (1967) - © SGS - Qualitest

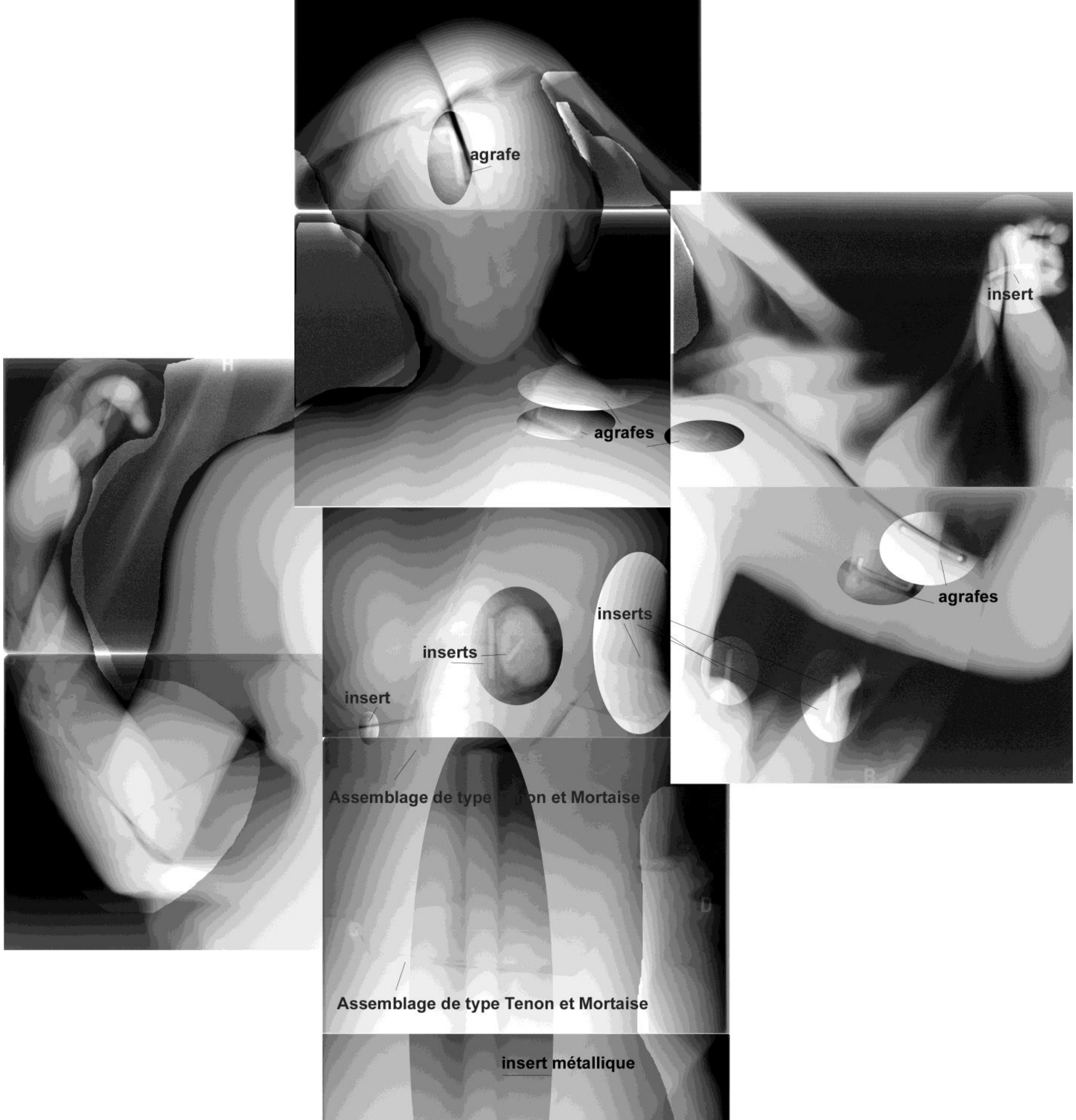
***Venus Genitrix* (*or Aphrodite)* – Roman marble replica (1st Century AD) of a bronze Greek original (5th Century BC) - Louvre Museum**
Examination before restoration
B. Bourgeois (C2RMF – Versailles),
B. Rattoni (CEA – Saclay)
& D. Bagault (C2RMF – Paris)



Gamma radiograph showing previous metallic restoration armatures

“*La Nature se dévoilant à la Science”*
(Nature unveiling herself in front of Science) (1899), by Louis Ernest Barrias (1841 – 1905), Orsay Museum, Paris
Marbre & polychrome Algerian onyx, grey granite terrasse, malachite scarab, lapis-lazzuli ribbon (H. 200 ; L. 85 ; P. 55 cm) - Examination before restoration - Gamma radiography using cobalt 60
(1,3 MeV) - Collaboration C2RMF Versailles & CEA - Saclay (2003)


B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insert
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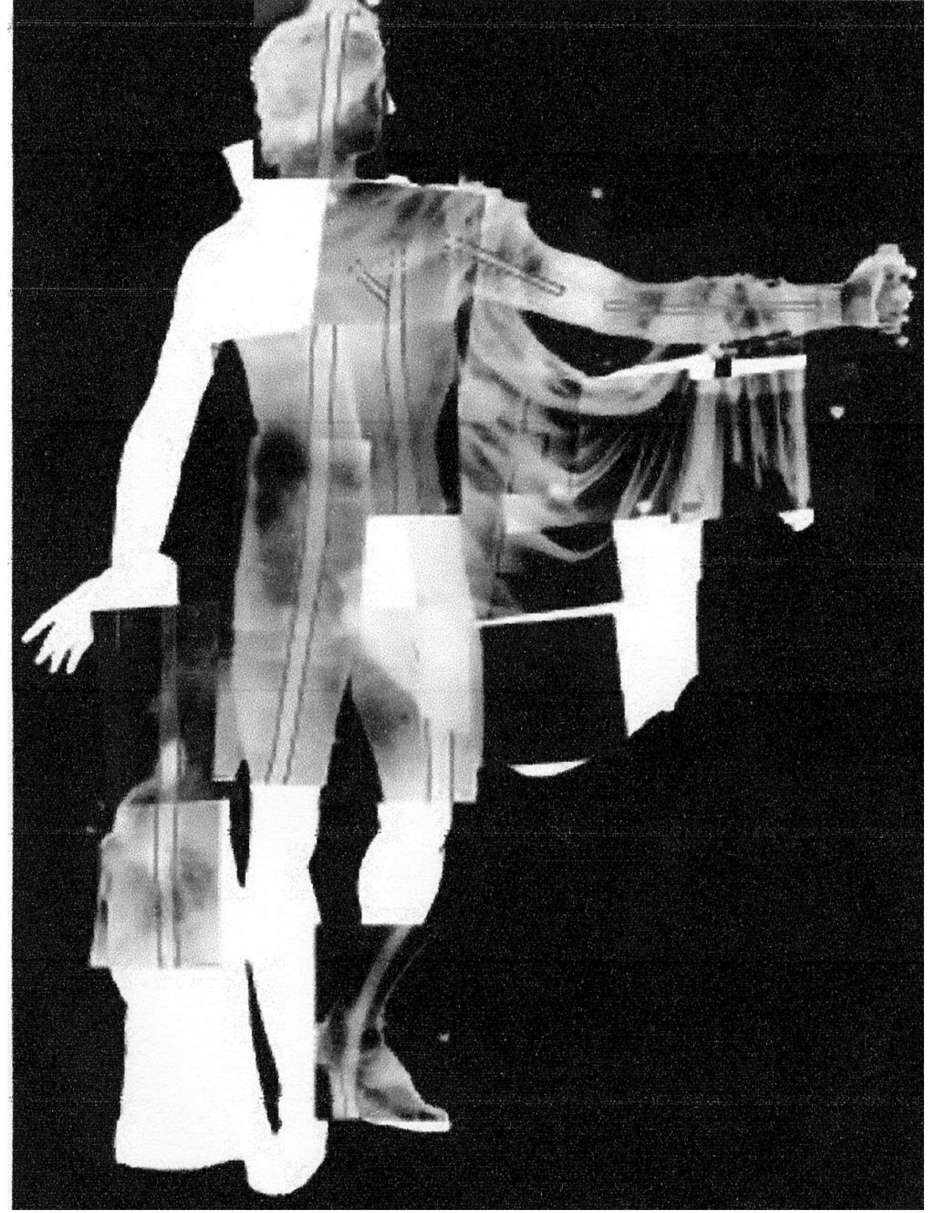
Assemblage de type Tenon et Mortaise
Assemblage de type Tenon et Mortaise
insert métallique

