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Blued steel sheets : history, manufacturing and conservation.

The case of a Ganz & Co projection and enlargement lantern conserved at the Collection Centre of the Swiss National Museum.

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Table of contents

Abstract

The Collections Centre of the Swiss National Museum, located in Affoltern-am-Albis, in the canton of Zurich, conserves a projection and enlargement lantern designed by a well-known local company selling projection and photography equipment. This device, dated from the early 20th century, has the particularity of having its lantern made of blued steel. This surface treatment offering both protection against corrosion and a coloured coating ranging from yellow, passing through blued, to dark grey, became widespread on many steel and puddled iron objects from the 19th and early 20th centuries. However, we note that these artefacts, now present in heritage collections, suffer from significant degradations which endanger the blued coating as well as its appreciation.

The technological and material study of this material has made it possible to define that heat bluing methods as well as chemical processes have coexisted for their implementation. Analytical studies have also made it possible to confirm the chemical composition of the blued stratum. Composed of a lower layer of magnetite and an upper layer of hematite, the question of the treatment of this complex material arises: how to remove the corrosion products of the ferrous alloy without altering the compounds of the same nature constituting this stratum?

Mechanical and chemical methods were investigated in order to define a treatment protocol adapted to this material. Chemical cleaning by complexation was unsuccessful, as the differentiation between the constituent products of the blued stratum and the corrosion products could not be achieved.

Four mechanical cleaning methods were combined in order to gradually allow the removal of surface corrosions. The use of steel wool first allows you to remove some of the corrosion, which will then be dusted with a nylon brush. The use of a flexible Caran d'Ache Genève 0149.310 eraser removes all deposits aggregated on the surface. Then the use of a flat steel tool allows to remove the corrosion very adherent on the metal.

Résumé

Le Centre des Collections du Musée National Suisse, situé à Affoltern-am-Albis, dans le canton de Zurich, conserve une lanterne de projection et d'agrandissement conçue par une entreprise locale renommée commercialisant des appareils de projection et de photographie. Cet appareil, daté des prémices du 20ème siècle, a la particularité d'avoir sa lanterne constituée d'acier bleui. Ce traitement de surface offrant à la fois une protection contre la corrosion et un revêtement coloré allant du jaune, en passant par le bleui, au gris sombre, s'est généralisé sur de nombreux objets en acier et en fer puddlé des 19ème et début du 20ème siècles. Cependant, on constate que ces artefacts aujourd'hui présents

dans les collections patrimoniales souffrent de dégradations importantes qui mettent en péril le revêtement bleui ainsi que son appréciation.

L'étude technologique et matérielle de ce matériau a permis de définir que des méthodes de bleuissage par la chaleur ainsi que des procédés chimiques ont coexisté pour leur mise en œuvre. Des études analytiques ont également permis de confirmer la composition chimique de la strate bleuie. Composée d'une strate inférieure de magnétite et d'une strate supérieure d'hématite, la question du traitement de ce matériau complexe se pose : comment retirer les produits de corrosion de l'alliage ferreux sans altérer les composés de la même nature constituant cette strate ?

Des méthodes mécaniques et chimiques ont été investiguées afin de définir un protocole de traitement adapté à ce matériau. Le nettoyage chimique par complexation n'a pas abouti, la différenciation entre les produits constitutifs de la strate bleuie et les produits de corrosion n'ayant pas pu être atteinte.

Quatre méthodes de nettoyage mécanique ont été combinées afin de permettre progressivement le retrait des corrosions superficielles. L'usage de laine d'acier permet dans un premier temps de retirer une partie des corrosions, qui seront ensuite dépoussiérées avec un pinceau en nylon. L'usage d'une gomme Caran d'Ache Genève 0149.310 flexible permet de retirer l'ensemble des dépôts agrégés sur la surface. Puis l'usage d'un outil en plat en acier permet de retirer les corrosion très adhérentes sur le métal.

Introduction

Steel is related to our life as an essential material in the modern economic society. The 19th and early 20th centuries grew with this material which was technically improved during all the eras. However, this metal mainly constituted of steel easily reacts with the atmosphere and its constituents : oxygen and water. These chemicals engage an electrochemical action with the material, which is easily damaged and deteriorated. Blueing was one of the easiest and most protective treatment against corrosion. The process consists in heating or spread with clever mixes of chemicals the steel object, to obtain such a layer. Blueing was also appreciated for the coloured finish given to the object. Monumental objects as locomotives as well as smaller one, as weapons or cinematic technical objects were blued for these purposes. However, we can observe in our heritage collections that these coatings dated from one to two hundred years are concerned by important degradation phenomena, which have an impact on the perception of this technology. The problematic will be deepened through a case study : a projection and enlargement lantern dated from the early 20th century, conserved at the Collection Centre of the Swiss National Museum, in Switzerland. The device is concerned by these degradation phenomena that will be investigated in the following chapters. A first chapter will develop the history, the manufacturing, and the use of blued steel sheets. Then, the case study will be introduced. A third chapter will develop the manufacturing of the material and the object. The functional study and the condition report will then be introduced. A diagnostic and a prognostic of the alterations will be expanded as well as the associated cultural values. Chapter 8 will develop the mandate and the propositions of treatments and chapter 9 the study of the removal of the corrosion products on blued steel. The interventions of conservation and preventive conservation measures will then be defined. A discussion around the project and a conclusion will end this thesis.

1 Blued steel sheets : history, manufacturing and use

1.1 A quick review on the production of iron-based materials

Pure iron is a soft white silvery metal (*Picture 1*), recognisable by its magnetic property at ambient temperature. Characterised by a high melting point of 1538°C and boiling a point of 2861°C, this metal is rarely found in pure state as it rusts* very easily. Thus, iron is associated with other chemical elements, mainly carbon, to become a more resilient alloy of steel, stainless steel or cast-iron, for example[1]. It is obtained by the melting of the material with carbon to decrease its melting point, which allowed the development of the manufacture of this metal, and the discovery of steel and cast-iron[2].

Picture 1 : Pure fragments of iron refined by electrolyse (left) and highly pure iron cube (right) ©Wikipédia

But the understanding of the composition, the manufacturing and the properties of modern iron alloys is not simple in the literature, as the need of a global nomenclature to define them has only been expressed in 1876 at the Universal Exhibition of Philadelphia and developed in the second half of the 20th century. Thus, when reading ancient documentation about alloys and more particularly iron, the terminology given to an alloy is not always the same in every country. This is also explained by the technological advances and local experiences at that time[3].

Between 1860 and 1920, we can differentiate the direct and incidental productions of iron. The direct production consists in ferrous paste obtained by combustion of iron ore in a low furnace (*Picture 2*). With this method, forged iron is produced and then hammered in a forge to remove scoria*[4], which are solid residues left from the treatment of metallic ore[5]. The obtained product of fluctuating quality was mainly used for locksmithing[6].

[1] Selwyn, Lyndsie, 2004, p.98

[2] Selwyn, Lyndsie, 2004, p.99

[3] de Bouw, Michael, *et al.*, 2010, p.1

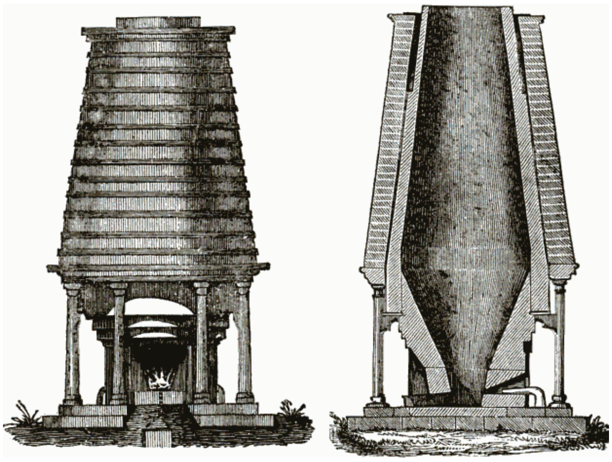
[4] de Bouw, Michael, *et al.*, 2010, p.4

[5] CNTRL, 2012, [Online]

[6] de Bouw, Michael, *et al.*, 2010, p.4

Picture 2 : Low furnace ©Ermina

Incidental production, always starting with the production of cast-iron, allows the manufacturing of melted iron, melted steel, welded iron and welded steel. Iron ore is melted in a blast furnace (*Picture 3*) until the production of liquid iron. Depending on the cooling rate, grey or white cast iron are obtained. Grey cast iron is used for moulded and casting pieces while white cast iron is made for refined produced as welded iron and steel or melted iron or steel. The difference between melted iron and melted steel is the refining rate and the carbon percentage, allowing different properties of the final product. Nevertheless, both alloys were called steel[7].



Picture 3 : Blast furnace from 1849, Hayange, Lorraine ©Wikipédia

[7] de Bouw, Michael, *et al.*, 2010, p.5

Concerning welded iron and steel, the difference is also made by the percentage of carbon. Case-hardening steel was obtained by putting together puddled iron with charcoal and heat them several days in hermetically sealed cases[8].

Nowadays, three different types of steel are counted in the category of ordinary steels. Low carbon steel alloy (0-0.3% carbon), also known as "soft steel", is one of the most used type of steel. It can be found as wires or car bodywork panel. Medium carbon steel alloy (0.3-0.6% carbon) are used to create gears or rail track, while high carbon steel alloy (0.6-1% carbon) are found as springs or thick wires.

The second category of alloyed steels concerns alloys of iron, carbon and other elements as chromium, nickel or molybdenum from 2 to 10%. Their mechanical properties are higher than those of ordinary steels.

The third is weathering steel (*Picture 4*), which is a highly resistant low alloy steel[9]. Containing 0.05 to 0.25% carbon content, it is also constituted of >2% of manganese and small quantities of other elements as phosphor and copper. It is acknowledged for its mechanical properties and resistance to atmospheric corrosion.

Picture 4 : The Abetxuko weathering steel bridge in Spain ©Metalsupermarkets

The last category is stainless steel, which is an alloy composed of iron, 0.03 to 1% carbon content and at least 10.5% of chromium. An invisible and adherent layer of oxide rich in chromium gathers at the surface of the metal, offering a strong protection against corrosion[10].

[8] de Bouw, Michael, *et al.*, 2010, p.5

[9] Selwyn, Lyndsie, 2004, p.105

[10] Selwyn, Lyndsie, 2004, p.106

Picture 5 : Stainless steel sculpture from the artist Bruce Beasley ©Aieregistery

The Unified numbering system (UNS) is a designation system for metals and alloys developed in 1972 in North America[11]. In Europe, steel alloys are ranked with the norm NF EN 10020[12].

Five phases characterize steel and carbon alloys. Ferrite ɑ constitutes the phase of iron at low temperature, under 912°C. This ductile, malleable, and magnetic cubic centred phase dissolves 0.02% of carbon and can be laminated or extended as wires. Austenite γ is a second phase, stable between 912 and 1394°C and dissolving until 2.1% of carbon. In comparison with ferrite ɑ, this non-magnetic phase can accommodate more atoms of carbon in its face cubic centred structure. Another ferrite δ phase is a cubic centred phase stable between 1394 and 1538°C, dissolving until 0.09% of carbon. The fourth phase is cementite or iron carbide, containing 6.67% of carbon. It is a brittle and hard material[13]. The last phase is graphite, which is a soft elemental carbon that can be found in some ferrous alloys[14].

1.2 History of production and use

The production of steel has been enabled with the invention of blast furnaces in the 14th century in Occident[15], but its fabrication in large amount started in the 18th century with the industrialisation of the blast furnace and the discoveries from the scientists Bethollet, Vandermonde and Monge. They defined the interaction between iron, cast-iron and steel and the role of carbon in this relation[16].

[11] Azo materials, 2021, [Online]

[12] Afnor boutique éditions, 2000, [Online]

[13] Selwyn, Lyndsie, 2004, p.103

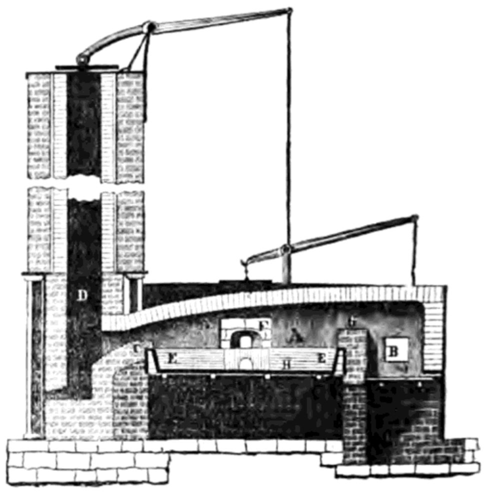
[14] Selwyn, Lyndsie, 2004, p.104

[15] Universalis, 2021, a, [Online]

[16] Maison de la métallurgie et de l’industrie de Liège, undated, [Online], p.1

The invention of blast furnaces has allowed a diminution of the working force and a rise of temperature up the melting point of iron. It has also permitted a quick evolution of iron and steel alloys. Blast furnaces allowed the manufacture of a steel which was a product between cast-iron and forged iron[17]. They were initially charged with a combustible of charcoal, which persisted in some countries in Europe despite the invention of coke*, as the final product was considered of a better quality than the metal obtained with the latter – which is not true[18].

In the late 18th century, Henry Cort has invented the puddling furnace (*Picture 6*). It was introduced in the early 19th century in Europe[19]. This device allowed the decarburization of cast-iron by its fusion with scoria full of oxygen while the ensemble is stirred ("puddled") with a hook. Thanks to the puddling, the impurities of the metal are removed in the scoria. The metal is shaped in an iron bloom by shingling, a technique of hammering of the mass of metal allowing the removal of the last scoria. This method was associated with a special ribbed roller allowing a faster removal of warm iron bars from the furnace to be forged. The production rose considerably with this technique[20].



Picture 6 : Puddling or reverberatory furnace ©Research Gate

The blueing of iron and steel sheets is known since the 15th century. Armourers and swordsmiths achieved the blueing of large plates of steel with heat treatment, as armours and swords blades from the Middle Ages and Renaissance testify nowadays. Plate armours were often blued for decorative

[17] de Bouw, Michael, *et al.*, 2010, p.1

[18] de Bouw, Michael, *et al.*, 2010, p.2

[19] de Bouw, Michael, *et al.*, 2010, p.5

[20] Universalis, 2021, b, [Online]

purpose and to prevent rusting (**Erreur ! Source du renvoi introuvable.**). Chemical methods rose in the 18th century, offering a different hue, but heat techniques were still in use as they were less expensive. Also, modern chemical methods named "Gun blue" are cold solutions applied on the surface, producing a blued layer with other compounds than oxides (selenides, sulphides) [21] (*Picture 8*).

Picture 7 : Blued steel armour of Lord Buckhurst, Wallace collection, inventory number A 62 ©Alan Williams

Picture 8 : Modern chemical blueing product ©Walmart

Blued steel surfaces are to be found in the horology field. Steel hands (*Picture 9*) and visible screws were and are still blued after a quench* of the metal. Many weapons are also blued for aesthetic and protective purposes. Also, steel razor blades were often blued. Some locomotive boilers of Wintherthur, Switzerlandd, were covered with a blued casing[22].

Regarding technical cinematic objects, blued steels sheets used to build projection lanterns were called "Russian sheets", as they were mainly produced in Russia[23]. Lanterns made of blued steel sheets generalized in the 1890's until the 1920's, as film projectors develop. Therefore, painted steel lanterns cohabitated with blued steel devices during this era. Models before the 1890's were generally

[21] Williams, Alan, *et al.*, 2019, p. 123

[22] Société des Ingénieurs Civils, 1889, [Online], p. 717

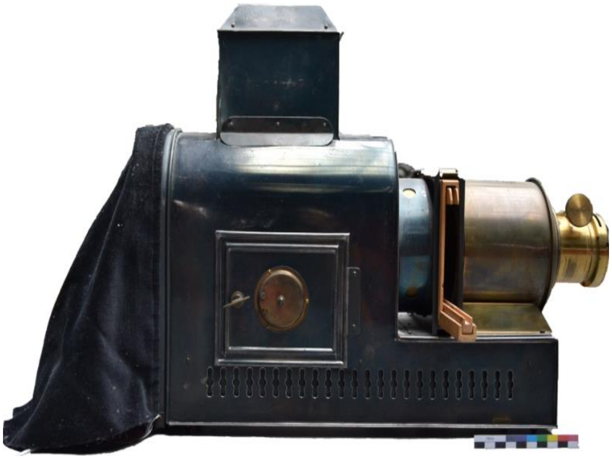
[23] Le Fascinateur, undated, p.297

made of painted, blackened or nickel-plated steel sheets. Tin plates and nickel-plated copper lanterns could also be found.

Picture 9 : Grande seconde tourbillon aventurine watch from Jaquet Droz, with blued steel hands ©Worldtempus

Picture 10 : Triple projection lantern Stereopticon in blued steel, dated from 1900, conserved at la Cinémathèque française, inventory number AP-14-2883 ©La Cinémathèque française

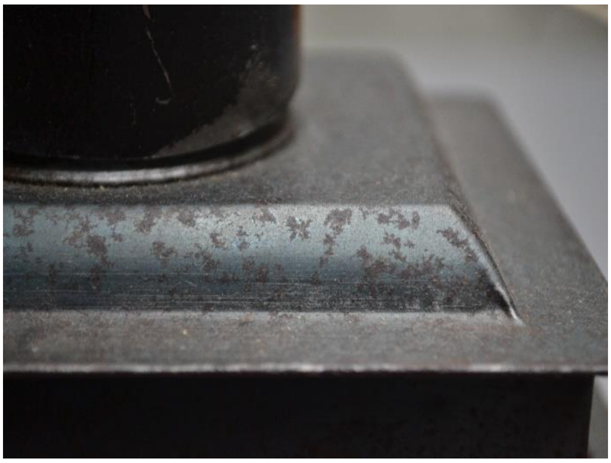
Collections of blued steel lanterns have been investigated in swiss institutions, to date the productions of these objects but also to have a global view of the condition of the material. Several objects conserved at the Camera Museum, in Vevey, and at the Cinematheque, in Bern have been observed and studied. It ensues that most of the blued steel surfaces are either in pristine conditions (*Picture 11*, *Picture 12*), or concerned by pitting or filiform corrosion (*Picture 13*, *Picture 14*), resulting in a loss of the blued coating. These corrosions can also extend as generalised corrosions (*Picture 15*, *Picture 16*). The degradations and sensitivities of the material will be developed in further details with the case study of this thesis.



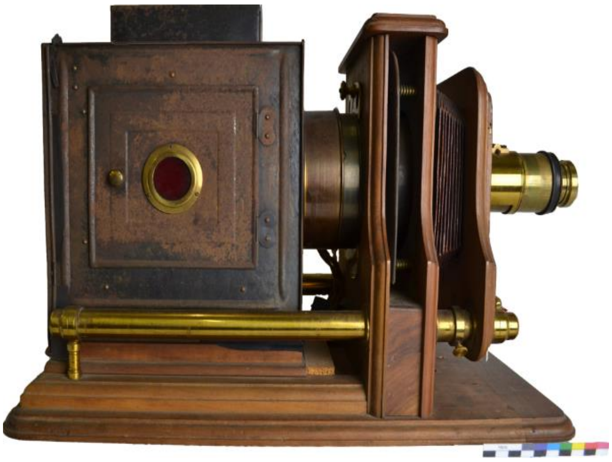
Picture 11 : ICA Trilby projector conserved at the Cinematheque of Bern, around 1915, inventory number 182027, ©HE Arc CR, A.L

Picture 12 : Pristine blued steel surface, ICA Trilby projector conserved at the Cinematheque of Bern, around 1915, inventory number 182027 ©HE Arc CR, A.L

Picture 13 : Cinematograph 35 mm, conserved at the Cinematheque of Bern, around 1900, inventory number GER 558 ©HE Arc CR, A.L



Picture 14 : Pitting and filiform corrosion on blued steel, Cinematograph 35mm conserved at the Cinematheque of Bern, inventory number GER 558, ©HE Arc CR, A.L



Picture 15 : Projection and enlargement lantern Meyer Ferd. Franz, around 1900-1920, conserved at the Camera Museum, inventory number 2701 ©HE Arc CR, A.L

Picture 16 : Generalized corrosion, projection and enlargement lantern Meyer Ferd. Franz conserved at the Camera Museum, inventory number 2701 ©HE Arc CR, A.L

1.3 Manufacturing techniques

1.3.1 The manufacture of steel sheets

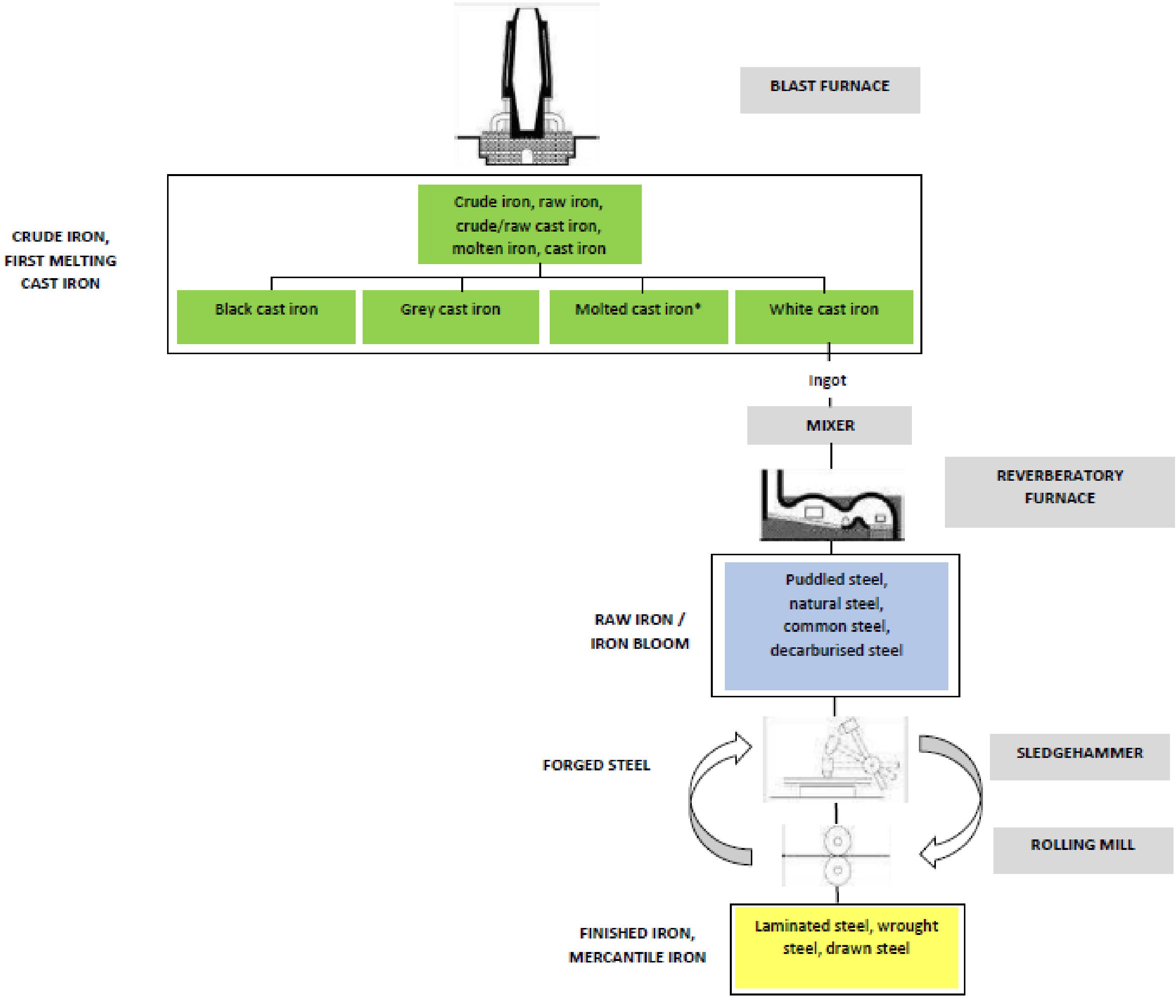


Diagram 1 : The production of laminated steel ©De Bouw Michael, HE Arc CR, A.L

In the late 19th and early 20th century, the manufacture of steel sheets started with the production of white cast iron* by the fusion of iron ore in a blast furnace charged with charcoal. In the case of Russian sheets, ore from the mines of Maloblagodatj, close to Oural mountains, was used. White cast iron was then prepared in ingots, which were transferred in a mixer. After this step, one of those two methods of refining of the cast iron where used. It could be treated in a reverberatory furnace in order to obtain puddled steel. The other method, called "franc-comtoise" but originated from Germany, consisted in gathering the two furnaces for heating and for refining in one. Thus, the single hearth allowed the refining and the warming of the ball of steel to ease the hammering[24].

[24] Musées des techniques et cultures comtoises, undated, [Online], p.10

Steel was laminated several times to obtain sheets of 0.75m sideways and annealed. Several layers of sheets were then superimposed with charcoal sprayed in between and laminated again, to get sheets of 1m x 1.4m. Bundles of 60 to 100 sheets were annealed for 6 hours in a near airtight room. The sheets were hammered with a hammer measuring 0.35 x 0.15m, weighting 1 ton. After 90 hammer hits spread on the surface, the bundle was annealed and hammered again. The metal finishing is made by hammering with a 0.5 x 0.4m hammer. The sheets develop a polished surface very similar to those of a mirror and a grey coloration provided by an oxide, preserving them from atmospheric agents. The adhesion of the oxide is important, as it does not detach from the sheets when they are folded. The sheets have a thickness of 5 to 6 tenth of a millimetre, are cut to a size of 1.4 x 0.7m and weight between 4.5 and 5.4 kg[25].

The use of Russian blued steel sheets was favoured for the construction of lanterns as it was more malleable and more resistant to rust. Also, the heat value of the light source could exceed 3000°C : steel sheets were then more suitable than wood or leather[26].

1.3.2 Blueing techniques

1.3.2.1 Nature, composition and properties

"Blueing" is a general term used to define methods of artificial oxidation[27] applied to ferrous and copper metal alloys. It is obtained by heat or chemical treatments and produces a thin layer of oxides* on the surface of the metal[28], reinforcing corrosion resistance and providing an aesthetic colouration[29]. The operation is made in an oxidising atmosphere, at a temperature between 220 and 330 Celsius degrees, allowing the formation of a thin layer of adherent oxide whose colour differs from yellow to grey[30]. By the way, there is a direct relation between the colour of the superficial oxide layer and the heating temperature. But the colour also depends on the time of heating : if a piece of steel is maintained at a low heating temperature, it will gradually take each oxide colour from yellow to grey[31]. The term "blueing" has very probably been chosen to name this process to refer to the blue colour which is the obtained with these techniques and also because the durability of blueing rises with the rising of the temperature : thus, the blued colour was almost always used[32].

[25] Société des Ingénieurs Civils, 1889, [Online], p. 717

[26] Le Fascinateur, undated, p. 296

[27] Ezv.admin.ch, 2020, [Online], p.72

[28] ISO.org, 2018, [Online], chapter 3.26

[29] Williams, Alan, *and al.,* 2019, p.123

[30] Reiser, Fridolin, 1897, p.101-103

[31] Reiser, Fridolin, 1897, p.103

[32] Kraus, Hugo, 1951, p.100

Temperature	Blueing colour obtained
220-230°C	Pale yellow
240°C	Dark yellow
255°C	Brownish yellow
265°C	Reddish brown
275°C	Purplish red
285°C	Purple
295°C	Purplish blue
315°C	Vivid blue
330°C	Grey

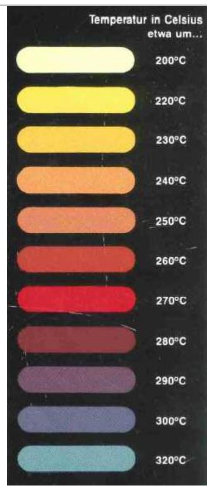


Table 1 : Relation between the heating temperature and the obtained colour of blueing on steel
©Reiser Fridolin, Forum Horlogerie suisse

The perception of the colour of a blued metal is related to the physical phenomenon of light reflection of light beams through the superior and inferior surfaces of the oxide layer. White light is composed of several coloured light beams of different wavelength. If the light beams encounter a difference in their path, which here is provoked by the reflection of the two different surfaces of the blued layer, the crest and valley waves of the light beam can cancel each other : an interference is created. Thus, the colour depends on the thickness of the oxide layer[33].

A duplex film is formed when steel is heated at a temperature between 200 and 300°C in an atmosphere rich in oxygen. The underlayer is composed of magnetite (Fe_3O_4) and the overlayer of hematite (Fe_2O_3)[34]. Both are mineral species : magnetite is composed of iron oxide II and III and shows a black colour, while hematite is a red or black iron oxide III.[35] First, a hematite layer grows, and after a certain extent, converts into magnetite[36]. The magnetite layer forms because of a lack of oxygen induced by the thickness of the layer, while a thin layer of hematite remains upwards. In the end, the layer is saturated by the heating process, generating a black layer made of bulk magnetite, reaching its saturating point at 285 nanometres[37]. The blued layer is adherent and porous, constituting a partial protection against corrosion[38].

[33] Kraus, Hugo, 1951, p.100
[34] Williams, Alan, *and al.,* 2010, p.125
[35] Selwyn, Lyndsie, 2004, p.110
[36] Williams, Alan, *and al.,* 2010, p.125
[37] Williams, Alan, *and al.,* 2010, p.126
[38] Montiel-García, A., *and al.,* 2018, p.203

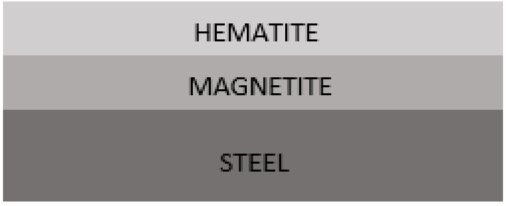


Diagram 2 : Stratigraphy of a blued steel sheet ©HE Arc CR, A.L

1.3.2.2 Heating methods of blueing

Different heat treatments were used to blue steel after a careful degreasing[39]. As explained in the previous chapter, the main method applied to blue steel sheets of large dimensions for the construction of a lantern consists in a succession of hammering and heating bundles of plates with charcoal sprayed underneath, then stocked in a near airtight room in order to create a grey nearly mirrored finish[40].

But other heat techniques were common. Small objects could be put on a gas flame, a combustible flame, an iron plate heated by a charcoal fire or a tin barrel turning on a charcoal fire or a gas fire[41]. Heating in a sand or air soak were also possibilities and are more even[42].

1.3.2.3 Chemical methods of blueing

Chemical methods were also in use. Soaks of melted metals composed of lead, tin or zinc were heated at a certain temperature to obtain the desired colour. The lead part grew gradually to get a darker colour. This technique was principally applied to blue tools[43].

Colour	Lead part	Tin or zinc part	Fusion point in °C
Yellow	2 parts	1 part of tin	228°C
Brown	3.5 parts	1 part of zinc	254°C
Purple	5 parts	1 part of zinc	265°C
Light blue	12 parts	1 part of zinc	284°C
Dark blue	25 parts	1 part of zinc	293°C

[39] Kraus, Hugo, 1951, p.21

[40] Société des Ingénieurs Civils, 1889, [Online], p. 717

[41] Kraus, Hugo, 1951, p.100

[42] Kraus, Hugo, 1951, p.101

[43] Kraus, Hugo, 1951, p.101

Table 2 : Parameters of the blueing soaks of melted metals ©Kraus, Hugo

A dark blue layer of blueing can also be obtained by soaking the metal in boiling linseed oil or a solution of sodium thiosulfate and lead acetate. Also, it is recommended to treat bigger objects by soaking in the cold solution and slowly heating it to boil.

A rarer technique consists in blueing steel and iron by soaking on a solution of 1L of water containing 5g of iron chlorides and 5g of potassium ferrocyanide.

A special method was common for the blueing of shotgun barrels. They were heated and rubbed with hematite[44].

1.3.3 Other techniques of surface coloration

Several other processes allow the colouring of steel and iron-based materials. They are mainly obtained through chemical methods. They are detailed in this chapter to allow their identification in collections and understand their manufacturing processes.

1.3.3.1 Browning

"Browning" is globally used to define both browning and blackening processes, as most browning methods can be used to produce both and inversely[45]. These methods are partly based on the production of artificial rust, as iron hydroxide or oxide, with the help of acids and the carbonisation of burnt oil layers. The operation, made in an oxidizing atmosphere, allows the formation of a thin layer of dark oxide on the metal after polishing[46].

The most popular technique consists in rubbing the metal with a linseed chiffon soaked with 1 part of antimony chlorine and 3 parts of olive oil or 10 parts of a solution of chlorohydric antimony acid with 1 part of olive oil. The objects are then left for a day standing. The rust forming on the surface is brushed and this method is repeated until a consistent browning is formed. More than ten rubbings are generally necessary to obtain an adherent layer. The browning can then be polished with hardwood or polishing steel and rubbed with linseed oil, waxed with a brush or varnished. The protection limits the corrosion of the browning layer.

Another method described by Lintner relies on the rub of a paste composed of 3 parts of zinc chloride and 2 parts of olive oil, then a mixture of 10g of iron chloride and $100cm^3$ of olive oil.

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[44] Kraus, Hugo, 1951, p.101

[45] Kraus, Hugo, 1951, p.101

[46] ISO.org, 2018, [Online], chapter 3.22

Beutel also introduces a simple solution containing 15g of iron chloride in 1L of water. Denatured alcohol can be added to reduce the browning effect[47].

Browning solutions containing iron chloride or chlorohydric acid offer colours from yellow to reddish brown, and those made of antimony chloride and olive oil allow to obtain a greenish brown colour[48]. Also, a more concentrated solution is rapidly effective, but the colour obtained is not as durable. The addition of a nobler metal, as mercury, bismuth or antimony also fastens the process[49].

1.3.3.2 Blackening

Blackening is possible by a combination of heating and brushing. Iron or steel objects can be rubbed with grease or oil and then heated for half an hour at 200 to 400°C, depending on the required colour. Suif grease is quite adapted, as well as linseed, walnut, poppy, hemp, castor oils. Darker tones can be obtained using 20 parts of tallow and 1 part of sulfur flower.
For ironwork, the process of combustion with linseed oil is used. The object is covered with a thin layer of linseed oil and heated on a charcoal or coke fire in order to carbonize the layer and then burn it. The layer is then rubbed several times with a dry cloth, the temperature lowered and the object rubbed with linseed oil. It is also possible to use this technique on a charcoal fire with metallic brushes.
Smaller objects are soaked in linseed oil and strongly heated in an iron jar[50]. They are then put in a heated rotating drum with 10 parts of dry sawdust and 1 part linseed oil at a lower temperature. A similar method consists in placing the object on a grid standing in a cast iron jar of a diameter of 5cm and filling it with charcoal. The bottom of the jar is then heated with a red flame for 15 minutes[51].
For large-scale operations, ozocerite, which is a natural stone composed of paraffinic hydrocarbons characterized by its waxy aspect[52], is melted around 100°C and objects are soaked in it until ozocerite ignites with a charcoal fire. An adherent black coating is then formed, and offers a good protection against acid, alkaline, air and water.

Armament and horology industries were also using blackening techniques to protect and colour shotgun barrels or watch casing[53]. These processes are known under the names "black swiss" or

[47] Kraus, Hugo, 1951, p.102
[48] Kraus, Hugo, 1951, p.103
[49] Kraus, Hugo, 1951, p.102
[50] Kraus, Hugo, 1951, p.103
[51] Kraus, Hugo, 1951, p.104
[52] Cameo, b, 2020, [Online]
[53] Kraus, Hugo, 1951, p.104

"swiss oxide'[54]. They were sanded and degreased with a chalk paste which is air dried and removed by rubbing. The blackening solutions introduced in the Table ? could be applied in a thin layer for 12 hours, re-applied for 12 hours and then immersed in boiling water for 5 to 10 minutes while rubbed with a steel rotative brush. The process is repeated 3 times[55].

Water	Alcohol	Saltpetre aether	Hydrochloric acid	Nitric Acid	Iron chloride	Copper chloride	Silver chloride	Bismuth chloride	Antimony chloride	Ammonium chloride	Iron vitriol	Copper vitriol
1000	100		120			20	40	20				
1000	100		100			20	50	25				
1000							50			50		
1000		10		15			4		30		50	20
1000	90			5	35							
1000	30			20	75							5
1000	50				15						30	12
1000	50			75	150							30

Table 3 : Blackening solutions used in the armament and horology fields ©Krause, Hugo

Another method described by Dr Wogrinz in 1914 consists in adding to a litre of water 70g of crystallised iron chloride, 10g of ferric chloride, 2g of mercury chloride and a few drops of chlorohydric acid. The yellow-green solution is applied as described for the armament and horology industries, but heated at 100°C during 20 to 30 minutes in a steel cabinet[56]. The objects are then put on a grid and exposed to water vapour for 20 to 30 minutes and put in boiling water for 20 minutes with cornflower extract, the process is repeated 3 times. The reddish rust layer is then converted into a black iron oxide.

Is also evoked the repeated coating of the objects with a solution of 2g of tartaric acid and 2g of tannic acid in 1L of water several times, and air drying.

Antimony coatings were also in use : the objects were soaked in a solution of water, antimony chloride, ferric chloride and a few drops of chlorohydric acid.

Vanino and Mauermeyer introduce a method consisting in soaking dry objects in pure fuming and red nitric acid, rinsing in water and rubbing the layer[57].

1.3.3.3 Annealing processes

Coloration related to the formation of a sulphur iron layer was also a possibility, by a 3 to 4 hours treatment in which iron is alternatively annealed in oxidizing and reducing atmospheres. The object is heated in a closed room and gazes rich in oxygen and gazes absorbing oxygen as carbon oxide or

[54] Kraus, Hugo, 1951, p.105

[55] Kraus, Hugo, 1951, p.104

[56] Kraus, Hugo, 1951, p.105

[57] Kraus, Hugo, 1951, p.106

hydrocarbon enter one at a time[58]. The result is a ½ to 2mm layer of iron oxide, characterized by its good adherence and resistance to water, relative humidity and friction.

A similar method consists in heating the metal red and expose it to overheated water vapour in a room heated at 260°C for 5 to 7 hours, depending on the thickness of the layer wished[59]. This black layer can be filed and chiselled[60].

Moreover, another technique involves the painting or soaking of objects in a heated silicate paste, which becomes liquid at a certain temperature and enters the pore of the metal, creating a dense, mat black layer[61].

1.3.3.4 Iron sulphur coloration

A protective black layer can also be obtained by the formation of iron sulphur. The metal was spread with a sulphur balm, or with a paste constituted of 20 parts of tallow and 1 part of sulphur flower or soaked in a solution of turpentine and sulphur boiled by double boiler. It is then dried at a low heat to obtain a regular colour.[62]

1.3.3.5 Caustic soda and oxidizing agents

A method described around 1935 evokes the black coloration of iron and steel by soaking it in a concentrated and heated caustic soda solution : the alkaline component and oxygen produce iron oxide[63].

1.3.3.6 Melted salts

Another blackening approach consists in immersing the metal in a melted mixture of 4 parts of caustic soda and 1 part of saltpetre. Molten potassium or sodium as well as nitrate can also be used[64].

[58] Kraus, Hugo, 1951, p.106

[59] Kraus, Hugo, 1951, p.107

[60] Kraus, Hugo, 1951, p.106

[61] Kraus, Hugo, 1951, p.107

[62] Kraus, Hugo, 1951, p.109

[63] Kraus, Hugo, 1951, p.111

[64] Kraus, Hugo, 1951, p.109

2 Introduction of the case study : a Ganz & Co projection and enlargement lantern conserved at the Collection Centre of the Swiss National Museum

2.1 The Collection Centre of the Swiss National Museum

The Swiss National Museum has been founded in 1898 in Zurich, after an extensive reflection related to the condition of federal state of Switzerland. Effectively, almost each canton possessed its own heritage collection, representative of its history. The concept of the Swiss National Museum was to represent the federal character of the young nation-state of Switzerland. An extension of the building completed the initial 19th century structure in 2016[65].

The Collection Centre of the Swiss National Museum, located in Affoltern-am-Albis, gathers the collections of the Swiss National Museum, as well as the conservation workshops, the management of the collections and the research in conservation. Opened in 2007, it allows the collaborators to cooperate, share and mobilise know-how and competences[66].

The infrastructure conserves 1822 objects donated by Thomas Ganz, former head of the company Ganz A.G in Zurich. Among these objects are preserved photographs, cinematic technical devices as cameras or projectors from the 20th to the early 21st century and accessories. A projection and enlargement lantern made of blued steel sheets and conserved under the inventory number LM-152706.1 will be the object of this study.

2.2 Identification form

[65] Landesmuseum, Zürich, 2021, [Online]

[66] Sammlunggszentrum, 2021, [Online]

Picture 17 : General view of the object

© HE Arc CR, A.L

Picture 18 : Detail of the object
©HE Arc CR, A.L

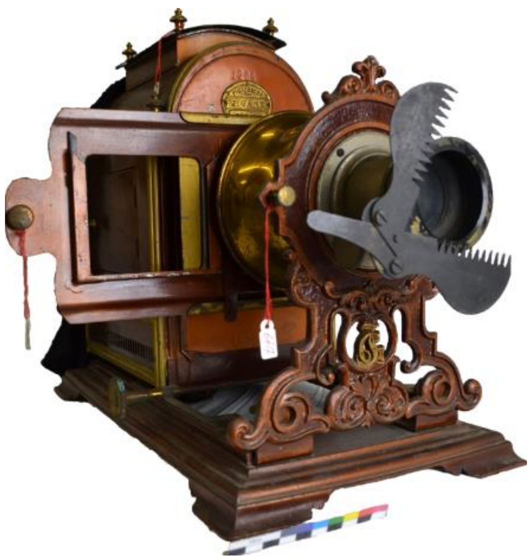
Inventory number		LM-152706.1
Name		Projection and enlargement lantern
Dimensions (H, L, W)		
	Projector	46.7 x 66.5 cm x 28cm
	Piece of furniture	119.5cm x 72.7cm x 41.2cm
	Ensemble	164.6cm x 72.7cm x 41.2cm
Weight		72.2 kg (with pallet)
Materials		Blued steel, copper alloy, ferrous alloy, glass, wood, plastic, paper, asbestos, textile, ceramic, painting, resin
Function		Device allowing the projection of photographic glass plates and the enlargement of the photographs
Provenance		Donation from Thomas Ganz, Ganz AG company (Zurich) on September 2006
Conservation		Collection Centre of the Swiss National Museum

Table 4 : Identification form of the object n° LM-152706.1

2.3 History

2.3.1 The Ganz family

The lantern is part of a donation of 1822 objects related to projection and photography made by Thomas Ganz between 1996 and 2006[67]. He was the director of Foto Ganz AG, a company based in Zurich specialized in photographic and projection devices. The firm has been created in 1844 by his great grandfather Johannes Ganz (1821-1886), lithographer and photographer. He started around 1872 the production of magic lanterns called "pinacoscopes" (*Picture 19*), that he invented to fit the teaching field and for which he received several honours. He was a pioneer of the photographic industry and was appointed manager of the photographic department of the Swiss National Exhibition.



Picture 19 : Pinacoscope conserved at the Camera Museum, Vevey, n°6617 ©HE Arc CR, A.L

He handed the company to his son Rudolf Ganz[68] (1848-1928). Formed by his father, he was a remarkable portraitist and exposed his work in an international exhibition organized at the Museum of applied arts in Zurich[69]. Electrical projectors were also built internally[70]. In 1902, he sold the portrait workshop and his son Emil[71] (1879-1962) took over the projection device company under the corporate name Ganz & Co. projection devices : "Ganz & Co. Spezialgeschäft für Projektion Zürich".