One example of radiography with an accelerator

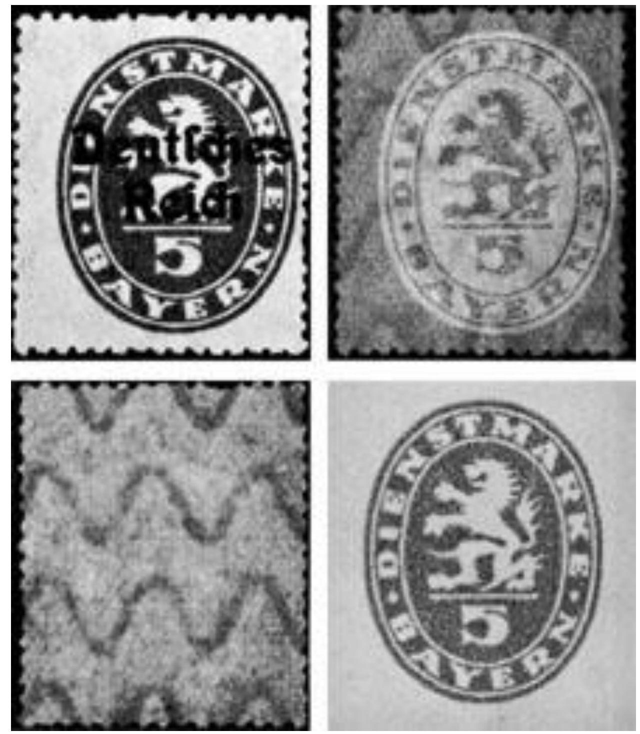


***Apollon du Belvédère*, copy of the Primatice original by Keller (1695), h = 215 cm**
Château de Fontainebleau
Radiograph with a MINAC 6 MV accelerator (© EDF-Valectra)

Beta radiography & secondary electron radiography

A B

C D



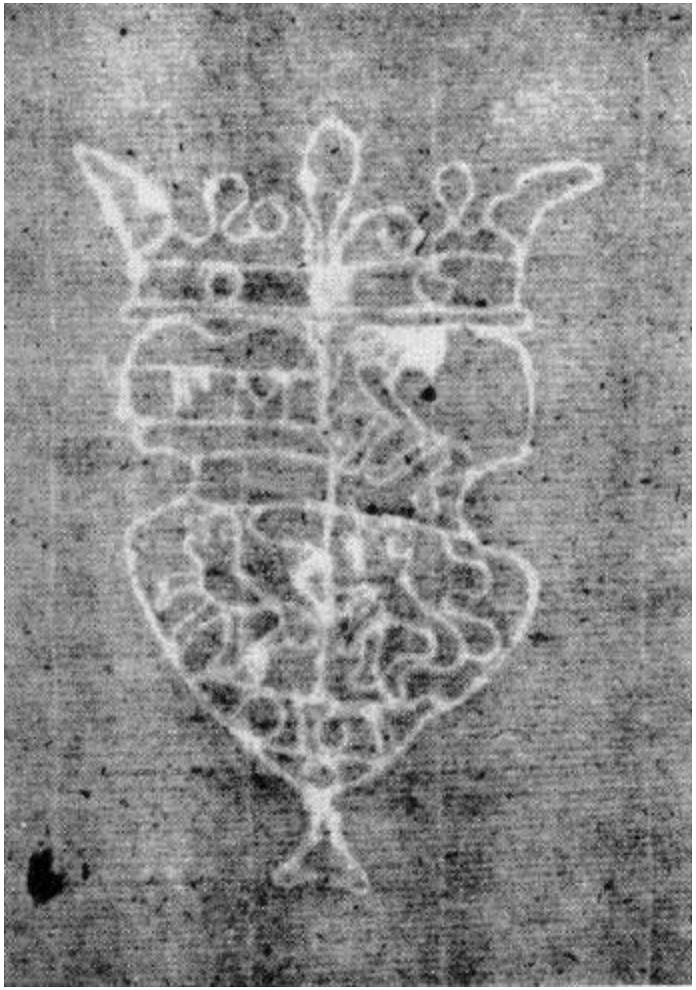
The three techniques: soft X-ray radiography, secondary electron radiography & electron-emission radiography can be compared using a postage stamp as a specimen (Bavarian stamp of 1920)

A - Photograph. The design is green and the "Deutsches Reich" overprint is black.

B - Soft X--ray radiograph. Details of both design and paper are visible. Design is "negative," indicating absorption of the X-rays by the mineral ink.

C – Secondary electron radiograph. Only the details of the paper structure including the “wavy line” watermarks are shown.

D - Electron emission radiograph. The design is "positive" indicating that the green ink has a high electron emission and hence that it contains some heavy elements which has a relatively high electron emission. The overprint (an organic black ink) cannot be seen.



Examples of beta radiographs of manuscripts showing various watermarks using a plane sheet source of ^{14}C radiolabelled plastics (poly-methylmethacrylate).
(E_{β} max = 156 keV ; T = 5730 y) & a fast monolayer film.
This permits to accurately determine the paper structure and specially its watermark.

Watermarks of British stamps from Queen Victoria to Queen Elizabeth II
Photography & beta radiography – A. Lemonnier (CEA – Saclay)

Filippo Baldinucci (1625 -1696)
Portrait of a man

Beta radiography of a XVIIth C. Italian drawing of the Louvre Museum collection
A. de la Chapelle, A. Le Prat

Autres exemples de filigrane et de leur bêtaradiographie

Other examples of watermarks and their beta radiographs.

Altri esempi di filigrane dell grafie corrispondenti

Malgré une apparente lisibilité, certains détails disp sent sous le graphisme à la sanguine ou à la pierre du dessin.

In spite of an apparent legibility, certain details c pear beneath the graphism of the red chalk (sang or black chalk of the drawing.

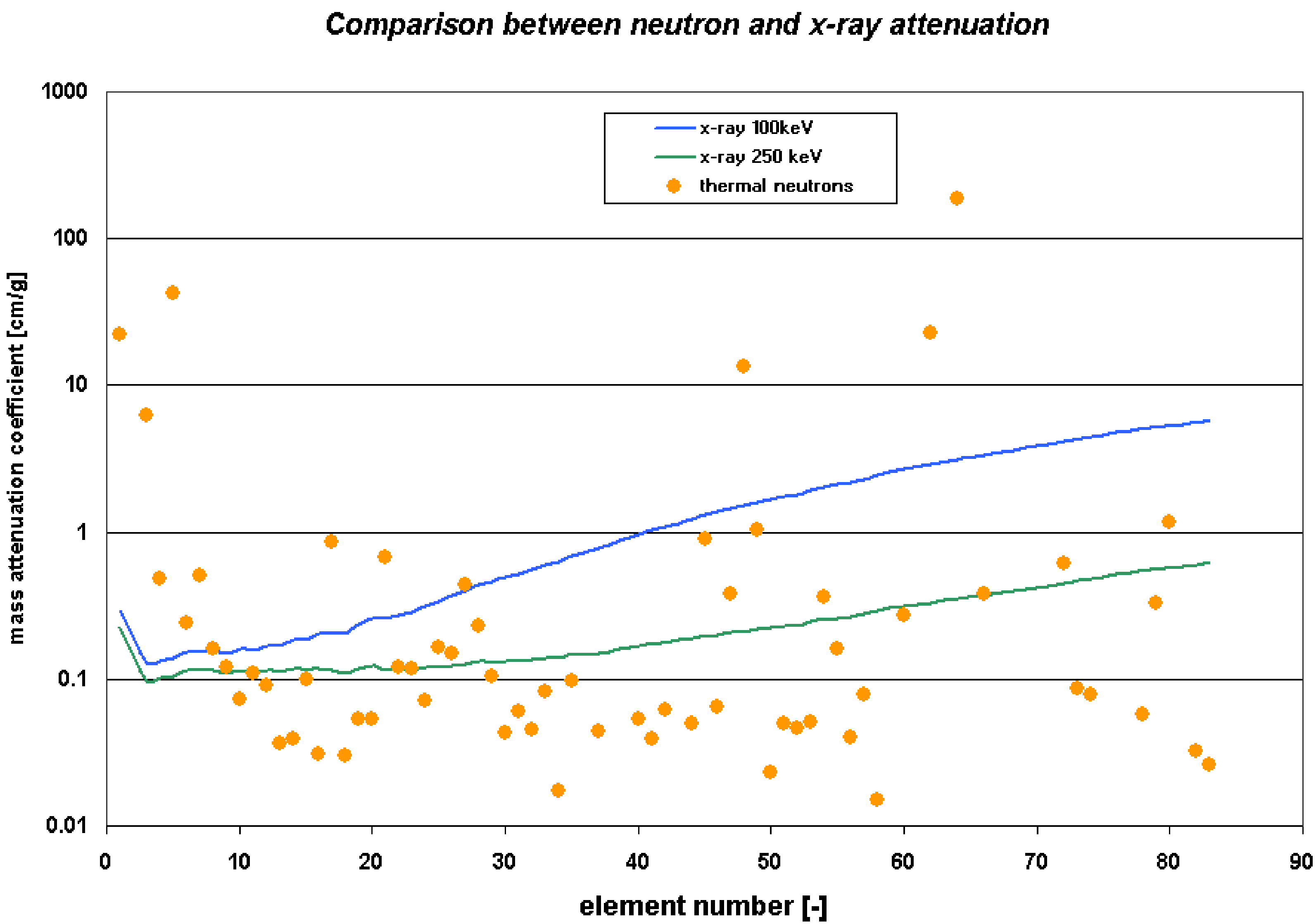
Nonostante un'apparente leggibilità, alcuni dettagli paiono sotto il segno grafico del disegno, tracciato tita rossa o nera.

Le contour précis de ce filigrane élaboré, parfaitement maîtrisé, est rendu dans ses moindres détails, y compris les points d'attache des clefs et de la fleur de lys.

The precise contour of this elaborate watermark, perfectly mastered, is rendered in its smallest details, including the attachments of the keys and of the fleur-de-lis.

Il contorno netto di questa filigrana elaborata, tracciato con assoluta precisione, è trascritto nei suoi minimi dettagli, comprese le attaccature delle chiavi e del fiore di giglio.

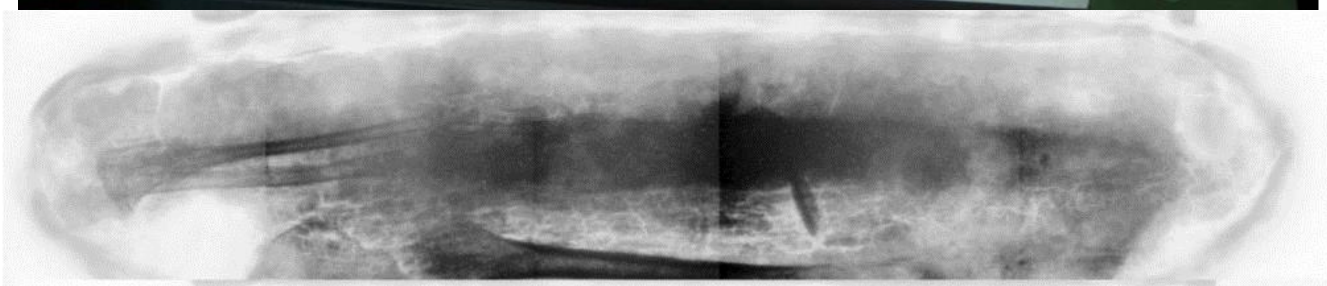
Neutron radiography



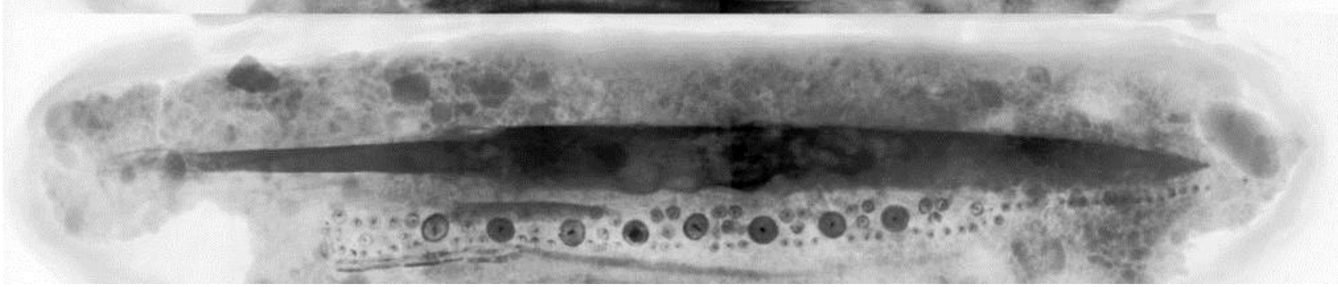
Variation of mass attenuation coefficients for X-rays (100 & 250 keV) & thermal neutrons vs atomic number

1

2



3

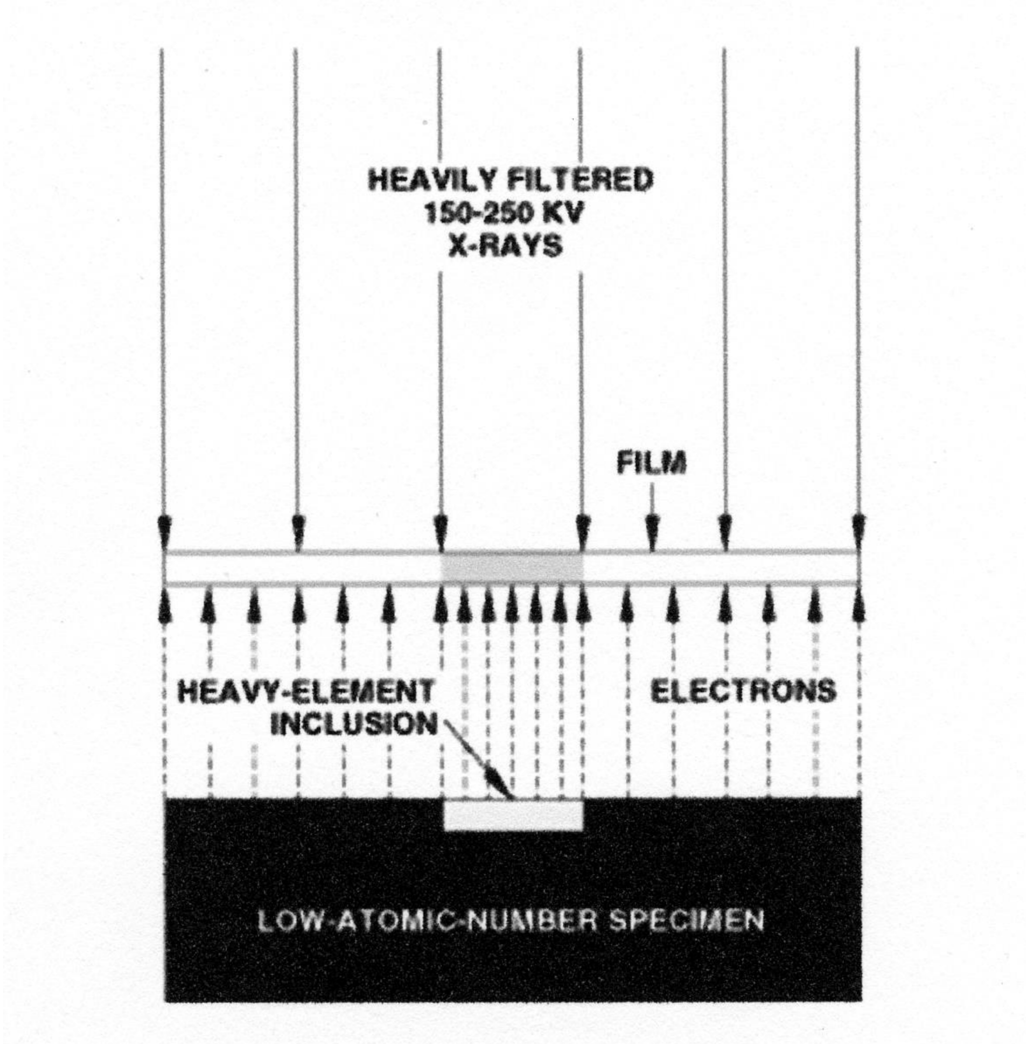


1 - **Block excavation done in Kanton Zug (CH) prepared for radiographic examination.**