[67] Swiss National Museum, 2021

[68] Dictionnaire historique de la Suisse, 2005, b, [En ligne]

[69] Dictionnaire historique de la Suisse, 2005, c, [En ligne]

[70] Audiovisual Ganz, 2021, [En ligne]

[71] Dictionnaire historique de la Suisse, 2005, c, [En ligne]

Emil also filmed the Jubilee of Queen Victoria in 1897 and was the swiss representative of the firm Zeiss Ikon in Switzerland[72].

In 1982, Ganz & Co became the public limited company Foto Ganz AG through Thomas Ganz (1920-2018) direction. He built his own devices and specialised the firm in the fields of multimedia and analogic cinema equipment. Moreover, he represented his own label Visalux as well as prestigious brands as Kodak[73] and was since the 1950's a collector of pre-cinema devices and optical toys. His collection has been sold at Christie's in 2007[74]. He was also one of the founding members of The Magic Lantern Society, an association focusing on pre-cinema devices founded in 1977[75] and published several patents related to projection apparatus[76] or the improvement of the sliding of transparencies[77]. His daughter Catherine Ganz managed the company renowned Audiovisual Ganz AG, specialising in digital systems and conference facilities[78], from 1997 until 2007 when she sold the company to go back to her scenic artist career[79]. The twelve branches of AV Ganz AG have closed in 2018 after 174 years of existence, due to bankruptcy[80].

Picture 20 : Johannes, Rudolf, Emil, Thomas and Catherine Ganz © Audiovisual Ganz AG

2.3.2 An object inscribed in its time

The context of the donation is related to the situation of the company in 2006. The firm was about to be sold the year after and Thomas Ganz has a look at the objects which were conserved in the back shops, to select those which could be interesting for the museum. He was also passionate with pre

[72] Dictionnaire historique de la Suisse, 2005, a, [En ligne]

[73] Audiovisual Ganz, 2021, [En ligne]

[74] Christie's, 2021

[75] The Magic Lantern Society, 2021, [Online]

[76] Worldwide Espacenet, undated, a, [Online]

[77] Worldwide Espacenet, undated, b, [Online]

[78] Christie's, 2006, [Online]

[79] Dioramanea, undated, [Online]

[80] Tages Anzeiger, 2018, [Online]

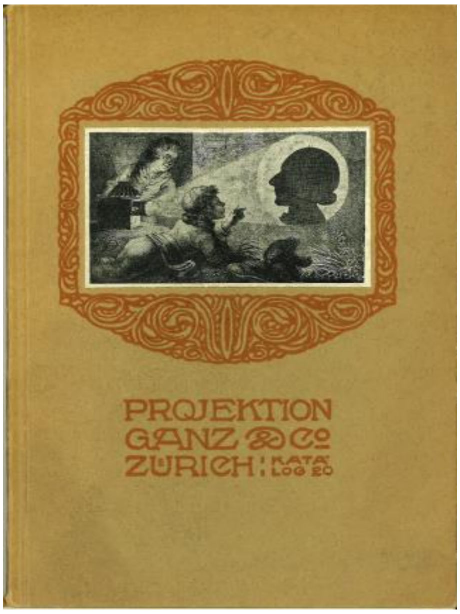
cinema devices and he often bought objects from flea markets[81]. The object of this study was part of this donation.

As no documentation was related the object, an investigation has been made in the literature and by direct observation.

A plate at the front of the device states "Ganz & Co. Spezialgeschäft für Projektion Zürich" : it is the corporate name given to the firm by Emil Ganz since 1902. We can thus deduce that the projection lantern has been produced after this date. Also, its characteristics correspond to those of an early 20th century projection device : a light source lightning a glass lantern slide*.

A brochure conserved at the Camera Museum (Vevey) dated from 1920 and presenting projection devices from Ganz & Co has been consulted and a similar lantern has been found. The model "Rigi", which is also made for projection and enlargement shows a very similar construction : a lantern made of steel sheets with removable top and chimney, equipped with a flexible bellow. It was dedicated to large-scale projection for schools and ads. Also, one of the devices introduced in the brochure, a "Ernemann Imperator" projector, has been dated around 1914, which allows us to approximately date the object of this study[82].

However, the lecture of this brochure and the study of the object allow to conclude that the wooden box and metallic structure carrying the lantern have been added later and that the current state of the object is not its original condition.



Picture 21 : Brochure « Projektion Ganz & Co Zürich : Katalog 20" and Rigi projection lantern @Ganz & Co Zürich

[82] Ganz & Co Zürich, 1920

3 Technologic study

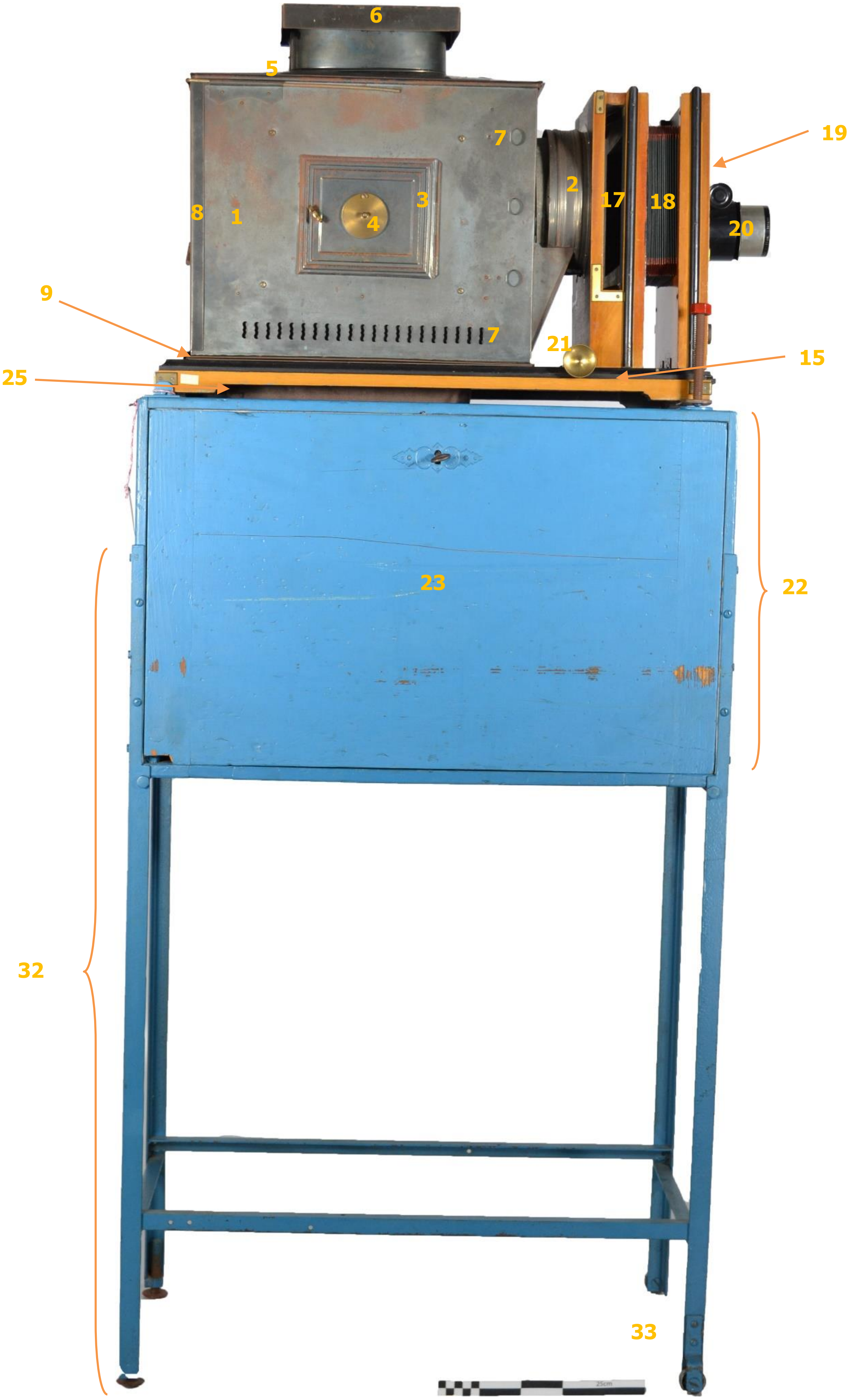
3.1 Description

The object is constituted of 3 main parts : a projection and enlargement lantern, a wooden box and a metallic structure. Each constitutive part has been numbered on *Picture 22*, *Picture 23* and *Picture 24* for a better understanding.

The lantern (1) is made of a rectangular box whose front is opened with a circular aperture (2), while sides are equipped with doors (3) bored with observation peepholes (4) and sliders. The top of the lantern (5), which carries the chimney (6), is removable. The ensemble is bored with circular openings (7) but all of them are covered with metallic blinds inside. The back of the lantern is a door (8) which can be lifted or removed completely. The lantern stands on a base (9) constituted of two metallic sheets allowing the sliding and the removal of the object thanks to grooves on the sides. Inside the lantern, five plates of asbestos (10) are screwed to the sides, doors and front walls. Furthermore, the inside is furnished of a metallic support (11) carrying a sliding plate (12) on which the condenser (13) is fixed. A light bulb stands (14) on a lamp cap in front of the condenser, maintained by a rod fixed on the metallic support. It is connected to the power cable of the object, as the bottom of the lantern is bored. The ensemble stands on a wooden base (15) whose front part contains from rear to front the lens carrier (16), the glass lens, the lantern slides chassis (17), the bellow (18), the removable lens carrier (19) and the Emil Busch A.G lens (20). The ensemble is moved by a rack-and-pinion drive screwed (21) on the wood base of the object. The lantern and its wooden support are fixed on a wooden box (22).

The rectangular painted wooden box is equipped with two handles on the sides and a main door (23) at the front, closed by a key. No other mechanical setting holds the door to the box. Inside, a textile (24) sticked to the support made of two metal plates (9) connects the interior of the lantern to the interior of the box : the bottom of the lantern and the top of the cabinet are bored with openings (25). The power cable (26) connected to the lamp cap stands at the bottom of the box. On the right, 8 curved ends screws (27) are fixed at the wall. On the left, a transformer (28) is screwed at the bottom of the box. A metallic grid (29) isolates this component from the rest of the box and carries the switch of the transformer (30). Upon these items stands an empty locker (31) closed by a screw.

A painted metallic structure holds the wooden box and the lantern (32). It is constituted of 8 brackets and two long screws carrying the wooden box. The bottom right side of the structure is equipped with wheels (33).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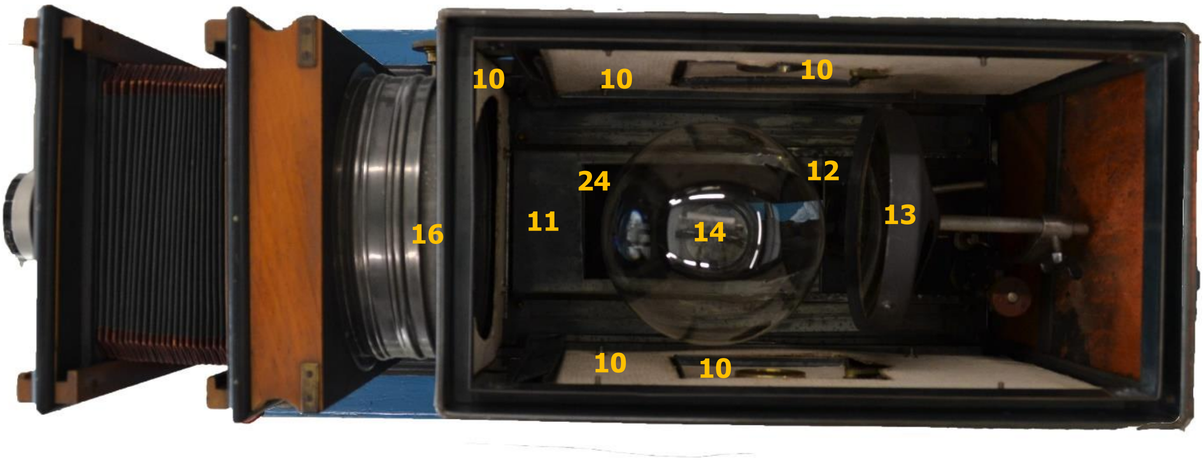
Picture 22 : Object LM-152706.1 with numbered constitutive parts ©HE Arc CR, A.L



Picture 23 : View from the top of the object with numbered constitutive parts ©HE Arc CR, A.L[83]

Picture 24 : View from the inside of the wooden box, with numbered constitutive parts ©HE Arc CR, A.L[84]

[83] This is a picture after restoration, as it would have been too unsafe to open the lantern with untreated asbestos plate to take a proper picture.

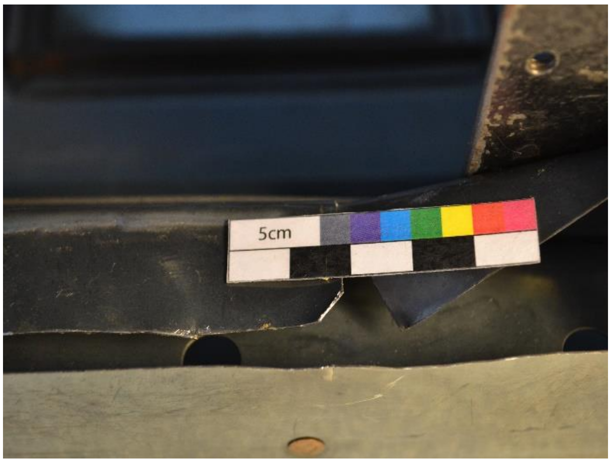
[84] This is a picture after the removal of the asbestos plates and the complete dusting of the object.

3.2 Puddled iron or steel?

Literature evokes both puddle iron and steel as base materials used to manufacture blued sheets. To determine the nature of the metal, for documentation purposes as well as for allowing the right choice of metallic coupons to test the treatments of conservation, a sample (*Picture 25*) has been collected on the object to be observed and analysed as a cross-section under inverted microscope and scanning electron microscopy. The sample (*Picture 28*) has been obtained by cutting the metallic sheet with a wire cutter, as the use of a chainsaw[85] was not possible on this object for access and construction reasons (*Picture 26*, *Picture 27*).

Picture 25 : Localisation of the sample at the bottom of the lantern ©HE Arc CR, A.L

Picture 26 : Area of the object before collecting the sample ©HE Arc CR, A.L

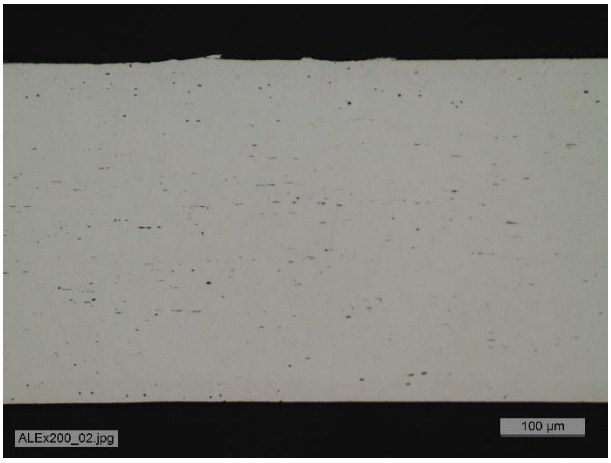


Picture 27 : Area of the object after collecting the sample ©HE Arc CR, A.L

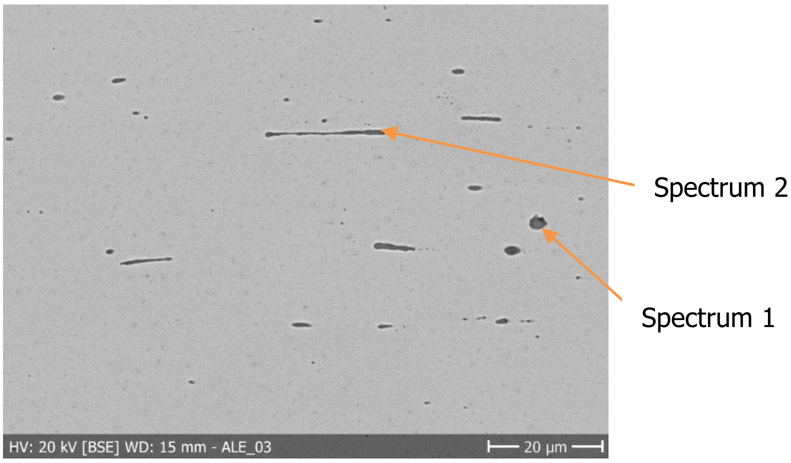
[85] Cséfalvay, Catherine, 2021

The observations under inverted microscope demonstrated a microstructure with a low quantity of impurities (*Picture 29*). A puddled iron would contain way more constitutive elements and inclusions as phosphor[86], aluminium, copper or molybdenum (*Picture 31*). Also, the composition of two areas of the sample have been analysed with scanning electron microscopy (*Picture 30*, *Picture 32*, *Picture 33*). Iron (Fe), manganese (Mn), silica (Si), sulphur (S) characterize a steel alloy as well as the microstructure[87].

Picture 28 : View of the sample under binocular magnifier ©HE Arc CR, A.L



Picture 29 : Microstructure of the sample ©HE Arc CR, A.L



Picture 30 : Localisation of the two areas analysed under scanning electron microscopy ©HE Arc CR, A.L

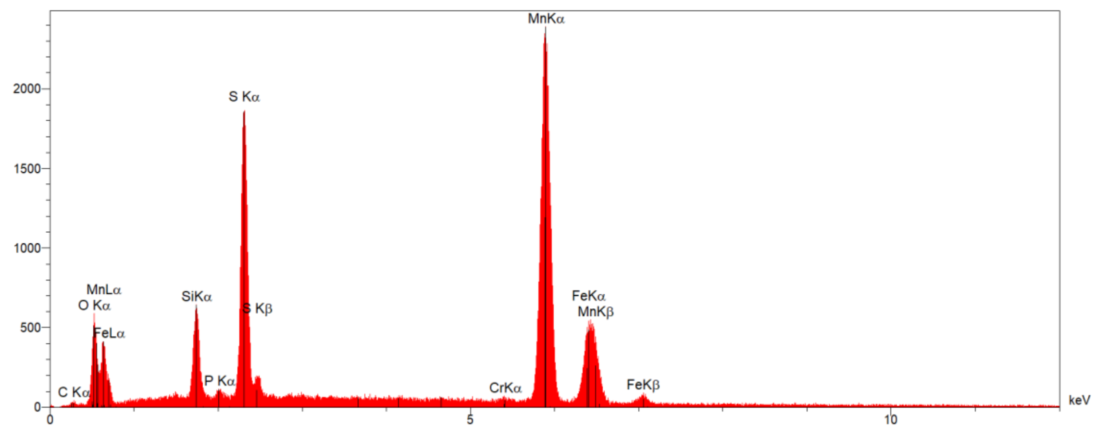
C	Mn	Si	S	P	Ni	Cr	Mo	Cu	Al	Fe
≤ 0,03	≤ 0,05	0,11	0,052	0,54	0,039	≤ 0,01	≤ 0,01	≤ 0,01	0,028	bal.

FIG. 1 – Composition chimique moyenne du fer puddlé de 1892 du viaduc de Lambézellec.

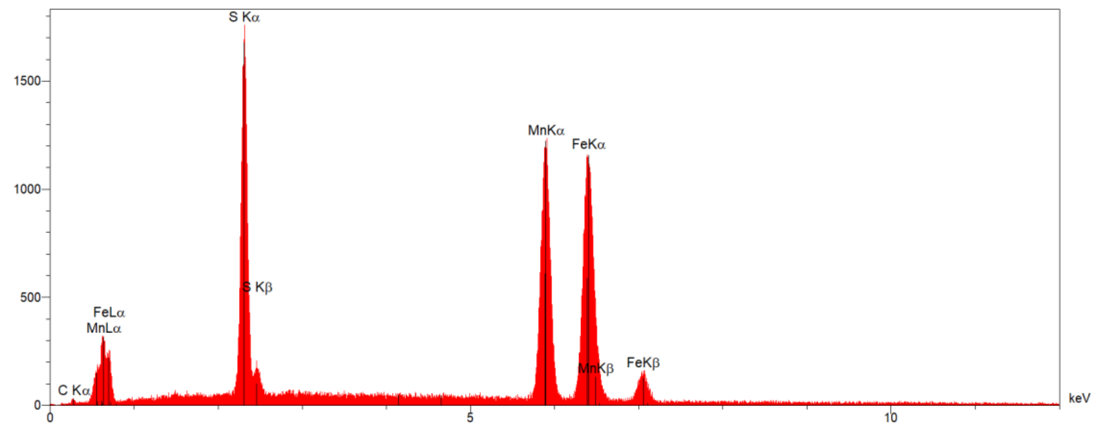
[86] Calloch, Sylvain, *et al.*, 2011, p.1

[87] Degrigny Christian and Ramseyer Stephan, 2021

Picture 31 : Chemical composition of the viaduct of Lambézellec (1892), made of puddled iron ©Sylvain Calloch



Picture 32 : Spectrum 1, scanning electron microscopy ©HE Arc CR, A.L



Picture 33 : Spectrum 2, scanning electron microscopy ©HE Arc CR, A.L

3.3 Constitutive materials

The object LM-152706.1 is a composite object, containing the following materials.

Blued steel

The lantern, its external sliding support and the glass lens support are made of blued steel.

Wood (bare, varnished, painted)

The wood base of the object is made of varnished and painted tropical wood (mahogany).
The wooden box is painted, except for the bottom part which remained bared.

Ferrous alloy (bare, painted)

Most mechanical assemblies (screws) and the structural elements of the transformer are constituted of ferrous alloy. Painted ferrous alloy also composes the structure of the object made of brackets and long screws, as well as the base of the light source.

Red lead

The paint covering the inside side of the backdoor of the lantern as well as the inside of the chimney is composed of red lead[88].

Copper alloy (bare, varnished)

The handles of the side doors of the lantern, the structure of the peepholes, the lamp cap, the rack-and-pinion drive and the rivets are constituted of brass. Copper alloy is also a constitutive material of the electrical wires.

Glass

Both lenses of the object, the bulb, the mirror of the condenser and the peepholes are made of glass.

Plastic

The electric cables, the wire clamps and the power socket (Bakelite) are constituted of plastic.

Ceramic (bare, painted)

Insulating parts of the lamp cap and the switch are composed of ceramic. The switch is covered with paint.

Asbestos

Five insulating plates of asbestos cover the walls inside the lantern.

Textile

The curtain fixed on the metallic base of the lantern.

Resin

The coils are coated with resin. It has also been used to stick the textile to the metallic base of lantern.

[88] See analysis on Appendix IV.6 p.140

3.4 Manufacturing techniques and assembly

3.4.1 Blueing of the steel sheets

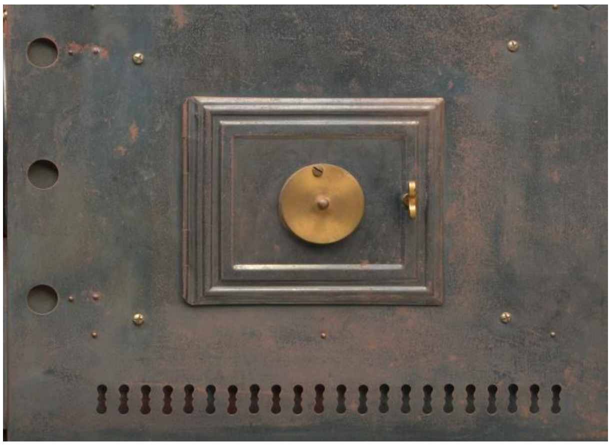
The blued layer of the object has been analysed thanks to Raman spectroscopy to define the type of blueing method used on the object. Fourier transformed infrared spectroscopy has also been performed to identify potential salts or oils on the surface, which would potentially indicate a chemical blueing. Hematite and magnetite have been identified as constituents of the blued layer[89] and no oils or salts have been found[90]. A blueing by heating as described on chapter 1.3.1 has very probably been achieved on the object.

3.4.2 Shaping and assembly of blued steel sheets

It is surprising to discover how a simple sheet of metal can become a technical object involving scientific principles. After the conjoint step of lamination and blueing of steel to obtain blued steel sheets (1.3.1), , the mercantile product is packed by ensembles of 100 kg packaged in raffia and transported by boat from Russia to Central Europe. Metal sheets are then sorted by thickness. The storekeeper prepares the right quantity of metal sheets for the manufacturing of a range of devices and distributes them in the workshops for machining.

In the sheet metal working workshop, the body of the lantern is created. The tracing and the cutting of the walls and the windows of the devices are achieved with a sheer, and a shape of dome is given to the top of the lantern thanks to stamping (*Picture 34*). A cutting machine is used to puncture the sheets to obtain aeration openings. Also, deep drawing is practiced to adorn the side doors or the lens carrier (**Erreur ! Source du renvoi introuvable.**).

Picture 34 : Shape of dome of the top of the lantern and mechanical assembling with a metal tube ©HE Arc CR, A.L



Picture 35 : Aerations opening obtained with cutting and deep drawing machines ©HE Arc CR, A.L

[89] Appendix IV.2, p.129

[90] Appendix IV.2 p. 129

An impressive work of folding of the edges of the sheets (*Diagram 3*, *Picture 36*) is then completed to allow their drilling. The assembly is achieved in the workshop of the fitters, by riveting or creating structures welcoming a metal tube (*Picture 34*). The sheets could also be rolled to create mechanical assembling, as hinges for the side doors or to maintain the metal tube of the backdoor of the lantern. In the instance, blued sheets of 0.8 mm were used to mount this object.

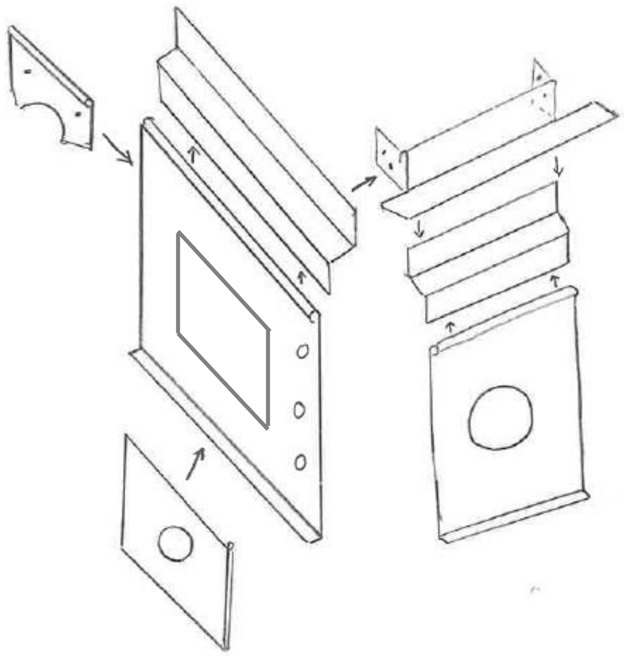


Diagram 3 : Exploded drawing of the assembly of the front and a side of the lantern ©HE Arc CR, A.L

Picture 36 : Work of folding on a door of the lantern ©HE Arc CR, A.L

Copper elements as the peepholes or the rack-and-pinion drive screwed are cut, drilled and threaded with a lathe. They could then be assembled by screwing pieces together, by screws or by soldering, as it is the case for the handles of the side doors.

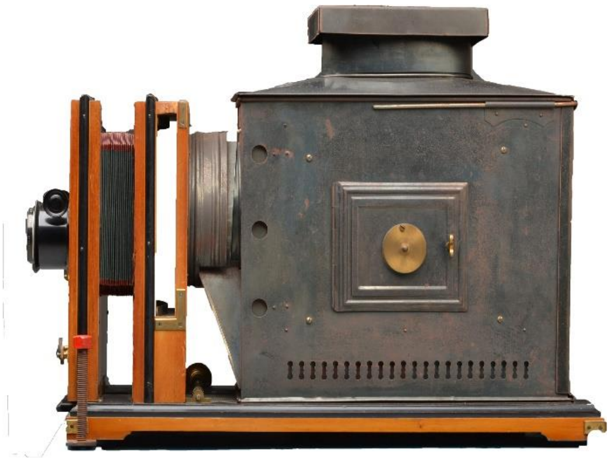
Picture 37 : Assembling by soldering of the handle of the side door ©HE Arc CR, A.L

Figure 38 : Assembling of two brass pieces by screwing them together ©HE Arc CR, A.L

3.4.3 Wood making techniques

The wooden plates constituting the wooden box and the wooden base of the lantern have been created by cutting and sanding wood material. A dovetail assembly has been performed for the 4 constitutive parts of the wooden box. However, we cannot define if an adhesive has completed this assembly as the object is completely painted. Also, a few nails are visible on the sides of the back of the object, but their use is not generalised. Several wood reinforcements are supplementing the ensemble inside the wooden box. The front door is made of several wood planks. A cavity inside the box mechanically maintains the door. The box has been repainted blue afterwards, as surplus of paint are visible on several parts of the object.

The wooden base of the lantern is more ornamented (*Picture 39*). Several planes have probably been used to create the shape of the feet of the object, as well as the flat part where the lantern lays. It is mainly assembled by rivets, except for the detachable parts, which can be removed thanks to brass elements (*Picture 40*).



Picture 39 : Ornamented base of the lantern ©HE Arc CR, A.L

Picture 40 : Brass elements allowing the removal and the movement of wooden items ©HE Arc CR, A.L

3.4.4 Extensive know-how of technical and electrical items

The plurality of materials involved in this object has necessitated the use of a considerable number of traditional and industrial techniques of fabrication, which will be developed in this chapter.

3.4.4.1 Metals

Many conventional techniques have been used to create this object. Folding allowed the fabrication of the 8 brackets constituting the metallic structure of the object. Bending has permitted the manufacture of the metallic structure of the Emil Busch A.G lens or the lens carrier. The key of the wooden box has been obtained by casting. The machining of circular pieces as control knobs has been obtained with a lathe.

The assembling of most elements is effective thanks to screws or the bending of a metallic material around another. Concerning coatings, galvanising (*Picture 41*) has been used on the Emil Busch A.G lens or several structural pieces of the support of the light source. Painting is also visible on these two parts of the object (*Picture 41*, *Picture 42*).

Picture 41 : Galvanising and painting of the Emil Busch A.G lens ©HE Arc CR, A.L

Picture 42 : Painting of the base of the light ©HE Arc CR, A.L

3.4.4.2 Glass

Several elements of the objects are made of glass, as the lens, the condenser or the bulb. The concave shape of the lens and the condenser seems to have been obtained by the industrial method of casting and pressing. It consists in pouring the molten glass into a metal cast iron or steel mould and press inside the latter to fit the shape of the mould[91]. In order to obtain a mirror surface on the condenser, an electroless plating has been made, using a solution made of a silver salt and a reducing agent. The metallic ions are reduced in metal and precipitate, generating a layer of metallic silver on the glass. This method is in use since the 1850's[92].

The bulb (*Picture 43*) equipping the lantern has been obtained by glassblowing[93]. It is received with a large collar, on which a marking is done. The electric conductors bringing the current from the outside to the inside of the bulb are made of three wires of copper, platinum and nickel brazed together. Then, a short tube of glass is heated by a blowtorch while rotating in a machine. When the border of the tube is softened, it is manually splayed with a tool. A baguette of glass is exposed to a blowtorch in another machine and takes a spherical shape. The 3 pieces – the electric conductors, the glass tube and the baguette - are soldered form the feet of the bulb. Several wires of molybdenum are trapped in a glass bead at the top of the baguette. The molybdenum wires will support the tungsten wire[94]. To obtain a tungsten wire, tungsten powder is heated at 3000°C in a mould and hammered to get a log. It is then wire drawing in several apron-drafting machines. The wire is inserted in between the molybdenum wires[95]. Then a blowtorch is used to soften the glass to solder the foot to the bulb where the marking has been done. Consequently, the collar breaks off[96]. The void is made in the bulb thanks to a pneumatic and mercury pump, and the copper socket is fixed with cement[97].

[91] Le magazine de Pro Antic, 2017, [Online]

[92] Selwyn, Lyndsie, 2004, p.10

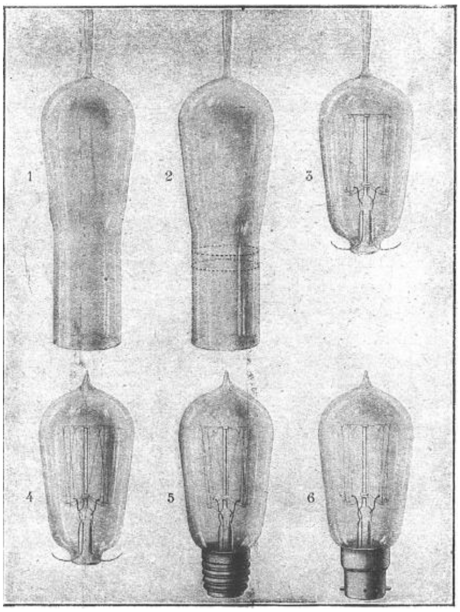
[93] Violland, Camille, 1917-1918, p.34

[94] Violland, Camille, 1917-1918, p.40

[95] Violland, Camille, 1917-1918, p.41

[96] Violland, Camille, 1917-1918, p.40

[97] Violland, Camille, 1917-1918, p.45



Picture 43 : Stages of the manufacturing of an incandescent bulb ©Violland Camille

Asbestos

The manufacturing of asbestos plates is not documented. But their observation allowed to conclude that they are made of several sheets of low agglomerated fibres[98]. The plates seem to be the result of a pressing and the use of a cutting machine.

Plastic

The fabrication of poly vinyl chloride (PVC) cables starts with the polymerization of the material from 50 to 75°C, to obtain PVC particles of a dimension of 50 to 250 µm. Additives as phthalates and stearic acid[99] are then added to the particles by stirring or grinding at a high speed, or by heating them before shaping[100].

Textile

The textile used as a blind in the lantern and the wooden box seems to be a cotton twill. It is a thick fabric whose weaving is characterised by fine obliques[101].

Transformer

[98] Lefebvre, Alexandra, 2019, p.27

[99] Shashoua, Yvonne, 2008, p.161

[100] Shashoua, Yvonne, 2008, p.48

[101] Mondial Tissus, 2021, [Online]

The magnetic circuit of the transformer is constituted of several plates of soft iron insulated from each other with a varnish. The windings are constituted of copper wires insulated with textile sheaths and covered with resin.

3.5 An experimental object

The study of the object conducted to the conclusion that it has been considerably modified from its original condition (*Picture 44*). The original object is the lantern and its wooden base. A comparison with a Ganz & Co lantern commercialized around 1914 could be done (*Picture 21*), as the dimensions and the configuration of the lantern, the length of the bellow (45cm), the size of the glass plates and the base of the light source of the object. The fact that asbestos plates are equipping the inside of the lantern was also questioned, as there is no need of them as heat protection for an incandescent bulb. The lantern was initially commercialized with a radial arc lamp (*Picture 45*), which explains the necessity of asbestos plates to control the released heat[102]. The evolution of the light sources and the depletion of charcoals needed to supply the arc lamp may be the reasons which pushed the owner of the object to operate a change of the light source[103]. It can be observed that the constitutive elements of the former arc lamp have been used to build the actual light source : the metallic base, the control knobs and the metallic body (*Picture 46*). To fit the new light system, holes have been bored at the bottom of the lantern and at the top of the wooden

Picture 44 : Added parts on the object, in red ©HE Arc CR, A.L

[102] Ganz & Co Zürich, 1920

[103] Schüle, Bernard, 2021

box (*Picture 47*). The bulb equipping the light source has been produced between 1926 and the 1994, if we refer to the Philips logo and a technical brochure introducing the device (*Picture 48*, *Picture 49*). A lot of elements show that these modifications have been made by an amateur. The finishing touches of the metal work as well as the soldering work on the light source and the lens are generally rough (*Picture 50*), and a light bulb which is not suitable for projection has been chosen. The Philips type 62 bulb with a power of 1000W was supposed to be used to enlighten theatres[104]. However, the lamp allowed the use of plastic diapositives, which would have been impossible with an arc lamp[105].

Also, the wooden box was initially a trunk, as shown by the handles on the sides : the object was made to be carried.

Moreover, the chimney at the top of the object is not the original one. It is a painted chimney, contrary to the whole blued steel object. Besides, it is generally removable and here, it has been riveted. Also, the base of the chimney is oval and should carry a conic chimney. The actual chimney is rectangular. Repaint inside the chimney, exceeding on the blued steel is also a hint to conclude that the chimney is an addition.

The painting of the inside of the chimney has been analysed and compared to the paint covering the inside of the backdoor of the

Picture 45 : Radial arc lamp, Ganz & Co Zürich ©Ganz & Co Zürich

Picture 46 : base of the light source constructed with former elements of the arc lamp ©HE Arc CR, A.L

Picture 47 : Bored bottom of the lantern ©HE Arc CR, A.L

[104] Philips, 1926, p.4

[105] Schüle, Bernard, 2021

lantern[106], as they are visually similar. Both are constituted of red lead, which would say that the backdoor of the lantern is also an addition. A curtain was very probably set up, as the setting wheels of the arc lamp exceeded the back of the lantern to allow the setting of the light source.

The modifications could have been done between the 1940's and the 1960's, as the bulb have been commercialized between 1938 and 1968 if we refer to the Philips logo, which changed afterwards. Also, PVC was invented in 1926 but marketed in the 1940's[107].

A nearly identical Ganz & Co lantern conserved at the Camera Museum has just arrived in the institution in July 2021, allow us to confirm some of our hypothesis (*Picture 51*, *Picture 52*). The original chimney is visible, as well as a curtain at the back of the lantern. The object is equipped with an official electrical light source, but the walls of the lantern are also covered with asbestos plate. The original light source was very probably an arc lamp too[108].

Picture 48 : Philips's logo through the years ©Philips

Picture 49 : Philips's logo of the bulb of the lantern ©HE Arc CR, A.L

Picture 50 : Rough modifications of the light source : soldering and cutting ©HE Arc CR, A.L

[106] Appendix IV.6, p.140

[107] Shashoua, Yvonne, 2008, p.48

[108] Schenker, David, 2021

Picture 51 : Ganz & Co projection and enlargement lantern conserved at the Camera Museum ©David Schenker

Picture 52 : Ganz & co projection and enlargement lantern conserved at the Camera Museum, view of the side ©David Schenker

4 Functional study

This object allows the projection of photographic glass plates of different formats (*Picture 53*, *Picture 54*) as well as the enlargement of photographs. It was rare to develop photographs of large dimensions in a darkroom, as it was difficult to obtain a satisfying result underneath 30x40cm in such conditions. It was also a pricey service. It was then preferred to get a small photographic cliché of 9x12cm on a glass plate to be used for enlargement[109].

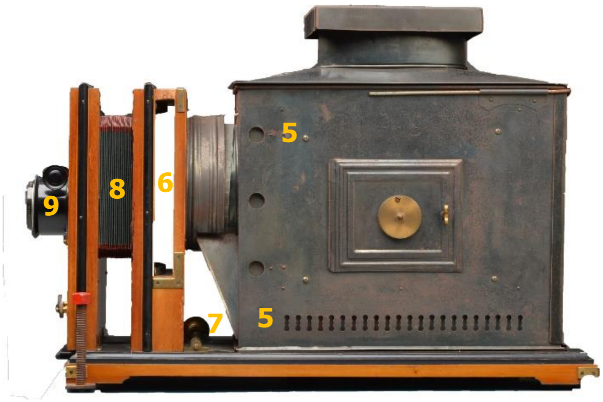
Picture 53 : Glass plate illustrating a local ad, 10x8.5cm, ©HE Arc CR, A.L

Picture 54 : Coloured glass plate illustrating marchers, 5x5cm ©HE Arc CR, A.L

[109] Coustet, Ernest, 1933, p.541

4.1 Nomenclature

Picture 55 : Nomenclature of the inside of the object ©HE Arc CR, A.L



Picture 56 : Nomenclature of a side of the object ©HE Arc CR, A.L

1. Lantern : box made of steel sheet, acting as a dark room.

2. Bulb : lamp furnishing light.

3. Condenser : concave light reflector concentrating the light behind the glass plate.

4. Lens : concave light reflector concentrating the light in front of the glass plate.

5. Openings : circular and fancy apertures in the lantern, allowing the combustion of the light source in the case of an arc or oxydric lamp.

6. Lantern slides chassis : wood support of the lantern slides, allowing the viewing and enlargement of different sizes.

7. Rack-and-pinion drive screwed : device allowing the mechanical advancement or the setback of the focus.

8. Bellow : light-tight device allowing the movement of the Emil Busch A.G lens relatively of the rest of the projector.

9. Emil Busch A.G lens : lens allowing the focus.

4.2 Modus operandi

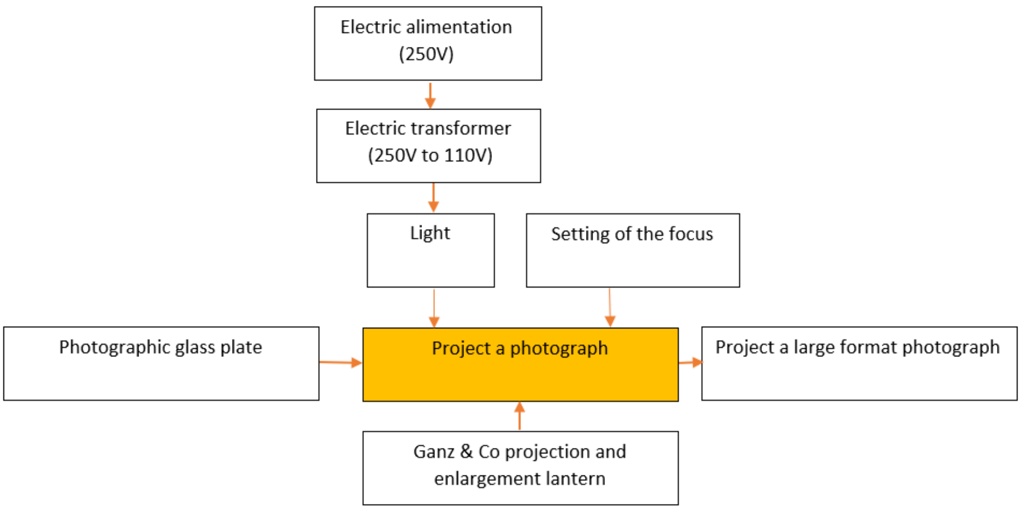


Diagram 4 : Operation diagram of the projection of a glass plate ©HE Arc CR, A.L

The projection of a photographic glass plate starts with the connecting of the power outlet to the power supply. The transformer is then turned on : this electric device transforms the high voltage current of the power supply (250V) in a low voltage current (110V) adapted to the device. The glass slide is inserted in the lantern slide chassis, and the latter in the aperture in front of the lens. The setting of the condenser and the focus is then done to allow the projection of a large format photograph on a wall or on a special screen (*Diagram 4*).