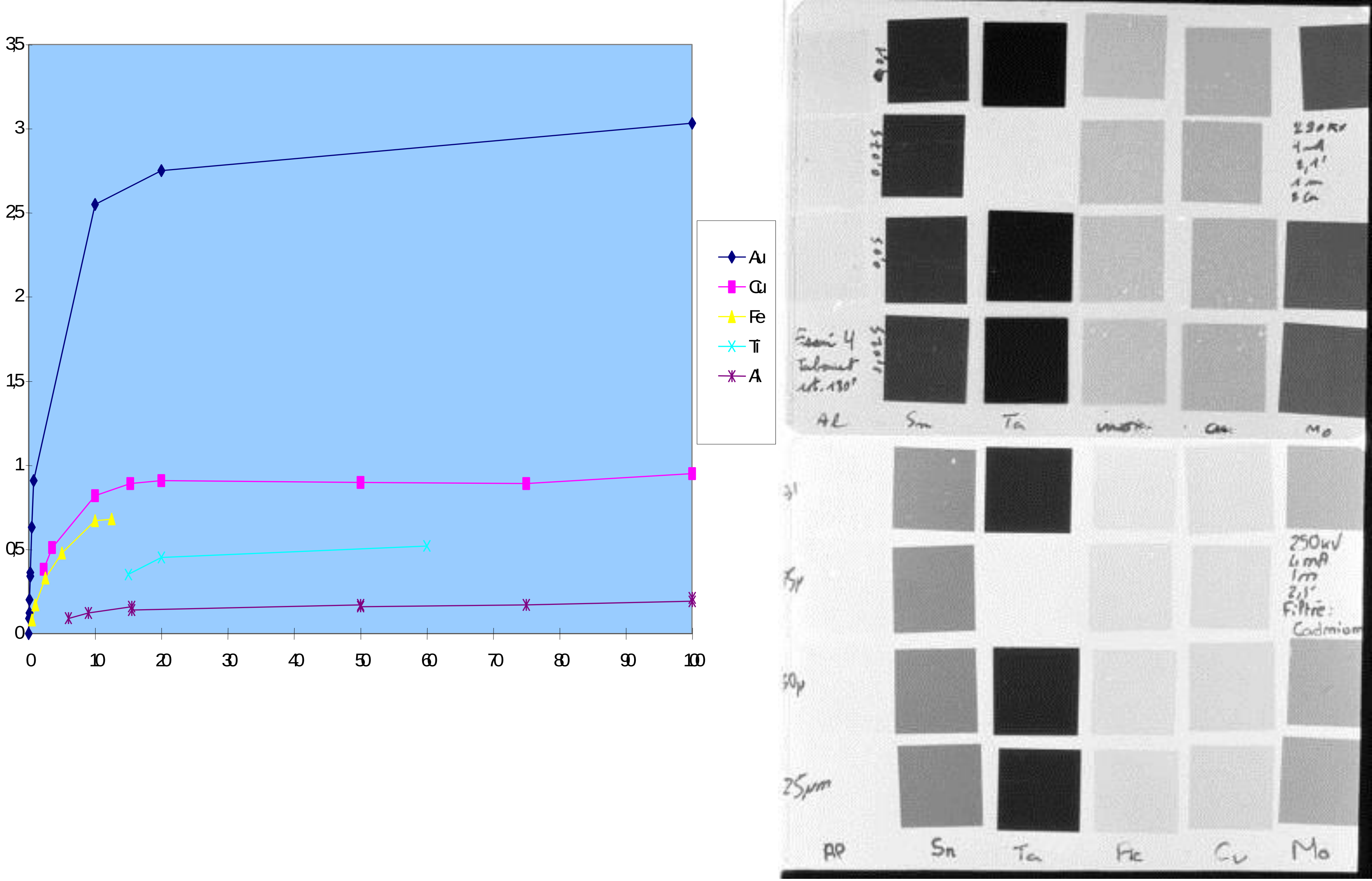
2 – Neutron radiograph showing bones & leather (PSI – Villigen - CH)

3 – X-ray radiograph showing sword, knife & metallic decoration

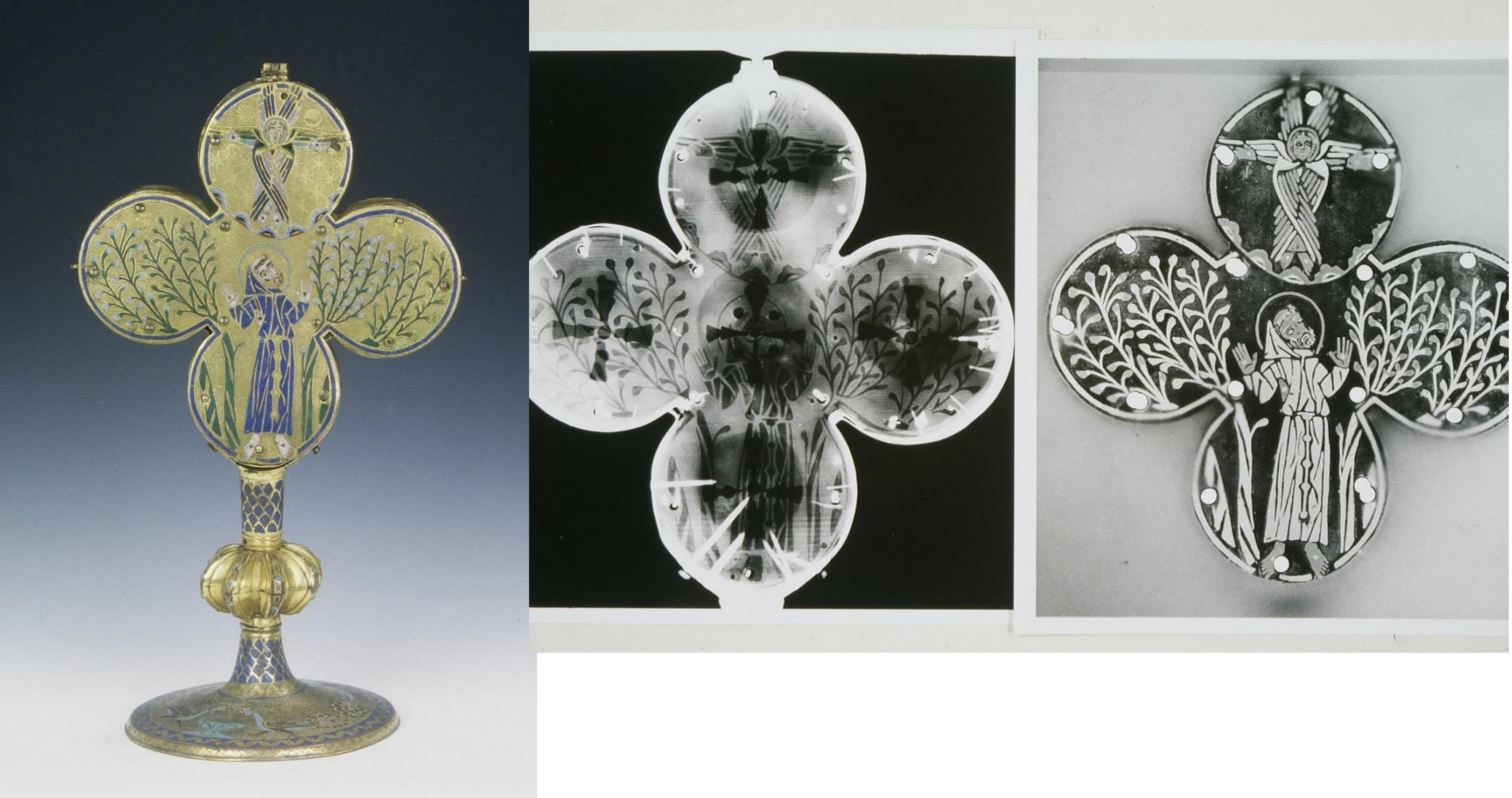
Electron emission radiography



Schematic diagram of the technique for making electron emission radiographs. More electrons are emitted from the areas of the specimen's surface that contain materials of high atomic numbers



Electron emission radiography - Variation of the film density according to the atomic number & the mass per unit area of the superficial material



A - Photography

B – X-ray radiography

C – Electron emission radiography

Electron emission radiography - Case of enamels on copper alloy substrate - Bishop’s cross, champlevé enamel, Limousin, Middle Age, Louvre Museum. Visualisation of surface micro-cracks & bubble areas in the vitreous layer

B

A

C

Electron emission radiography - Cult object, Byzantine art, cloisonné enamel, Cluny Museum

Autoradiography

Application of autoradiography to paintings

After irradiation, the neutron-induced radioactivity decays with time. About a dozen different light and heavy isotopes – emitting β- (electrons) and γ-radiation – are created (the most important isotopes and their half-lives are presented in table 1). The induced β-decay is used to blacken highly sensitive films or imaging plates to reveal the spatial distribution of the pigments. It is a big advantage of neutrons that different pigments can be represented on separate films. This is due to a contrast variation created by the differences in the half-life times of the isotopes.

Isotope	Half life	Pigment
^{56}Mn	2.6 h	Brown colours, Umber, Ocre
^{64}Cu	13 h	Azurite, Malachite
^{76}As	1.1 d	Smalt, Realgar, Auripigmente
^{122}Sb ^{124}Sb	2.7 d 60 d	Naples-Yellow
^{32}P	14 d	Bone-black
^{203}Hg	47 d	Vermilion
^{60}Co	5.3 a	Smalt

Figure 1: Tiziano Vecellio, "Titian" ,
The Girl with a Platter of Fruits (c. 1555),
Gemäldegalerie zu Berlin

Figure 2: TizianoVecellio "Titian" ,
X-ray radiography, with permission of the
Gemäldegalerie Berlin
(K. Slusallek, Rathgenlabor GMD)

Autoradiographs from « *Girl with a platter of fruits* » (c. 1555) by Tiziano Vecellio, called Tizian – Gemälde Galerie (Berlin)

C. Laurenze-Landsberg, C. Schmidt, C.O. Fischer, B. Schröder-Smeibidl

BENSC Report – Berlin (2001)

Fig. 3: 2nd neutron autoradiography, composed of 12 imaging plates, exposure 1d 7 h to 1d 11 h after activation.