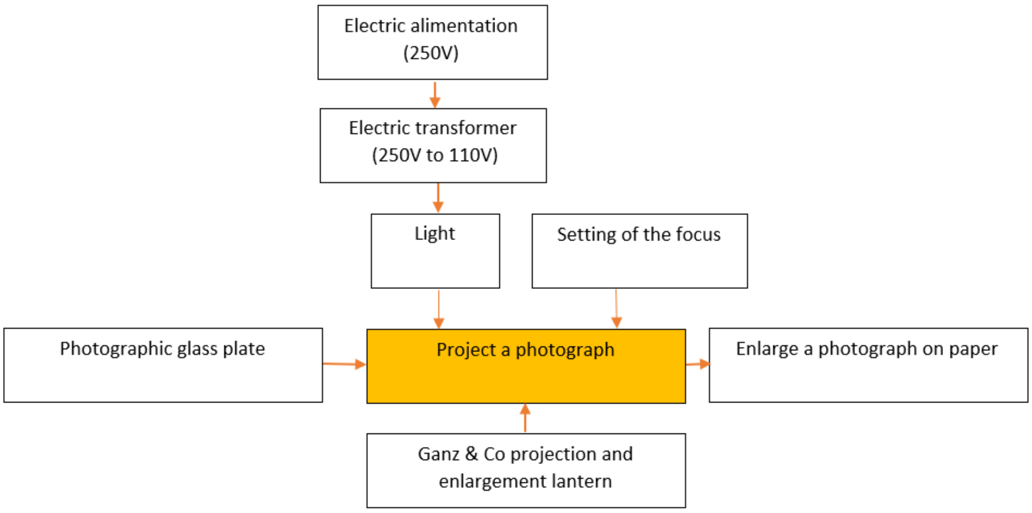


Diagram 5 : Operation diagram of the enlargement of a photograph ©HE Arc CR, A.L

The enlargement of a photographic glass plate starts with the implementation of a photosensitive paper on the projection screen. A shutter can protect the paper from the light before and after the exposure, or an inactinic filter put in front of the setting lens to avoid the exposure of the paper. The condenser is removed from the lantern as it is often a source of aberration. Indeed, a red-blue halo can appear if the lamp is not centred in front of the condenser. The shutter or the inactinic filter is removed from the front of the lens and the paper is exposed. An enlarged photograph on paper is obtained. A gelatine process paper, composed of brome compounds in suspension in gelatine, could be use (*Diagram 5*)[110].

4.3 Determination of the working regime

A partial study of the working regime has been carried on, as the dismantling of the grid locking the transformer would have damaged the painting layer put through it. Nonetheless, the condition of the object has been assessed and resistance measurements carried on for the bulb and the power cable.

[110] Coustet, Ernest, 1933, p.542

Two elements run counter to a prospective functioning of this object. The first is the presence of asbestos in the device, which does not allow the functioning of the projection lantern[111]. The second is the voltage of the power of the object, which is not assured anymore nowadays, as Switzerland delivers 230V.

However, the lantern and its equipment (condenser, bulb, lens, bowel, rack-and-pinion drive screwed, Emil Busch A.G lens) are complete and in good conditions of conservation.

The electric system has been studied partially as the condenser was not accessible and sparsely visible. The power cable is complete, but its sheath is degrading. The 2 coils of the transformer seem in good condition. The resistance of the bulb and the power cable is about 0.00 ohm, which means that the consumer and the conductor are operational.

5 Condition report of the alterations

5.1 General overview

All the constitutive parts of the lantern show general surface dust and soiling. Its blued steel sheets principally show red corrosion products of different thicknesses. Pitting (*Picture 57*), filiform (*Picture 58*) and generalized corrosion (*Picture 60*) have been identified. The inside of the lantern is covered with localised areas of filiform corrosion, except where the base of the light source is placed (*Picture 59*). Occasional black corrosion products are visible on the upper part of the lantern. Losses of the grey protective layer (*Picture 61*) are also noticeable, mainly on the outside sides of the sheets. Mechanical alterations as scratches (*Picture 63*), as well as structural alterations, as deformation and dents are also perceptible. Chemical alterations as fingerprints and localized whitish surface dirt are also visible, as well as sheen of the blueing layer. A lot of halos (*Picture 62*) are also perceptible on the blued steel, as well as sag of repaint (*Picture 64*).

Ferrous elements mainly show corrosion products whereas brass parts unveil tarnishing and scratches. Concerning glass, both peepholes from the doors are cracked, the lens shows glass corrosion, and the condenser is silver tarnished. Asbestos plates are concerned by a lifting and detachment of fibres and fraying of their edges.

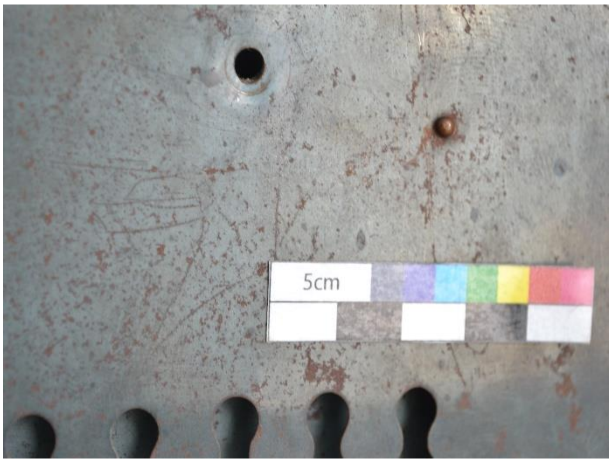
[111] Confédération suisse, 2005, [Online], chapter 1, article 1, a

The inside and outside parts of the wooden box are covered with surface dust and grime. Several long cracks and splits are visible. Bare and painted wood are covered with dents, scratches, holes and chips. Tidelines, paint and wood losses, paint liftings, whitish and brownish surface dirt, sags and fingerprints are also visible occasionally on the painted wood and iron grid. Varnished wood is concerned by a lifting and a reticulation of the medium. Iron and zinc elements are covered with generalised corrosion.

All electric components show general grime. The yellow cable is concerned by hardening and yellowing and the black cable by white blooms and a strong new car seat smell. Ceramic elements show red deposits of painting and soiling.

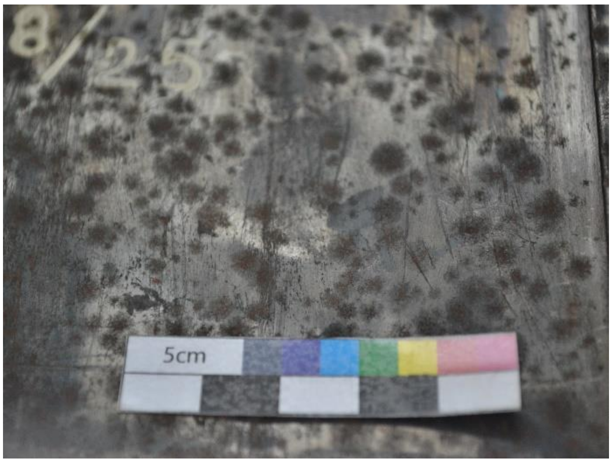
The painted structure made of ferrous alloy carrying the wooden box is covered with dust and grime. Paint losses and orangey stains are also visible. Ferrous assembly elements show punctual corrosion and the zinc-plated wheels coating losses.

A detailed condition report ranked by material, with a diagnostic of each alteration is available on appendix I Detailed condition report, p.4.

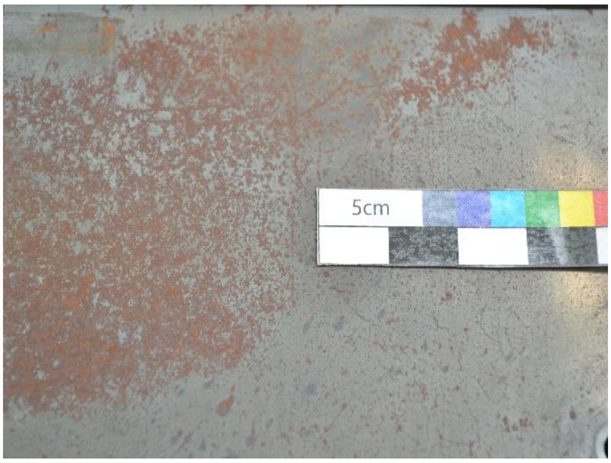


Picture 57 : Pitting corrosion on blued steel
©HE Arc CR, A.L

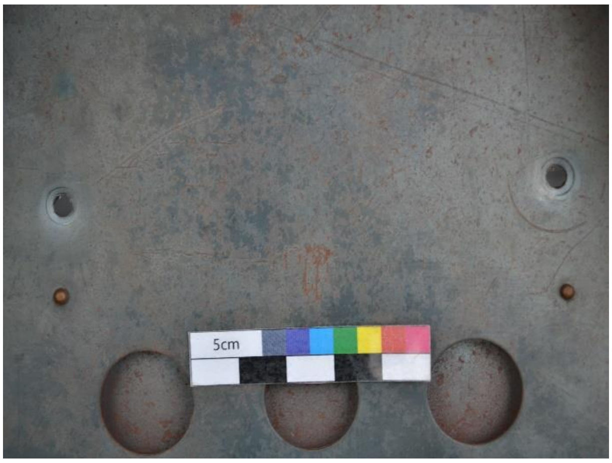
Picture 58 : Filiform corrosion on blued steel
©HE Arc Cr, A.L



Picture 59 : Localised filiform corrosion on blued steel ©HE Arc CR, A.L

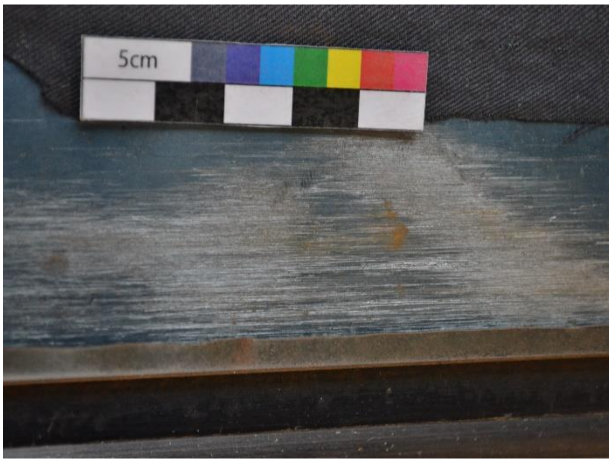


Picture 60 : Generalized corrosion on blued steel ©HE Arc CR, A.L



Picture 61 : Losses of the blued layer ©HE Arc CR, A.L

Picture 62 : Halo on the blued layer ©HE Arc CR, A.L



Picture 63 : Scratches on the surface of the sliding plate of the lantern ©HE Arc CR, A.L

Picture 64 : Sag of repaint on the bottom part of the chimney ©HE Arc CR, A.L

5.2 Description and identification of the corrosion products

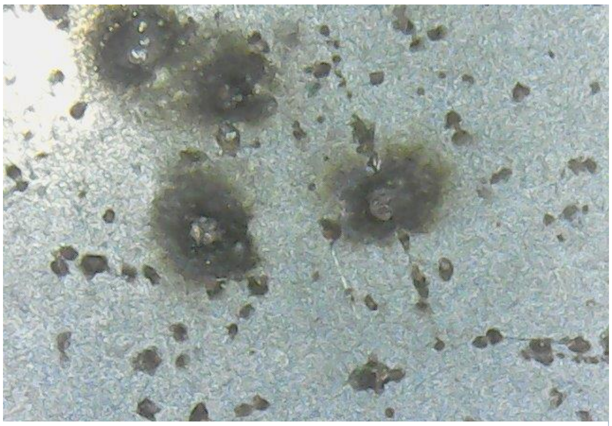
Three types of corrosion have been identified on the blued steel sheets of the object.

Pitting corrosion (*Picture 65*) forms cavities at the surface of the metal and initiates with the presence of chloride ions[112]. It sparked everywhere on the blued steel sheets, except on areas covered with another piece of metal or asbestos plates. Few pristine blued areas are found on the outside walls of the lantern.

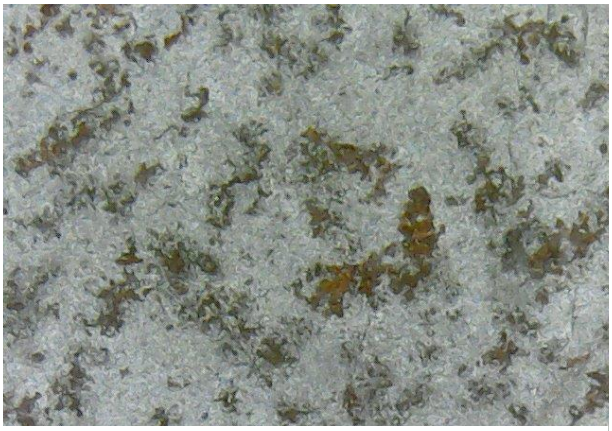
Filiform corrosion (*Picture 66*) develops under the blued coating as the form of filaments[113]. It is punctually developed on the outside walls of the lantern, but hundreds of small, localised areas of filiform corrosion are punctuating the bottom of the inside of the lantern, as well as the borders of the side doors.

Extensive filiform corrosion (*Picture 67*) is a developed form of filiform corrosion. It is characterised by an underlayer of black filaments covered with a thick and layer of red corrosion products. It is generally developed on the upper parts of the sides of the lantern, and completely generalised at the front. Also, the areas of bending and stamping of the sheets are very much impacted by generalised corrosion.

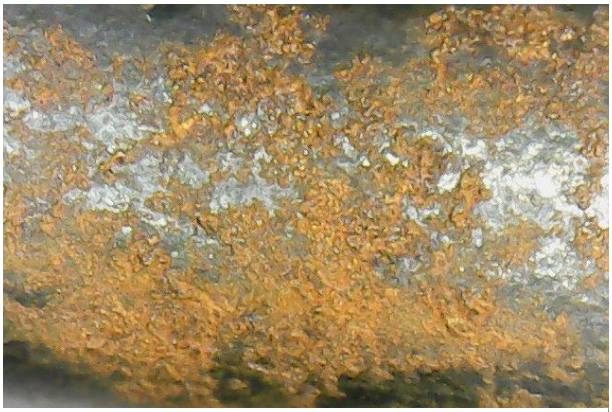
A lot of surfaces of the object are concerned by extensive filiform corrosion (*Picture 68*), and punctual pitting corrosion close to general corrosion.



Picture 65 : Pitting corrosion on blued steel ©HE Arc CR, A.L



Picture 66 : Filiform corrosion on blued steel ©HE Arc CR, A.L



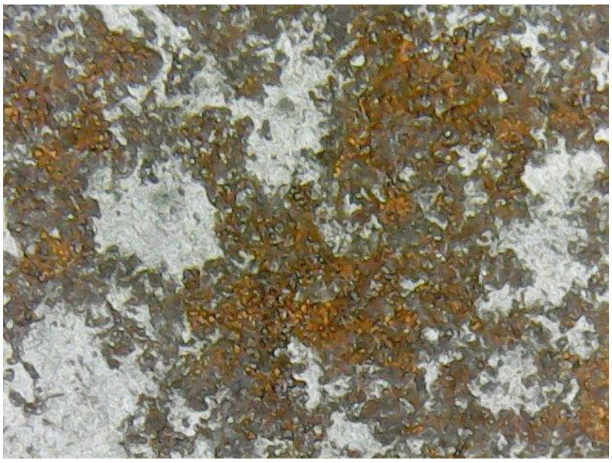
Picture 67 : Extensive filiform corrosion on blued steel ©HE Arc CR, A.L

112 Selwyn, Lyndsie, 2004, p.212

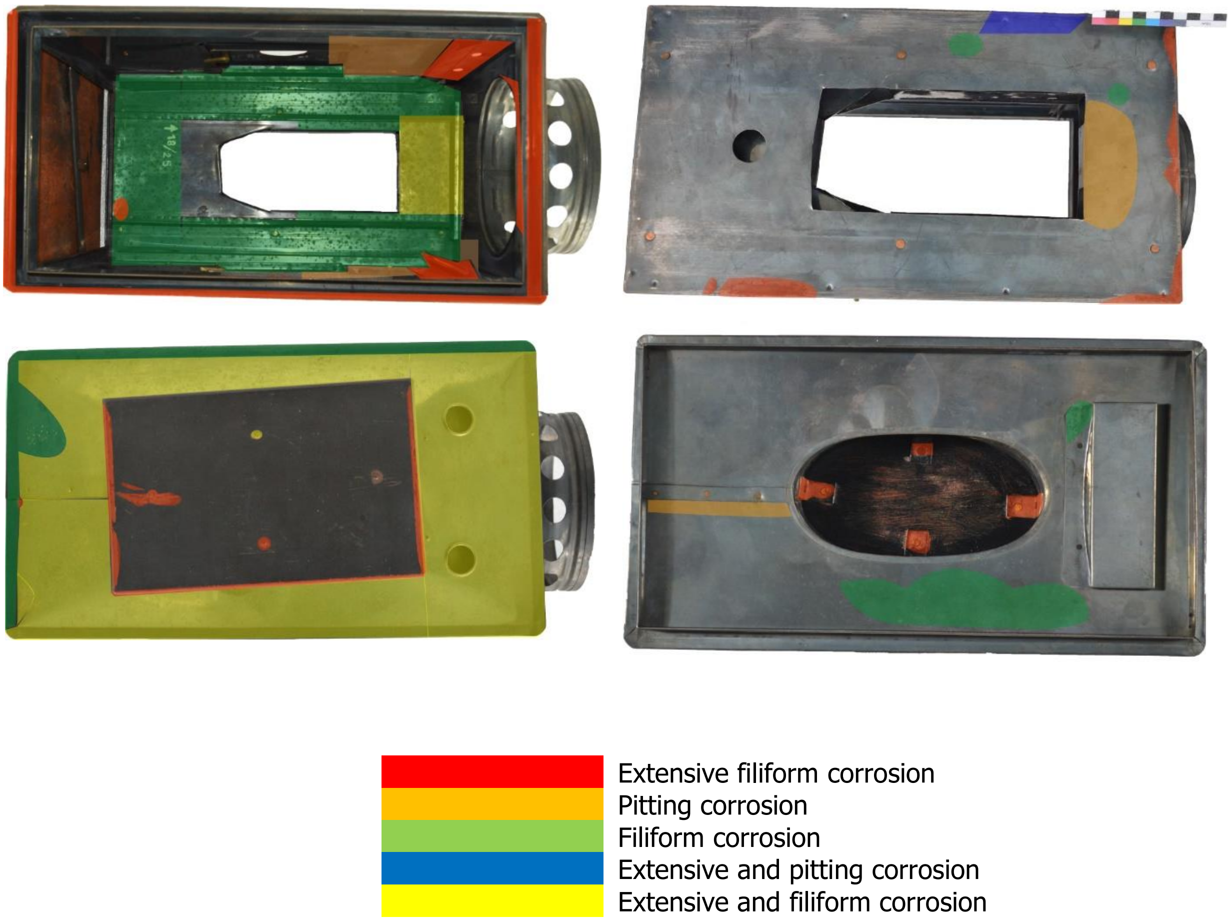
113 Selwyn, Lyndsie, 2004, p.212

A mapping of the distribution of the corrosion products on the blued surface is available on *Picture 69*.

Akaganeite, lepidocrocite and goethite have been identified with Raman spectroscopy. Hematite and magnetite too, but they are mainly constituents of the blued layer.



Picture 68 : Extensive filiform corrosion ©HE Arc CR, A.L



Picture 69 : Mapping of corrosion of the different sides of the object ©HE Arc CR, A.L

5.3 Stratigraphy

Extensive filiform corrosion is characterised by three textures of corrosion products : a very powdery overlayer, a moderately adherent layer in between and an adherent underlayer. All of them are characterized by a red-orange colour.

Pitting corrosion is composed of a single moderately adherent layer, of a red-orange or black colour. Filiform corrosion is composed of a single very adherent layer, of a black colour. Some pristine areas of the blued metal sheet are also preserved (*Diagram 6*).

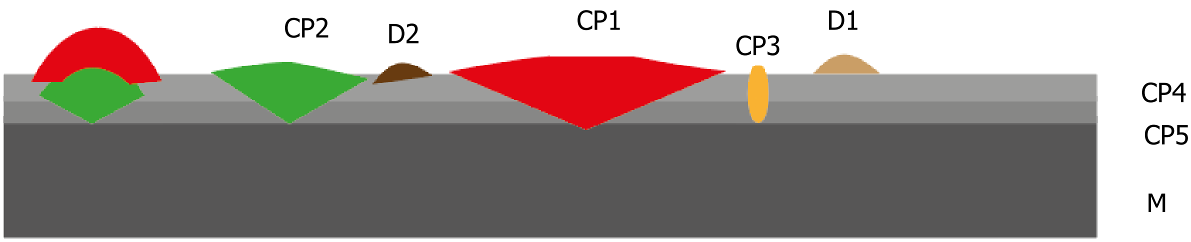


Diagram 6 : Stratigraphy of the blued steel sheet of the object ©HE Arc CR, A.L

Diagram 6 and *Table 5* describes the different layers of the object and have been created according to Regis Bertholon methodology[114].

	Stratum	Marker	Colour	Description
	D1	Superior : soiling	Grey	Thin layer of soiling on the metallic surface
	D2	Superior : paint deposits	Blue, white	Dots of paint on the metallic surface
	CP1		Red	Very powdery overlayer, moderately adherent layer in between and adherent underlayer
	CP2		Black	Very adherent layer of filiform corrosion
	CP3			Moderately adherent pitting corrosion
	CP4	Corresponding	Grey	Overlayer of blueing, made of hematite
	CP5		Grey	Underlayer of blueing, made of magnetite
	M		Light grey	Steel sheet

Table 5 : Description of the stratigraphy of the object ©HE Arc CR, A.L

6 Diagnosis and prognostic

6.1 Origins of the alterations

Life of the technical object

Some of the alterations are intrinsically related to the life of the technical object. The manipulation and setting of the lantern by the operator may have generated the deposit of chlorides on the blued steel sheets, allowing the development of akageneite. Preferential areas of the blued steel sheets are

[114] Bertholon, Régis, 2000

then corroded, and a relation can be made with the manipulation of the object. Some mechanical alterations, as scratches or weaknesses in the blued layer could be related to the same cause. Fingerprints have also been observed on the object but seems to have been caused before the blueing of the metal. The same phenomenon has been observed while preparing blued metallic coupons for the testing of the treatments.

The manipulation has also caused the preferential soiling of some areas of the wooden box, notably the edges, which were manipulated to position the lantern at the right place for projection or enlargement purposes. The edges of the front door, which was removed to switch on the transformer, shows the same localized soiling areas. Losses of wooden material and paint could also be associated to this cause.

An exposure of the PVC material to the light of the lantern has probably caused its hardening by photooxidation.

Nature of the material

The porous nature of the blued layer of the lantern allowed interactions between the metal and the atmosphere, contrary to some painted surfaces, as the base of the light source. Thus, corrosion may form easily on such a substrate and the losses of the blued layer are the consequence of the growth of corrosion.

Also, copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products.

Nature of the manufacturing

Sheen of the blued layer is related to a lack of homogeneity of the blueing technique used on the sheets. A lighter colour of blueing is then visible.

The bending of the sheets has very probably caused the development of thicker corrosion products, as the microstructure of the metal has been modified by the manufacturing.

Concerning PVC cables, the use of polar additives incompatible with the polymer has generated the chemical degradation of the plastic, manifested by blooms.

The elaboration of asbestos plates by pressing fibres and cutting plates correlates with the degradation of the fibrous mediums.

Conditions of conservation

It seems that the object has been exposed to flows, has a lot of halos are visible on the top of the bulb and inside the lantern. The localized drops of water allowed the start of the process of corrosion, generating filiform corrosion on the metal. It has also permitted the agglomeration of soiling on the glass of the bulb, and halos on painted surfaces. An exposure to a varying climate may have also allowed the formation of cracks and splits in the wood. Also, the reticulation and the lifting of the varnish on wood, especially on the lens carrier of the object, seems to be related to an exhibition to heat input. Blisters and losses of the varnish have consequently occurred.

Modifications brought to the object

Some modifications brought to the object, especially the amateur cutting and the filing of some metallic pieces, has left the metal bare in several area, allowing a direct interaction with the atmosphere. It is notably the case on the base of the light source. Also, a lot of paint deposits are visible on the object. They are related to its repaint.

However, we can affirm that the exposition of the object to flows happened after the modifications of the object. Indeed, some of the modified parts have preserved the material they were covering. It is notably the case with the base of the light source, which preserved an area from the bottom of the lantern from corrosion.

6.2 Impacts and outcome of the alterations

Even though it is a technical object, the amount of agglomerated soiling and the red corrosion products covering the blued steel and other ferrous materials give an untidy aspect to the object. They also testify of the abandonment of the device. The corrosion products are stable, but the perception of the blued material is impeded by the thick corrosion products.
Some materials are also concerned by degenerative alterations, as paint or varnish lifts as well as chemical degradation of the PVC objects. The former can be secured, but it is more difficult to solution the latter. Also, asbestos generates huge health and safety issues pour the institution and its collaborators.

7 Associated cultural values

The in-depth study of the object and the cultural values theorized by Barbara Appelbaum[115] allowed the following considerations about the object.

The historical value has been connected to this object, as it is associated to the era from the 1890’s to the 1920’s – and more, due to its modifications -, when the projection and the enlargement of glass photographic plates was possible with this device.

[115] Appelbaum, Barbara, 2007

The age value has also been associated to this object, whose manufacturing and technology are representative of the era before the generalization of the film projectors.

The associative value can be considered, as the object has been built by the local manufacture Ganz & Co in Zürich, Switzerland. The family has also donated the object to the museum and participated to the transmission of the local technical heritage.

A research value can be related to the study of the evolution of these devices through their modification, which occurred while new cinematic inventions were made.

Lastly, an educational value can be highlight, as the observation of the device can allow the comprehension of scientific principles as projection or the use of a lens.

The impact of corrosion on the cultural values is mainly related to the aesthetical value of blued steel sheets. Even if they are chemically stable, they give an untidy aspect to the object. They also testify of the abandonment of the device, as a large amount of them developed after an exposure to water flows. The perception of the mirrored blued surface is impeded by the thick corrosion products.

8 Mandate and propositions of treatment

The objectives of the treatments are to decontaminate the object while conserving the asbestos mediums in the device, a mitigating of the soiling, a stabilization of the mechanical alterations of the paint and varnish layers and the removal of the corrosion products on the blued steel sheets.

A securing and an enhancement of its aesthetical aspect are aimed.

Despite of the hazard issues encountered with asbestos, this material is considered as intrinsically part of the object and its history. Their conservation is requested.

A mitigating of the soiling of the object is wished, in order to anneal the untidy aspect of the object.

The stabilization of the paint and varnished layers will be carried on to limit the losses of these constitutive materials of the object. A care of the degraded PVC power cable should also be considered.

Finally, the removal of the corrosion products on the blued steel and ferrous surfaces to enhance the perception of the blued layer.

The following interventions are proposed :

- Decontamination of the object, consolidation of the asbestos plates and packaging of the contaminated textile : a semi-confined workspace will be created to partially dismantle the object and the asbestos plates. A careful vacuum cleaning will be carried on the object to remove asbestos fibres. The consolidation of the plate will be conducted to secure the medium, respecting its aspect.

- Stabilization of the lifted paint and varnish : these materials could detach from the surface of the object and generate losses. The securing of the material will be completed with compatible, retreatable and stable conservation materials.

- Mitigation of the soiling : the removal of the powdery and adherent deposits as repaint stains will be completed, while the soiling will be mitigated to obtain a homogeneous aspect of this technical object.

- Cleaning and packaging of the PVC cable out of the wooden box : the removal of the blooms at the surface of the material will be carried on, and an open packaging will be created to limit the accumulation of the smell of degraded plastic inside the object.

- Removal of the corrosion products from the blued steel sheets and ferrous elements : the corrosion products should be removed while conserving those constituting the blued layer, in order to enhance the perception of the material.

This file will develop the study and restoration of the blued steel sheets of the object. The selection of the treatment parameters and test of treatments as well as the treatment of conservation are available in Appendix II p.81 and III p.114 :

Theme	Test of treatments	Treatment of conservation
Stabilization of asbestos mediums	p.81	p.114
Mitigation of the soiling on glass	p.95	p.119
Mitigation of the soiling on painted wood	p.98	p.120
Mitigation of the soiling on painted metal	p.102	p.121

Mitigation of the soiling on copper alloys	p.104	p.123
On coated paper	p.105	p.123
Painting consolidation	p.106	p.124
Retouching of the wooden losses	p.108	p.125
Resettling of the lifted varnish on wood	p.109	p.125
Removal of the blooms from the PVC cable	p.112	p.126

9 Study of the removal of the corrosion products on blued steel sheets

9.1 Problematic

The aim of the treatment here is to operate the selective removal of the corrosion products which are not initially part of the blued iron sheets. Thus, hematite and magnetite composing the blued layer should be conserved. On the contrary, akageneite for example, which is a red corrosion product developed through time and generating losses of the blued layer, should be removed.

In order to select and test appropriate treatment parameters, blued steel coupons reproducing the composition and surface treatment of the object have been created. Some of the coupons have been blued only, for purposes of testing if they damage the blued layer. Other coupons have been blued and corroded artificially, and after the artificial corrosion process, received the treatments that have been previously selected.

The chemical, mechanical and combined treatments which have been considered are described in the next paragraphs. 3 tests have been performed for each technique.

9.2 Mechanical methods of cleaning

Eight individual mechanical cleaning methods have been approached for the cleaning of blued steel sheets.

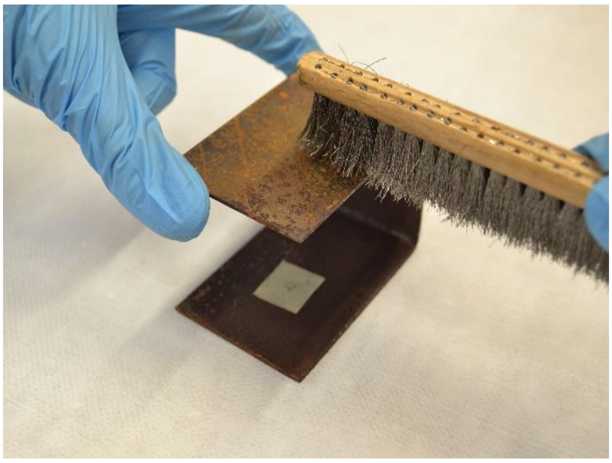
9.2.1 Brushing

A selection of five brushes (*Figure 70*) whose hardness covers very flexible to rigid has been tested on the surface of the blued corroded coupons. Synthetic nylon brushes have been favoured for their neutral composition and their durability, while steel brushes have been selected to work with the same nature of alloy as a different one could generate the deposit of fibres on the surface and produce galvanic corrosion*.

Figure 70 : Nylon very flexible brush, flexible brush, rigid brush, steel brush medium, steel brush rigid

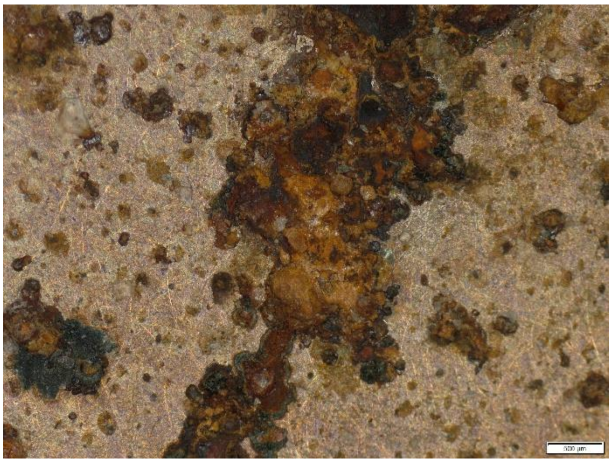
©HE Arc CR, A.L

The mode of application of the mechanical cleaning consisted in applying the brush in a parallel incidence, in a vertical direction, from the bottom to the top of the surface for 20 times. A cleaning with a cotton swab soaked with ethanol has then been done, rolling twice on the surface (*Picture 71*).

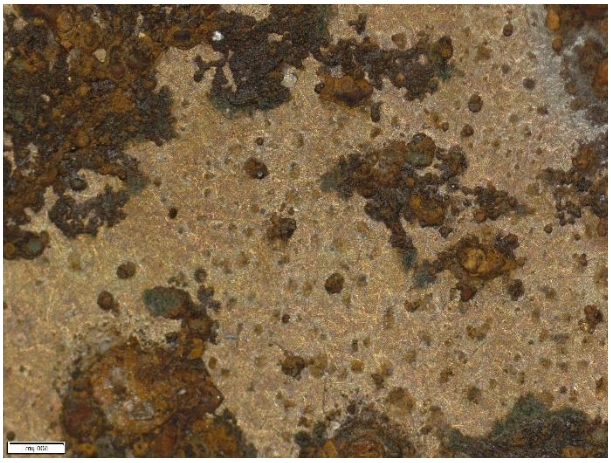


Picture 71 : Mode of application of the brush cleaning ©HE Arc CR, A.L

Both very flexible and flexible nylon brushes allowed the removal of the very low adherent powdered corrosion products, while the rigid nylon brush spread all the powdered corrosion products, inducing minor scratches on the blued surface. Both medium and rigid steel brush swatted and spread the corrosion products and induced scratches from their first application on the surface (*Picture 72*).



Very flexible nylon brush



Flexible nylon brush

Rigid nylon brush

Medium steel brush

Rigid steel brush

Picture 72 : Cleaning tests by brushing on the blued corroded coupons ©HE Arc CR, A.L

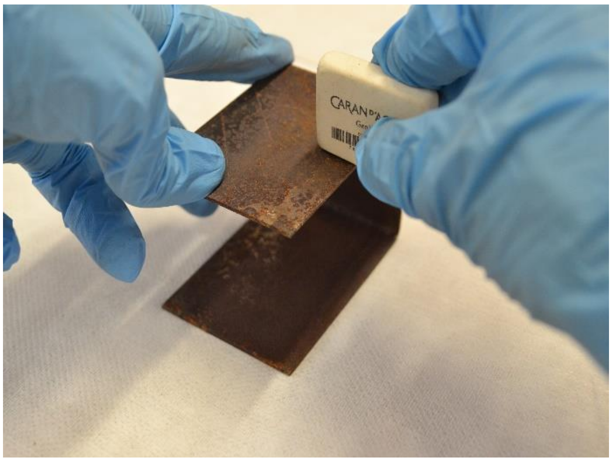
The use of a flexible nylon brush could be considered as a complementary technique for the removal of the very low adherent powdered corrosion products.

9.2.2 Erasing

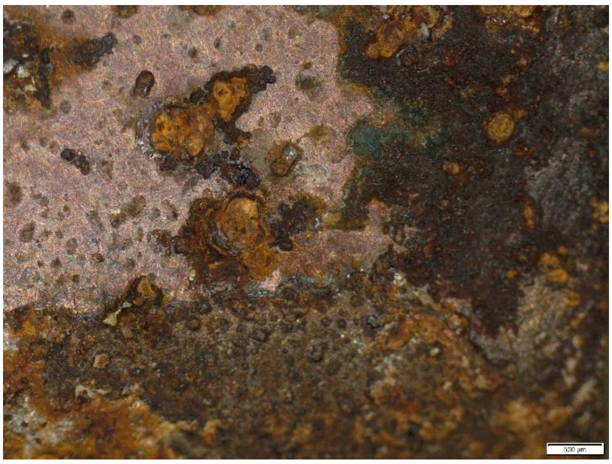
5 erasers from different hardness have been evaluated on the corroded blued steel coupons.

Picture 73 : Läufer Plast-0140 very flexible, Staedtler Mars plastic very flexible, Caran d'Ache Genève 0149.310 flexible, Caran d'Ache Genève 0149.340 flexible-rigid, Pelikan WS 30 rigid ©HE Arc CR, A.L

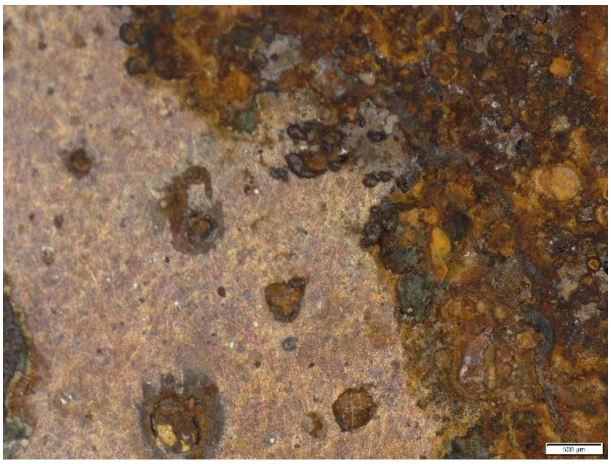
The mode of application consisted is applying the eraser in a vertical incidence, in a vertical direction, one way gesture from the top to the bottom of the coupon, for 20 times (*Picture 74*).



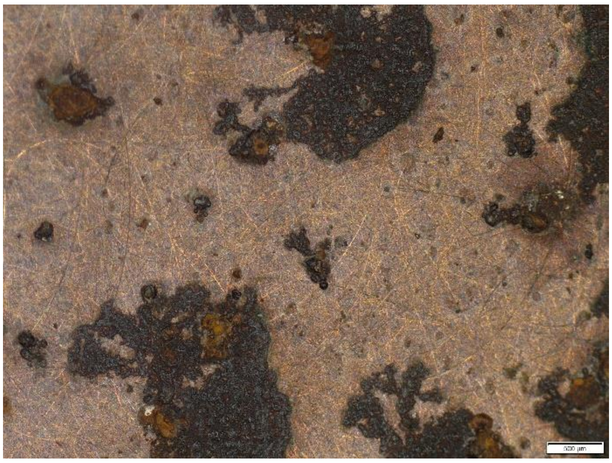
Picture 74 : Mode of application of the eraser ©HE Arc CR, A.L



Läufer Plast-0140 very flexible

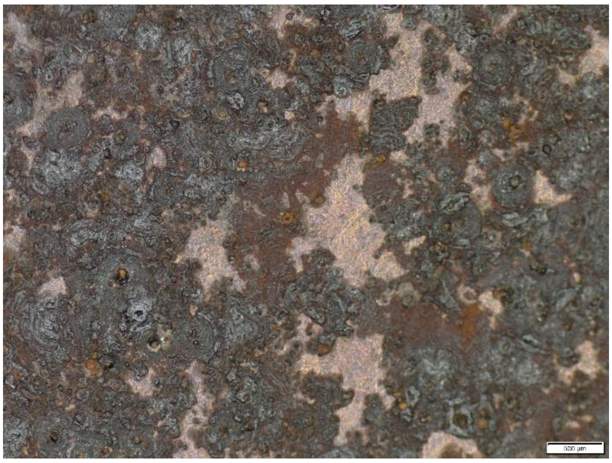


Staedtler very flexible



Caran d'Ache 0149.310 flexible

Caran d'Ache 0149.340 flexible-rigid



¨Pelikan WS 30 rigid

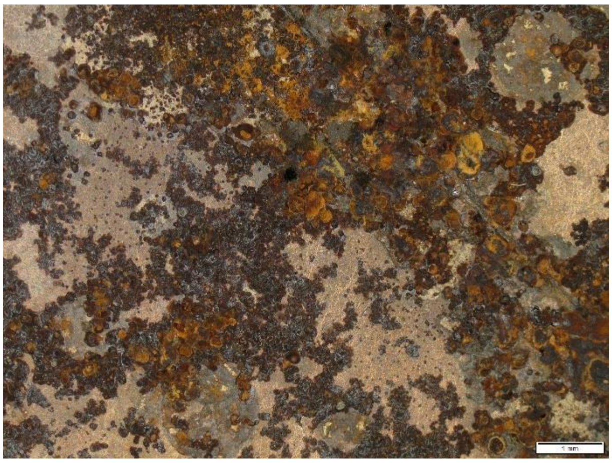
Picture 75 : Cleaning tests by erasing on the blued corroded coupons ©HE Arc CR, A.L

What is interesting with this method is that the corrosion products associate with the eraser peels. All the erasers except the most flexible allowed the removal of the powdery corrosion products. However, Läufer Plast-0140 and Staedler Mars plastic erasers let some shiny marks on the surface. The flexible eraser Caran d'Ache Genève 0149.310 has an interesting shape which could be helpful to access stamped surfaces as well as flat ones *(Picture 75)*.

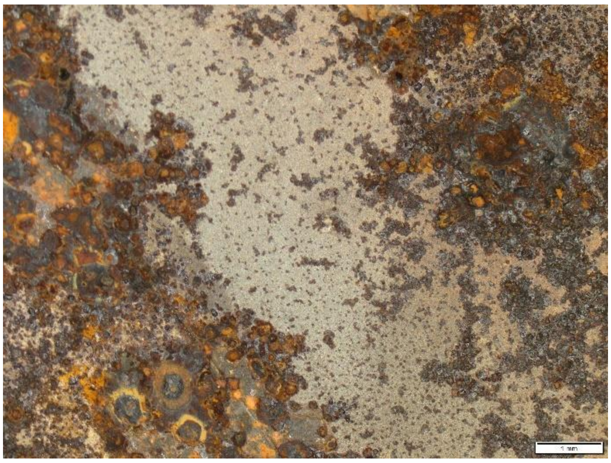
9.2.3 Sandblasting

A mechanical cleaning by sandblasting has been considered. Three different products have been tested : glass beads 0-50, biloxit 220 and thermoset beads Emsodur. No organic product has been tested to avoid their deposit on the object.

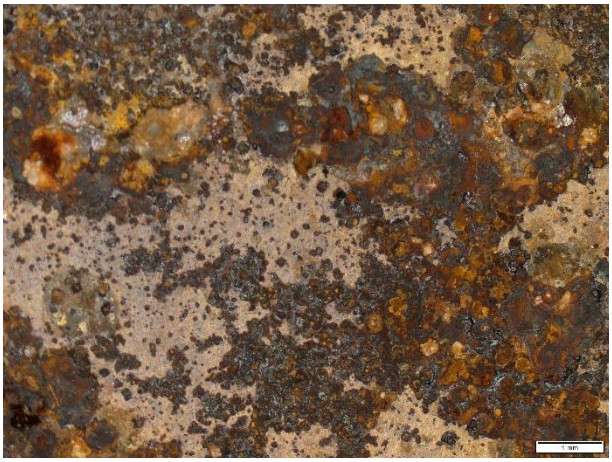
They were applied with a grazing incidence on the surface, in a horizontal direction, at a low pressure of 0.5 and a debit of 1.



Glass beads 0-50



Biloxit 220



Emsodur thermoset beads

Picture 76 : Cleaning tests by sandblasting on blued corroded coupons ©HE Arc CR, A.L

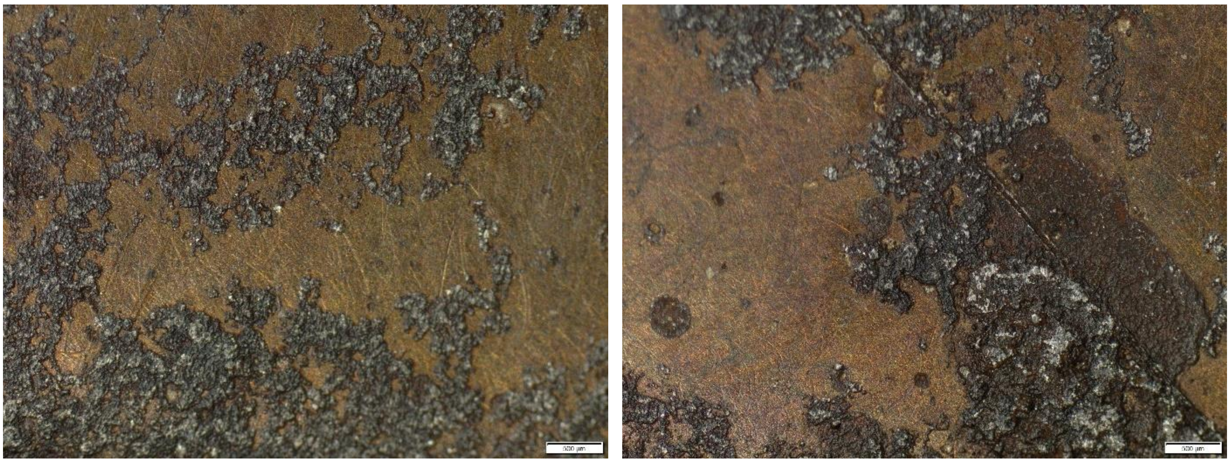
Glass beads and biloxit damaged the blued layer, while Emsodur allowed a very slow removal of the soft and semi-rigid corrosion products. This method is not suitable for the removal of the corrosion products on blued steel (*Picture 76*).

9.2.4 Aluminium foil and paraffin oil

A flat buffer (*Picture 77*) of aluminium foil has been created in order to be applied with a vertical incidence on the surface of the coupons. Both sides of the foil have been tested – mat and shiny.

Application has been achieved by rubbing vertically the surface. A double rinsing with a cotton swab soaked in ethanol has been carried out after the cleaning.

Picture 77 : Aluminium buffer on the surface of the coupon ©HE Arc CR, A.L



Shiny side of the aluminium foil *Mat side of the aluminium foil*

Picture 78 : Cleaning with aluminium foil and paraffin oil on blued corroded coupons ©HE Arc CR, A.L

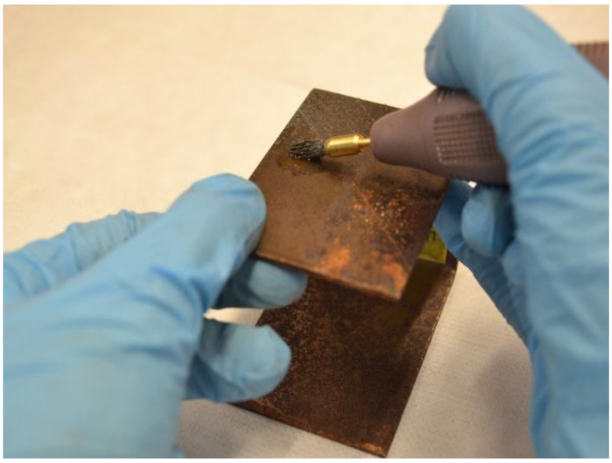
This method allows the removal of the powdery and moderately adherent corrosion products. Also, it slightly mats the blued surface. The cleaning is fast but incomplete and the buffer should be changed quickly as aluminium pieces come off. However, the buffer adapts to angular and rounded areas.

Oil does not improve the removal of the adherent corrosion products. It compacts them on the surface of the metal. The aluminium foil removes partially the corrosion products, but the process is not convenient (*Picture 78*).

9.2.5 Rotative steel brush Bijoutil 53526 and paraffin oil

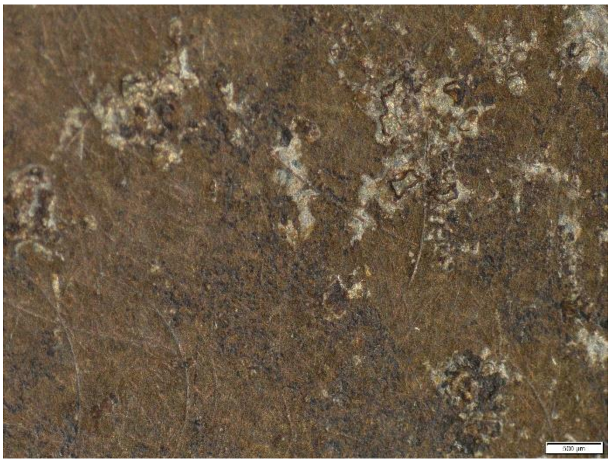
This rotative brush has been selected as it is constituted of the same material than the object and has been pre-used to limit the scratches on the surface of the metal.

It has been applied on the surface with a vertical movement from left to right and inversely. A speed of 10, 5 and 2.5 x 1000 revolutions per minute have been applied on the coupons (*Picture 79*).



Picture 79 : Mode of application of the Bijoutil 53526 brush ©HE Arc CR, A.L

2.5x1000 revolutions per minute



5x1000 revolutions per minute

10x1000 revolutions per minute

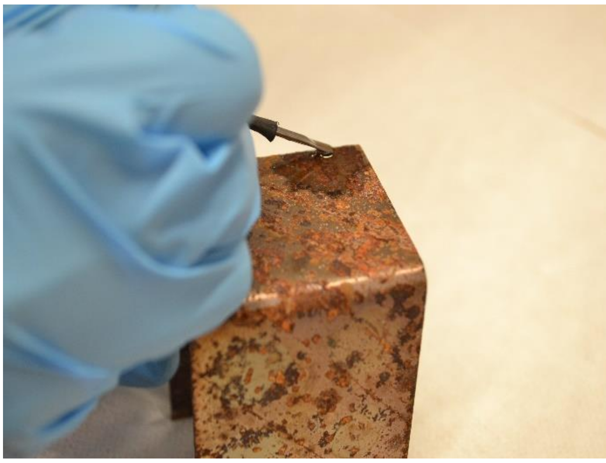
Picture 80 : Cleaning tests with a rotative steel brush Bijoutil 53526 and paraffin oil ©HE Arc CR, A.L

Despite of the small quantity of oil, this method generates important projections of oil on the periphery of the object and on the collaborator. The removal of the corrosion products is nearly total, but a brightness is brought on the blued layer, which seemed polished. Here again, it is difficult to control the cleaning with the presence of oil (*Picture 80*).

9.2.6 Flat steel tool and paraffin oil

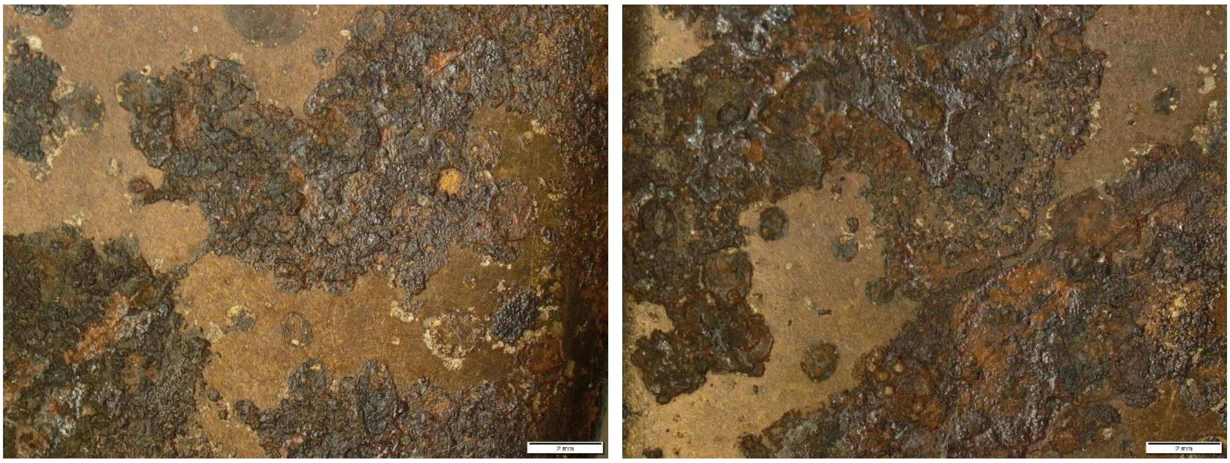
This flat steel tool has been created by Martin Sauter[116], conservator of metals and weapons. It consists in a flat spatula whose bottom is slightly rounded with a grinded machine. The result is a tool which does not scratches steel.

The mode of application is from top to bottom, with a grazing incidence. The residues of oil are removed with a double rinsing with a cotton swab soaked in ethanol (*Picture 81*).



Picture 81 : Mode of application of the flat tool ©HE Arc CR, A.L

[116] Fontaine, Célia, 2021



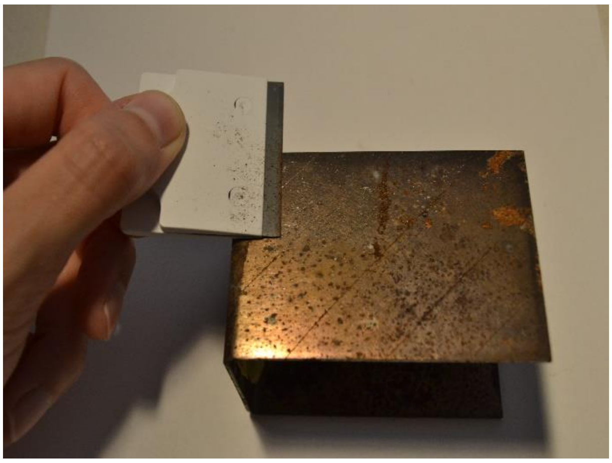
Flat steel tool, picture one *Flat steel tool, picture two*

Picture 82 : Cleaning with the flat steel tool of the blued corroded coupons ©HE Arc CR, A.L

Associated with a drop of paraffin, the tool allows the corrosion products to be suspended in the liquid. When applied several times locally, it allows the push the adherent corrosion products. However, the oil agglomerates the corrosion products and does not allow a complete removal. A dry application should be preferred (*Picture 82*).

9.2.7 Razor blade with clipper

A razor blade with a clipper has been used to test the removal of the corrosion products of the blued surface. This mechanical technique may allow a homogeneous removal.
It has been applied from top to bottom, with a grazing incidence on the surface (*Picture 83*). A film of paraffin oil has been initially dropped on the surface on all the length of the tool. The residues of oil have been removed with a double rinsing with a cotton swab soaked in ethanol.



Picture 83 : Mode of application of the razor blade clipper ©HE Arc CR, A.L


Razor blade with clipper, one time


Razor blade with clipper, three times

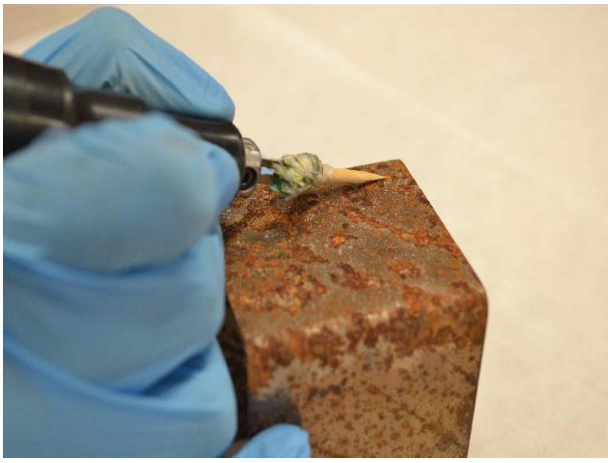
Picture 84 : Cleaning with razor blade with clipper of the blued corroded coupons ©HE Arc CR, A.L

This method has generated scratches, as the blade push on the very adherent corrosion products. The quantity of oil is also not the easiest to clean (*Picture 84*).

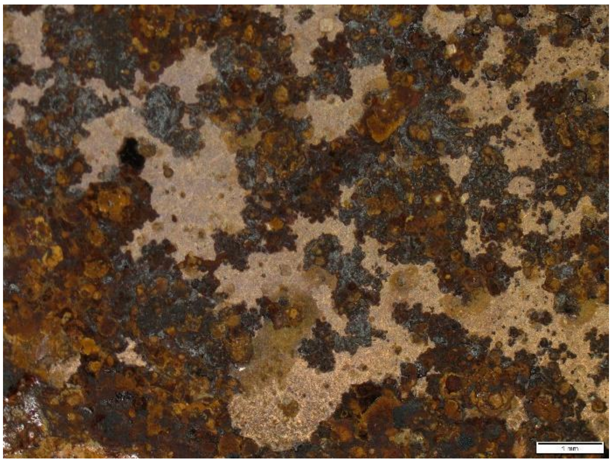
9.2.8 Ultrasonic and wood tool

With the base of an ultrasonic tool, a flat and pointy end has been cut from a wooden stick and attached to a scalpel blade with a wire and cyanoacrylate (*Picture 85*). The idea was to be able to remove the corrosion products with a softer tool than a scalpel blade. This method has been discussed with Alexander Dittus, conservator of archaeological objects at the Collection Centre of the Swiss National Museum.

The ultrasonic tool has been tested with all the scale of power, from 1 to 10.



Picture 85 : Application mode of the ultrasonic wood tool ©HE Arc CR, A.L

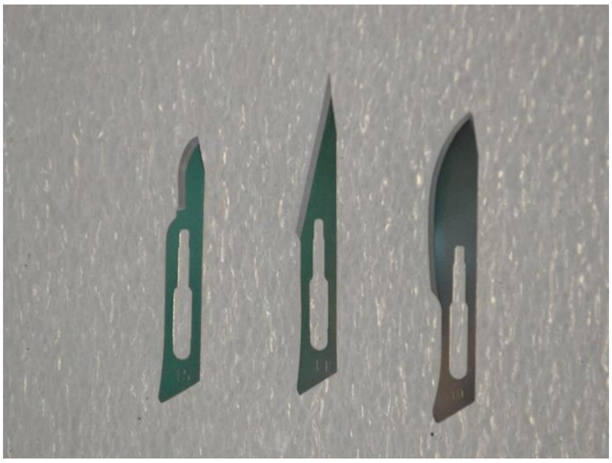


Picture 86 : Cleaning with ultrasonic and a wood tool of the blued corroded coupons ©HE Arc CR, A.L

The method allowed the removal of powdery and semi-adherent corrosion products. Adherent corrosion products could not be removed. The blued layer has not been damaged. However, it is not a method adapted to the cleaning of large surfaces, as it is quite slow. The treatment is moderately rapid, and several nozzles should be prepared as they warm a bit the cyanoacrylate (*Picture 86*).

9.2.9 Scalpel blade

Three types of scalpel blades have been tested on the coupons : 15, 11 and 10.



Picture 87 : Scalpel blades 15, 11 and 10 tested on the coupons ©HE Arc CR, A.L

They have all been applied with a grazing incidence, in a diagonal direction, with a one-way gesture.

Every blade induced scratch on the surface of the blued coupons. Blade 15 allowed an efficient removal of the porous corrosion products, but it was difficult to put pressure on the other blades on the irregular corroded surface.

9.2.10 Steel wool

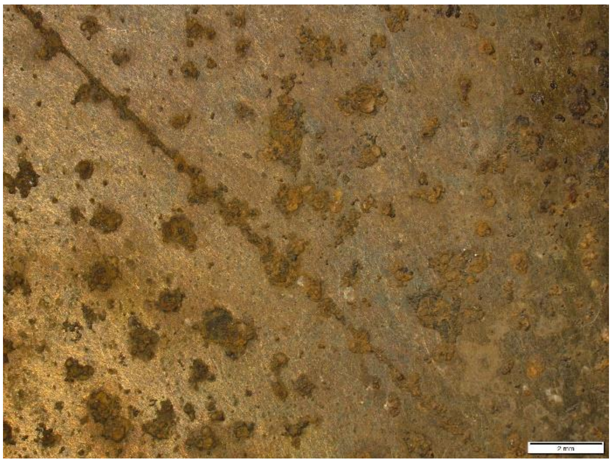
From the three pre-tested steel wool (000, 00 and 1), the thinnest steel wool (000) has been tested with and without paraffin oil on the coupons as it did not polish the surface.

Steel wool with a drop of oil has been applied doing circular movements, as well as dry steel wool.

The same issue than the one encountered with aluminium and oil occurred here. Oil agglomerates the adherent corrosion products. The tests without oil were more interesting.

Steel wool 000 + paraffin oil

Steel wool 000



Untreated surface

Picture 88 : Cleaning with steel wool 000 of the blued corroded coupons ©HE Arc CR, A.L

The use of dry 000 steel wool was conclusive. No damage was made on the blued layer and the corrosion products are removed until the original surface of the material. However, it leaves powdery deposits on the surface. This method could be the main technique to decrease the corrosion until the limitos, without oil. (*Picture 88*).

9.3 Chemical method of cleaning

Cleaning tests with chelators have been carried out in order to remove corrosion production from the blued steel sheets. Chelators are ligands which are characterized by their multi-dentate structure, allowing the complexation of the metallic cations. The idea is to complex preferentially the ferrous corrosion products and conserve the blued layer constituted of magnetite and hematite.

As inorganic compounds in aqueous medium with a solubility product (pKs) superior to 4-5 are not enough soluble in water, another type of action is needed. A salt-splitting action by chelators is possible at the proper pH. Thus, by sequestering the metal cation, the chelator will render the compound more soluble in water[117].

The chosen mode of application is rigid gel, to facilitate the comparison of the results between each test. Agar, a polysaccharide gelling agent requiring physical activation by heat and cooling has been selected, as it can form thermo-reversible rigid gel[118].

4 chelators have been selected at different ranges of their buffer range of, as the reduction of Fe_{3+} ions in Fe_{2+} ions is more likely to happen in a neutral medium[119] :

- EDTA, pH 6, 7, 10 and 11 buffered with NaOH ;
- Triammonium citrate, pH 5 buffered with acetic acid[120], pH 6, 7 buffered with NaOH ;
- DTPA, pH 8, 9, 10 and 11;
- Citric acid, pH 6 buffered with acetic acid 1M, pH 7.5 not buffered, pH 8.5[121] buffered with NaOH.

A concentration of 1% has been applied, as the values for a concentration of 0.025mM were not known for DTPA.

Two modes of fabrication of the agar gels have been tested :

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[117] Cremonesi, Paolo, 2021, *unpublished*

[118] Cremonesi, Paolo, 2021, *unpublished*

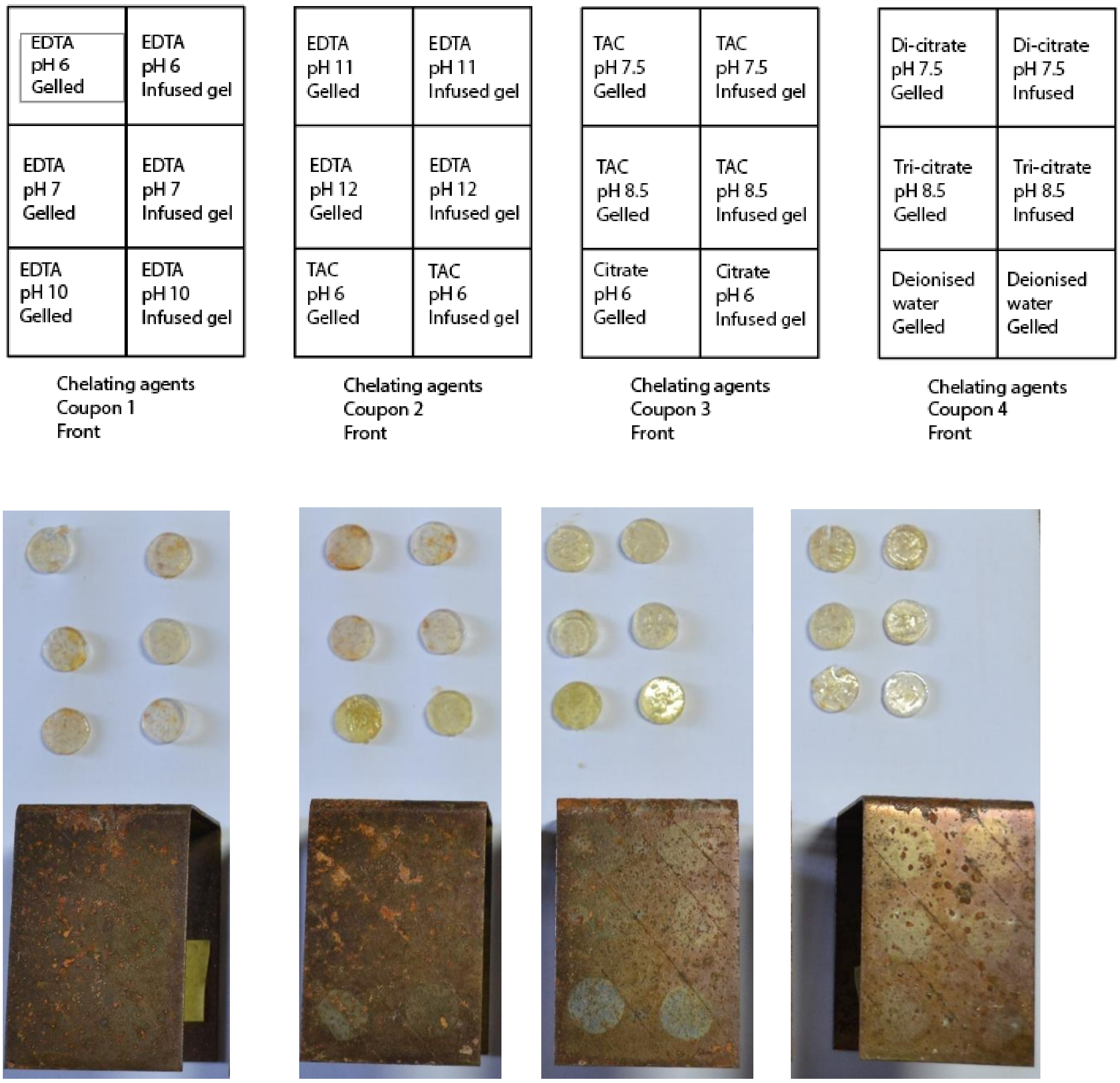
[119] Cremonesi, Paolo, 2021, *unpublished*

[120] HCl was unfortunately not available at the laboratory.

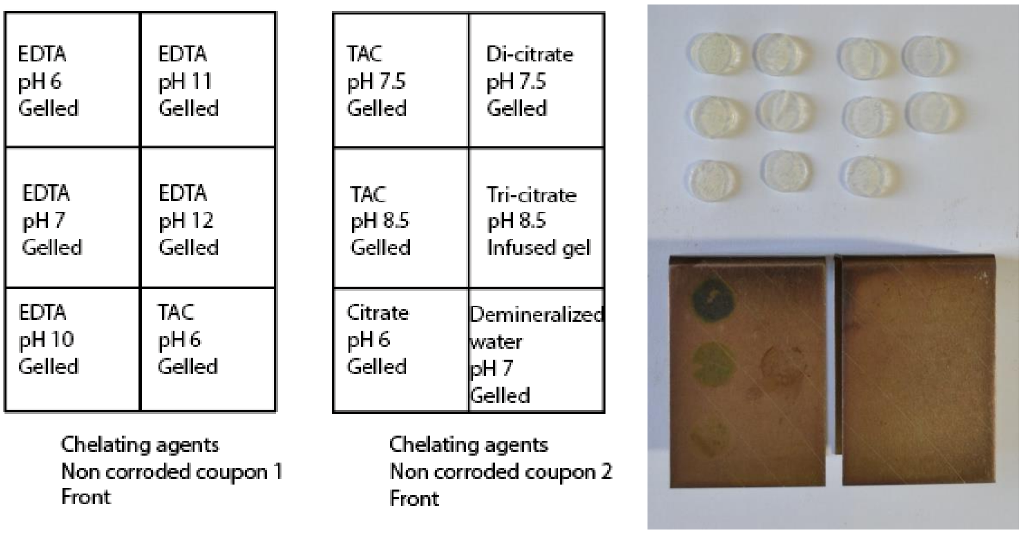
[121] The pH of 8.5 is not included in the buffered range of DTPA.

- Rigid gels of Agar at 4% in deionised water (0.8g, 20mL), prepared in a microwave at 600W, infused in the chelators for 30 minutes ;
- Rigid gels of Agar at 4% in deionised water (0.8g, 20mL), prepared in a microwave at 600W, with the chelators included in the blend.

The gels have been applied on uncorroded coupons to observe their effect on the blueing layer (*Picture 90*), as well as on corroded coupons (*Picture 89*), to understand their effect on the corrosion products.



Picture 89 : Chelating agents on corroded coupons ©HE Arc CR, A.L



Picture 90 : Chelating agents on blued coupons ©HE Arc CR, A.L

Citric acid and TAC gels at a pH of 7.5 and 8.5 leaved an undamaged blued layer and slightly tackled the corrosion layer. However, TAC and EDTA gels attacked the blued layer : the gels became green, and the blued layer has been reduced.
As TAC and citrate gels at a pH of 6 have been buffered with acetic acid, the action of the chelator may have been modified and these tests may be reconduced.

9.4 Overview of the different methods

4 mechanical cleaning methods seem to be adapted to the removal of the corrosion products on blued steel surfaces by complementing each other :

- Steel wool 000 for the general removal of the corrosion products – except for the very adherent ones ;
- The flat steel tool to push very adherent corrosion products ;
- Erasers, particularly to remove powdery and low adherent corrosion products without leaving corrosion deposits ;
- Nylon brush, for the removal of powdery and very low adherent corrosion products.

2 chemical methods seem to have preserved the blued layer, and tackled the corrosion products :

- Citrate gel at a pH of 7.5 and 8.5;
- TAC gel at a pH of 7.5 and 8.5.

9.5 Protocol of treatment

Five of the 6 methods enunciated in the previous paragraph have been tested on the blued surface of the object. The association of the 4 mechanical cleaning methods allow a satisfying removal of the corrosion products from blued steel sheets.

The combination of these 4 methods allows the progressive reduction of the corrosion layer :

- 1. Wool steel 000 is gently rubbed on the corroded surface, allowing the removal of low from adherent corrosion products ;
- 2. A flexible nylon brush is used to remove the corrosion deposits generated by the wool steel 000 ;
- 3. The flexible eraser Caran d'Ache Genève 0149.310 is rubbed on the same surface to agglomerate the remaining detached corrosion products ;
- 4. The flat steel tool is used on the very adherent corrosion products to push them from the surface ;
- 5. The wood steel 000 and the eraser can be used again, as the very adherent corrosion products have been reached.

This protocol can be repeated until a smooth surface is perceived with the fingertips. It is also recommended to check the advancement of the treatment with magnifying glasses.

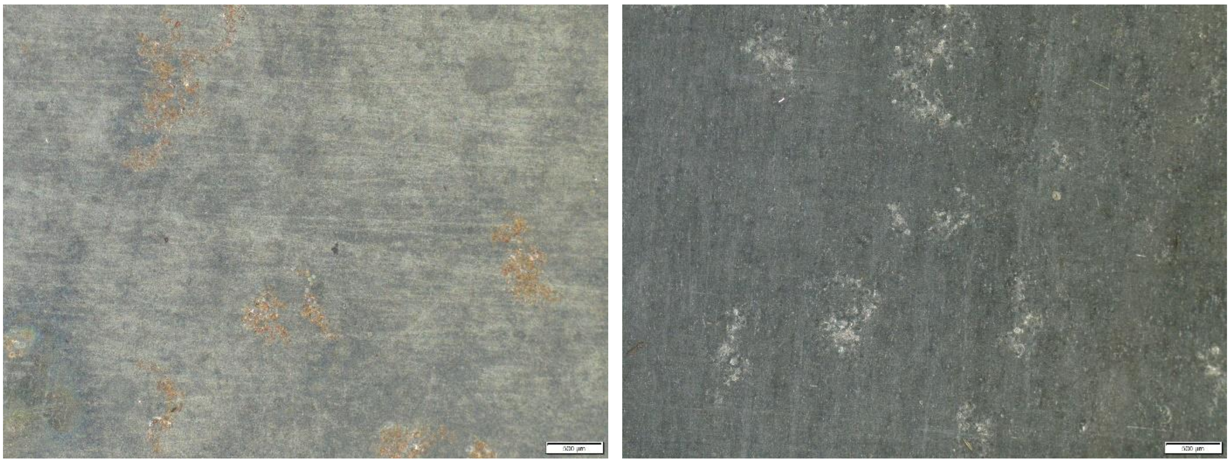


Figure 91 : Blue steel layer before and after treatment ©HE Arc CR, A.L

However, a small citrate gel at a pH of 7.5 and a conductivity of 500µS/cm has been tested for one minute on the surface of the object, after having measured the pH and the conductivity of the blued layer (pH 7.5, conductivity 203 µS/cm). The gel did not affect the adherent corrosion products remaining after a mechanical cleaning done with the protocol described above. However, the blued surface became lighter, meaning that it has been reduced, contrary to the black corrosion products. A chemical selective removal has not been possible.

10 Interventions of conservation-restoration

The protocol of treatment enunciated in chapter 9.5 has been applied to the outside and inside surfaces of the blued lantern. Some areas which were not easily accessible with a piece of wool steel have been treated with a wool steel swab or with a small wool piece directed with a wood stick.

Picture 92 : Corrosion removal in a narrow area with wool steel 000 and a stick ©HE Arc CR, A.L

This method allowed the removal of the different types of corrosion products found on the object. The retouching of the losses, which has been considered at the beginning of the thesis, has not been fully explored as the condition of the surface was very satisfying after cleaning. However, the method of re-heating the object is completely excluded, as it could influence the microstructure of the object.









Picture 93 : Pictures before (left) and after (right) restoration of the object ©HE Arc CR, A.L

11 Preventive conservation measures

The presence of hazards and the composite nature of the object require preventive conservation measures.

The manipulation of the object should be taken over by two collaborators, as the object is quite heavy (~70kg). The wear of a P3 mask, gloves, a blouse and glasses is recommended if the wooden box has to be opened, as the contaminated textile of the object is partially packaged because of the configuration of the object. The watch of the consolidation of the asbestos plate can be carried out every year. The signage for asbestos should be well visible for the collaborators and a mention of it can be added to the inventory form of the object.

A temperature under 20°C, a relative humidity from 40 to 50% and an illumination of 150 lux would be suitable for this composite object (*Table 6*).

Material	**Optimal relative humidity**	**Optimal temperature**	**Maximal illumination (lux)**
Metals	40 to 55%	16 to 25°C	300 lux
Wood	40 to 55%	< 25°C	150 lux
Painting[122]	40 to 60%	16 to 25°C	100-200 lux
Glass	40 to 50%	< 20°C	Not sensible
Plastics	40 to 55%	15 to 20°C	150 lux
Paper[123]	50 to 60%	< 20°C	150 lux
Asbestos	40 to 55%	18°C	/

Table 6 : Conditions of conservation for each constitutive material ©HE Arc CR, A.L

12 Discussion

The deepen study of the technology, the nature and the alterations of blued steel materials allowed the understanding of its mechanisms of degradation. This step was essential to attempt the achievement of a complete protocol of treatment. The project showed that combined mechanical methods of cleaning were suitable for the removal of corrosion on blued steel mediums, as the blued layer is very adherent and resistant mechanically.

This method allowed the diminution of the corrosion on the surface and can be employed on non-demountable objects as it does not necessitate any rinsing.

Even though a coloured protection has been considered on the losses, the condition of the limitos after cleaning including preserved blued layer, small losses of a slightly lighter colour and decreased corrosion products allows a satisfying global perception of the blued surface.

[122] Gouvernement du Canada, 2017, [Online]

The question of the removal of erasers residues seemed satisfying visually with a repeated cleaning with ethanol. However, a FTIR analysis could have completed this approach, to identify potential rubber residues, while the eraser does not contain phthalates.

As a personal review, I would like to add that I would have liked to select the alloy and corrode the coupons earlier in my timeline, but I was not sure that the method would work, as no climate chamber was available.

I would have liked to analyse the corrosion products on the coupons, to compare their nature with those of the object. However, their stratigraphy is very similar.

Lastly, I appreciated to settle in this project, which involved a material for which I have a significant interest, as well as a goal to propose a cohesive condition for this technical object.

Conclusion

This master thesis allowed to put in evidence the technologic background and the conservation issues of a material which is sparsely documented, as it was considered as a very common material during its era of intensive manufacture, through a deep documenting, study and analysing process of the medium.

The identification of the constitutive materials of the blued layer as well as the degradation processes allowed the definition of a protocol of treatment standing on the combination of different mechanical methods, as the use of chelators to differentiate the constituents of the blued layer and the corrosion products of the same nature has been inconclusive. This method can be used on non-demountable composite objects.

The challenges offered by this very composite technical object were of high interest to restitute a cohesive aspect. The choice of keeping asbestos, a hazardous material, as a complete part of the object was also a decision that has been possible after an investigation of the legal aspects, in order to transmit a complete vision of this object during its functioning time.

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List of pictures

List of tables

List of diagrams

Corrigendum

Page 54, the paragraph about generalised corrosion has been replaced by the following one : **Extensive filiform corrosion (*Picture 67*) is a developed form of filiform corrosion. It is characterised by an underlayer of black filaments covered with a thick and layer of red corrosion products. It is generally developed on the upper parts of the sides of the lantern, and completely generalised at the front. Also, the areas of bending and stamping of the sheets are very much impacted by generalised corrosion.**

A lot of surfaces of the object are concerned by extensive filiform corrosion (*Picture 68*), and punctual pitting corrosion close to general corrosion.

Page 56, on chapter 5.3 Stratigraphy, "Generalised corrosion" has been changed with "Extensive filiform corrosion". On Diagram 6, the stratigraphy has been modified.

Page 57, the following sentence has been added : ***Diagram 6* and *Table 5* describes the different layers of the object and have been created according to Regis Bertholon methodology.**

Page 60, on chapter 7. Associated cultural values, the following paragraph has been added **: The impact of corrosion on the cultural values is mainly related to the aesthetical value of blued steel sheets. Even if they are chemically stable, they give an untidy aspect to the object. They also testify of the abandonment of the device, as a large amount of them developed after an exposure to water flows. The perception of the mirrored blued surface is impeded by the thick corrosion products.**

Page 60-61, this table has been added :

Theme	Test of treatments	Treatment of conservation
Stabilization of asbestos mediums	p.81	p.114
Mitigation of the soiling on glass	p.95	p.119
Mitigation of the soiling on painted wood	p.98	p.120
Mitigation of the soiling on painted metal	p.102	p.121
Mitigation of the soiling on copper alloys	p.104	p.123
On coated paper	p.105	p.123
Painting consolidation	p.106	p.124
Retouching of the wooden losses	p.108	p.125
Resettling of the lifted varnish on wood	p.109	p.125
Removal of the blooms from the PVC cable	p.112	p.126

Page 64, **Picture 72** has been added.

Page 65-66, **Picture 75** has been added as well as this sentence **"However, Läufer Plast-0140 and Staedler Mars plastic erasers let some shiny marks on the surface. The flexible eraser Caran d'Ache Genève 0149.310 has an interesting shape which could be helpful to access stamped surfaces as well as flat ones *(Picture 75)*."**

Page 67, **Picture 76** has been added.

Page 68, **Picture 78** has been added.

Page 69, **Picture 80** has been added.

Page 72, **Picture 84** has been added.

Page 73, **Picture 86** has been added.

Page 74, **Picture 88** has been added as well as this sentence : **"This method could be the main technique to decrease the corrosion until the limitos, without oil. (*Picture 88*)."**

Page 76, Picture 89 has been added.

Page 77, Picture 90 has been added.

Page 77, a modification has been made :

- **Citrate gel at a pH of 7.5 and 8.5;**
- **TAC gel at a pH of 7.5 and 8.5.**

Pages 79-80-81-82, the before and after picture have been reorganised.

Page 83-84, the following paragraph has been added :

Even though a coloured protection has been considered on the losses, the condition of the limitos after cleaning including preserved blued layer, small losses of a slightly lighter colour and decreased corrosion products allows a satisfying global perception of the blued surface.

The question of the removal of erasers residues seemed satisfying visually with a repeated cleaning with ethanol. However, a FTIR analysis could have completed this approach, to identify potential rubber residues, while the eraser does not contain phthalates.

As a personal review, I would like to add that I would have liked to select the alloy and corrode the coupons earlier in my timeline, but I was not sure that the method would work, as no climate chamber was available.

I would have liked to analyse the corrosion products on the coupons, to compare their nature with those of the object. However, their stratigraphy is very similar.

Lastly, I appreciated to settle in this project, which involved a material for which I have a significant interest, as well as a goal to propose a cohesive condition for this technical object.

Page 84, these paragraphs have been modified :

The identification of the constitutive materials of the blued layer as well as the degradation processes allowed the definition of a protocol of treatment standing on the combination of different mechanical methods, as the use of chelators to differentiate the constituents of the blued layer and the corrosion products of the same nature has been inconclusive. This method can be used on non-demountable composite objects.

The challenges offered by this very composite technical object were of high interest to restitute a cohesive aspect. The choice of keeping asbestos, a hazardous material, as a complete part of the object was also a decision that has been possible after an investigation of the legal aspects, in order to transmit a complete vision of this object during its functioning time.

Blued steel sheets : history, manufacturing and conservation.

The case of a Ganz & Co projection and enlargement lantern conserved at the Collection Centre of the Swiss National Museum.

Appendix

Thesis presented by :

Alexandra Lefebvre

For the obtention of the

Master of Arts HES-SO in Conservation-restoration
Specialized in scientific, technical and horological objects

Academic year 2020-2021

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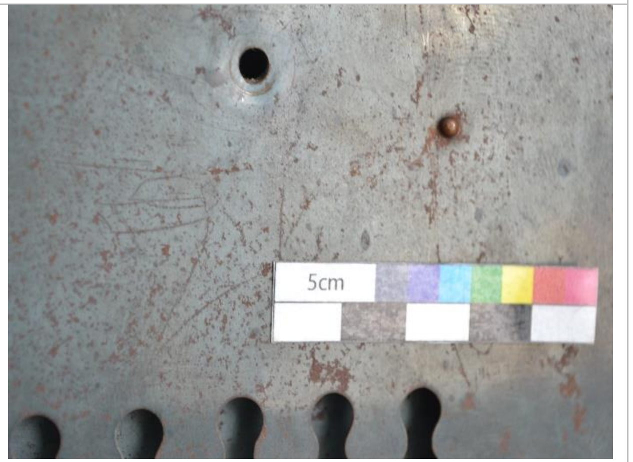
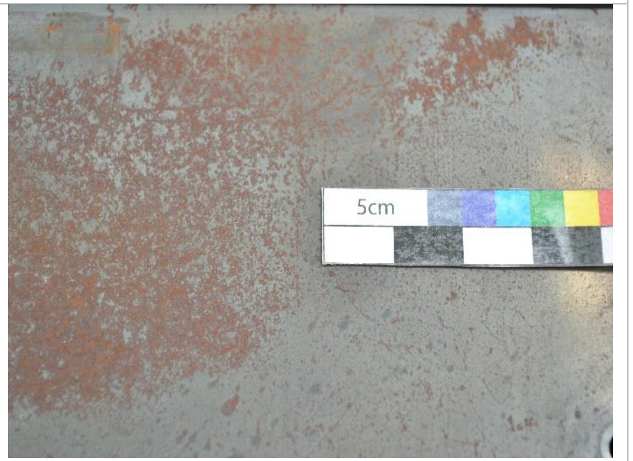
Number of pages *: 162*

Table of contents

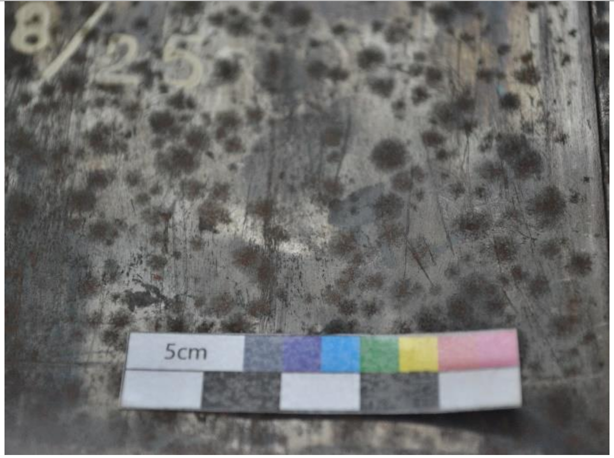
I. Detailed condition report

I.1 Alterations of ferrous elements

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel	Soiling				As it is a technical object, soiling can be related to the manipulation of the device. Also, the conditions of conservation before joining heritage collections can be a cause.	

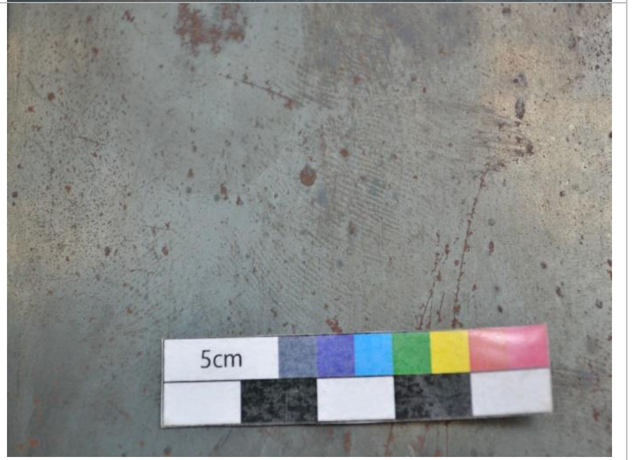
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel	Pitting corrosion				The porous nature of the blued layer and the manipulation of the object, causing scratches and weaknesses in the protective layer helped the development of pitting corrosion, which forms cavities at the surface of the metal, initiated by chloride ions.	
Lantern, walls and upper part	Ferrous alloy, blued steel	Generalised corrosion				The porous nature of the blued layer and the manipulation of the object, causing scratches and weaknesses in the protective layer helps the development of generalised corrosion. A general and even tapering of the metal occurs as it reacts with the atmosphere[1].	

[1] Selwyn, Lyndsie, 2004, p.212

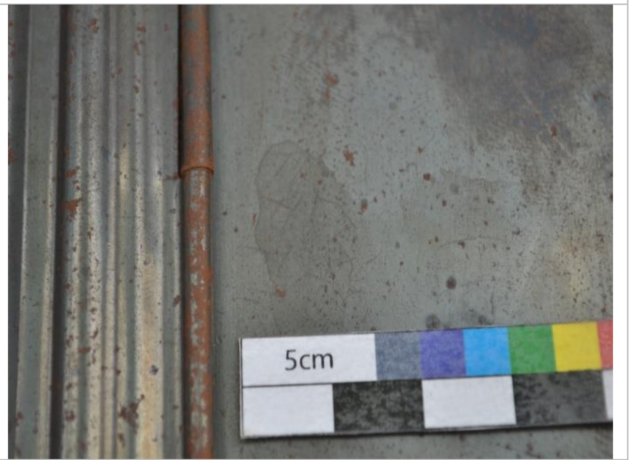
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel	Filiform corrosion				The porous nature of the blued layer and the manipulation of the object, causing scratches and weaknesses in the protective layer helps the development of filiform corrosion which develops under the blued coating as the form of filaments[2].	
Lantern: bottom part, inside and borders of the side doors	Ferrous alloy, blued steel	Localised filiform corrosion				It seems that the object has been exposed to flows. Drops of water stood on the surface. It allowed an electrochemical reaction between the metal and the atmosphere[3], reuniting the conditions for the development of filiform corrosion.	

[2] Selwyn, Lyndsie, 2004, p. 212

[3] Selwyn, Lyndsie, 2004, p.212

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel		Losses of the blued layer			Losses of the blued layer occur when corrosion weakened and raised the layer. Some ancient traces of filiform corrosion are visible where the losses are.	
Lantern, walls and upper part	Ferrous alloy, blued steel	Fingerprints				Fingerprints are intrinsically related to the manipulation of the object, very probably before the blueing process, as this phenomenon has also been observed while preparing the blued steel coupons.	

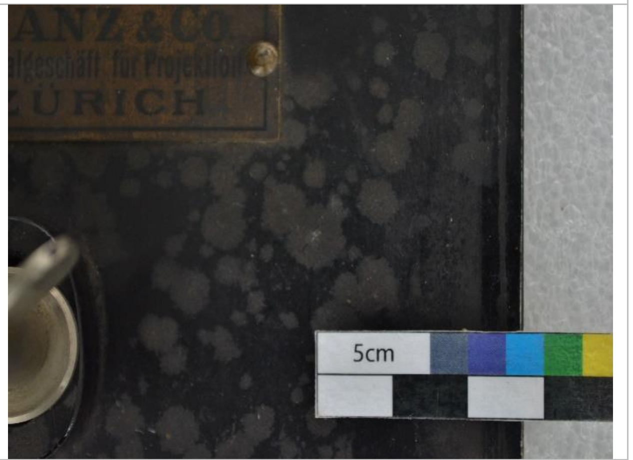
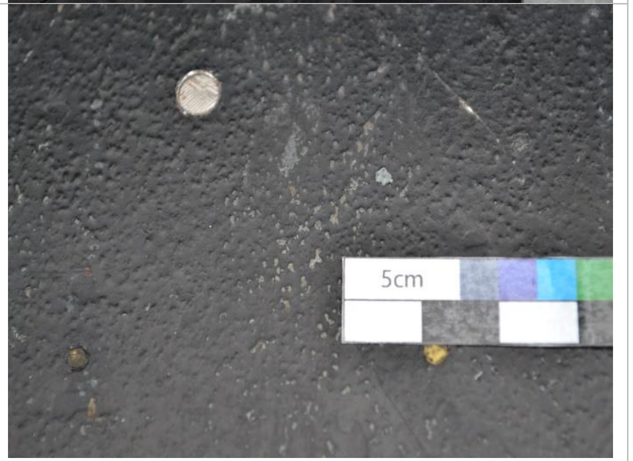
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel	Scratches				As it is a technical object, scratches can be related to the manipulation of the device. Scratched surfaces corroded preferentially.	
Lantern, walls and upper part	Ferrous alloy, blued steel	Sheen				Sheen is related to the lack of homogeneity of the blueing technique used on the sheets. A lighter colour of blueing (here, blue) is visible.	