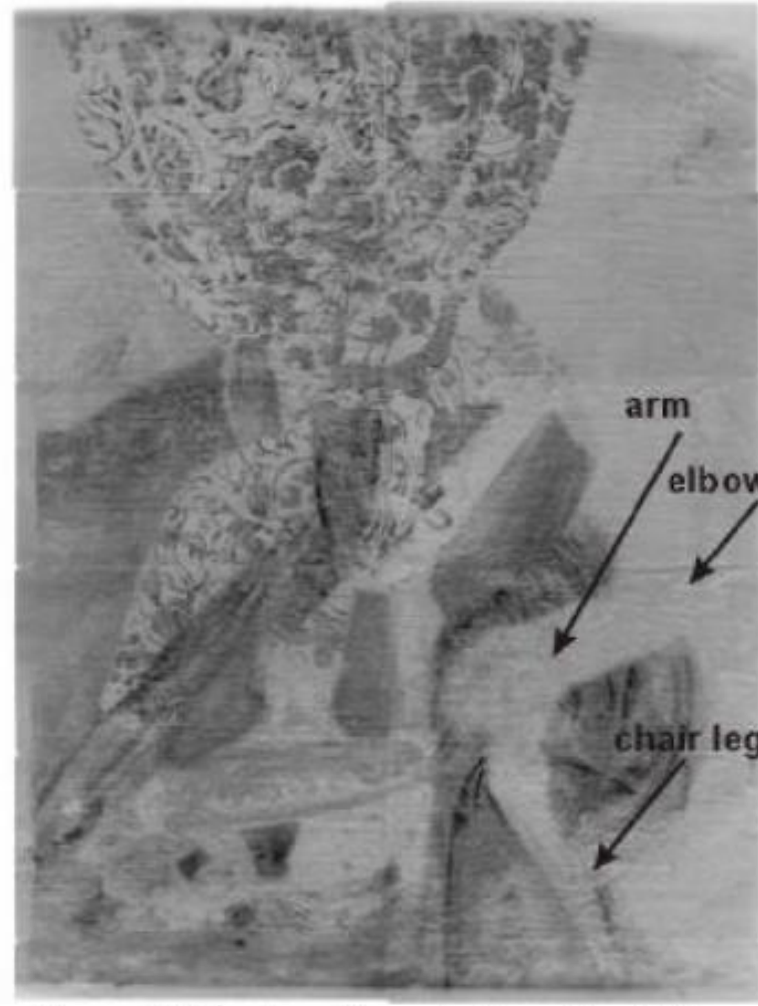
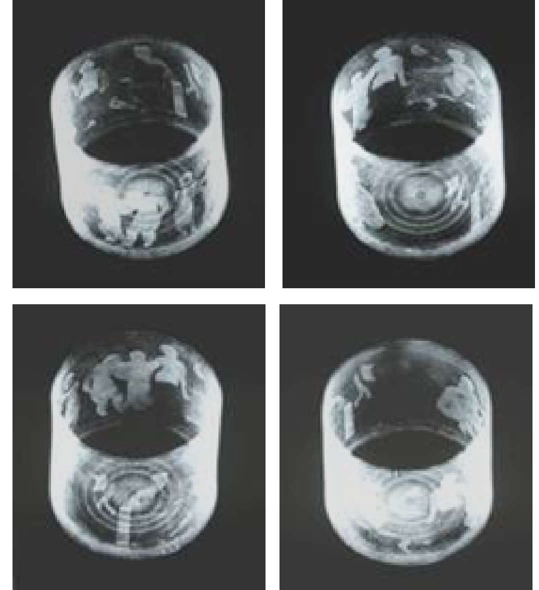
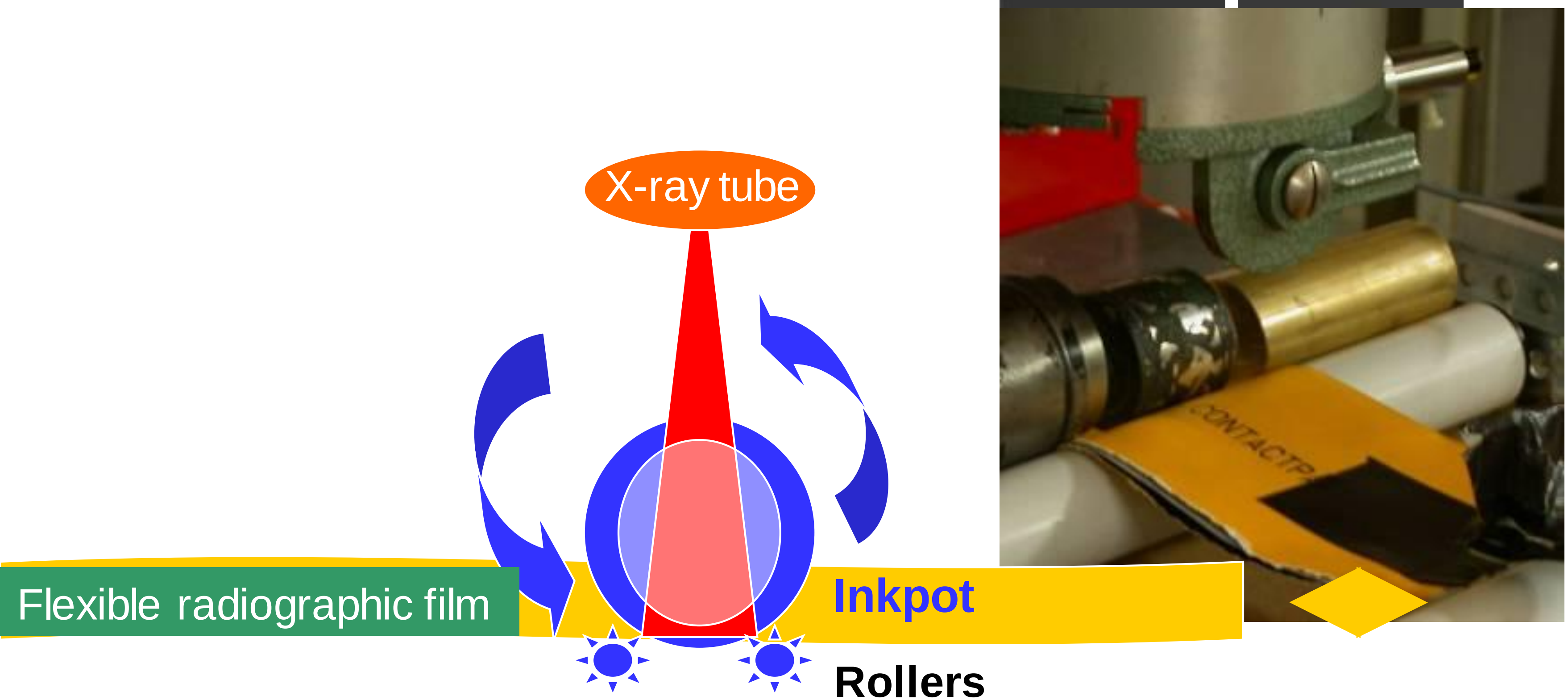


Figure 4: 2nd autoradiograph: turned by 180°

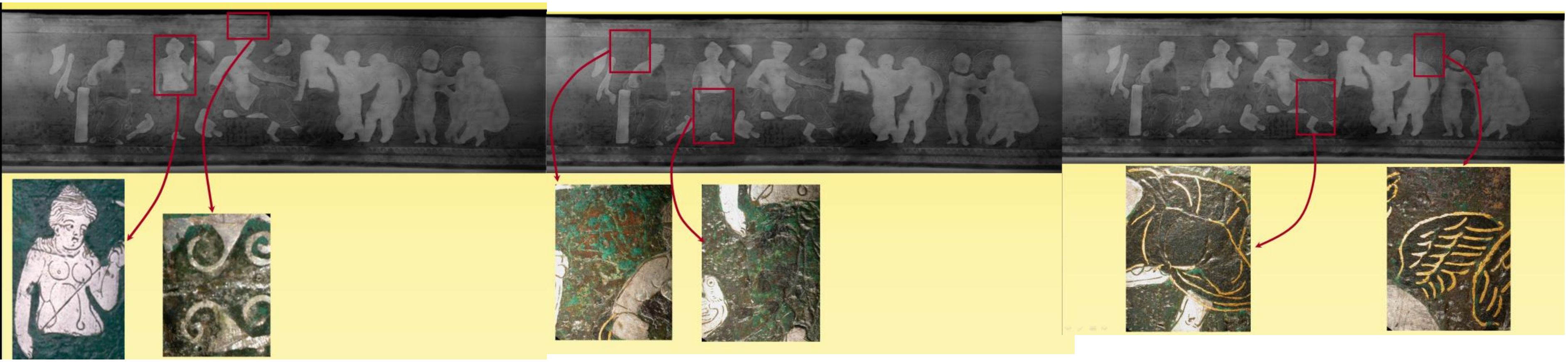
Principle of « unrolling » radiography

The object is driven by the moving of the film. So, the image is sharp for the surface details in close contact with the film, the X-ray tube, being at a short distance from the object, gives a fuzzy image of its opposite side from the film, streaming inversely of the rotation direction.





Inkpot of Vaison-la-Romaine, cylindrical, cast and inlayed - Dimensions: H = D = 4.4 cm,
Roman Empire, 1st Cent. AD, Cu-Zn alloy, Cu, Ag, Au & black bronze inlays
Louvre Museum



Silver

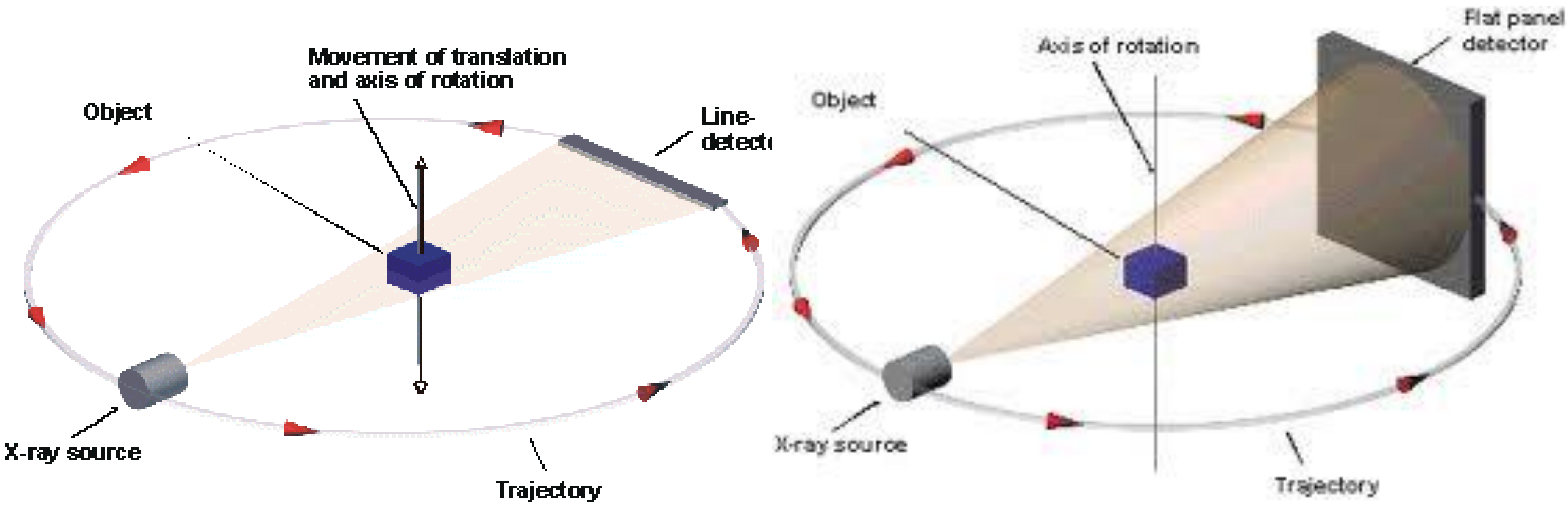
Copper

Black bronze & gold

Inkpot from Vaison-la-Romaine, details of the inlays

Modern simulation of the original colors

Computer assisted tomography (or tomodensimetry)



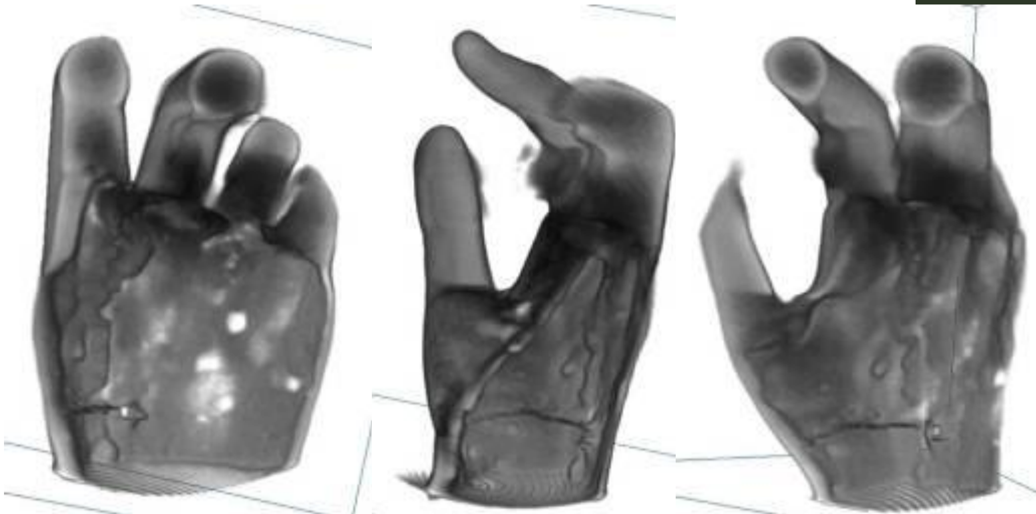
a **b**

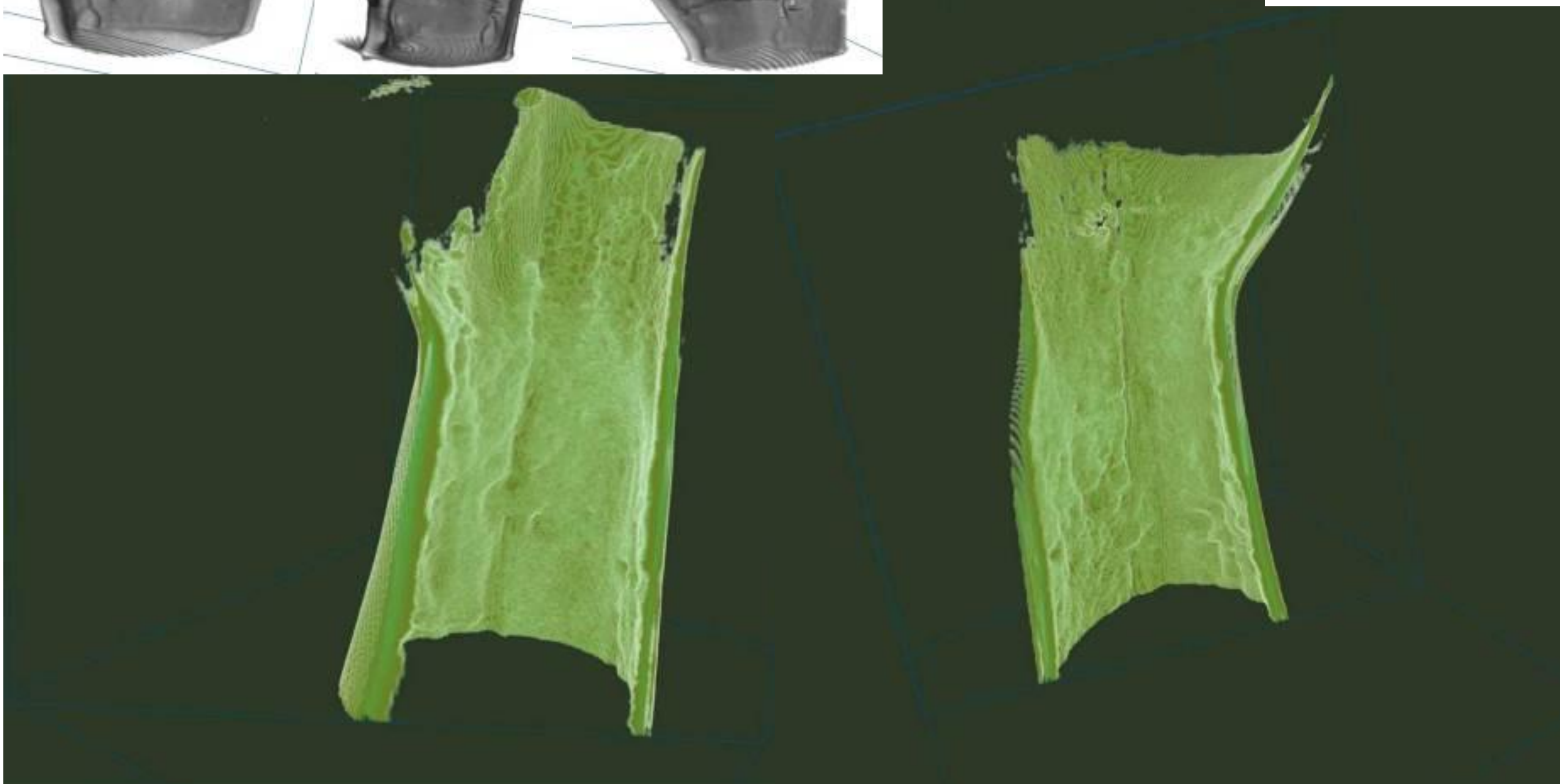
Principle schemes of
a: 2D tomography (linear array detector)
b: 3D cone-beam tomography (2D pixelised flat detector)

Ref.: M. Simon & C. Sauerwein, Quality control of light metal castings by 3D computed tomography, http://www.ndt.net/article/wcndt00/papers/idn730/idn730.htm