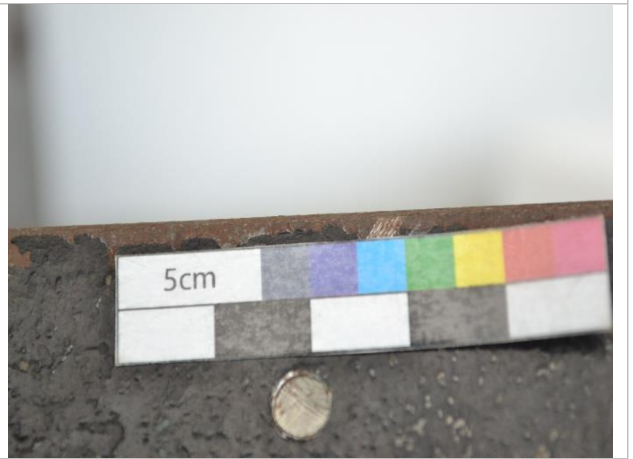
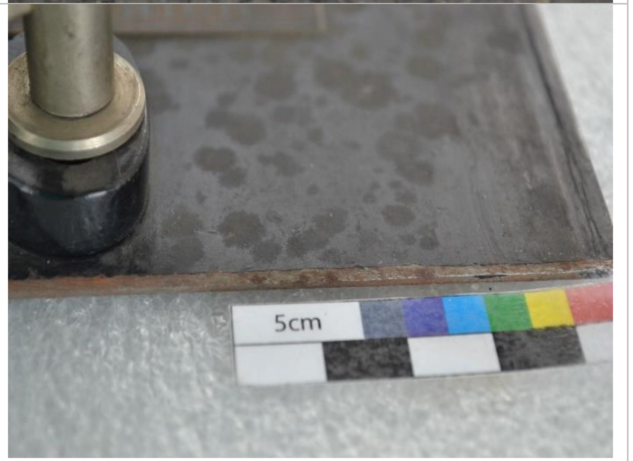
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, walls and upper part	Ferrous alloy, blued steel	Halos				A lot of halos are visible on the object : it seems that it has been exposed to flows.	
Lantern, inside, bottom part	Ferrous alloy, blued steel				Cutting	The bottom of the lantern has been intentionally cut to obtain space for the bulb and its support. It is part of the whole modification of the object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, upper part	Ferrous alloy, blued steel				Sinking	Sinking seem to be related to the modification of the upper part of the lantern. Another chimney has been fixed to it, generating these alterations.	
Lantern, upper part	Ferrous alloy, painted steel sheet				Non-linear orientation	The "new" chimney has been fixed to the upper part of the lantern in a non-linear orientation.	

Localisation	**Material**	**Surface alteration**	**Structural alteration**	**Functional alteration**	**Modifications, previous restorations**	**Diagnostic**	**Picture**
Lantern, upper part	Ferrous alloy, painted steel sheet				Repaint	The inside of the "new" chimney has been painted black while the modification has been done.	
Lantern, back door	Ferrous alloy, blued steel, minium paint		Losses of the read lead layer			Adherence between the metallic sheet and the painting may have been poor, generating losses of the red lead layer.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, back door, aperture closing system	Ferrous alloy, steel				Abrasion	Abrasion is here related to the manufacturing of the aperture and closing system of the back door.	
Lantern, inside, bottom part	Ferrous alloy, blued steel, paint				Inscription "18/25"	It is an indication on the focusing parameters of the object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, painted steel	Halos				A lot of halos are visible on the object : it seems that it has been exposed to flows.	
Lantern, inside, base of the light source	Ferrous alloy, painted steel		Losses of the paint layer			Adherence between the metallic piece and the painting may have been poor and abrasion may have generated losses of the layer.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, painted steel	Generalised corrosion				The losses of the paint layer, very probably caused by filiform corrosion, let the unprotected metallic surface in direct contact with relative humidity. As the object has been exposed to flows, it may have generated generalised corrosion. A general and even tapering of the metal occurs as it reacts with the atmosphere[4].	
Lantern, inside, base of the light source	Ferrous alloy, painted steel				Cutting	The base of the light source has been cut intentionally, when all the modifications have been brought to the object.	

[4] Selwyn, Lyndsie, 2004, p.212

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source, steel rod	Ferrous alloy, painted steel				Abrasion	This rod carrying the condenser, seems to have been modified by abrasion. The whole support of the light source is concerned by modifications.	
Lantern, inside, base of the light source, wheel	Ferrous alloy, galvanized steel	Pitting corrosion				Pitting corrosion can be related to weaknesses of the metallic coating, which, when in contact with high relative humidity, forms cavities at the surface of the metal, initiated by chloride ions[5].	

[5] Selwyn, Lyndsie, 2004, p. 213

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, painted steel				Cutting	The circular part carrying the support of the bulb has been cut in order to obtain space for the rod carrying the bulb. It is part of the modifications brought to the object, concerning here a change of the light source.	
Lantern, inside, base of the light source	Ferrous alloy, steel	Pitting corrosion				Pitting corrosion forms cavities or pitting at the surface of the metal, generally because of the presence of chloride ions[6].	

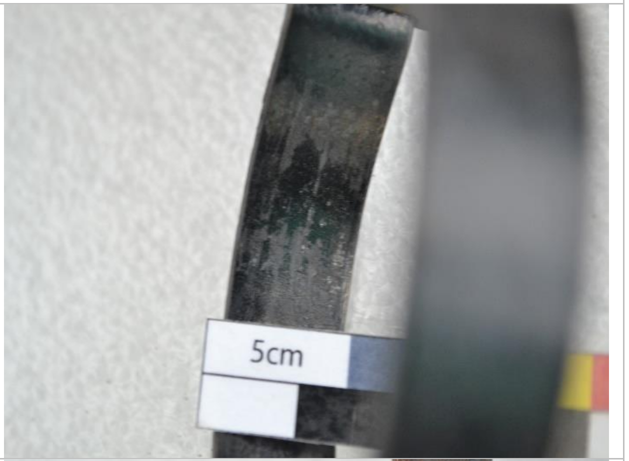
[6] Selwyn, Lyndsie, 2004, p. 213

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, galvanized steel	Scratches				The manipulation of this rod and the support of the light source might have created scratches on the surface.	
Lantern, inside, base of the light source	Ferrous alloy, galvanized steel	Pitting corrosion				Pitting corrosion forms cavities or pitting at the surface of the metal, generally because of the presence of chloride ions[7].	

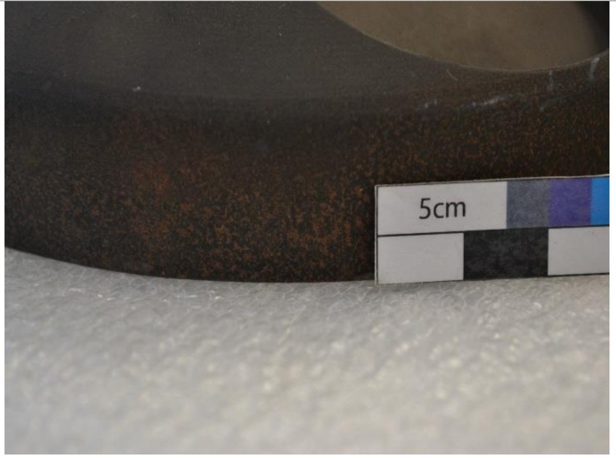
[7] Selwyn, Lyndsie, 2004, p. 213

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, steel	Generalised corrosion				As the object has been exposed to flows, it may have generated generalised corrosion. A general and even tapering of the metal occurs as it reacts with the atmosphere[8].	
Lantern, inside, base of the light source	Copper alloy on ferrous alloy, steel				Soldering	Two solderings have been added to assemble the different part of the support of the light source. It is part of the modifications brought to the object, concerning here a change of the light source.	

[8] Selwyn, Lyndsie, 2004, p.212

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source	Ferrous alloy, painted steel		Losses of the paint layer			Abrasion between the bulb and this ring carrying it may have altered the painting, as well as a lack of adhesion between the substrate and the paint.	
Lantern, inside, base of the light source	Ferrous alloy, steel			Partial loss of the screw head		This loss may be related to the setting and the maintenance of the light source.	

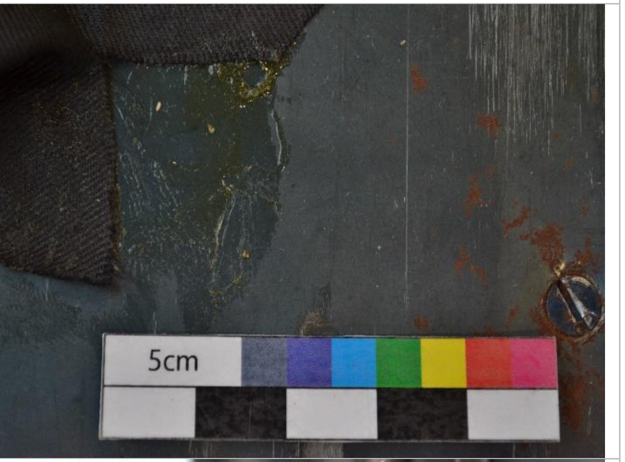
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, lens	Copper alloy on ferrous alloy, steel				Solderings	Three solderings have been added to the lens of the object. They are similar to those made to modify the light source of the object. We can consider than these solderings are also part of the modifications brought to the object.	
Lantern, inside, lens	Ferrous alloy, galvanized steel		Losses of the zinc layer			A lack of adherence between the substrate and the metallic coating, the friction between the lens and the lens carrier as well as its manipulation may have caused losses of the zinc layer.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, lens	Ferrous alloy, metallic coating		Losses of the metallic coating			A lack of adherence between the substrate and the metallic coating and contact between the glass lens and its metallic structure may have caused losses of the zinc layer.	
Lantern, inside, condenser	Ferrous alloy, painted steel	Pitting corrosion				Pitting corrosion forms cavities or pitting at the surface of the metal, generally because of the presence of chloride ions[9]. Also, the object has been exposed to flows.	

[9] Selwyn, Lyndsie, 2004, p. 213

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Sliding plate under the lantern	Ferrous alloy, blued steel	Generalised corrosion				The porous nature of the blued layer and the manipulation of the object, causing scratches and weaknesses in the protective layer helps the development of generalised corrosion. A general and even tapering of the metal occurs as it reacts with the atmosphere[10]. Here, the generalised corrosion is located on the edges of the sliding plate.	
Sliding plate under the lantern	Ferrous alloy, blued steel		Losses of the blued steel layer			The sliding of the lantern of this plate seems to have caused losses of the blued layer, as it scratches the surface.	

[10] Selwyn, Lyndsie, 2004, p.212

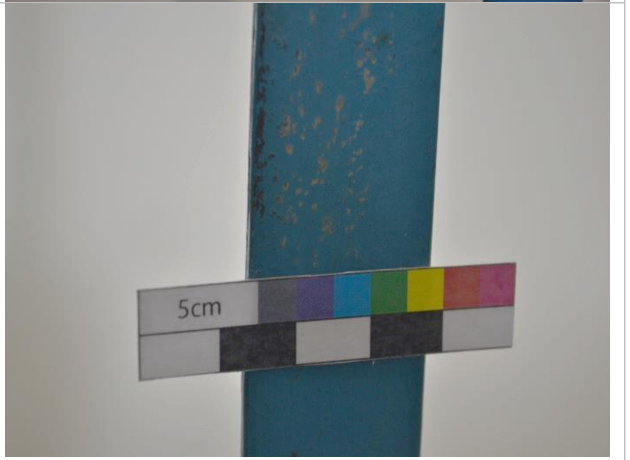
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Sliding plate under the lantern	Ferrous alloy, blued steel, adhesive		Yellowing			The chemical ageing of the adhesive has caused its yellowing.	
Wooden base of the lantern, half lens carrier	Ferrous alloy, blued steel				Repaint	Several parts of the object have been repainted while the modifications were brought to the object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Ferrous alloy, steel				Missing handles	Two handles are missing on the wooden box. This is very probably due to the modification of the box, from a trunk to its actual state or to a previous loss.	
Wooden box, inside	Ferrous alloy, steel	Corrosion				An electrochemical reaction occurs between the metal and its atmosphere, causing its deterioration by reactions of oxidation and reduction[11].	

[11] Selwyn, Lyndsie, p.212

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside	Ferrous alloy, steel				Stains of blue paint	The stain of blue paint shows that the repaint of the wooden box has been done afterwards. It may originally was in the wooden box before the modifications.	
Metallic structure	Ferrous alloy, steel, paint	Soiling				The metallic structure is exposed to the atmosphere and could have been soiled easily during its active life and storage before it became heritage.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Metallic structure	Ferrous alloy, steel, paint		Losses of the painting layer			A lack of adherence between the paint layer and the substrate may have caused the losses.	
Metallic structure	Ferrous alloy, steel, paint	Scratches of the painting				The manipulation of this technical object may have generated scratches on the paint layer.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Metallic structure, right side	Ferrous alloy, steel, paint				Inventory number	This is the actual inventory number of the object.	
Metallic structure	Ferrous alloy, steel, paint	Brownish stains				The metallic structure is exposed to the atmosphere and could have been soiled easily during its active life and storage before it became heritage.	

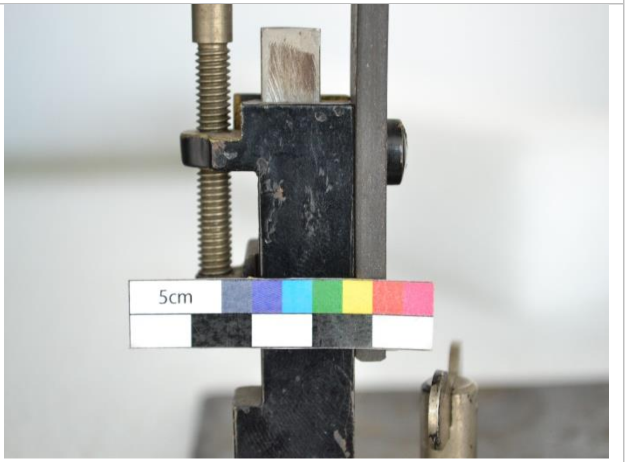
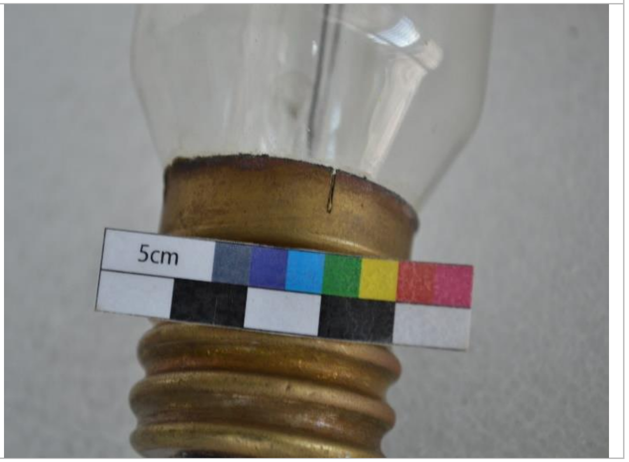
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Metallic structure	Ferrous alloy, steel, paint	Halos				The object has been exposed to flows, causing halos.	
Wooden box, transformer	Ferrous alloy, steel	Generalized white deposits				The powdery white deposits were probably already present on the transformer during the modifications as a fingerprint removed a bit of it. As all the modifications brought to the object, they have been done in a very crafted way.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, transformer	Ferrous alloy, steel	Fingerprint				The manipulation of the transformer during its installation may have caused a fingerprint mark.	

I.2 Alterations of other metals

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern: rivets, plates, handles of the side doors, peepholes' structure, lamp cap, rack-and-pinion drive	Copper alloy, varnish	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[12].	
Lantern, inside, base of the light source	Copper alloy, brass, paint, varnish	Tarnishing				This plate has been highly exposed to flows, generating tarnishing of the brass plate.	

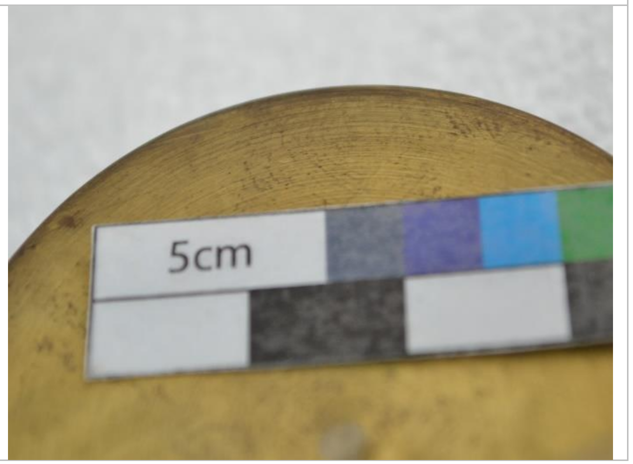
[12] Selwyn, Lyndsie, 2004, p. 221

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source, black piece	Copper alloy, brass, paint		Losses of the paint layer			The manipulation and the settings of this part of the support of the light source may have cause losses of the paint layer.	
Lantern, inside, lamp cap	Copper alloy	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[13].	

[13] Selwyn, Lyndsie, 2004, p. 221

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, lamp cap	Copper alloy	Copper alloy (brass?) deposit				The copper deposit seems to have been generated by the contact between the lamp cap and the copper of the socket.	
Lantern, inside, base of the light source	Copper alloy	Corrosion				An electrochemical reaction occurs between the metal and its atmosphere, causing its deterioration by reactions of oxidation and reduction[14].	

[14] Selwyn, Lyndsie, p.212

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, sides, peepholes	Copper alloy, brass	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[15].	
Lantern, sides, peepholes	Copper alloy, brass	Fingerprint				Fingerprints on brass are related to the manipulation of the object as well as the development of tarnishing where the potential chlorides of the finger have been placed.	

[15] Selwyn, Lyndsie, 2004, p. 221

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, sides, peepholes	Copper alloy, brass	Halos				A lot of halos are visible on the object : it seems that it has been exposed to flows.	
Lantern, inside, lens	Copper alloy, painted brass	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[16].	

[16] Selwyn, Lyndsie, 2004, p. 221

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, lens	Copper alloy, painted brass		Losses of the paint			A lack of adhesion between the metal and the paint, as well as the friction between the lens and the lens carrier, may have caused losses of the paint.	
Wooden base of the lantern, front, lens carrier	Copper alloy, brass	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[17].	

[17] Selwyn, Lyndsie, 2004, p. 221

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden base of the lantern	Copper alloy, brass	Pitting corrosion				Pitting corrosion forms cavities or pitting at the surface of the metal, generally because of the presence of chloride ions[18]. Also, the object has been exposed to flows.	
Wooden base of the lantern	Copper alloy, brass	Scratches				The manipulation of the object and the configuration of the settings may have caused scratches.	

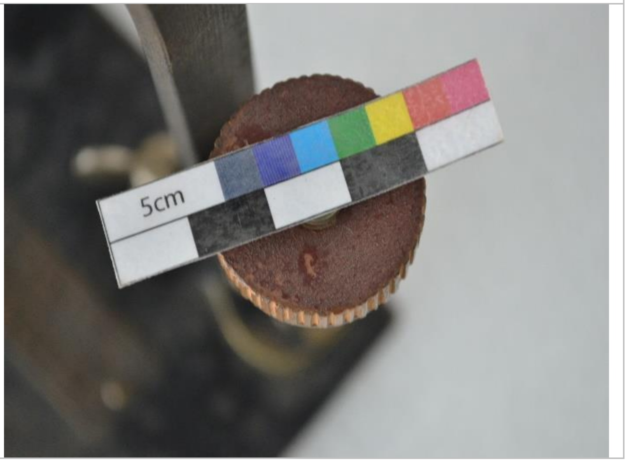
[18] Selwyn, Lyndsie, 2004, p. 213

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, socket	Copper alloy, brass	Tarnishing				Copper alloys, when exposed to oxygen and humidity, develop tarnishing which is a discolouration of the surface of a metal when it is covered with a thin layer of corrosion products[19].	
Wooden box, inside, cabinet	Ferrous alloy, galvanised steel	Corrosion				An electrochemical reaction occurs between the metal and its atmosphere, causing its deterioration by reactions of oxidation and reduction[20]. The manipulation of the handle, favouring the deposit of chlorides, may have helped the process.	

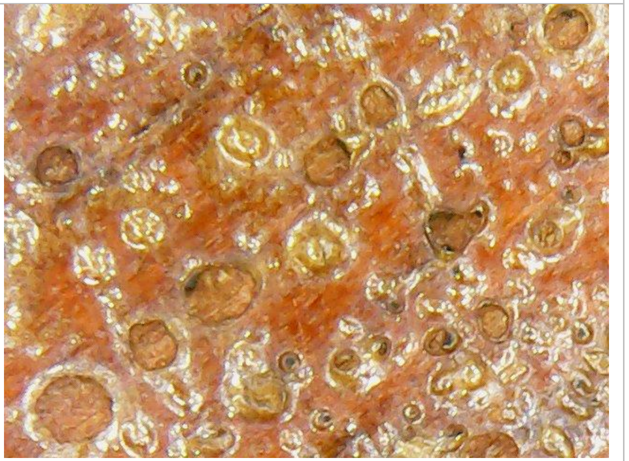
[19] Selwyn, Lyndsie, 2004, p. 221

[20] Selwyn, Lyndsie, p.212

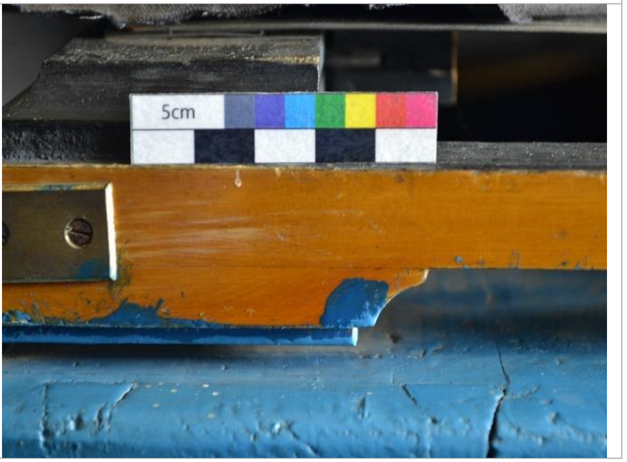
I.3 Alterations of wooden elements

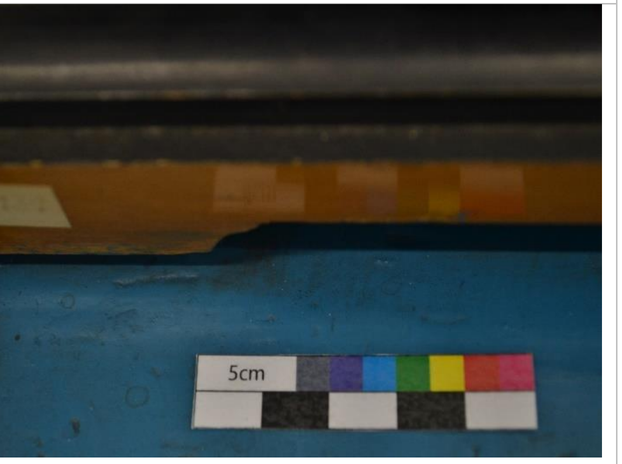
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, base of the light source, wheel screw	Wood	Soiling				The soiling of this part of the object can be related to its manipulation, to get the right settings.	
Lantern, inside, base of the light source, wheel screw	Painted wood		Losses of the paint layer			The losses of the paint layer can be related to a lack of adherence between the support and the painting.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac	Discolouration				The previous conditions of conservation and an exposition to UV light may have caused a discolouration.	
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac		Cross-linking of the varnish			A heat input may have caused the reticulation of the varnish.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac		Blisters of the varnish			A heat input may have caused blisters of the varnish.	
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac		Losses of the varnish			A heat input, causing the reticulation of the varnish as well as blisters, has consequently generated losses of the varnish.	

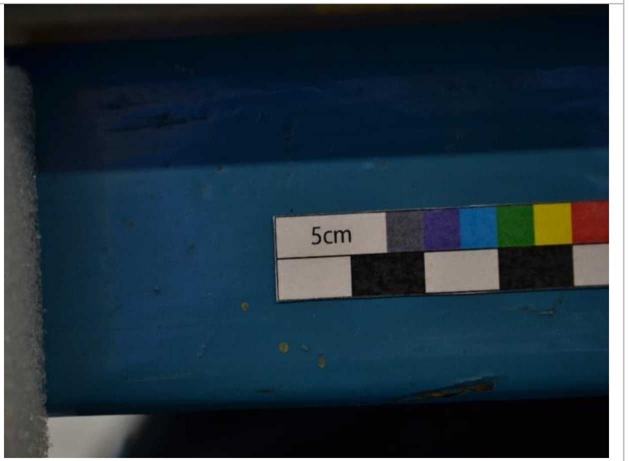
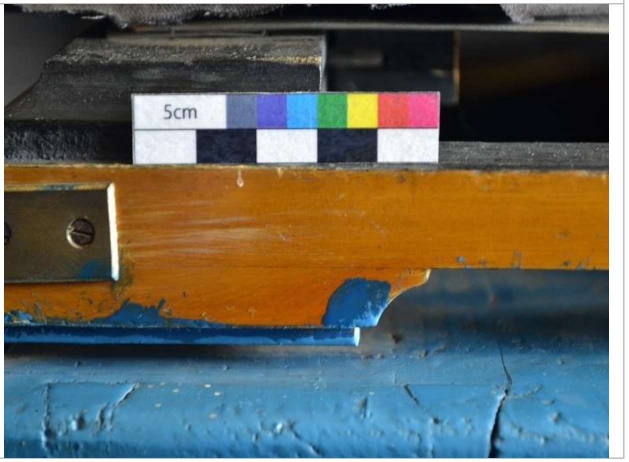
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac	Scratches				The manipulation of the lens carrier may have caused scratches.	
Wooden base of the lantern, front, lens carrier	Varnished wood, shellac		Losses of the wood			The manipulation of the lens carrier may have caused losses of the wood.	

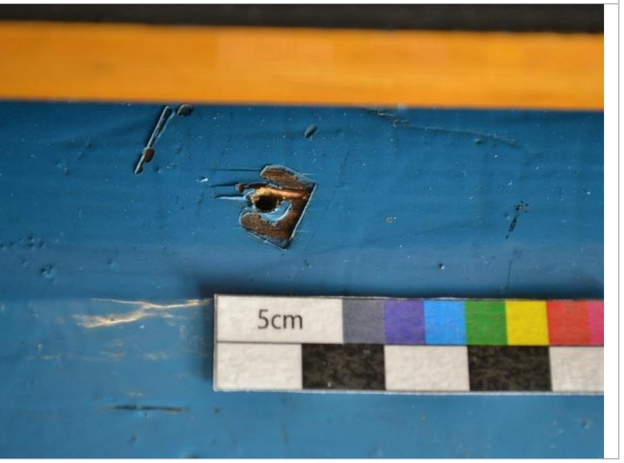
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden base of the lantern	Painted wood	Soiling				The previous conditions of conservation of the object have caused an agglomeration of soiling.	
Wooden base of the lantern	Varnished wood	White deposits				The previous conditions of conservation and the repaint of some parts of the object may have caused these white deposits.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	Soiling				The previous conditions of conservation may have caused soiling.	
Wooden box	Painted wood	Dents				The blue repaint is still present on the dents, meaning that these alterations were made before the modification of the trunk as the wooden box of the projector.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	Halos				The object has been exposed to flows, generating halos.	
Wooden box	Painted wood		Losses of the wood			The losses of wood may be related to the manipulation and the use of this technical object.	

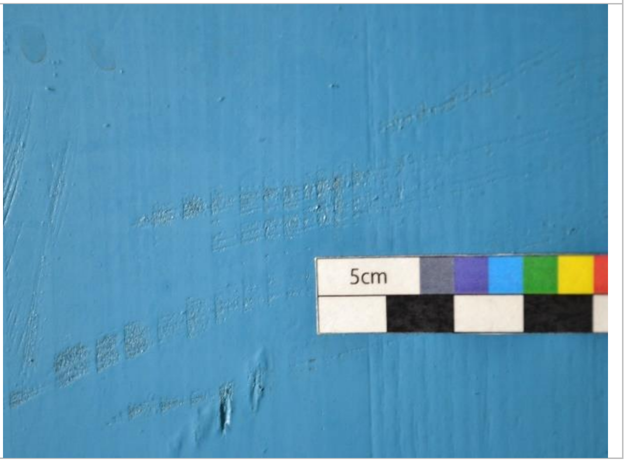
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood		Losses of the paint			The losses of paint may be related to the manipulation and the use of this technical object.	
Wooden box	Painted wood	Scuffs				The blue repaint is still present on the scuffs, meaning that these alterations were made before the modification of the trunk as the wooden box of the projector.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	White stains				The inside of the wooden box has been repainted white. These stains might be paint from this modification.	
Wooden box	Painted wood				Repaint	While its modifications, the wooden box of the object has been repainted blue, after the technical assembly and modifications of the object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	Sags				The object has been exposed to flows, generating sags.	
Wooden box	Painted wood				Hole	It may be part of the modifications of the object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	Sinking				The blue repaint is still present on the sinkings, meaning that these alterations were made before the modification of the trunk as the wooden box of the projector.	
Wooden box	Painted wood		Cracks			These straight-lined openings, more or less long, following the orientation of the internal structure of the material[21], are caused by constraints in the material, generally because of the variations of the climate from a dry to a humid atmosphere.	

[21] Centre de conservation Québec, 2014, [Online]

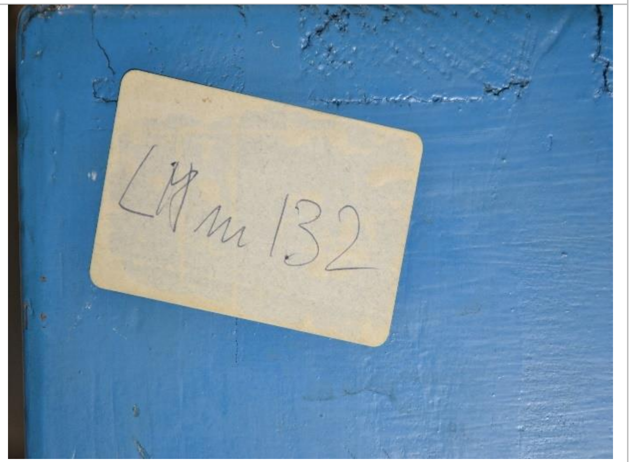
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood		Splits			These opening in the mass of the wood following an area of weakness[22], are caused by the variations of the climate from a dry to a humid atmosphere.	
Wooden box	Painted wood	Scratches				The blue repaint is still present on the scratches, meaning that these alterations were made before the modification of the trunk as the wooden box of the projector.	

22 Centre de conservation Québec, 2014, [Online]

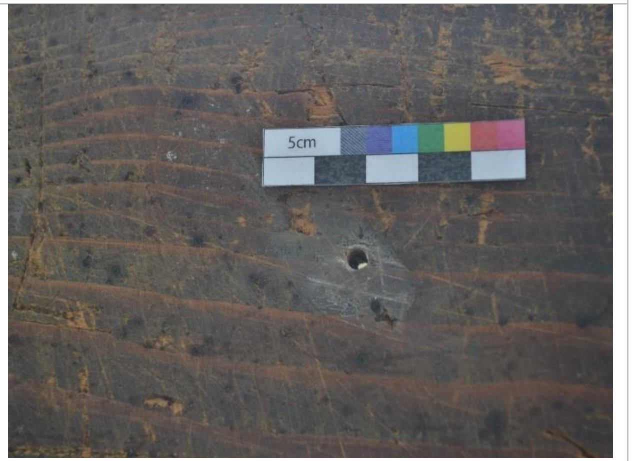
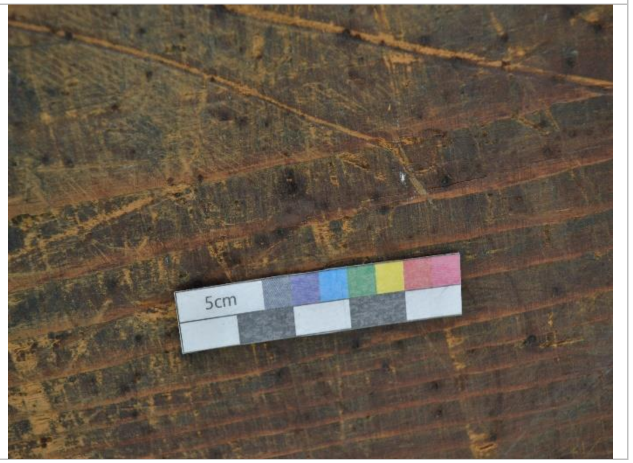
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box	Painted wood	Chalky deposit				The manipulation of the front door of the wooden box may have caused the accumulation of deposits.	
Wooden box, inside	Painted wood	Black deposit				Soiling could have accumulated easily on this technical object, during its use and after.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside	Painted wood		Lifting of the paint layer			A lack of adherence between the paint layer and the support may have caused the lifting of the paint layer.	
Wooden box, inside	Painted wood	Black deposits				Black deposits having the form of scuffs are visible inside the wooden box, on the bottom part. They might be related to the drop and output of the PVC cable laying in the box.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, front door	Painted wood				Cut	The cut is part of the modification of the object, to let the power cable out of the box.	
Wooden box	Painted wood				Adding of a sticker	The adding of a sticker might be part of the ancient inventory protocol.	

Localisation	**Material**	**Surface alteration**	**Structural alteration**	**Functional alteration**	**Modifications, previous restorations**	**Diagnostic**	**Picture**
Wooden box	Painted wood				Adding of two stickers with inventory numbers	The adding of two stickers may be part of the ancient inventory protocol.	
Wooden box	Painted wood				Adding of the inventory number	The current inventory number has been added to the object for identification.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, bottom part	Bare wood	Abrasion				The previous use of the box as a trunk may have caused abrasion.	
Wooden box, bottom part	Bare wood	Scratches				The previous use of the box as a trunk may have caused scratches.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, bottom part	Bare wood		Holes			The holes may be part of the modifications brought to the box, or from its original state as a trunk.	
Wooden box, bottom part	Bare wood	Black shiny deposits				The deposits may have agglomerated to the wood while using it as a trunk, as it was probably moved from a floor to another.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, bottom part	Bare wood		Split			Strain on wood may have caused a split.	
Wooden box, inside part of the door	Bare wood		Crack			These straight-lined openings, more or less long, following the orientation of the internal structure of the material[23], are caused by constraints in the material, generally because of the variations of the climate from a dry to a humid atmosphere.	

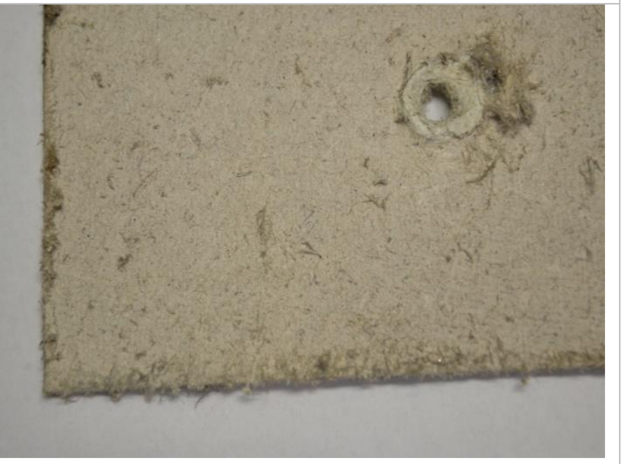
[23] Centre de conservation Québec, 2014, [Online]

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside part of the door	Bare wood		Losses of the wood			The manipulation of the removable door may have caused losses.	
Wooden box, inside part of the door	Bare wood	Impacts				The manipulation of the removable door may have caused impacts.	

Localisation	**Material**	**Surface alteration**	**Structural alteration**	**Functional alteration**	**Modifications, previous restorations**	**Diagnostic**	**Picture**
Wooden box, inside part of the door	Bare wood	Abrasion				The manipulation of the removable door may have caused abrasion.	
Wooden box, inside part of the door	Bare wood				Sag of blue paint	The repaint of the wooden box has generated a sag of blue paint.	

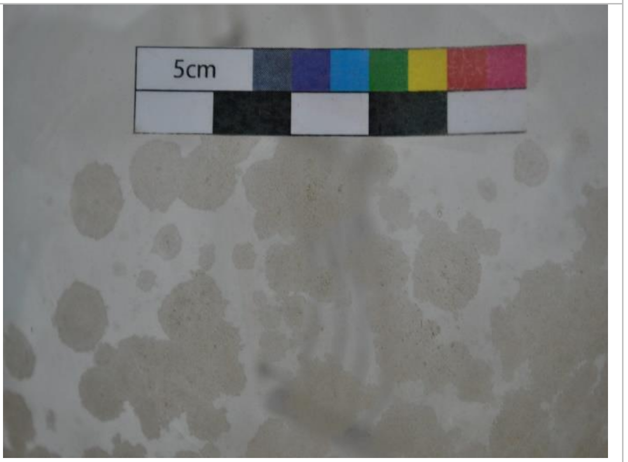
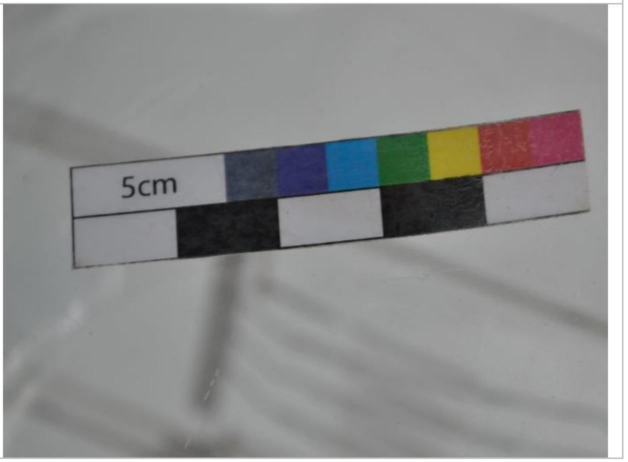
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside part of the door	Bare wood	Scratches				The manipulation of the removable door may have caused scratches.	
Wooden box, inside part of the door	Bare wood	Black deposits				The manipulation of the removable door may have generated black deposits while it was laid on surfaces.	

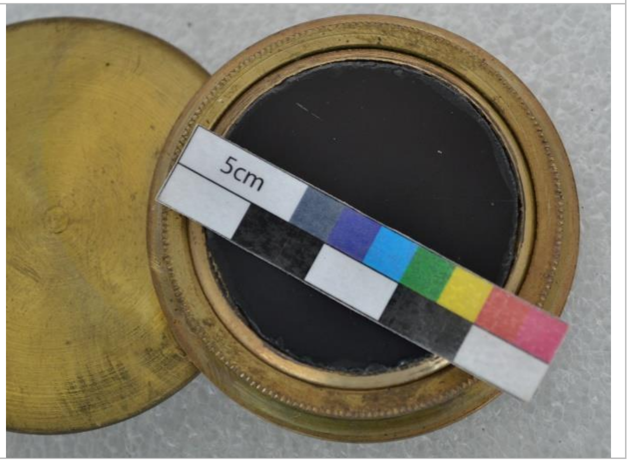
I.4 Alterations of asbestos plates

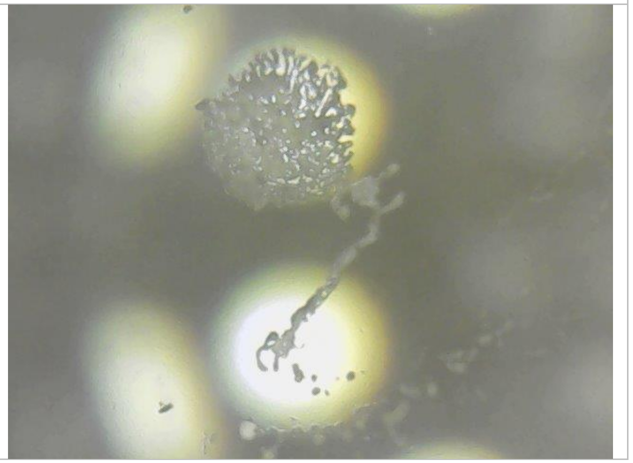
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
General	Asbestos	Lifting of fibres				Asbestos plates are support which are unstable by nature, as they are mode of an agglomeration of sheets of fibres. The lifting, detachment and fraying of the edges is then easy for this substrate.	
General	Asbestos		Detachment				

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
General	Asbestos		Fraying of edges				

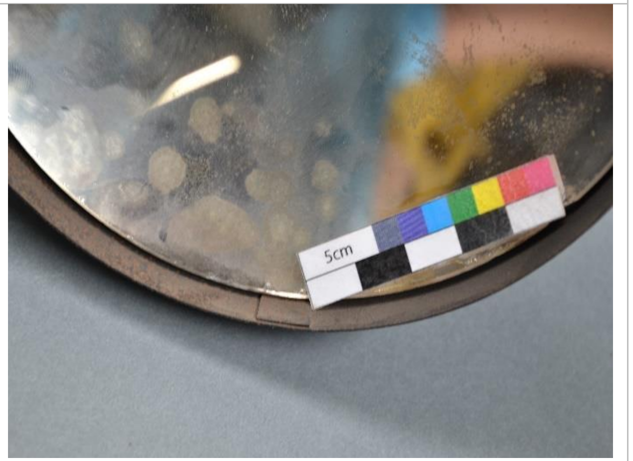
I.5 Alterations of glass

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, bulb	Glass	Soiling				A lot of halos are visible on the object : it seems that it has been exposed to flows, generating here an agglomeration of soiling where the drops where standing.	
Lantern, inside, bulb	Glass	Scratches				Scratches on glass may be related to the manipulation of this fragile object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, sides, peepholes	Tinted glass		Cracks			The cracks of the glass may be related to the manipulation of the peepholes or the doors of the lantern.	
Lantern, sides, peepholes	Tinted glass	Scratches				The scratches of glass may be related to the manipulation of the doors of the lantern.	

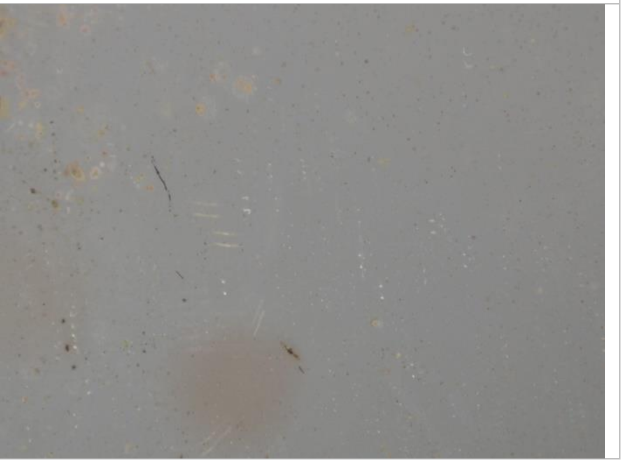
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, lens	Glass	Soiling				The lens is supported by the front of the lantern, which does not protect completely the object from the dust and grime.	
Lantern, lens	Glass	Corrosion				Glass corrosion is due to electrochemical reactions of the material with its atmosphere, generally water attack or acid or alkaline chemical attacks[24]. In the case of this object, the water attack would be plausible.	