Arm of a Roman Emperor from Essegney (Vosges), bronze sculpture, L = 44 cm, Gallo-Roman, 1st – 3rd Cent. AD, lead bronze (primary castings: [Sn] = 11 %, [Pb] = 6 % / secondary castings: [Sn] = 11 %, [Pb] =: 4 %), Epinal Museum

- The tomography shows the assembly joint of the wax semi-shells & the wax drops in the hands
- The software permits the at will choice of the cross section adapted to the looked for information
- Visualisation of non accessible areas by direct observation, including endoscopy: sedimentation)





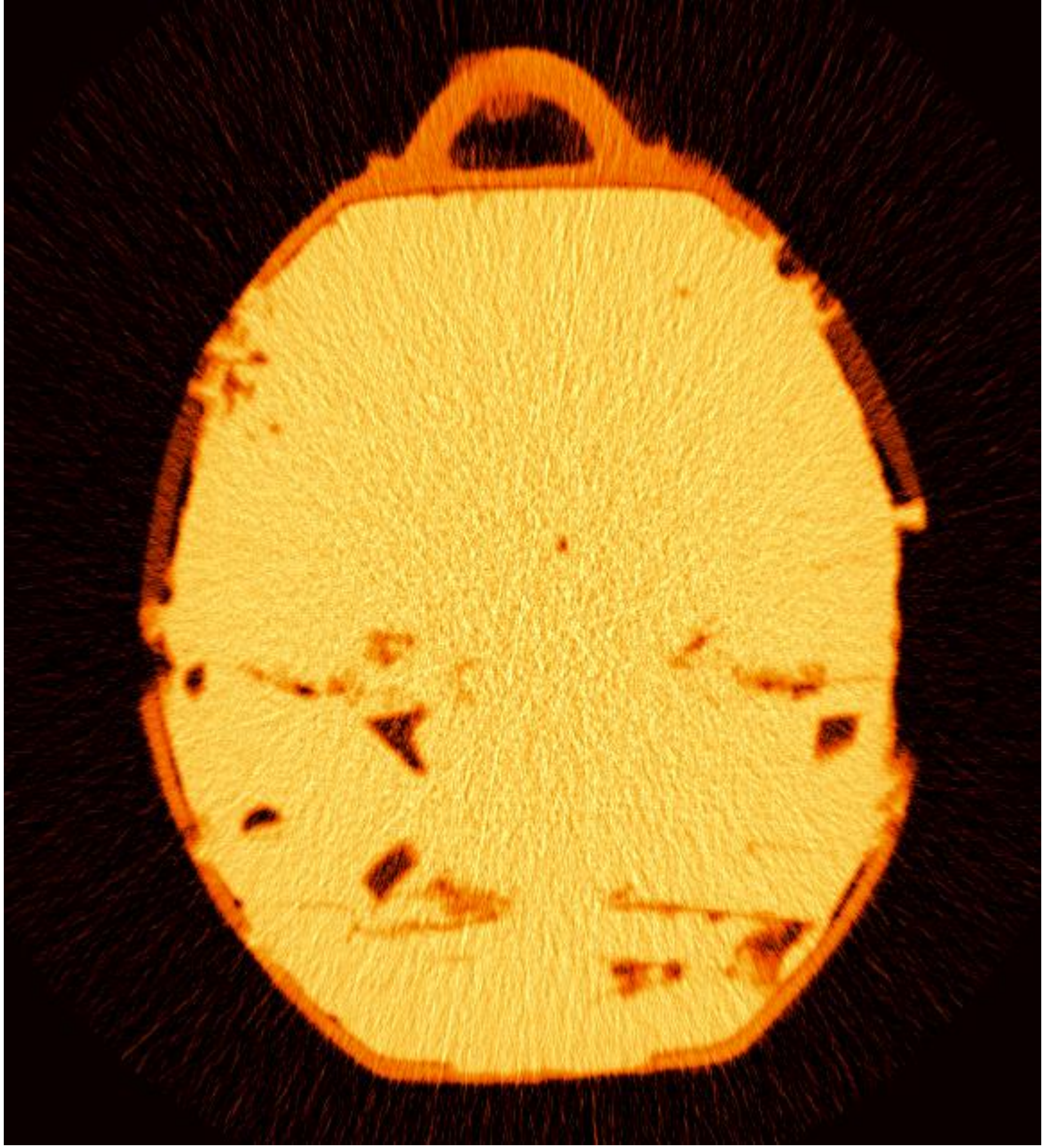
The *Leopards weight* from Shahi Tump

The artefact was discovered in a grave, in the Kech Valley, in Balochistan, southern part of Pakistan.

It belongs to the Shahi Tump – Makran civilisation (end of 4th millennium – beginning of 3rd millennium BC). Height: 200 mm; weight: 13.5 kg. The shell (e = 3 mm) has been manufactured by lost-wax foundry of a copper alloy (12.6 % Pb, 2.6 % As), then it has been filled up with lead (99.5 %) foundry. The shell is engraved with figures of leopards hunting wild goats, made of polished fragments of shellfishes.

No identification of the artefact's use has been given

The *Leopards weight* from Shahi Tump - Photography



The *Leopards weight* from Shahi Tump – Cross section by tomography with 8 MV accelerator (© CEA Grenoble)

Microradiography, microtomography

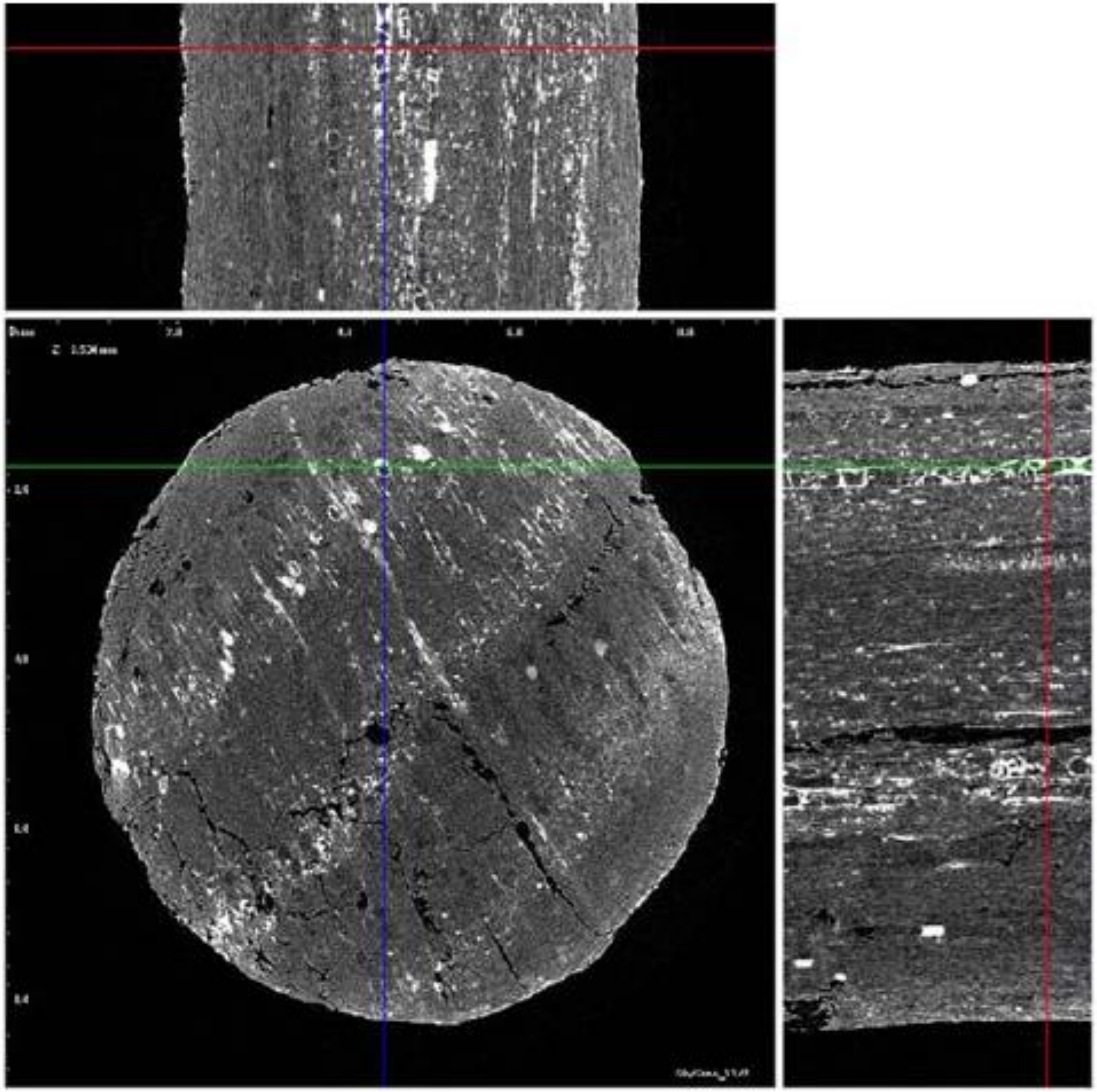


Figure 1 – Cross section of a sample of Quercus caducifolia *impregnated with a mixture of PEG 1500 al 20% in PPG 425, obtained by μ-CT*

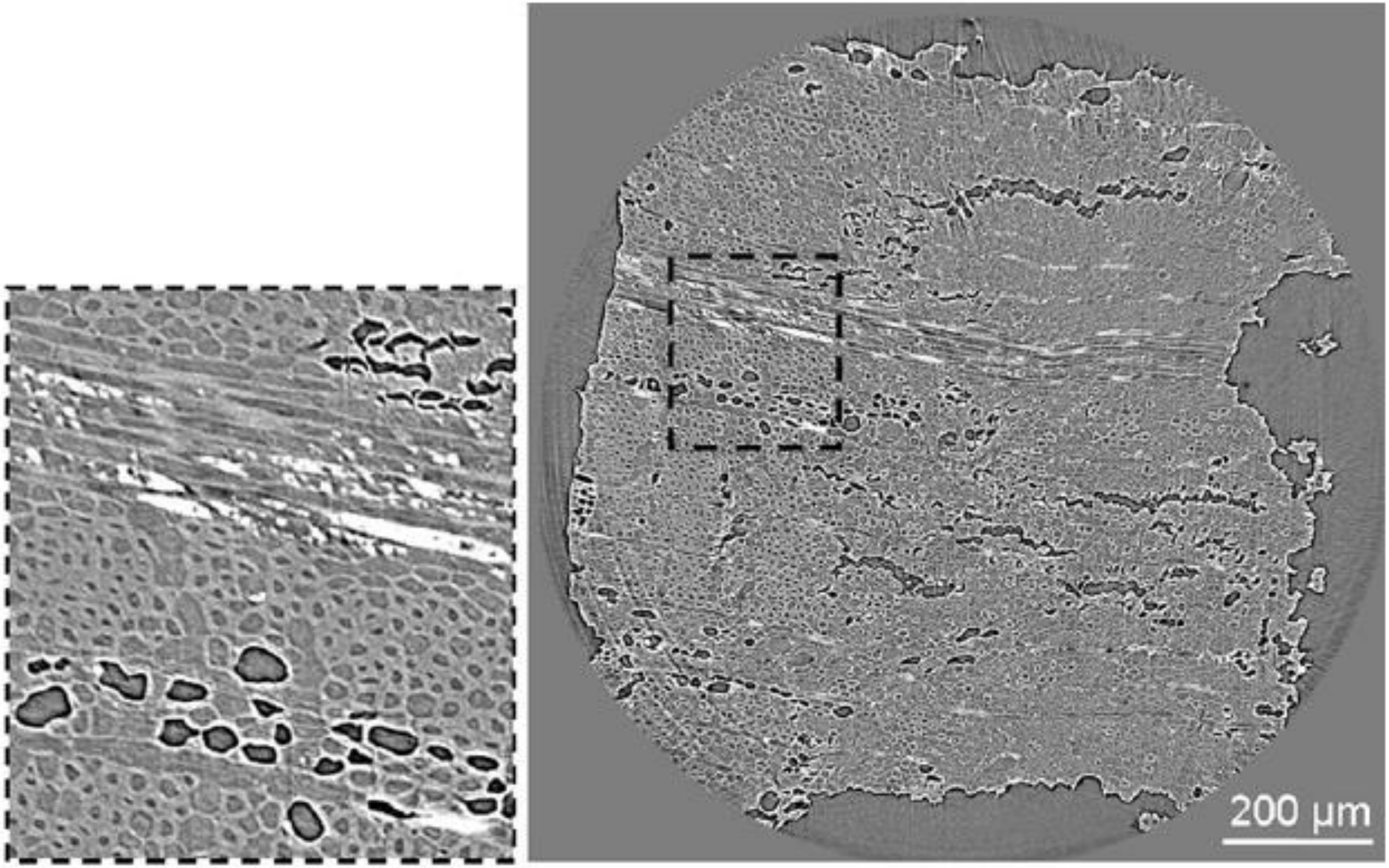


Figure 3 - Cross section of a sample of Quercus caducifolia *impregnated with a mixture of PEG 1500 al 20% in PPG 425, obtained by SR-CT.*

Simone BUGANI & al. (U. Bologna)
Evaluation of conservation treatments for archaeological waterlogged wooden artefacts
9th International conference on NDT of Art, Jerusalem Israel, May 25-30 2008
http://www.ndt.net/article/art2008/papers/162Bugani.pdf

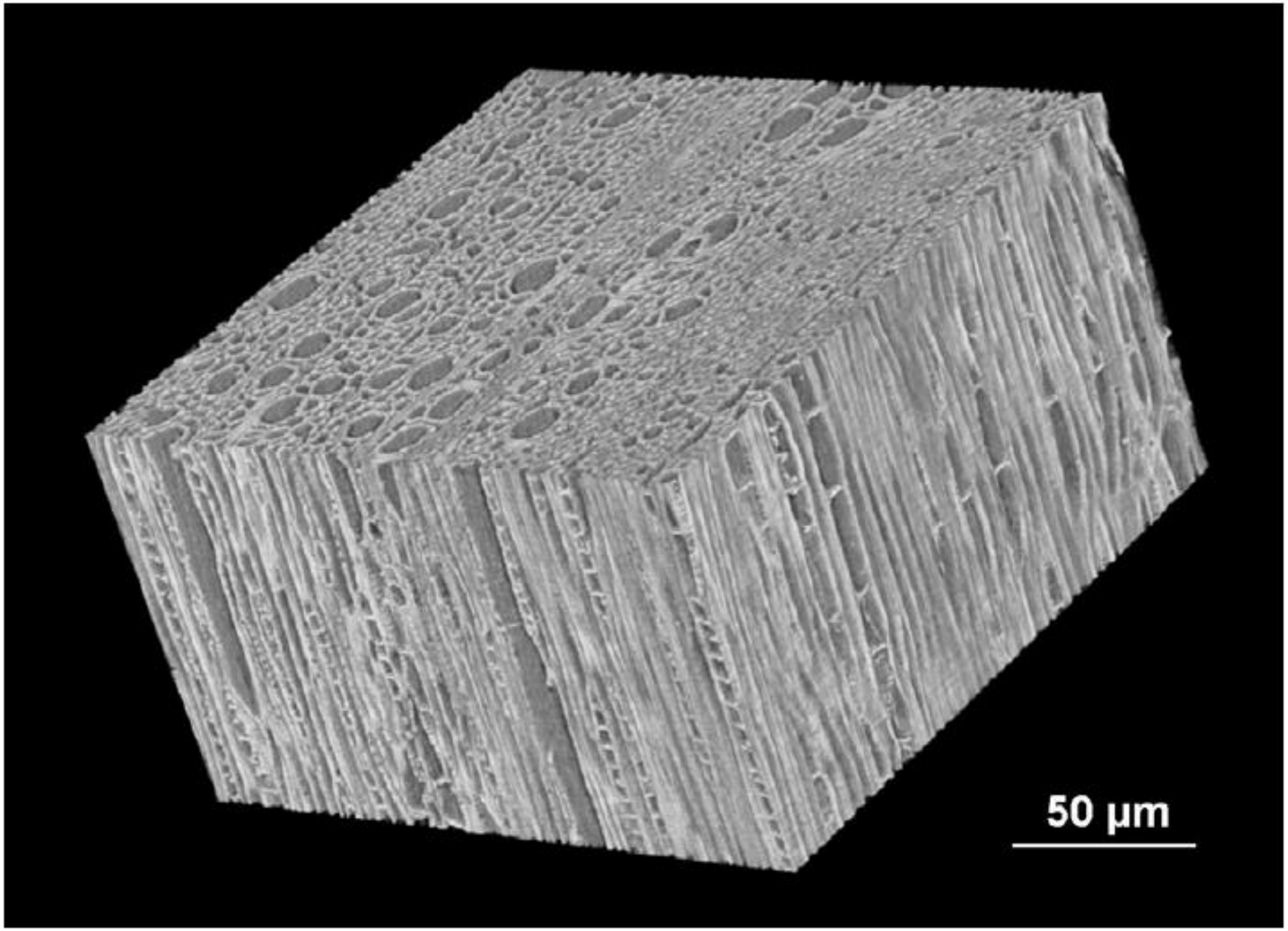


Figure 4 – Three dimensional rendering of a sample of Quercus caducifolia *impregnated with isoeugenol polymerized, obtained by SR-CT.*

Conclusion

I hope that this presentation has shown that radiography offers a relatively large & flexible palette of techniques.

If this palette is used by a competent & skilled technician,
& if there is a real dialogue between himself & the curator,
or the conservator-restorer, or the art historian, or the historian of techniques, or the archaeologist, or the metallurgist…,
it can provide many pertinent elements, contributing to a deeper knowledge of the cultural heritage artefact

Thank you for your attention