[24] Corrosionpedia, 2018, [Online]

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, condenser	Glass, silver coating	Corrosion				Glass corrosion is due to electrochemical reactions of the material with its atmosphere, generally water attack or acid or alkaline chemical attacks[25]. In the case of this object, the water attack would be plausible.	
Lantern, inside, condenser	Glass, silver coating	Tarnishing				Glass is covered with a silver coating to obtain a mirror surface thanks to silvering by electroless plating[26]. Silver can tarnish when exposed to sulphur gazes in reduced oxidation state (hydrogen sulphur or carbonyl sulphur) and elementary sulphur.	

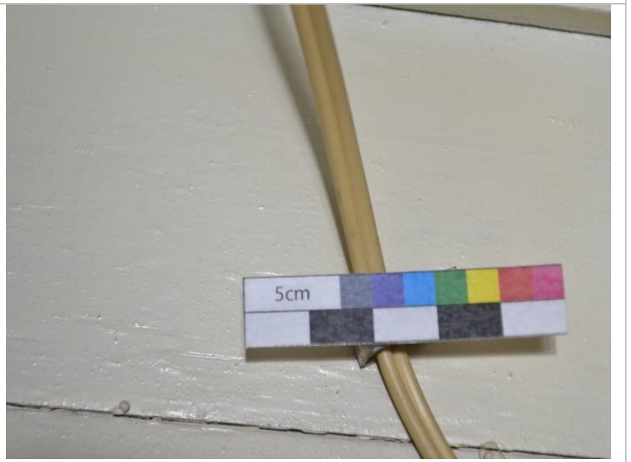
[25] Corrosionpedia, 2018, [Online]

[26] Selwyn, Lyndsie, p.148

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, condenser	Glass, silver coating	Chipping				The manipulation of the condenser while parameterizing the settings may have caused chipping.	
Lantern, inside, condenser	Glass, silver coating	Scratches				The manipulation of the condenser while parameterizing the settings may have caused scratches.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, condenser	Glass, silver coating	Fingerprint				The manipulation of the condenser, generating the filing of chlorides on the surface of the glass, as well as the expositions to flows may have generate the marking of the fingerprint.	

I.6 Alterations of plastics

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, unconnected cable from the transformer	Plastic, PVC?	Yellowing				Photo-oxidation has caused the yellowing of the cable, being directly exposed to the light source of the lantern. It is related to the loss of hydrogen chloride from the plastic[27].	

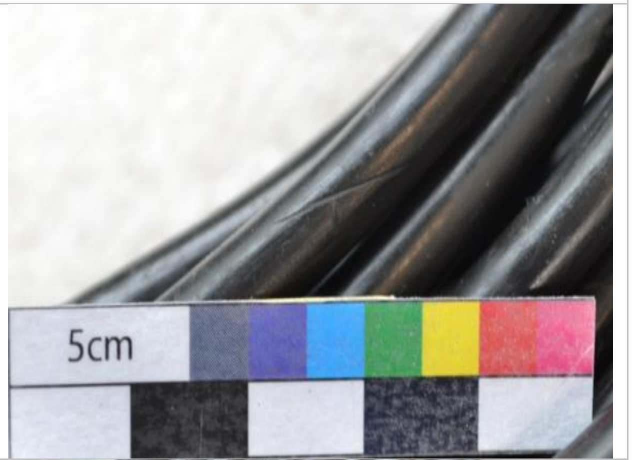
[27] Shashoua, Yvonne, 2008, p. 162

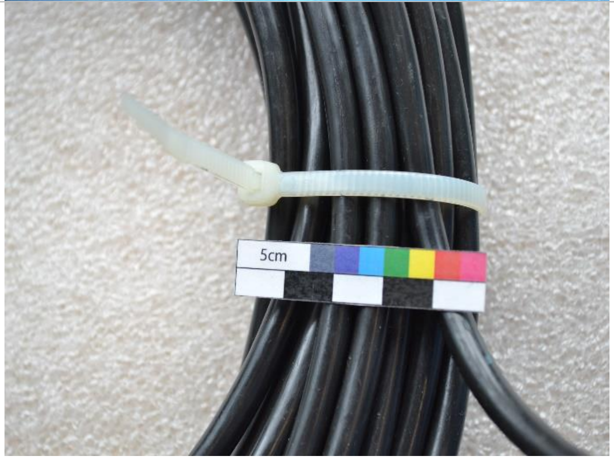
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, unconnected cable from the transformer	Plastic, PVC?		Hardening			The loss of plasticizers causes brittleness and hardening of plastics[28].	
Wooden box, inside, power cable	Plastic, PVC	Surface dust				The power cable, during its use and storage, was easily in contact with dust.	

[28] Shashoua, Yvonne, 2008, p. 159

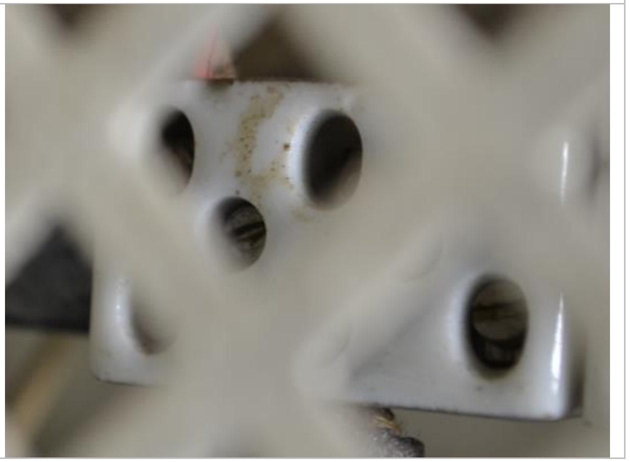
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, power cable	Plastic, PVC	Painting deposit and fingerprint				The repaint of the wooden box has been done after the technical modifications of the object.	
Wooden box, inside, power cable	Plastic, PVC	Bloom				Ancient flexible PVC are generally very unstable chemically. Their plasticizer migrates at the surface, being sticky first and crystallising as bloom. Also, the loss of lubricant from the PVC (stearic acid) is common, as it is a very non-polar material in comparison with PVC. It results in the deposit of white crystals at the surface[29].	

[29] Shashoua, Yvonne, 2008, p. 161

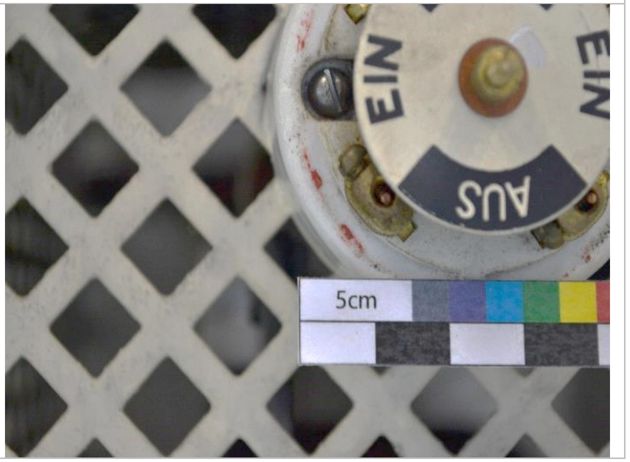
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, power cable	Plastic, PVC	Scratch				The manipulation and use of the power cable may have caused scratches.	
Wooden box, inside, power cable	Plastic, PVC				Spot of blue paint	The repaint of the wooden box has been done after the technical modifications of the object.	

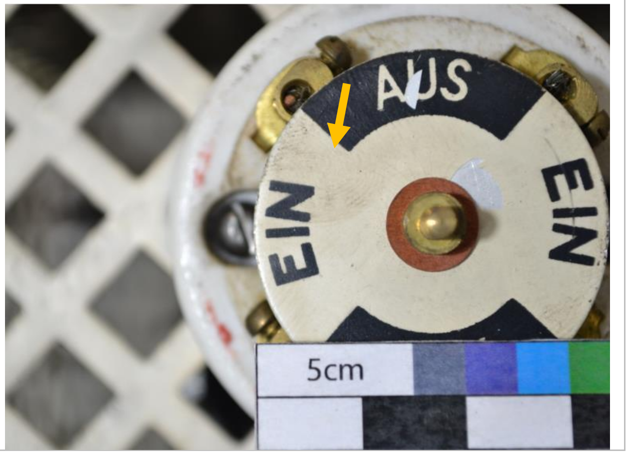
Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, power cable	Plastic, PVC		Smell of new car seats			The chemical degradation of PVC, volatilizing its plasticizer[30], allows this smell.	
Wooden box, inside, power cable	Plastic, PVC				Plastic tie	A plastic tie has been added after the final use of this object.	

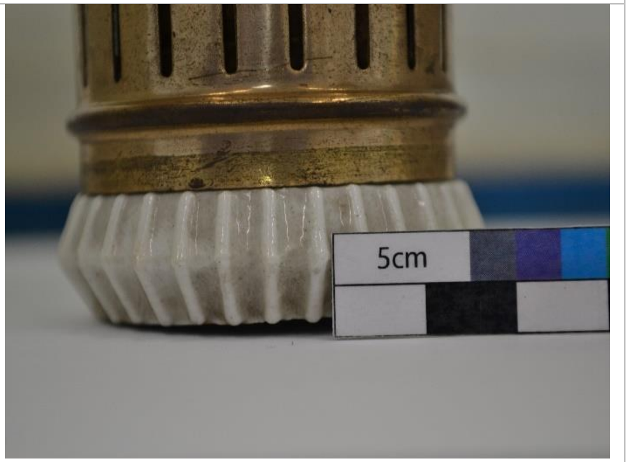
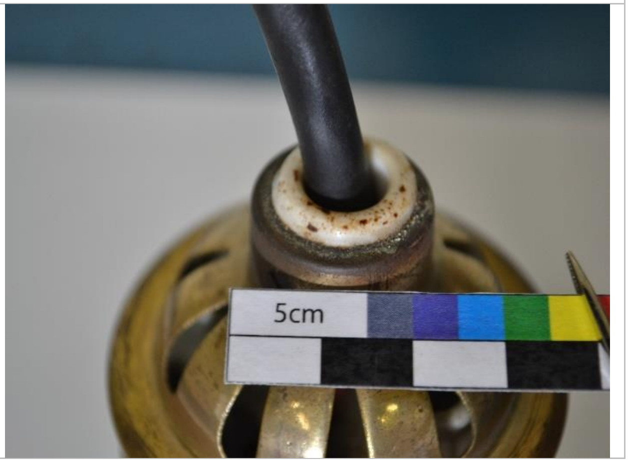
[30] Shashoua, Yvonne, 2008, p. 119

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, transformer, wire nut connectors	Plastic	Grime				Grime may have easily accumulated on this open part of the object.	

I.7 Alterations of ceramic elements

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, transformer switch	Ceramic	Grime				Grime could easily accumulate between the switch and its cover.	
Wooden box, inside, transformer switch	Ceramic	Deposit of red paint				The red paint has been deposited by contact with the cover of the switch which is painted.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, inside, transformer switch	Ceramic	Painted ceramic		Loss of the paint layer		The low adherence between the paint and ceramic may have caused losses of the paint layer, as well as the vibrations .	
Wooden box, inside, transformer switch	Ceramic	Fingerprint				The manipulation of the painted ceramic part of the object has generated fingerprint mark.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Lantern, inside, socket	Ceramic	Grime				The socket was easily exposed to dust and grime in the lantern.	
Lantern, inside, socket	Ceramic	Brownish deposits				Soiling has accumulated on this part of the socket.	

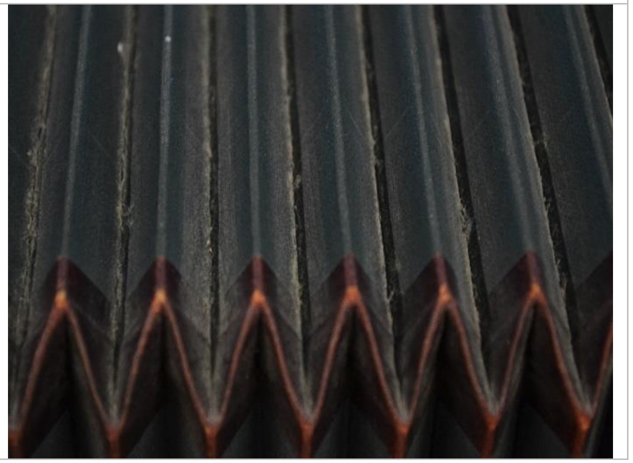
I.8 Alterations of textile

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Wooden box, edge of the power cable	Textile		Fraying			The edge of the power cable has required to cut the cable, meaning its plastic and textile elements. Fraying can then be expected here.	
Wooden box, transformer	Coated textile	Paint stains				The repainting of the inside of the box may have caused paint stains on the transformer.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Sliding plate under the lantern	Textile on ferrous alloy, blued steel				Adding of a piece of textile	A piece of textile has been added while all the modifications have been brought to the object, in order to avoid the penetration of light between the wooden base of the lantern and the wooden box.	
Sliding plate under the lantern	Textile		Holes			The holes may have been already present on the textile before it was stuck on the sliding plate under the lantern; or caused by the multiple settings of the technical object.	

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Sliding plate under the lantern	Textile	White stains				The stains may be the result to an accumulation of grime when flows generated halos at the surface of the textile.	
Sliding plate under the lantern	Textile		Fraying			The fraying may have been already present on the textile before it was stuck on the sliding plate under the lantern; or caused by the multiple settings of the technical object.	

I.9 Alteration of paper

Localisation	Material	Surface alteration	Structural alteration	Functional alteration	Modifications, previous restorations	Diagnostic	Picture
Bellow	Coated paper, leather	Dust				The outside parts of the bellow are directly exposed to the ambient atmosphere. Dust could easily accumulate on its surface.	

II. Selection of the treatment parameters and tests of treatments

II.1 Stabilization of asbestos mediums

The object LM152706.1 contains 6 objects made or contaminated with asbestos :

- 2 wide plates of low clustered asbestos covering the sides ;
- 1 medium plate of low clustered asbestos covering the front of the lantern ;
- 2 small plates of low clustered asbestos covering the side doors (*Picture 1*);
- A textile contaminated with asbestos fibres (*Picture 2*).

Picture 1 : View of the 5 plates of asbestos inside the lantern, in the hood and protective tent ©HE Arc CR, A.L

Picture 2 : View from the top of the contaminated textile, in the hood and protective tent ©HE Arc CR, A.L

II.1.1 What is asbestos?

Asbestos is a natural material, a fibrous and crystalline material, extracted from the metamorphic stones. Its name comes from the latine word *asbestos*, which signifies incombustible. It is originated from two families of stones :

- Amphibole stones, providing 5 ranges of asbestos : tremolite, anthophyllite, actinolite, amosite and crocidolite. Brown amosite asbestos and blue crocidolite asbestos were the most commonly used ;
- Serpentine stones, providing one range of asbestos named chrysotile. It is characterized by its white colour.

These varieties are mainly composed with silicon (Si) and oxygen (O) atoms, whose structure is tetrahedral (SiO_4). They differentiate as their oxygen atoms combine with other atoms as iron (Fe), sodium (Na) or magnesium (Mg) (*Table 1*). The size of their fibres is also different and 400 to 2000 times smaller than a human hair, as they are capable to divide lengthwise, forming fibrils[31].

Family	Serpentine	Amphibole	
Range	Chrysotile	Amosite	Crocidolite
Colour	White	Brown	Blue
Maximal length of the fibres	40 mm	70 mm	70 mm
Diameter of the fibrils	0.02 µm	0.1 µm	0.08 µm
Associated atoms to the asbestos basic structure SiO_4	Magnesium (Mg)	Magnesium (Mg), Iron (Fe)	Iron (Fe), Sodium (Na)
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$(Fe,Mg)_7Si_8O_{22}(OH)_2$	$Na_2(Fe+++_3Fe+++_2)Si_8O_{22}(OH)_2$

Table 1 : Characteristics of the 3 main ranges of asbestos ©INRS

Several physical and chemical properties characterize asbestos. It is a great insulating material, thanks to its low thermal, acoustic and electric conductivities. It is also incombustible, as it is resistant to fire.

[31] Lefebvre, Alexandra, 2019, [Online], p. 11-12

It is mechanically resistant, but with a certain elasticity. Asbestos is rot-proof and resists to the corrosivity of chemicals. This low-cost material can easily be weaved and spined, as well as mixed to cements and resins[32].

Asbestos mining is practiced periodically from the Antiquity to the 18th century. Its exploitations became industrial and commercial around 1860. It is used for its properties in different mediums as building materials, automobile, laboratory devices, household appliance and cinematic objects. However, its use is reduced from 1975, in conjunction with the instructions of the worker protection and the limited exposure to asbestos mediums, until its ban in Switzerland in 1990. Nevertheless, Switzerland allowed in June 1st 2019 the use of serpentinite for restoration and repair purposes, if no other material suits aesthetically, despite the disagreement of the Swiss League against cancer[33].

Most of the asbestos mediums free a large number of fibres of microscopic scale, which make them invisible in atmospheric dust. The fibres can easily be inhaled and housed in the pulmonary alveoli, the peritoneum and the pleura, and remain there for several decades. They can cause severe respiratory diseases after a short exposure, although a repeated exposure can rise the risk of disease. The smaller, longer and thinner the fibres are, the more they settle in the respiratory system as the organism can only partially eliminate them.

Asbestos can cause pleural plaques, which is a benign fibrous thickening of the parietal pleura. It is also responsible for asbestosis, a progressive disease of the lungs that can lead to respiratory failure or lung cancer. Mesothelioma, which is a malignant tumour of the pleura – a protective membrane around the lungs – and the peritoneum – a membrane that covers the abdominal organs – can also occur and spread as metastases to other parts of the body. These illnesses start between 15 and 40 years after exposure. 120 people die from mesothelioma induced by exposure to asbestos each year in Switzerland. These four asbestos-related diseases are recognized as occupational diseases by the Swiss Federal Law on Accident Insurance and are covered as such[34].

In this object, we deal with plates of low clustered asbestos (*Picture 3*), which are used as thermal insulators[35]. Visually, it looks like a plate whose thickness is about 5 mm, and whose angles show an inception of several sheets of asbestos. The aspect of the material is very fibrous as it is low clustered (*Picture 4*). The fibres can then easily detach from the plates, contrary to highly clustered asbestos plates. They are fixed to the sides of the lantern with screws, flat washers and bolts. The small plates

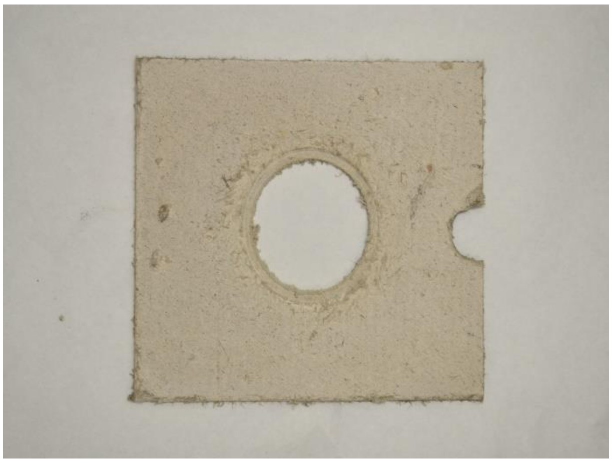
[32] Lefebvre, Alexandra, 2019, p. 12

[33] Lefebvre, Alexandra, 2019, p. 13

[34] Lefebvre, Alexandra, 2019, p. 14

[35] Echinard, Jane, undated, [Online], p.3

covering the side doors are mechanically fixed thanks to the brass structure of the peepholes. The textile is covered with asbestos fibres which detached from the asbestos plates (*Picture 5*).



Picture 3 : Low clustered plate of asbestos, in the hood and protective tent ©HE Arc CR, A.L

Picture 4 : Detachment of asbestos fibres, in the hood and protective tent ©HE Arc CR, A.L

Picture 5 : Asbestos fibres on the textile, in the hood and protective tent ©HE Arc CR, A.L

II.1.2 Legal framework

In order to take over the conservation of the asbestos plates contained in the object safely, the legal framework of the storage, manipulation and treatment of asbestos in Switzerland has been defined by consulting the Federal Office for the Environment (OFEV) as well as documentation provided by the SUVA.
Thus, the use of preparations and objects containing asbestos is generally banned[36] except for those which have been used before June 1st, 2019[37]. As for the object of this study, it has been conserved in the museum before this date (2006). For that reason, no authorisation is mandatory to care for this object.

Moreover, the Directive n°6503[38] from the Federal Coordination Commission for Occupational Safety (CFST) doesn't mention that asbestos disposal is mandatory or that it is prohibited to cover the substrate with a material. However, safety measures must be taken to control or avoid the release of asbestos fibres in the air, and the exposure limit value kept as low as possible[39]. In the other countries of Europe, it is not allowed to treat asbestos[40].

II.1.3 Safety protocol

The removal of light panels of asbestos plates under 0.5m² is possible by a specialist in asbestos disposal, equipped with a half-mask with P3 filters compatible with the norm EN149:2001, a single use Tyvek protective suit of category 3 and type 5-6[41] compatible with the directive EPI 89/686/CEE[42] with a hood, shoe covers, rubber gloves[43] and safety glasses[44]. The work area should be secured and contain asbestos signage (*Picture 6*). A suction of the asbestos dust should be made with an industrial vacuum cleaner for dust category H according to the EN 60335-2-69 norm. A measurement of the air is recommended but not mandatory[45]. Also, a containment with an airlock chamber and decompression is not mandatory to work on light panels under 0.5m²[46].

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36 Confédération suisse, 2005 (ORRChim, appendix 1.6, chapter 2, letter d), [Online]

37 Confédération suisse, 2005 (ORRChim, appendix 1.6, chapter 6, point 1), [Online]

38 Confédération suisse, 2008, [Online]

39 Confédération suisse, 2008, [Online], p. 17

40 Meyer Zu Bargholz, Wolf, 2020

41 SUVA, 2020, [Online]

42 Confédération suisse, 2008, [Online], p. 19

43 SUVA, 2016, [Online]

44 Meyer Zu Bargholz, Wolf, 2020

45 SUVA, 2020, [Online]

46 Schneebeli, Simon, 2021

An insulated chamber equipped with a H filtered ventilation should be settled to treat the object, with signage indicating the danger of asbestos. The stabilization of asbestos plates is only possible using pure acrylic resin[47]. However, a contaminated textile can't be fully treated, as asbestos fibres can still hang on the textile fibres[48]. A container of water should be available to rinse all to tools in contact with the contaminated object. A bag with signage should also be available to isolate waste, as the single use protective suit or single use gloves[49].

Picture 6 : Signage for objects, storage and area containing asbestos @Chemsuisse

Concerning waste disposal, waste containing low clustered asbestos are considered as special waste. They must be packed in airtight to dust bags which can be closed and eliminated. The bags must be labelled with asbestos signage[50] (*Picture 6*). The transport of the waste should be accompanied by a follow-up document from the ordinance on the movement of waste RO 2005 4423[51] (OMoD) and be dropped in a type E dump[52].

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[47] Meyer Zu Bargholz, Wolf, 2020

[48] Meyer Zu Bargholz, Wolf, 2020

[49] Meyer Zu Bargholz, Wolf, 2020

[50] SUVA, 2016, [Online]

[51] Confédération suisse, 2005, (OMoD)

[52] Association Suisse des consultants d'amiante, 2016, [Online], p.11

II.1.4 Criteria of treatment

The aim of covering asbestos substrates is to coat the microscopic fibres in order to avoid their detachment from their support and, if they come off, to be big enough to be eliminated from the human body.

Four criteria of treatment have been defined to treat the asbestos plates of the object :

- A good covering of the asbestos substrate ;
- The use of pure acrylic resin is mandatory ;
- The obtention of a matt finish close to those of asbestos plates ;
- A change of colour as limited as possible.

The binding agent Plexigum® PQ611 is a 97% acrylic copolymer[53] soluble in esters, ketones, aromatic hydrocarbons and aliphatic hydrocarbons[54]. It is used by conservators to cover asbestos mediums in petroleum benzine with a boiling point of 100-140[55]. Two contentrations and three modes of application have been tested with two different concentrations of Plexigum® PQ611 in benzine 100-140 in order to respond to the defined criteria of treatment.

II.1.5 Comparison of the different methods

The tests have been carried out at the back of the small plate of asbestos covering the right door of the lantern. Concentrations of 10 and 15% of Plexigum® PQ611 have been tested on the substrate, to obtain a safe consolidation and limit the gloss of the surface. No matter the mode of application, a concentration of 15% darkened a lot the material. A 10% concentration offered a safe consolidation of the fibres and yellows slightly the original colour of asbestos, darkening very slightly the surface. However, both concentrations maintain the mat finish of the material.

The three modes of application tested on the substrate are the syringe, the nylon brush and soaking. The syringe appeared more satisfying of the flat surfaces of the plates, covering evenly the material. It also offers a more controlled application of the resin on flat surfaces, which may explain the slight change of the colour – contrary to the brush or the soak. However, it was not satisfying on the edges of the plates as all the fibres were not covered. The nylon brush was the right alternative to consolidate the edges of the plates : it coats all the fibres evenly while flattening them slightly. The soaking offers a safe consolidation of the plates but darkens a lot the surface.

[53] Kremer Pigmente, 2019, p. 2

[54] Kremer Pigmente, undated, p. 1

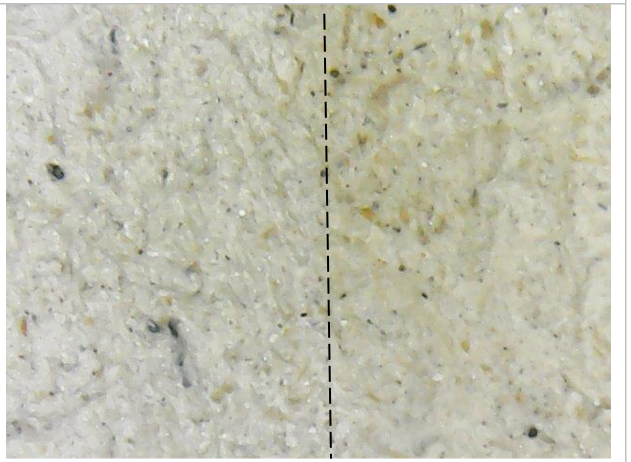
[55] Meyer Zu Bargholz, Wolf, 2020

Table 2 details the different results of the tests technically and visually. Pictures of the surfaces before and after testing have been taken with Dino Lite to evaluate the treatments.

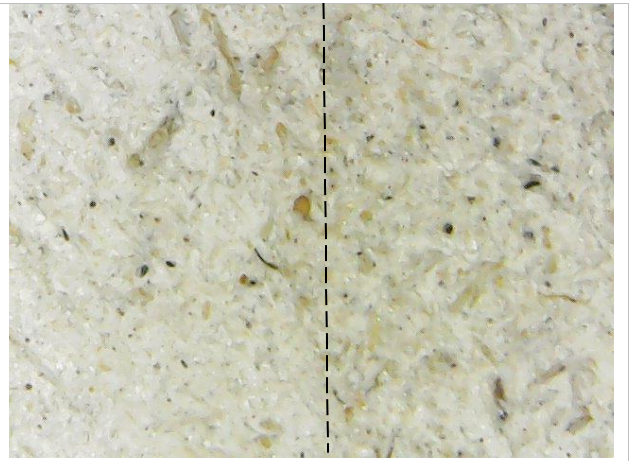
<table>
<tr><th>Resin concentration</th><th>Application technique</th><th>Results</th><th>Pictures before and after treatment</th></tr>
<tr><td>10%
in benzine 100/140</td><td>Syringe, 1 drop</td><td>Application
+
- Can penetrate the substrate and the powdered edges
- The fibres are not shifted

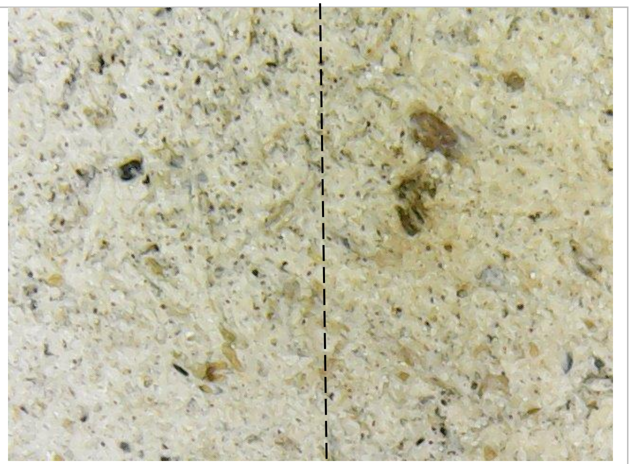
-
- The application gives an uneven result on the edges

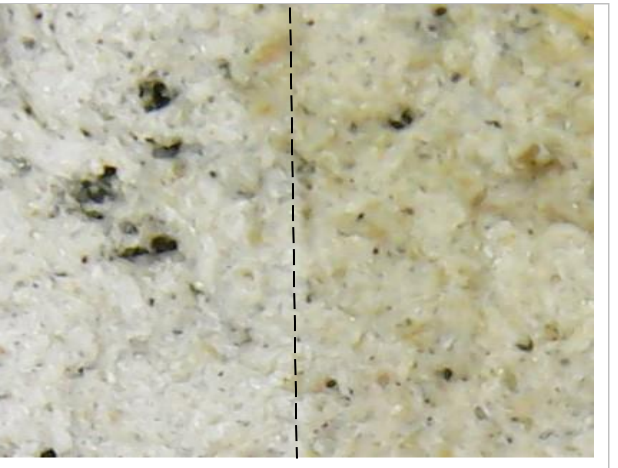
Resin concentration
+
- The surface keeps its matt finish

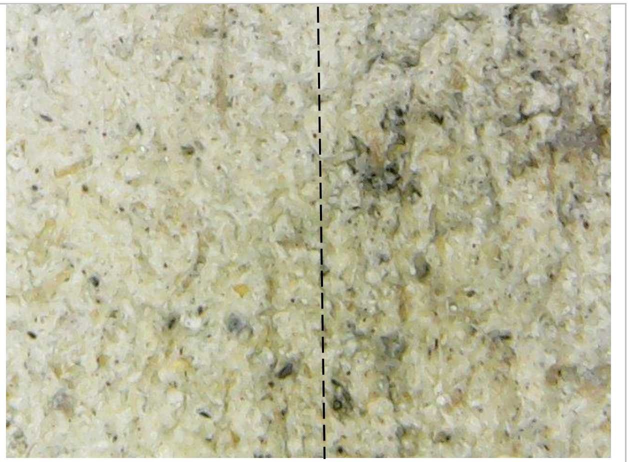
-
- Asbestos appear darker and slightly yellow
- Unsure if all the fibres on the edges are well impregnated</td><td>
Picture 7 : Before and after treatment ©HE Arc CR

Picture 8 : Edges after treatment ©HE Arc CR</td></tr>
</table>

10% **in benzine 100/140**	**Flat brush, dropped on the surface**	**Application** **+** - The application gives an even result **-** - The brush collects a few fibres of asbestos - The application can move or flatten some fibres **Resin concentration** **+** - The surface keeps its matt finish **-** **-** Asbestos appear darker and more yellow than with the seringe - Fibres on the edges are well consolidated	 *Picture 9 : Before and after treatment ©HE Arc CR*  *Picture 10 : Edges after treatment ©HE Arc CR*

10% **in benzine 100/140**	**Soak, 2 seconds**	**Application** **+** - Can penetrate the whole substrate - The application gives an even result - The fibres are not shifted **-** - A drop of resin can take shape on the edge of the asbestos plate when removed from the soak, but can be easily removed **Resin concentration** **+** - The surface keeps its matt finish - Fibres on the edges are well consolidated **-** **-** Asbestos appear darker and slightly brown	 *Picture 11 : Before and after treatment ©HE Arc CR*  *Picture 12 : Edges after treatment ©HE Arc CR*

15% **in benzine 100/140**	**Syringe, 1 drop**	**Application** **+** - Can penetrate the substrate, as the powdered edges - The fibres are not shifted **-** - The application gives an uneven result **Resin concentration** **+** - The surface keeps its matt finish **-** **-** Asbestos appear darker than with the 10% concentration applied with the syringe, and yellow - Unsure if all the fibres on the edges are well impregnated	 *Picture 13 : Before and after treatment @HE Arc CR*  *Picture 14 : Edges after treatment @HE Arc CR*

15% in benzine 100/140	**Flat brush, dropped on the surface**	**Application** **+** - The application gives an even result **-** - The brush collects a few fibres of asbestos - The application can move or flatten fibres **Resin concentration** **+** - The surface keeps its matt finish **-** **-** Asbestos appear darker than with the 10% concentration applied with the brush, and more yellow than with the syringe - Fibres on the edges are well consolidated	 *Picture 15 : Before and after treatment @HE Arc CR*  *Picture 16 : Edges after treatment @HE Arc CR*

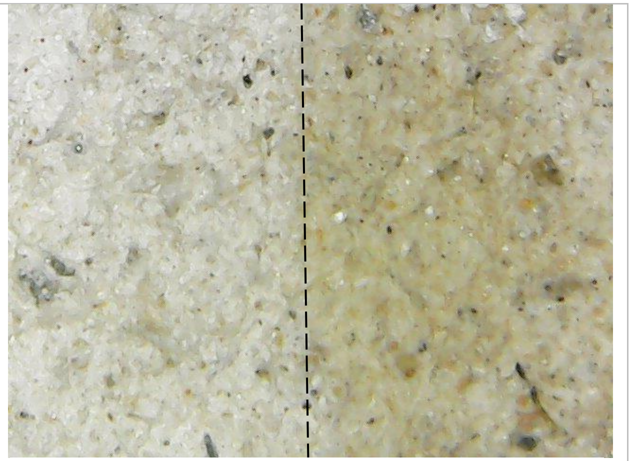
15% **in benzine 100/140**	**Soak, 2 seconds**	**Application** **+** - Can penetrate the whole substrate - The application gives an even result - The fibres are not shifted **-** - A drop of resin can take shape on the edge of the asbestos plate when removed from the soak, but can be easily removed **Resin concentration** **+** - The surface keeps its matt finish **-** **-** Asbestos appear darker and slightly brown - Fibres on the edges are well consolidated	 *Picture 17 : Before and after treatment @HE Arc CR*  *Picture 18 : Edges after treatment @HE Arc CR*

Table 2 : Testing of two concentrations and three modes of application on asbestos plates

©HE Arc CR, A.L

II.1.6 Textile contaminated with asbestos

The textile in contact with asbestos fibres is stuck to the sliding plate under the lantern and avoid the entrance of light between the bottom of the lantern and the top of the wooden box. This small part of the textile is in contact with the atmosphere and can potentially release asbestos fibres.

Picture 19 : Localization of the contaminated textile in contact with the atmosphere @HE Arc CR, A.L

A textile contaminated with asbestos cannot be fully treated and must be packed to limit the release of fibres[56]. The configuration of the piece of textile is complex here, as it is stuck to a part of the object. The aim of the intervention will be to vacuum clean the textile and limit the release of fibres from the small part of the textile in contact with the atmosphere.

II.2 Mitigation of the soiling

II.2.1 On glass

II.2.1.1 Problematic

Six elements of the objects contain soiled glass : the bulb, the lens, the Emil Busch A.-G. lens, the peepholes and the condenser. These elements are made of composite materials and one of them, the

[56] Meyer Zu Bargholz, Wolf, 2020

bulb, is an electric device on which an inscription is printed. The pictures of the objects before restoration are introduced here.

Picture 20 : Bulb of the object ©HE Arc CR, A.L

Picture 21 : Lens of the object @HE Arc CR, A.L

Picture 22 : Emil Busch A.G lens @HE Arc CR, A.L

Picture 23 : Right peephole @HE Arc CR, A.L

Picture 24 : Left peephole @HE Arc CR, A.L

Picture 25 : Condenser @HE Arc CR, A.L

II.2.1.2 Methodology

After a dusting of the object with a soft nylon brush and a vacuum cleaner, it has been decided to favour a local cleaning instead of a soak, in view of the composite nature of the objects. Thus, the chosen mode of application is the cotton swab, with a soft paper to dry the surface evenly after cleaning because of the architecture of each object and the good stability of the glass, allowing a mechanical action. Also, unstable objects as the bulb will be secured with cotton weights. Three solvent and solutions have been selected to be tested :

- Deionised water, which is generally sufficient for the cleaning of glass[57] and isn't an issue in terms of ionicity as we care here for inorganic well preserved glass ;
- A solution of deionised water and ethanol 30-50 : the adding of a part of polar solvent could be useful if the soiling is stubborn[58] ;
- A solution of deionised water and ethanol 50-50 : the concentration of the polar solvent is higher if the previous solution is not sufficient.

II.2.1.3 Comparison of the different methods

Table 3 details a comparison of the three cleaning methods tested on each glass object.

<table>
<tr><th>Object</th><th>Deionised water cleaning</th><th>Deionised water and ethanol 50-50 cleaning</th><th>Deionised water and ethanol 30-70 cleaning</th></tr>
<tr><td>Bulb</td><td colspan="3">
The cleaning with deionised water is more efficient and avoid the risk of erasing the inscription on the glass.</td></tr>
<tr><td>Lens</td><td colspan="3">
The cleaning with deionised water is more efficient.</td></tr>
</table>

[57] Koob, Stephen P., 2006, p.40

[58] Koob, Stephen P., 2006, p.40

<table>
<tr><th>Object</th><th>Deionised water cleaning</th><th>Deionised water and ethanol 50-50 cleaning</th><th>Deionised water and ethanol 30-70 cleaning</th></tr>
<tr><td>Lens Emil Busch A.-G. Rathenow Mod. W F=25cm 321632</td><td colspan="3">
A light soiling covers the glass. The three methods are equally efficient. Deionised water is then sufficient for this cleaning.</td></tr>
<tr><td>Peepholes</td><td colspan="3">
A light soiling covers the glass. The three methods are equally efficient. Deionised water is then sufficient for this cleaning.</td></tr>
<tr><td>Condenser</td><td colspan="3">
The cleaning with deionised water is more efficient.</td></tr>
</table>

Table 3 : Comparison of the different treatments on glass @HE Arc CR, A.L

II.2.2 On painted wood

II.2.2.1 Problematic

The wooden base of the lantern and the wooden box are both partly covered with a paint layer. They are covered with two types of soiling : dusty and soiling deposits (*Picture 26*, *Picture 29*) and stains generated by liquids or drops of repaint (*Picture 27*, *Picture 28*).

Picture 26 : Soiling of the blue paint ©HE Arc CR, A.L

Picture 27 : Stain on the blue paint ©HE Arc CR A.L

Picture 29 : Soiling of the black paint ©HE Arc CR A.L

Picture 28 : Paint stain on the black paint ©HE Arc CR, A.L

II.2.2.2 Methodology

In order to mitigate these two types of soiling, mechanical methods have been privileged as a first try to have an action on dusty deposits. Vacuum cleaning and mechanical cleaning with a nylon brush as well as latex eraser have been selected to be tested on both types of deposits. Also, solvents covering different polarities, a solution of deionised water buffered at the pH of the surfaces, deionised water and artificial saliva and deionised water and a non-ionic surfactant are to be tested if the mechanical cleaning is not sufficient.

II.2.2.3 Comparison of the different methods

pH and conductivity of both dirty and clean surface have been measured on the wooden cabinet and the base of the lantern with an Agar gel at 4% for 1 minute. The difference of pH between the dirty and clean surface is very low and navigates around 6.5 and 7 for the two parts of the object (*Table 4*).

Localization	**pH**	**Conductivity**
Wooden box, dirty surface	6.44	246 µS/cm
Wooden box, clean surface	6.51	61 µS/cm
Wooden base of the lantern, dirty surface	7.12	253 µS/cm
Wooden base of the lantern, clean surface	7.01	504 µS/cm
Agar gel 4%	7.56	157 µS/cm

Table 4 : pH and conductivity of the painted wood surfaces ©HE Arc CR, A.L

The solubility of each painted surface has also been tested, with 4 solvents offering a range of polarity from very polar to non-polar : deionised water, ethanol, acetone and Shellsol T. While the painting from the wooden box is slightly sensitive to ethanol, the painting from the wooden base of the lantern is more sensitive and only not soluble in hydrocarbon (*Table 5*).

Solvent	**Solubility of the painting of the wooden box**	**Solubility of the painting of the wooden base of the lantern**
Deionised water	Not soluble	Soluble
Ethanol	Soluble	Soluble
Acetone	Not soluble	Soluble
Shellsol T	Not soluble	Not soluble

Table 5 : Solubility of the painted wood surfaces ©HE Arc CR, A.L

A mechanical cleaning with a latex eraser has been tested on both types of deposits and has been considered efficient to mitigate the dusty soiling. On the contrary, stains and chemical deposits could not be mitigated.

While solvents were not efficient, Mucin at 0.1g in 100mL of deionised water has been applied with a latex eraser and was efficient to mitigate the soiling inside the irregularities of the wood. Mucin in deionised is generally used as a rinsing solution for enzymes but is also efficient for surface cleaning.

It has not been buffered as the proteins buffer themselves around a pH of 7[59]. However, it cleaned too deeply the white chalky deposits. The use of a scalpel allowed the removal of these deposits without an overcleaning of the painted surface around.

Figure 30 : White chalky deposit before cleaning ©HE Arc CR, A.L

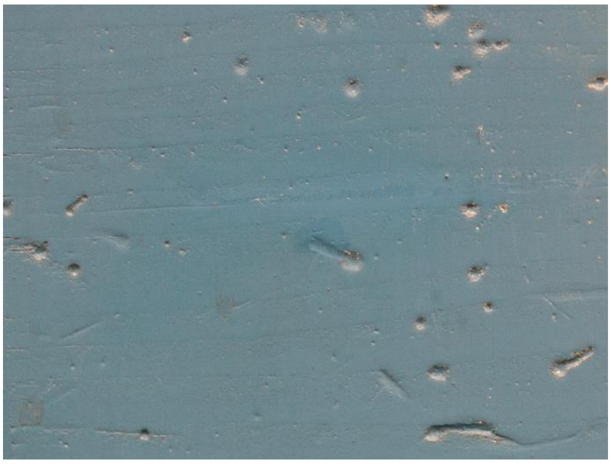


Figure 31 : Too deep cleaning test with Mucin ©HE Arc CR, A.L

A solution of deionised water with 2 drops of the non-ionic surfactant[60] Brij L4 buffered at a pH of 7 with HCl has been tested, to get a detergency effect. Its conductivity has been adjusted to the conductivity of the object, to work in isotonic conditions. In order to work at the pH of the surface and as non-ionic surfactants have an activity depending on the pH, the pH of the solution has been adjusted. The solution gave great results at mitigating the generalized soiling and removing the halos (*Table 6*). Both black and blue painted surfaces responded the same way to the tests of cleaning. Deionised water buffered with NaOH at a pH of 7 has been used for rinsing.

Solvent or solution	**Result**
Deionised water and artificial saliva (Mucin)	Mitigating of the soiling in the irregularities of the painted wood
Deionised water and non-ionic surfactant Brij L4 buffered with HCl (pH 7) conductivity ~200µS/cm	Mitigating of the generalized soiling and removal of the halos
Ethanol	No cleaning effect
Acetone	No cleaning effect
Shellsol T	No cleaning effect

Table 6 : Synthesis of the cleaning tests on painted wood @HE Arc CR, A.L

[59] Cremonesi, Paolo, 2021

[60] Cremonesi, Paolo, 2021

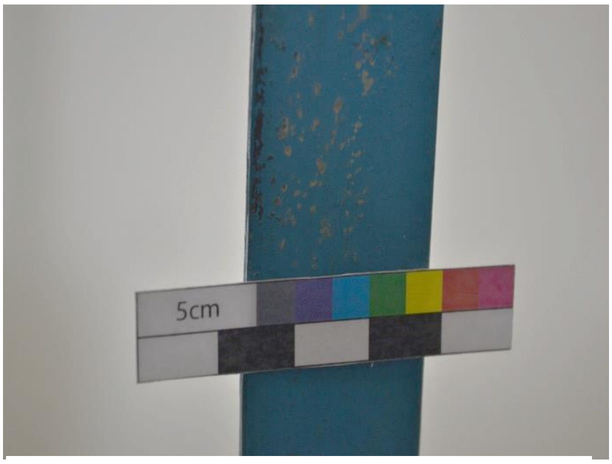
II.2.3 On painted metal

II.2.3.1 Problematic

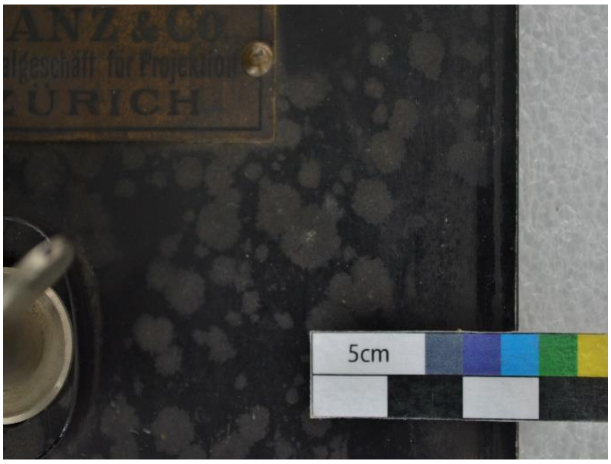
Two constitutive parts of the lantern made of painted steel are covered with two types of soiling : dusty and soiling deposits and stains generated by liquids or repaint (*Picture 34*, *Picture 35*). the structure carrying the wooden box (*Picture 32*), and the base of the light source (*Picture 33*).

Picture 32 : Structure of the wooden box ©HE Arc CR, A.L

Picture 33 : Base of the light source ©HE Arc CR, A.L



Picture 34 : Soiling and repaint stains ©HE Arc CR, A.L



Picture 35 : Halos caused by flows ©HE Arc CR, A.L

II.2.3.2 Methodology

The same tests than those made on the painted wooden box (II.2.2.2 and II.2.2.3) have been carried out on the painting of the structure of the metal as they are covered with the same paint. Also, three solvents of different polarities have been chosen to be tested on the surface of the base of the light source, in order to clean the hallos from the surface : deionised water, ethanol and Shellsol T.

II.2.3.3 Comparison of the different methods

As for the painted surface of the wooden box, a mechanical cleaning with a latex eraser allowed the cleaning of dusty deposits. Deionised water with 2 drops of the surfactant Brij L4 buffered with HCl at a pH of 7 permitted the mitigation of the soiling from the surface. A combination of the application of the solution of artificial saliva in deionised water and the mechanical action of the scalpel allowed the removal of repaint stains.

On the base of the light source, a mechanical cleaning with a latex eraser helped reducing the dusty soiling. Ethanol wasn't efficient in the removal of the halos and the painting was soluble in Shellsol T. The test with deionised water allowed the removal of the halos (*Table 7*).

Solvent	Cotton swab after testing	Result
Deionised water		Deionised water allowed the removal of the halos without damaging the paint layer.
Ethanol		Ethanol have not allowed the removal of the halos. However, the paint is not soluble in ethanol.
Shellsol T		The paint is soluble in Shellsol T.

Table 7 : Cleaning tests on the base of the light source ©HE Arc CR, A.L

II.2.4 On copper alloys

II.2.4.1 Problematic

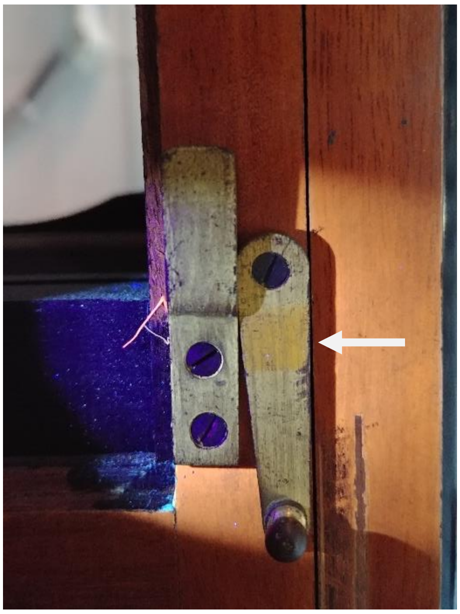
Several decorative and mechanical elements of the object are made of brass. All of them are concerned by a generalized soiling (*Picture 36*, *Picture 37*).

Picture 36 : A few brass elements of the object ©HE Arc CR, A.L

Picture 37 : Soiling of a peephole ©HE Arc CR, A.L

II.2.4.2 Methodology

Each brass element has been observed under UV light in order to determine if they are covered with a varnish. A few remains of varnish were observed, mainly on hidden areas (*Picture 38*). The fluorescence being orange, shellac* was suspected, as it was frequently used on scientific and technical objects from the 18th to the 20th century. A mechanical cleaning with a latex eraser has first been tested and a non-polar solvent has been tried to avoid the removal of this varnish.



Picture 38 : Remains of varnish on a hidden area ©HE Arc CR, A.L

II.2.4.3 Comparison of the different methods

After achieving the removal of the powdery deposits with a latex eraser, the degreasing test of the brass parts was satisfying with Shellsol T.

II.2.5 On coated paper

II.2.5.1 Problematic

The gusset of the lantern, made of coated paper, is entirely covered with powdery soiling (*Figure 39*).

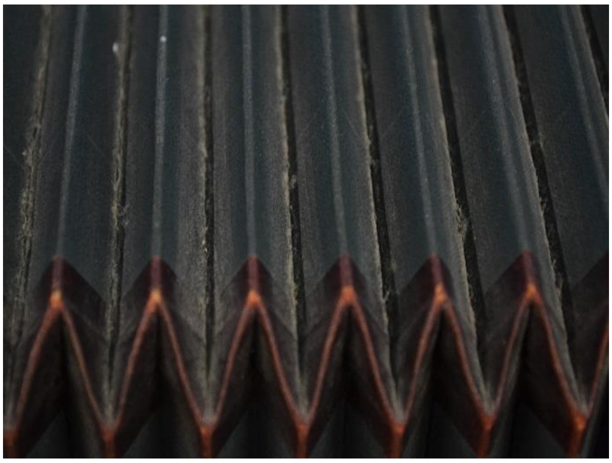


Figure 39 : Powdery soiling at the surface of the gusset ©HE Arc CR, A.L

II.2.5.2 Methodology

A cleaning test by vacuum cleaning and brushing with a nylon brush has been planed at the surface of the gusset, to limit any mechanical action and weight on the sensitive paper surface of this hollow part of the object.

II.2.5.3 Comparison of the different methods

The cleaning test, combining vacuum cleaning and slight brushing allowed the cleaning of the dust and powdery deposits.

II.3 Painting consolidation

II.3.1 Problematic

Some liftings of the painting are visible in the wooden box, on the right side, in front of the transformer (*Picture 40*).

Picture 40 : Lifting of the paint inside the wooden box ©HE Arc CR, A.L

II.3.2 Methodology

The solubility of the painting has been tested (*Table 5*). It is sensitive to ethanol. A water-based adhesive would be adequate to avoid damaging the substrate. A hydrocarbon would also be a possibility but the major par of the adhesives are soluble in polar solvents. In terms of properties, the adhesive should be moderately brilliant and smooth to moderately smooth to suit the rigid paint without breaking.
Three adhesives have been selected to be tested, but only two of them have been tested due to time constraints :

- Aquazol 200 is a synthetic adhesive which is regularly used for paint consolidation. It has a good elasticity at low relative humidity and is convenient under 85% relative humidity[61]. Its adhesive strength is moderate at its molecular weight (200.000)[62]. Its pH is neutral in aqueous solutions and its glass transition temperature is around 69 to 71°C[63]. It could be preferred to sturgeon glue as it is not subject to molds. A concentration from 5 to 10% would be adequate for consolidation[64].
- Jun-funori is a water-soluble polysaccharide seaweed standardized glue. It is particularly suited to consolidate paint layers. It does not modify the aspect of paints and does not create halos. Its bonding power is low but it keeps its flexibility over time[65]. A 1% to 1.5% concentration is recommended for consolidation[66].
- Sturgeon glue is a natural animal glue with great bonding power. This flexible adhesive should be used under 55°C. It might create halos and can be subject to molds[67]. A 1% concentration has been chosen to compare with jun-funori.

The three adhesives can be retreated with warm deionised water. The mode of application used for the tests is a thin brush.

II.3.3 Comparison of the different methods

1% of jun-funori in deionised water and 1% sturgeon glue in deionised water has been applied with a thin brush between the lifted paint and the wood substrate. A silicon paper and a weight has been placed on the collage for ten minutes.

Jun-funori allowed a satisfying consolidation of the lifted paint. No halos were visible around the lifting and the rigid paint has been attracted to its wood support by the adhesive.

Sturgeon glue shew poorer results as the consolidation was not achieved, even by pressing the lifting through the silicon paper with a wood stick.

[61] CTS France, undated, p.1

[62] Arslanoglu, Julie, 2004, p.10

[63] CTS France, undated, p.2

[64] Arslanoglu, Julie, 2004, p.10

[65] Sindaco, Claudia and Elias, Mady, undated, [Online] p.7

[66] Sindaco, Claudia and Elias, Mady, undated, [Online] p.7

[67] Sindaco, Claudia and Elias, Mady, undated, [Online], p.7

II.4 Retouching of the wooden losses

II.4.1 Problematic

Some losses on the door of the wooden box are extremely noticeable on the door of the wooden box, as their colour is way clearer than the losses nearby. A mitigation of these losses is requested. The painting is sensitive to alcohols (*Picture 41*, *Picture 42*).

Picture 41 : Localization of the losses
©HE Arc CR, A.L

Picture 42 : Detail of the losses
©HE Arc CR ©A.L

II.4.2 Methodology

In order to mitigate these losses, a retouching has been chosen. This painting is very probably a synthetic paint and its aspect is quite shiny. Gamblin® conservation colours for retouching in conservation-restoration of painted work are paste colours composed of crushed high stability pigments bound to Laropal A81 aldehyde resin. This resin offers great characteristics of resistance to aging, both for their optical properties and for their chemical stability and retreatabilty. They offer coverage, contrary to watercolour on wood. Moreover, we want to limit the water intake on the material. Gamblin® conservation colours can be diluted in hydrocarbons, which is appropriate in the case of this painting sensitive to alcohols. A tone lighter than the wood areas around the losses will be chosen to differentiate them. Shellsol A has been chosen to reactivate the colours for application.

II.4.3 Testing

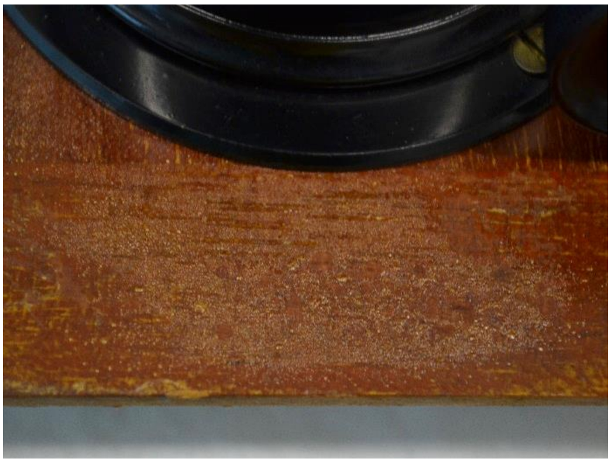
The most satisfying method was to apply a layer of white Gamblin® colours and let it dry for half and hour. The retouching colour was then applied on the white layer to obtain the appropriate retouching colour.

II.5 Resettling of the reticulated varnished on wood

II.5.1 Problematic

The lens carrier at the front of the lantern (*Picture 43*) is covered with a lifted varnish (*Picture 44*), causing a difference of perception of its initial colour as air is located in between the wood medium and the varnish. The aim is to resettle the varnish on its surface. A small area of the top of the wooden structure of the lantern is also concerned with this issue (*Picture 45*).

Picture 43 : Lens carrier ©HE Arc CR, A.L



Picture 44 : Detail of the lifted varnish ©HE Arc CR, A.L

Picture 45 : Detail of the lifted varnish at the top of the wooden structure ©HE Arc CR, A.L

II.5.2 Methodology

An observation under ultraviolet light of the varnish has been achieved to determine the nature of the varnish. An orange fluorescence has been observed (*Picture 46*). We suspect a natural shellac varnish, as for the brass elements of the object (II.2.4.2).

Picture 46 : Ultraviolet fluorescence of the varnish of the lens carrier ©HE Arc CR, A.L

The solubility of the varnish has also been tested. While it is soluble in ethanol, it is not sensitive to acetone (*Figure 47*).

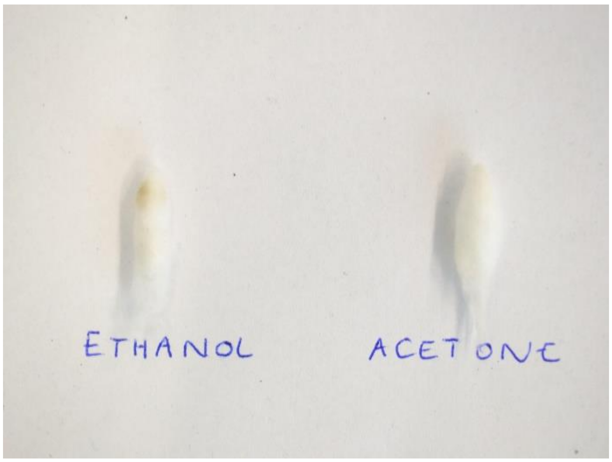


Figure 47 : Solubility of the varnish of the lens carrier in ethanol and acetone ©HE Arc CR, A.L

Two methods to resettle the varnish have been discussed with Gaby Petrak, conservator of furniture and wooden objects at the Collection Centre of the Swiss National Museum. The first method consists in applying a small quantity of ethanol on the varnish, place a sheet of Mylar® on the surface, and roll a cotton swab on the sheet to resettle the varnish. Mylar® is an inert polyethylene terephthalate (PET) film, which can be heated until 150°C[68].

The second method consists in placing a sheet of Mylar® on the surface and using a heat spatula to reactivate the varnish and resettle it, starting at the lower temperature and gradually rising it.

II.5.3 Comparison of the different methods

A test with the first method combining ethanol, a Mylar® sheet and a cotton swab has been carried out on a small varnished area. The method reduces the irregularities of the varnished surface but didn't resettled the varnish on the wood (*Picture 48*).

Picture 48 : Test of resettling of the varnish with ethanol and Mylar® film ©HE Arc CR, A.L

The second method implying the use of Mylar® film and a heat spatula has been tested starting at a temperature of 60°C (*Picture 49*). The heat spatula was leaved a few seconds on the Mylar® to localize the heating and allow the varnish to reactivate. Then, the spatula was gently rubbed from left to right on the surface to allow the varnish to resettle. A temperature of 130°C was satisfying to resettle the varnish (*Picture 50*).

[68] Centre de conservation Québec, Préserv'Art, 2008

Picture 49 : Resettling of the varnish with a heat spatula ©HE Arc CR, A.L

Picture 50 : After testing the resettling of the varnish with a heat spatula ©HE Arc CR, A.L

II.6 Removal of the blooms from the PVC power cable

II.6.1.1 Problematic

The power cable of the object (*Picture 51*) is made of poly vinyl chloride (PVC) plasticized with phthalate. Ancient flexible PVC are generally very unstable chemically. Their plasticizer migrates at the surface, being sticky first and crystallising as bloom. Also, the loss of lubricant from the PVC (stearic acid) is common, as it is a very non-polar material in comparison with PVC. It results in the deposit of white crystals at the surface (*Picture 52*)[69].

Picture 51 : Power cable of the object ©HE Arc CR, A.L

Picture 52 : Blooms and accumulated dust on the PVC surface ©HE ARC CR, A.L

[69] Shashoua, Yvonne, 2008, p. 161

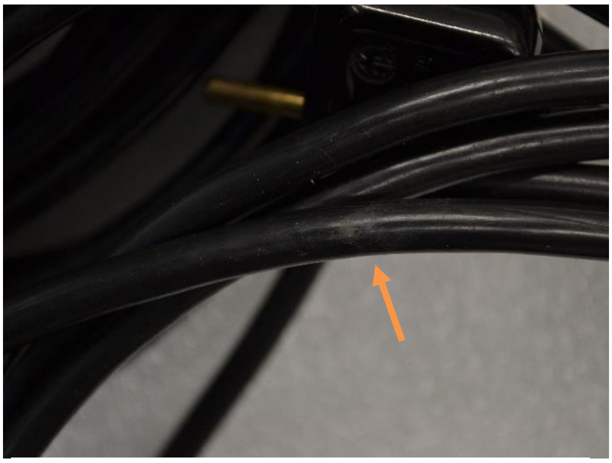
II.6.1.2 Methodology

pH and conductivity of the plastic have been measured to work in isotonic conditions on this sensitive material. A gel of Agar at 4% has been applied during 1 minute for this purpose (*Picture 53*). A pH of 6.84 and a conductivity of ~200µS/cm have been measured. As the material is conductive, it should be possible to remove the blooms with water. Thus, a solution of deionised water with 2 drops of non-ionic surfactant buffered with HCl at a pH of 7 and a conductivity of ~200µS/cm has been prepared as well as deionised water buffered at a pH of 7 for rinsing.

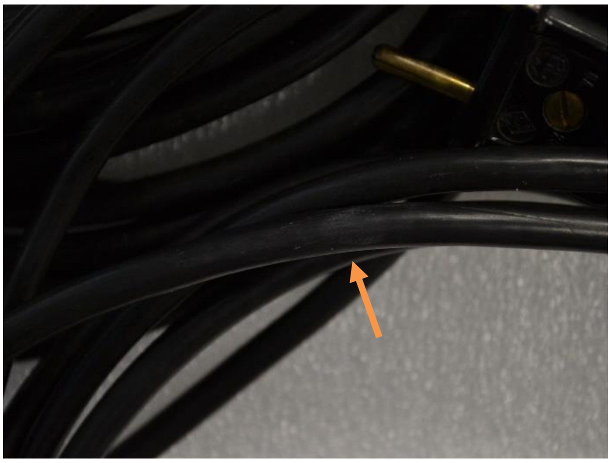
Picture 53 : Application of the Agar gel to measure pH and conductivity of the plastic ©HE Arc CR, A.L

II.6.1.3 Testing

The cleaning test with a solution of deionised water with 2 drops of non-ionic surfactant buffered with HCl at a pH of 7 and a conductivity of ~200µS/cm applied with a cotton swab allowed the removal of the bloom at the surface of the PVC (*Picture 54*, *Picture 55*). The deionised water rinsing solution buffered at a pH of 7 with NaOH has also been applied with a cotton swab, and dried with a soft paper.



Picture 54 : Blooms at the surface of the PVC cable before testing ©HE Arc CR, A.L



Picture 55 : Surface of the PVC cable after testing ©HE Arc CR, A.L

III. Interventions of conservation

III.1 Stabilization of asbestos mediums

The stabilization of asbestos mediums was the first task to achieve for health and safety issues. It has been carried out under the supervision of Tino Zagermann, conservator and head of the technical collections at the Collection Centre of the Swiss National Museum, as he is qualified to work with asbestos. The following protocol has been validated by Tino Zagermann and Simon Schneebeli.

In order to work in a safe space for all the collaborators, a semi-confined space has been created around the hood of the workshop in order to be able to dismantle the asbestos plates and vacuum clean the object in a safe area (*Diagram 1*). A tent has been built from 2 pallets, a made to measure wood structure and a double layer of polyethylene film fixed with staples and adhesive tape (*Picture 56*). It has been directly connected to the hood which is equipped with a H filter. A second layer of polyethylene film covers the opening at the front of the tent. Overpressure is limited as the air can flows at the bottom of the tent, under the pallets. The exhaust air of the Renggli AG hood was set at 720 m^3/h. Asbestos signage has been displayed on the tent.

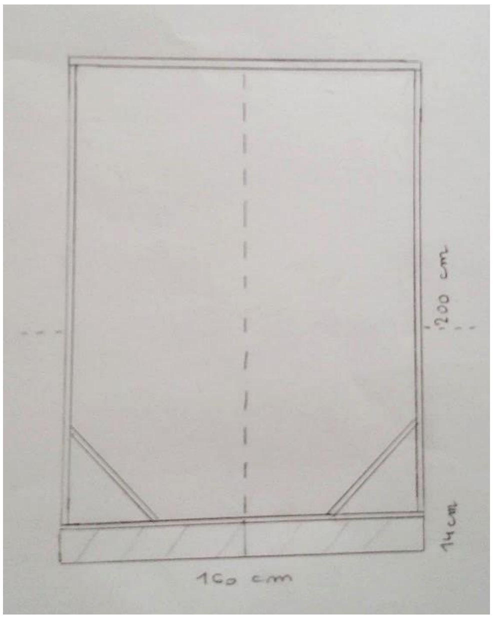


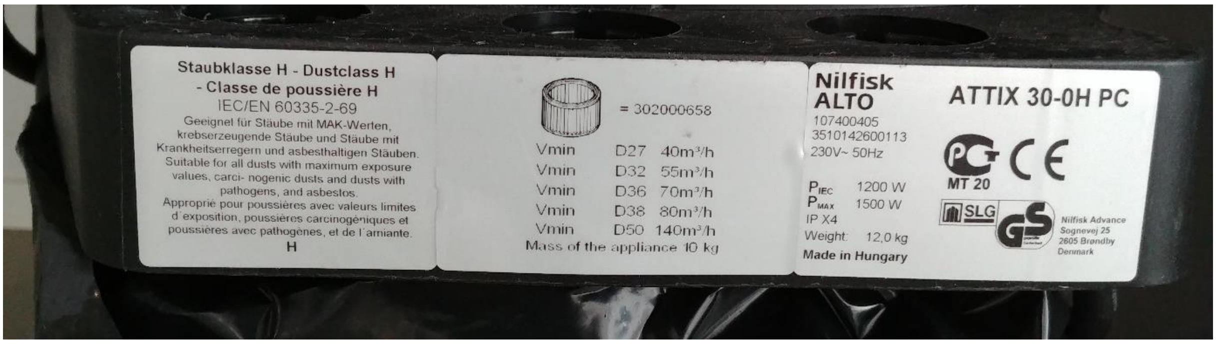
Diagram 1 : Plan of the tent, view from the back ©HE Arc CR, A.L

Picture 56 : General view of the semi-confined space ©HE Arc CR, A.L

The individual equipment of protection has been worn to work in safe conditions : a P3 mask, a single use Tyvek protective suit of category 3 and type 5-6 with a hood, shoe covers, transparent shoe covers, gloves and safety glass. Adhesive tape has been used to fix the gloves with the suit and the suit with the shoe covers to avoid the access to asbestos fibres (*Picture 57*).

Picture 57 : Individual equipment of protection for asbestos ©HE Arc CR, A.L

The object has been placed in the tent, then the light source and lens have been dismantled to allow the removal of the lantern from its wooden base by sliding. The asbestos plates have then been dismantled from the lantern with a screwdriver and a wrench, and stored Minigrip bags with asbestos signage. All the dismantled pieces and the whole object have been vacuum cleaned with a nylon brush and a Nilfisk ALTO ATTIX 30-0H PC vacuum cleaner equipped with a H filter (*Picture 58*) and stored in Minigrip with dismantling informations.



Picture 58 : Characteristics of the vacuum cleaner used for dusting asbestos fibres ©HE Arc CR, A.L

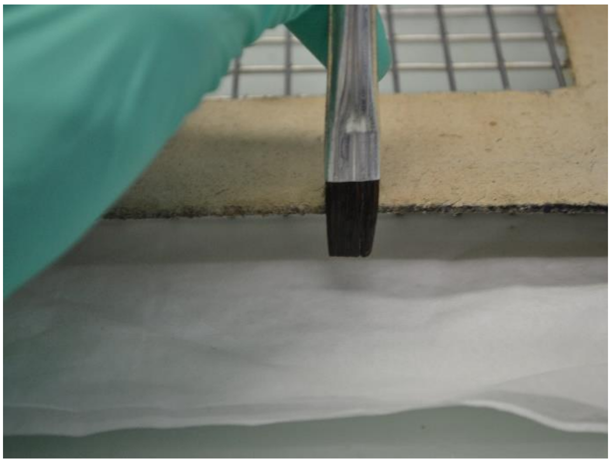
All the tools that have been in contact with the object have been soaked in a basin of water and cleaned with greasy baby wipes to remove the asbestos fibres[70]. All the single use protective gear has been carefully removed and place in a airtight bag with signage.

The object has then been safely released from the tent. The space has then been entirely vacuum cleaned and carefully dismantled.

The covering of the asbestos plates has achieved in the hood, on metal grids to allow their drying. They have been covered with a 10% Plexigum PQ611 resin in benzine 100/140. The flat surfaces were treated by injection with a syringe (*Picture 59*) and the edges by dropping a flat nylon brush on the surfaces (*Picture 60*). The injection has been carefully done drop by drop, by areas to allow an even drying of the adhesive. The collaborator was equipped with a P3 mask, protective glasses, a blouse and single use gloves.

[70] Meyer Zu Bargholz, Wolf, 2020

Picture 59 : Covering of an asbestos plate by injection (undried surface) ©HE Arc CR, A.L



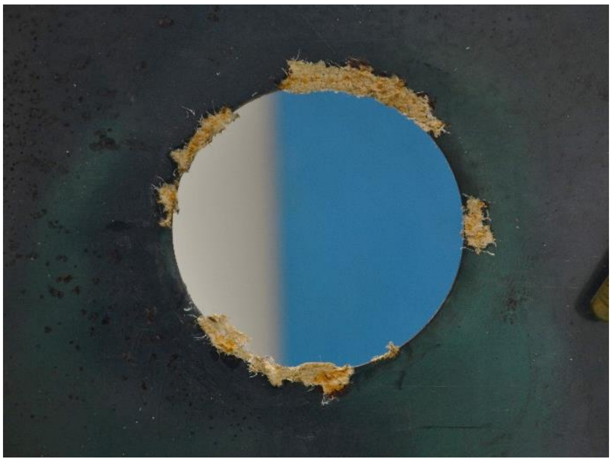
Picture 60 : Covering of the edges of an asbestos plate with a flat brush ©HE Arc CR, A.L

The screw threads allowing the settling of the asbestos plate and the holes welcoming the peepholes has amounts of asbestos fibres stuck on these areas, because of the mechanical constraint of the mounting. It has been decided to remove these amounts of fibres to secure the reassembly of the object for the collaborator and also for further dismantling in the future.

A method has been developed to achieve this issue. A non-woven fabric has been placed against the surface of the object and 10% Plexigum PQ611 resin in benzine 100/140 has been injected through the fabric to trap the asbestos fibres (*Picture 61*). The fabric has then been carefully removed from the surface and a scalpel could be used to help placing the consolidated bunch of asbestos fibres on it if necessary. The fabric covered with asbestos was then re-injected with adhesive to ensure that the fibres will stay on the medium and put in the specific waste bag (*Picture 62*).

Picture 61 : Non-woven fabric applied on the surface covered with asbestos ©HE Arc CR, A.L

Picture 62 : After the deposit of the bunch of asbestos fibres ©HE Arc CR, A.L



Picture 63 : Before mitigating the bunch of asbestos on the peephole ©HE Arc CR, A.L

Picture 64 : After mitigating the bunch of asbestos on the peephole ©HE Arc CR, A.L

Concerning the contaminated textile, after a careful vacuum cleaning, a made to measure polyethylene packaging has been sewn with nylon thread (*Picture 65*). Both materials have been chosen for their inert and stability characteristics. It has been fixed to the bottom of the sliding plate of the lantern with 4 thin magnets to limit the release of asbestos fibres between the lantern and the wooden box. The bottom of the packaging had to be left opened as the socket carrying the light bulb of the lantern goes through the textile. A collaborator who would like to open the door of the wooden box or of the lantern should then wear protection equipment as a P3 mask, a blouse, gloves and protective glasses, but the object could be exhibited this way in a showcase. Although, asbestos signage is placed on the object to inform the collaborators about the general issue on this object. Waste containing low clustered asbestos has been dropped to the type E dump next to the Collection Centre.

Picture 65 : Polyethylene packaging fixed with magnets to limit the release of asbestos fibres between the lantern and the wooden box ©HE Arc CR, A.L

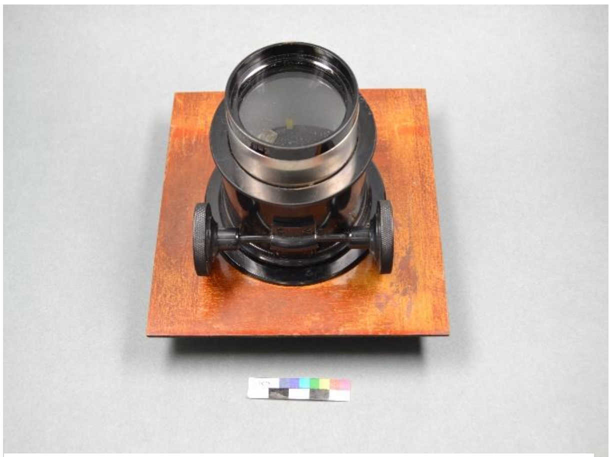
III.2 Mitigation of the soiling

III.2.1 On glass

Deionised water applied with a cotton swab has been used to mitigate the soiling on glass objects. A soft paper removed the excess of water on the glass surface (*Picture 66*, *Picture 67*, *Picture 68*, *Picture 69*, *Picture 70*).

Picture 66 : Bulb after restoration ©HE Arc CR, A.L

Picture 67 : Lens after restoration ©HE Arc CR, A.L



Picture 68 : Emil Busch A.G lens after restoration
©HE Arc CR, A.L

Picture 69 : Peepholes after restoration
©HE Arc CR, A.L

Picture 70 : Condenser after restoration
©HE Arc CR, A.L

III.2.2 On painted wood

Powdery deposits have been removed with a latex eraser, while the mitigating of the soiling has been carried out with a solution a deionised water with 2 drops of non-ionic surfactant Brij L4 buffered with HCl at a pH of 7 with a cotton swab. The white chalky deposits have been removed with a scalpel while the surface was wet. A rinsing has been performed with deionised water buffered with NaOH at a pH of 7 with a cotton swab. The deposits in the irregularities of the painted wood have been mitigated with a solution of deionised water and artificial saliva (Mucin). A soft paper has been used to absorb the excess of water on the surface (*Picture 71*, *Picture 72*).

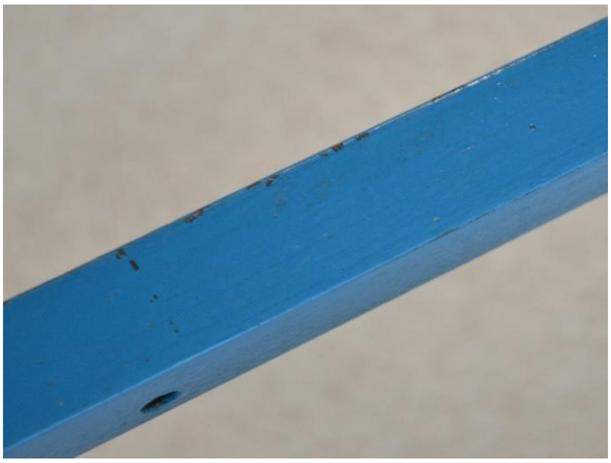
Picture 71 : Painted wood before restoration
©HE Arc CR, A.L

Picture 72 : Painted wood after restoration
©HE Arc CR, A.L

III.2.3 On painted metal and ceramic

As for the painted surface of the wooden box, a mechanical cleaning with a latex eraser allowed the cleaning of dusty deposits on the metallic structure of the object. A cotton swab with deionised water with 2 drops of the surfactant Brij L4 buffered with HCl at a pH of 7 permitted the mitigation of the soiling from the surface. It has then been rinsed with a cotton swab and deionised water buffered with NaOH at a pH of 7. A combination of the application of the solution of artificial saliva in deionised water and the mechanical action of the scalpel allowed the removal of repaint stains (*Picture 73*, *Picture 74*).

Picture 73 : Painted metal before restoration
©HE Arc CR, A.L



Picture 74 : Painted metal after restoration
©HE Arc CR, A.L

On the base of the light source and on ceramic, a soft cleaning with a latex eraser permitted the reducing of the dusty soiling. A cotton swab with deionised water allowed the removal of the halos from the surface. The materials were then carefully dried with a soft paper (*Picture 75*, *Picture 76*, *Picture 77*).

Picture 75 : Base of the light source before restoration ©HE Arc CR, A.L

Picture 76 : Base of the light source after restoration ©HE Arc CR, A.L

Picture 77 : Before and after cleaning of a ceramic element ©HE Arc CR, A.L

III.2.4 On copper alloys

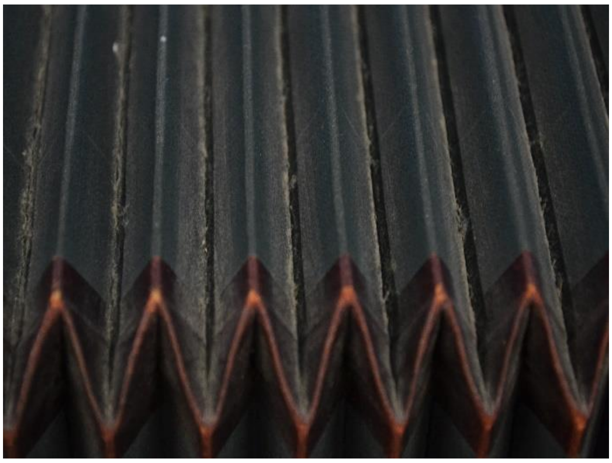
A mechanical removal of the dusty deposits has been carried out with a latex eraser and the degreasing of the copper pieces has been achieved with a cotton swab and Shellsol T. A soft paper has been used to absorb the surplus of solvent (*Picture 78*, *Picture 79*).

Picture 78 : Copper element before restoration ©HE Arc CR, A.L

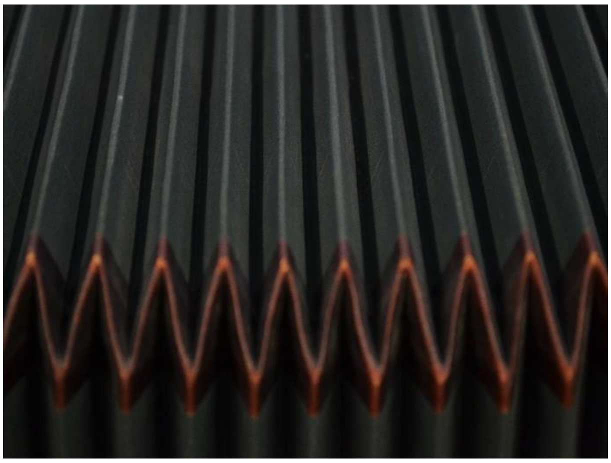
Picture 79 : Copper element after restoration ©HE Arc CR, A.L

III.2.5 On coated paper

A combination of vacuum cleaning and a slight brushing with a nylon brush allowed the cleaning of the dust and powdery deposits on the coated paper (*Picture 80*, *Picture 81*).



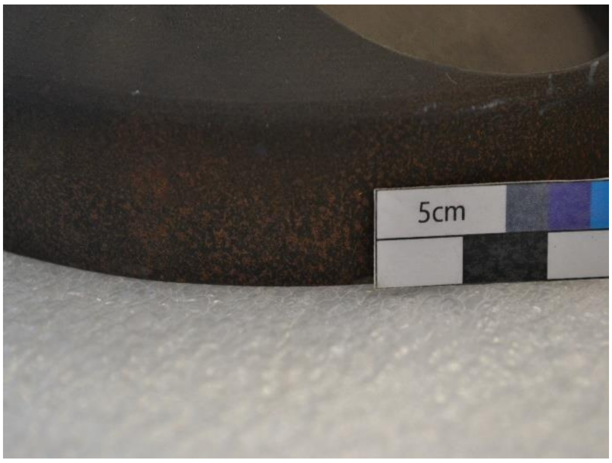
Picture 80 : Coated paper before restoration ©HE Arc CR, A.L



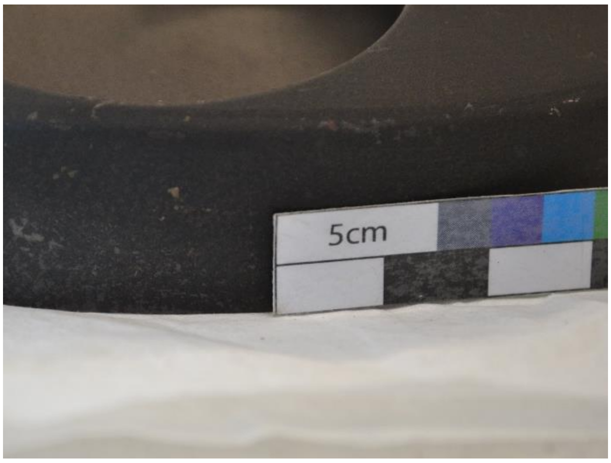
Picture 81 : Coated paper after restoration ©HE Arc CR, A.L

III.2.6 Mitigation of the corrosion products on non-blued surfaces

The corrosion products on painted or galvanised surfaces have been mitigated with the same method than the protocol used on blue steel. Steel wool 000 has been carefully rubbed on the surfaces. An eraser as then been used to remove the corrosion products (*Picture 82*, *Picture 83*).



Picture 82 : Corroded painted surface of the condenser before restoration ©HE Arc CR, A.L



Picture 83 : Painted surface of the condenser after restoration ©HE Arc CR, A.L

III.3 Painting consolidation

The paint liftings have been consolidated with 1% jun-funori in deionised water. A sheet of Mylar paper and a weight were installed on the surface to ease the bonding (*Picture 84*, *Picture 85*).

Picture 84 : Paint lifting before restoration ©HE Arc CR, A.L

Picture 85 : Paint after restoration ©HE Arc CR, A.L

III.4 Retouching of the wooden losses

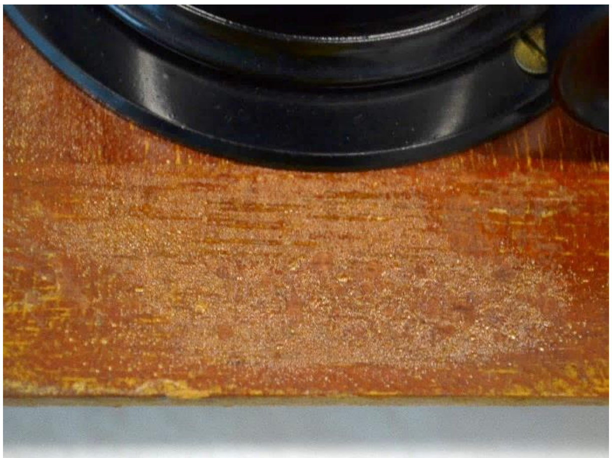
Some areas on the door of the wooden box show losses of the original paint and wood : these are quite pronounced in comparison with the rest of the surface. In order to mitigate this difference, Gamblin colours® in Laropal A81 have been used. The colours have been reactivated with Shellsoll A and a first layer of white painting has been applied on the losses as a preparation layer. A colour with a tone lighter to those of the wooden door has then been applied.
This retouching is retreatable as a hydrocarbon solvent as Shellsol A can be used to remove the layer without damaging the original painting, which is sensitive to alcohols (*Picture 86*, *Picture 87*.

Picture 86 : Door of the wooden box before cleaning and retouching ©HE Arc CR, A.L

Picture 87 : Door of the wooden box after cleaning and retouching ©HE Arc CR, A.L

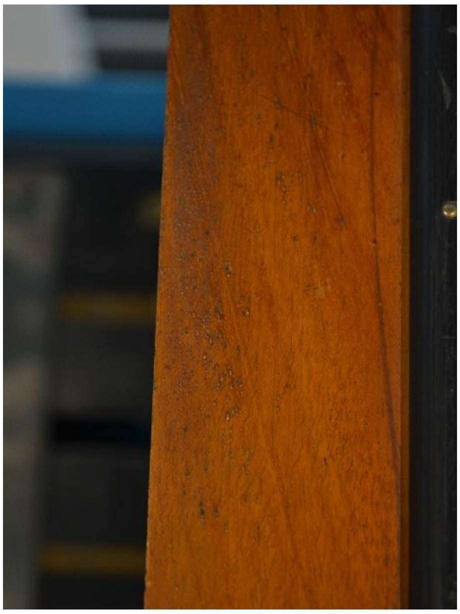
III.5 Resettling of the lifted varnish on wood

In order to resettle the lifted and reticulated varnish on the surface of the wood, a Mylar® film has been placed between the surface and a heat spatula at a temperature of 130°C. The heat spatula was leaved a few seconds on the Mylar® to localize the heating and allow the varnish to reactivate. Then, the spatula was gently rubbed from left to right on the surface to allow the varnish to resettle (*Picture 88*, *Picture 89*, *Picture 90*, *Picture 91*).

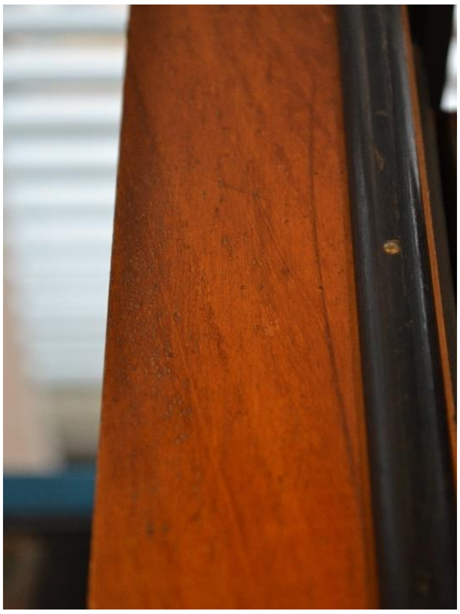


Picture 88 : Surface of the lens carrier before restoration ©HE Arc CR, A.L

Picture 89 : Surface of the lens carrier after restoration ©HE Arc CR, A.L



Picture 90 : Surface of the wooden base of the lantern before restauration ©HE Arc CR, A.L



Picture 91 : Surface of the wooden base of the lantern after restoration ©HE Arc CR, A.L

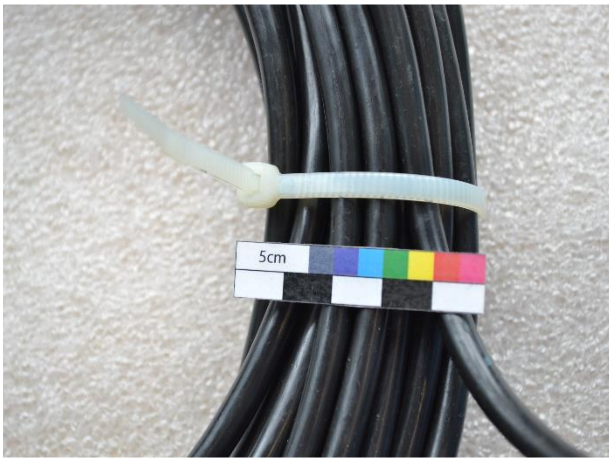
III.6 Treatment and packaging of the PVC power cable

The removal of the blooms from the PVC cable has been carried out with a solution of deionised water with 2 drops of non-ionic surfactant buffered with HCl at a pH of 7 and a conductivity of ~200µS/cm, applied with a cotton swab. The deionised water rinsing solution buffered at a pH of 7 with NaOH has also been applied with a cotton swab, and dried with a soft paper.

Also, as the cable disseminates a strong smell due to the degradation of PVC, it has been decided to conserve the cable outside of the wooden box, to avoid its accumulation inside, while a collaborator would open the door of the box. Stearic acid, which is a fatty acid used as a lubricant from the PVC, is a non-toxic material. Its only issue is that it is combustible[71], which is not an issue for its conservation in a museum storage. A packaging covered with Tyvek has been created to be placed on the metallic structure of the object, in order to be able to shift the object easily (*Picture 92*).

Picture 92 : Packaging of the PVC cable ©HE Arc CR, A.L

The plastic tie gathering the cable together (*Picture 93*) has been cut and replaced by 2 made to measure cotton and Velcro removable ties (*Picture 94*, *Picture 95*). An Oddy tested black cotton has been used for this purpose. This set up will allow an easy displacement of the cable.



Picture 93 : Plastic tie damaging the plastic cable ©HE Arc CR, A.L

[71] Cameo, 2020, c, [En ligne]

Picture 94 : Cotton and Velcro tie ©HE Arc CR, A.L

Picture 95 : Cotton and Velcro tie on the object ©HE Arc CR, A.L

III.7 Time of intervention

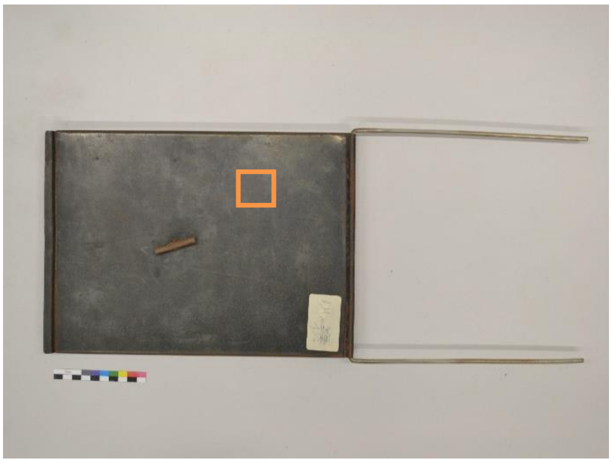
The time of intervention, without the testing and researching of treatments, is exposed here.

Material	Time of intervention
Asbestos : mounting of a tent, partial dismantling, dusting of the whole object, consolidation of the asbestos plates	15h
Blued steel : corrosion removal, cleaning	20h
Glass : cleaning the soiling	1h30
Wood : spreading of the lifted varnish	2h30
Plastic : cleaning and sewing of 2 fasteners	1h
Painted wood : consolidation	1h
Textile : sewing of a polyethylene protection	1h
General mitigation of the soiling	6h
Total	48 hours

IV. Scrutiny and analysis

IV.1 Identification of the alloy

X-ray fluorescence analysis have been achieved in order to identify the composition of the alloy of the blued sheets. It has been carried out with a Niton® XL3t – Thermo fisher device on the outside side of the back door of the lantern (*Picture 96*). The results are helpful to understand the material and to choose an alloy to prepare coupons to reproduce the material as close as possible, even if the carbon content remains unknown.



Picture 96 : Localization of the XRF analysis ©HE Arc CR, A.L

Element	**Percentage**
Fe	98.68%
S	0.389%
Mn	0.356%
Si	0.277%
Cr	0.061%
Ti	0.046%
Cu	0.023%
V	0.019%

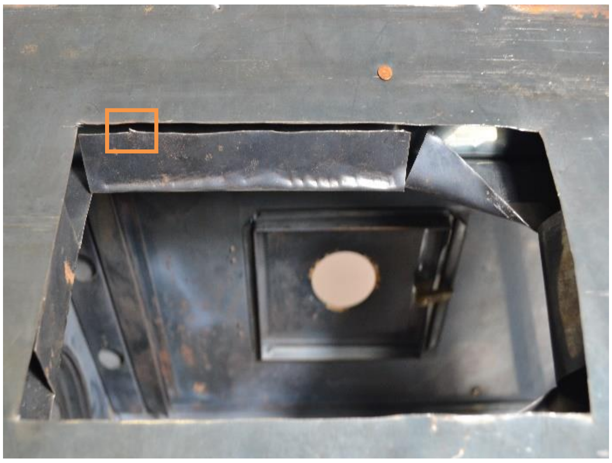
Table 8 : XRF results of the composition of the alloy of the object ©HE Arc CR, A.L

Table 8 shows the results of the XRF analysis made with the General metals program, for 60 seconds. It indicates that the metal is a ferrous alloy, containing sulphur, which is coming from the ore, as well as manganese and silica. European ore is generally rich in phosphor[72], but it is not the case here.

IV.2 Identification of the composition of blued steel

IV.2.1 Raman spectroscopy analysis

Raman spectroscopy analysis have been carried out to determine the nature of the blued steel layer of the steel sheets. A LabAramis Horiba-Jobin-Yvon device has been used to analyse the samples.
A sample of the blued layer has been collected, as the previous tests made with the external arm of the device to analyse the corrosion products were not conclusive. It has been collected at the bottom of the lantern, where the sheets have been modified, to be as unobtrusive as possible (*Picture 97*, *Picture 98*).



Picture 97 : Localization of the sample for Raman spectroscopy analysis ©HE Arc CR, A.L

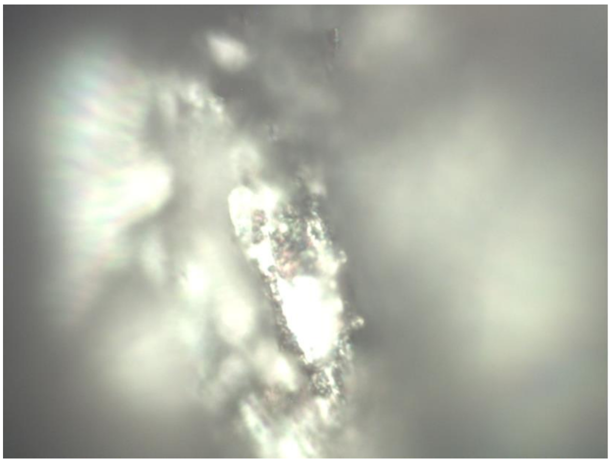
Picture 98 : Close up of the localization of the sample for Raman spectroscopy analysis ©HE Arc CR, A.L

Two graphs will be introduced in this chapter, the first representing a black area of the sample and the second demonstrating a red area of the sample, while it did not appear red under microscope.

As detailed in chapter 3.2 of the thesis, a blued layer obtained by a heating process is composed of a layer of hematite and an underlayer of magnetite. This analytical approach has been conducted to determine if the technology used to blue the object is heating, of which a hematite-magnetite layer is distinctive, or another one. A red area has also been investigated, to conclude if it is akageneite or another type of corrosion product.

[72] de Bouw, Michael, *et al.*, 2010, [Online], p.3

IV.2.1.1 Black area of the sample



Picture 99 : View of the black area of the sample under Raman spectroscopy ©HE Arc CR A.L

In the literature, the principal distinctive peak of hematite is localized at 289 cm^{-1} and the secondary peaks at 223 and 404cm^{-1}. A large peak at 1310 cm^{-1} is also distinctive of this corrosion product[73]. The spectrum (*Picture 100*) shows a peak at 291 cm^{-1} and two others at 221 and 406 cm^{-1}. A third peak at 1312 cm^{-1} confirms the nature of the area studied as hematite.
A peak on the spectra reaches 663 cm^{-1} and is too high to be representative of hematite. It is very probably magnetite as its main distinctive peak is located around 666 cm^{-1} [74].

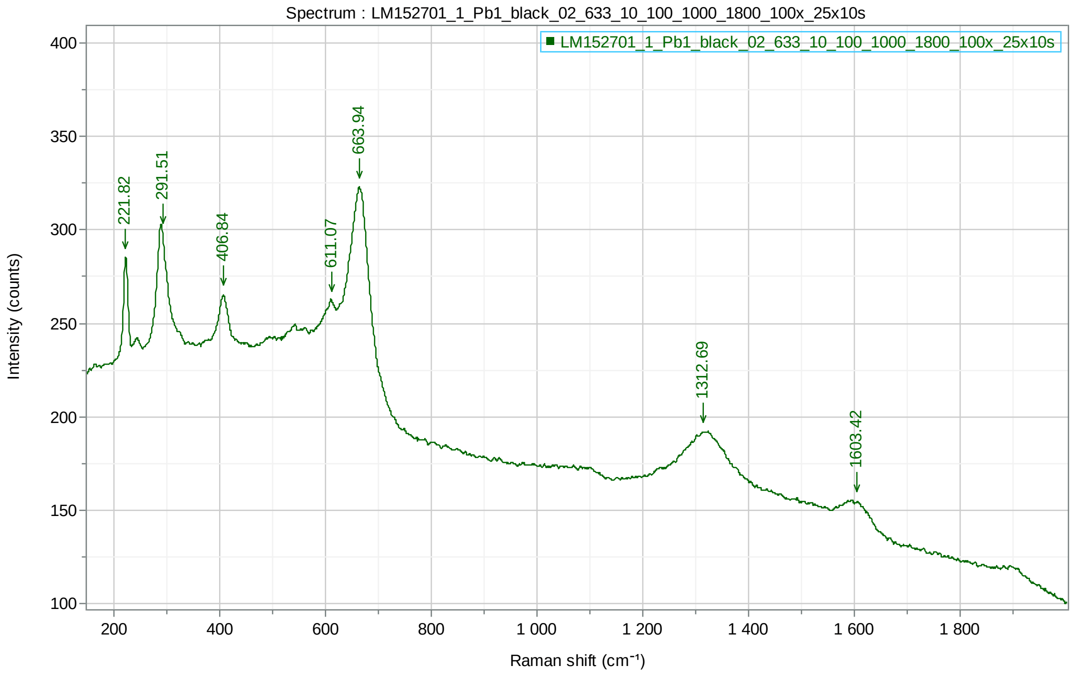
The peak reaching 1603 cm^{-1} could characterize wood charcoal : in the literature, the two distinctive peaks are around 1311-1329 cm^{-1} and 1577-1580 cm^{-1}[75]. This result could be related to the manufacturing of the blued sheets, as they were covered with powdery charcoal to gather the heat on the metal and ease the blueing. Also, as the object was initially equipped with an arc lamp where charcoals were crossed by an electric arc. Deposits of this material could also be considered.

The analyses tend to merge that the blued layer is composed of an upper layer of hematite, which is clearly visible in the spectrum; and an overlayer of magnetite, which is less detectable as it is covered with another compound. Thus, a heat treatment of the steel sheets has very probably been carried out in view of the composition of the layer. The presence of charcoal also tends with this idea.

[73] Neff, Delphine, 2003, p.74

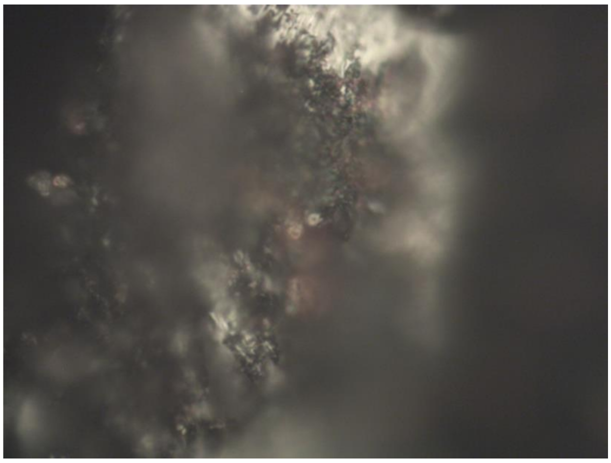
[74] Neff, Delphine, 2003, p.73

[75] Coccato, Alessia, *et al.*, 2015, p.1011



Picture 100 : Black area spectrum, confirming the presence of hematite, magnetite and charcoal ©HE Arc CR, A.L

IV.2.1.2 Red area of the sample



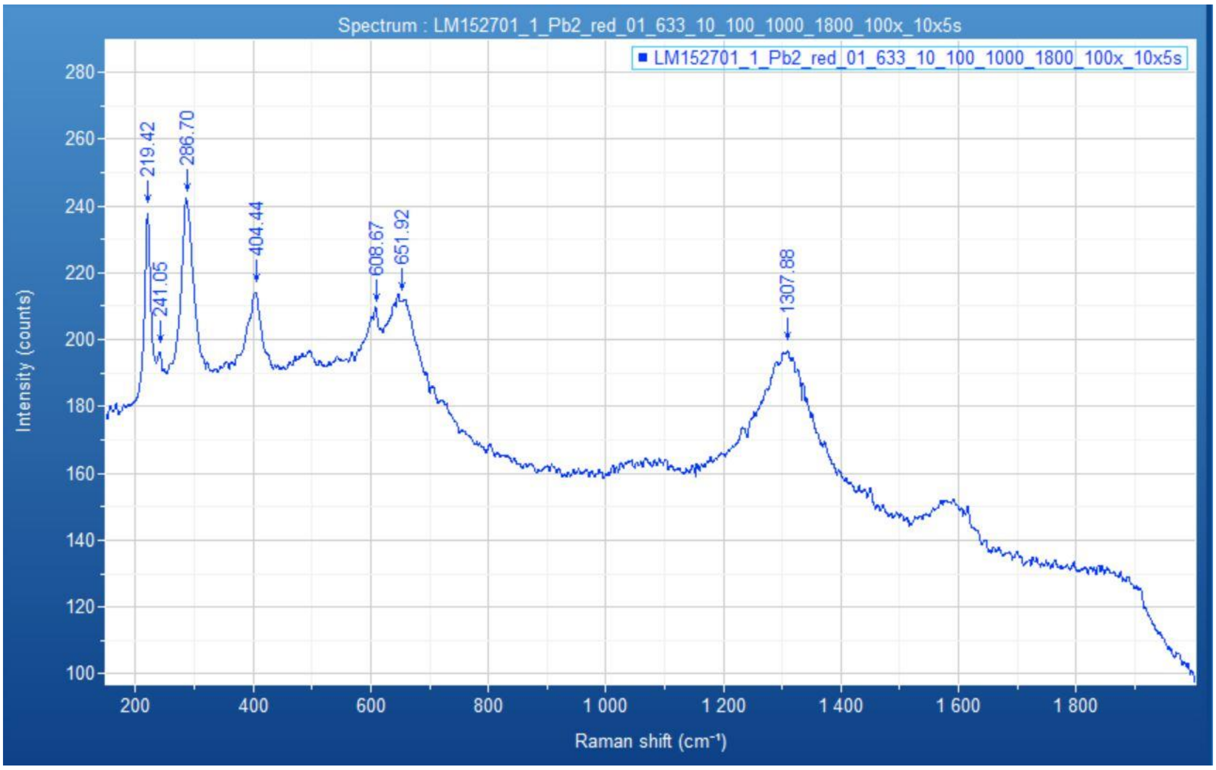
Picture 101 : View of the red area of the sample under Raman spectroscopy ©HE Arc CR, A.L

The spectrum of the red area of the sample (*Picture 102*) shows very similar results than the spectrum of the black area of the sample (*Picture 100*). The peaks 219, 286, 404 and 1307 cm^{-1} are distinctive of hematite[76], and the peak 663 cm^{-1} characterizes magnetite[77]. The last peak of the spectrum[78] has the

[76] Neff, Delphine, 2003, p.74

[77] Neff, Delphine, 2003, p.73

same intensity than the distinctive peak of charcoal in the spectrum of the black area of the sample (*Picture 102*). The hypothesis of the presence of akageneite can then be withdrawn.



Picture 102 : Red area spectrum, confirming the presence of hematite, magnetite and charcoal ©HE Arc CR, A.L

IV.2.2 Fourier transformed infrared spectroscopy

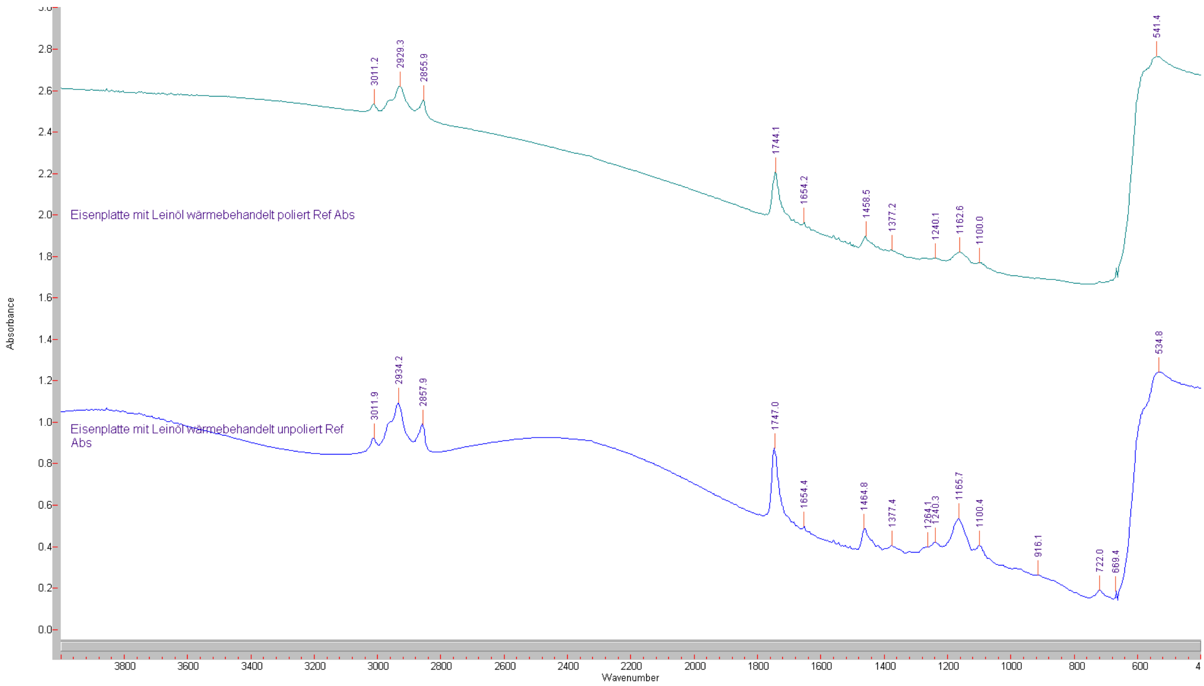
In order to detect the presence of potential oils or salts which could have been used to blue chemically the steel sheets, FTIR has been performed in a non-invasive way on the object (*Picture 103*) with A BIO RAD UMA-500 device.

Picture 103 : Localization of the FTIR analysis ©HE Arc CR, A.L

[78] The last peak of the spectrum is the one which is not labelled.

Also, a piece of steel has been blued in a linseed oil bath to be able to compare the results of a chemical blueing to those of the object.

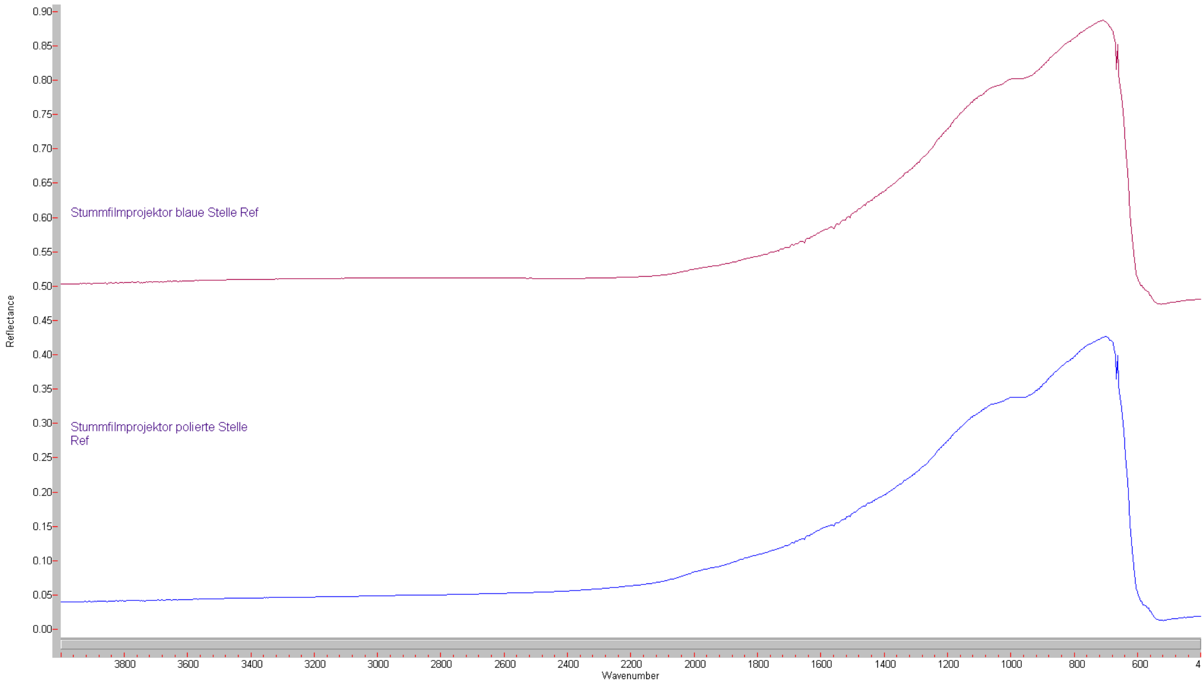
The FTIR spectra on *Picture 104* show the results obtained on the piece of steel blued in linseed oil. Both polished and unpolished blued surfaces have been analysed. The characteristic peaks of linseed oil have an intensity of 3010, 2925, 2856 and 1744 cm^{-1} [79].



Picture 104 : FTIR spectra of the piece of steel blued with linseed oil ©HE Arc CR, A.L

The FTIR spectra on *Picture 105* shows the results obtained on the blued steel at the top of the lantern. No oils or salts have been detected, nor other organic compound.

[79] Balanuca, Brindusa, *et al.*, 2014, p.134



Picture 105 : FTIR spectra of the blued steel of the lantern ©HE Arc CR, A.L

IV.2.3 General interpretation

The results of the Raman spectroscopy and FTIR analysis allow to conclude that the steel sheets have not been blued chemically. Indeed, no organic compound as oils or salts, which were commonly used to blue steel, have been detected by FTIR. Nevertheless, the FTIR and Raman spectroscopy results merge to say that the steel has been blued thanks to a heating process. As no organic substances are constitutive of the material, and the composition of the layer is made of hematite and magnetite, which are characteristic of a blueing obtained by a heating process. Also, the presence of charcoal could also be related to the heating technique of blueing, as charcoal was directly put in contact with the steel sheets during the bluing process to concentrate the heat on the material. Therefore, charcoal could also be related to the use of an ancient light source, as an arc lamp.

IV.3 Identification of the corrosion products

Raman spectroscopy analysis have been carried out to determine the nature of the corrosion products on the steel sheets. A LabAramis Horiba-Jobin-Yvon device has been used to analyse the samples.

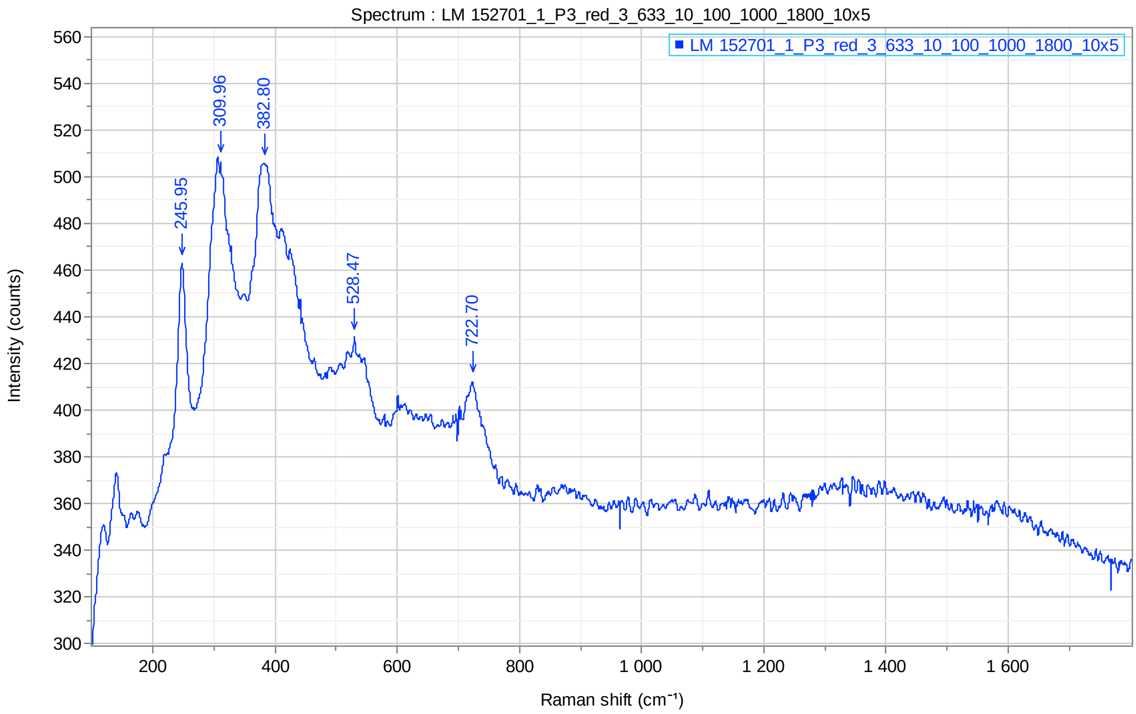
Two samples have been collected on the object : one from the red corrosion products, and another from the black corrosion products (*Picture 106*).

Picture 106 : Localization of the samples of the red corrosion products (red square) and the black corrosion products (orange square) ©HE Arc CR, A.L

IV.3.1 Red corrosion products

The two following spectra detail the nature of the red corrosion products of the object.

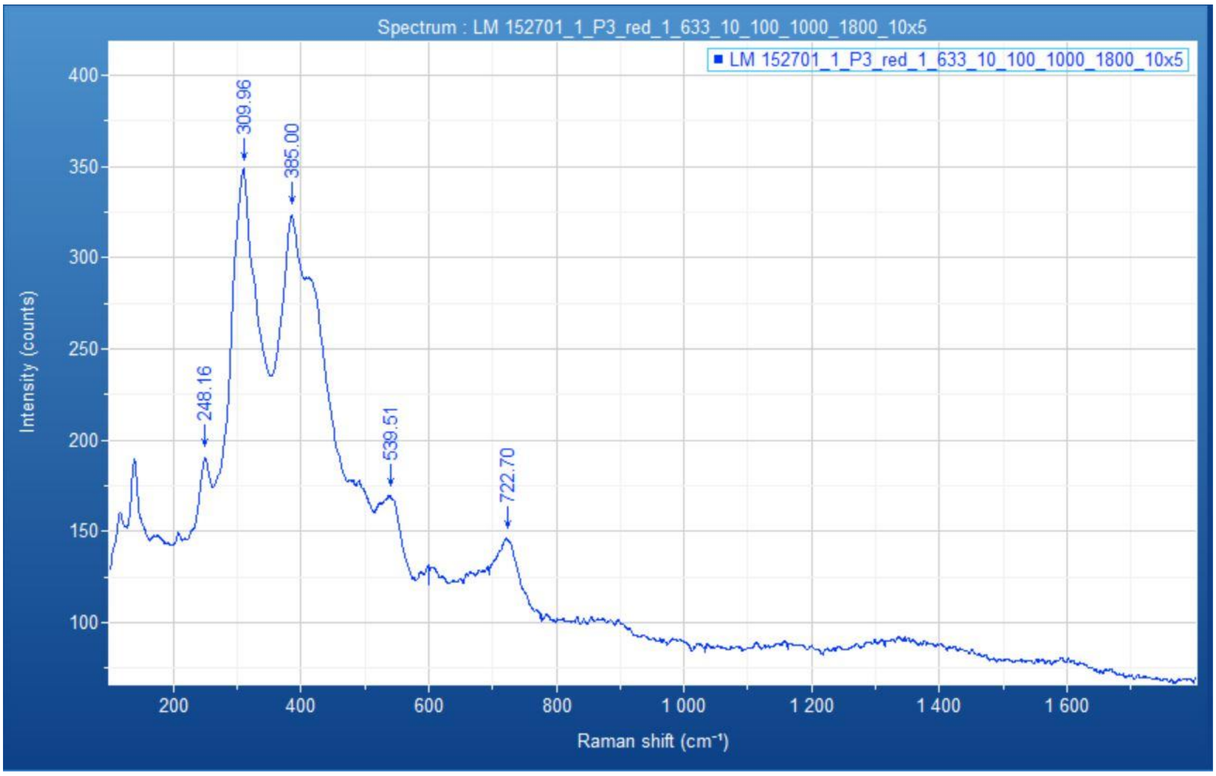
Literature evokes two main peaks around 310 and 386 cm^{-1} for akaganeite. A peak at 725 cm^{-1} is also documented[80]. The spectrum on *Picture 107* is distinctly characterized by three peaks 309, 382 and 722 cm^{-1} corresponding to akageneite.



Picture 107 : Raman spectrum of the P3 sample, third measurement, confirming the presence of akageneite ©HE Arc CR, A.L

[80] Neff, Delphine, 2003, p.76

Also, lepidocrocite has also been identified with Raman spectroscopy on this sample. The peaks on the spectrum of the *Picture 108* reach 248 and 385 cm^{-1} and literature evokes peaks at 252 and 380 cm^{-1} for this corrosion product[81].



Picture 108 : Raman spectrum of the P3 sample, first measurement, announcing the presence of lepidocrocite ©HE Arc CR, A.L

IV.3.2 Black corrosion products

The two following spectra detail the nature of the corrosion products found on the sample.

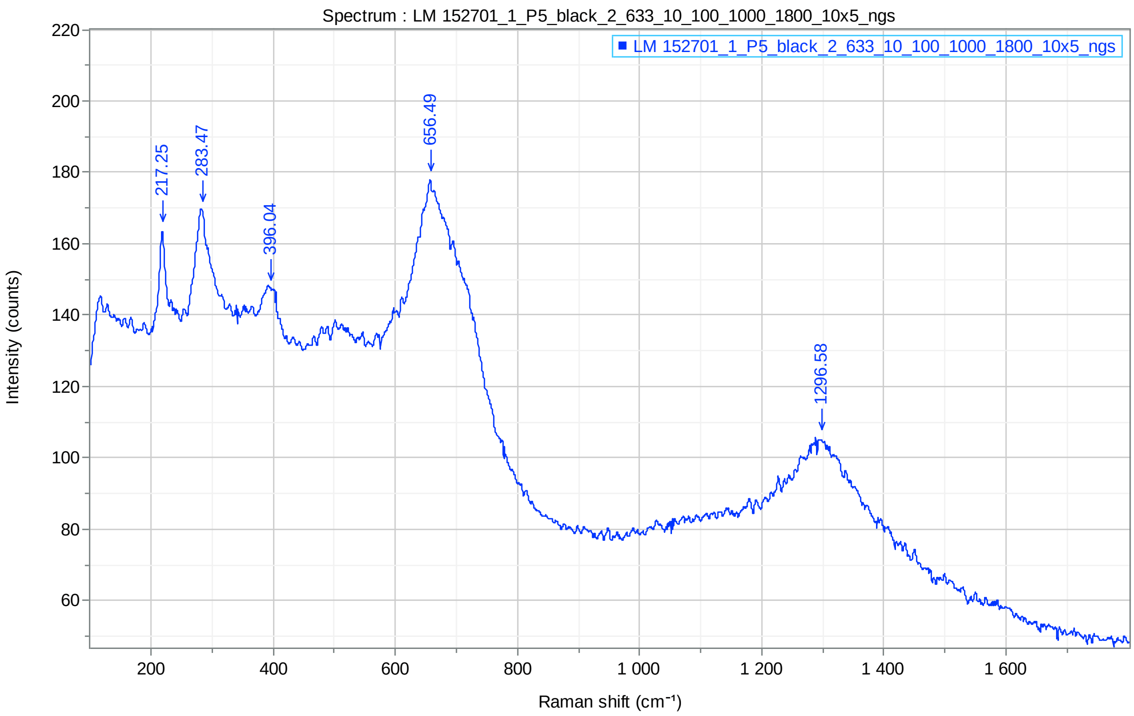
The spectrum on *Picture 109* shows two distinctive peaks at 217 and 283 cm^{-1}. In the literature, the peaks of hematite are defined around 225 and 295 cm^{-1}. A third peak is also characteristic at 413 cm^{-1} [82]but it is not that clear on the spectrum of the sample, where a peak at 396 cm^{-1} is visible.

A peak at 656 cm^{-1} could be evocative of magnetite. Its distinctive peak generally reaches 666 cm^{-1} [83].

[81] Neff, Delphine, 2003, p.75

[82] Neff, Delphine, 2003, p.74

[83] Neff, Delphine, 2003, p.73



Picture 109 : Raman spectrum of the P5 sample, second measurement, raising the presence of hematite and magnetite ©HE Arc CR, A.L

Besides, the spectrum on *Picture 110* raises the presence of goethite, with a peak at 380 cm^{-1}. In literature, the main peak of goethite is located around 385 and 397 cm^{-1} [84].

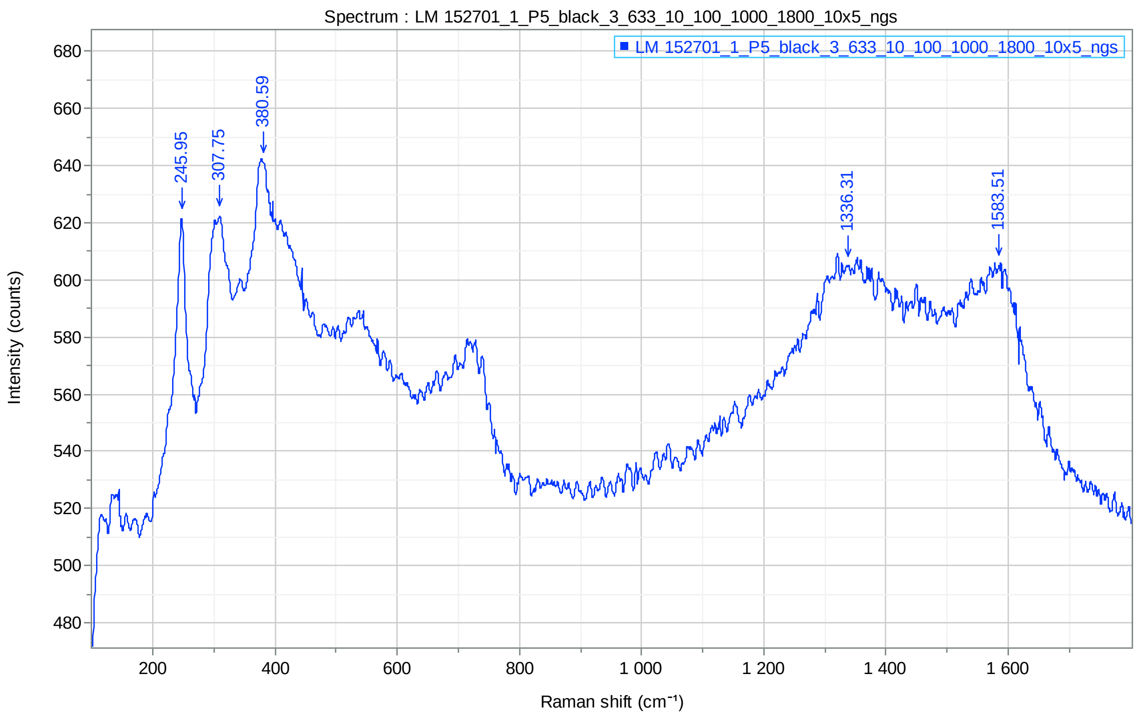
Also, two significant peaks attaining 1336 and 1583 cm^{-1} correspond to furnace black (1346-1399 cm^{-1} and 1587-1592 cm^{-1} in literature[85]). Furnace black, which is also known as "carbon black" is a material obtained by the incomplete combustion of organic materials as oils, resins, natural gas, wood or bone as well as petroleum products[86]. Several hypotheses can be formulated about this result. The light source of the object may have been an oil (*Picture 112*) or petroleum lamp (*Picture 111*) in the past : light sources of this type were commercialised by Ganz & Co in 1920 to equip the lanterns. But the Rigi model which resembles the object of this study was only commercialised with an arc lamp (*Picure 113*) or an electric incandescent lamp[87]. The most likely hypothesis is that charcoal, which is made of carbonized wood, has been used as a combustible on the previous arc lamp, diffusing furnace black on the object.

[84] Neff, Delphine, 2003, p.75

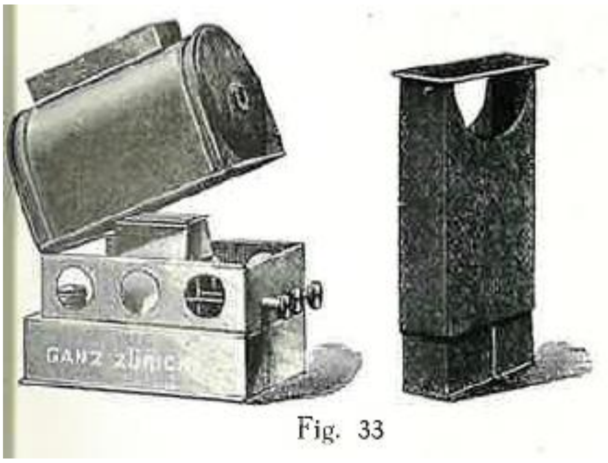
[85] Coccato, Alessia, *et al.*, 2015, p.1011

[86] Cameo, 2020, a, [Online]

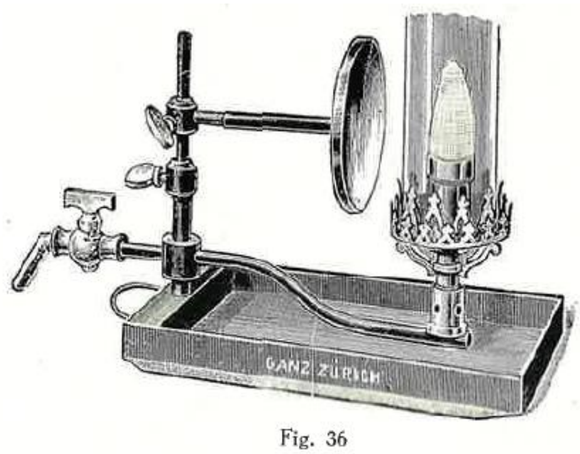
[87] Ganz & Co Zürich, 1920,



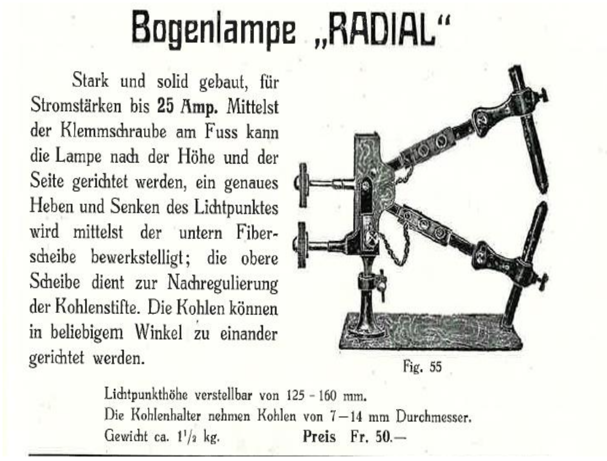
Picture 110 : Raman spectrum of the P5 sample, third measurement, raising the presence of goethite and furnace black



Picture 111 : Ganz petroleum lamp ©Ganz & Co



Picture 112 : Ganz oil lamp ©Ganz & Co



Bogenlampe „RADIAL“

Stark und solid gebaut, für Stromstärken bis **25 Amp.** Mittelst der Klemmschraube am Fuss kann die Lampe nach der Höhe und der Seite gerichtet werden, ein genaues Heben und Senken des Lichtpunktes wird mittelst der untern Fiberscheibe bewerkstelligt; die obere Scheibe dient zur Nachregulierung der Kohlenstifte. Die Kohlen können in beliebigem Winkel zu einander gerichtet werden.

Fig. 55

Lichtpunkthöhe verstellbar von 125 - 160 mm.
Die Kohlenhalter nehmen Kohlen von 7—14 mm Durchmesser.
Gewicht ca. $1^1/_2$ kg. **Preis Fr. 50.—**

Picure 113 : Radial arc lamp provided with the Rigi projection lantern ©Ganz & Co

IV.4 Identification of plastic and research of polychlorinated biphenyls

A strong smell coming from the power cable of the object has been detected (*Picture 114*). As the modifications brought to the object have been estimated between the 1940s and the 1960s, the presence of bitumen and polychlorinated biphenyls is questioned as they were often use in cables for their insulating properties.

Picture 114 : Localisation of the cable ©HE Arc CR, A.L

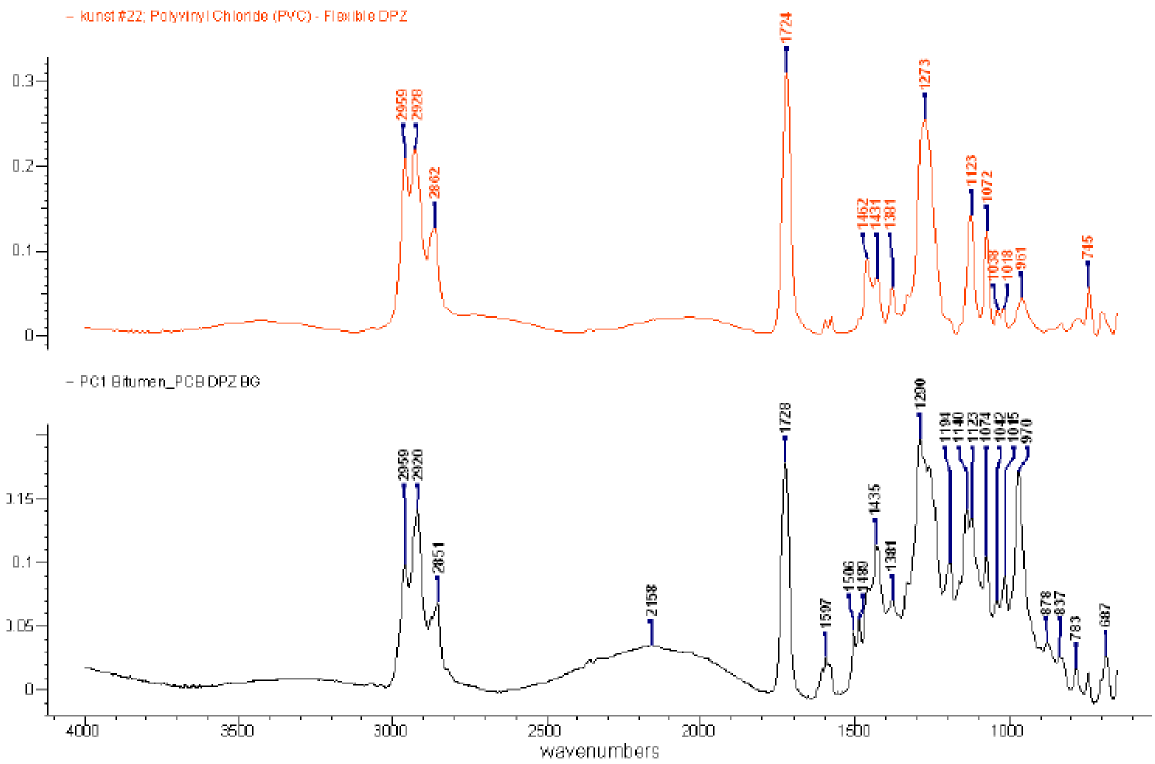
Three samples have been collected for FTIR analysis and dissolved in hexane and analysed. They are introduced in *Table 9*.

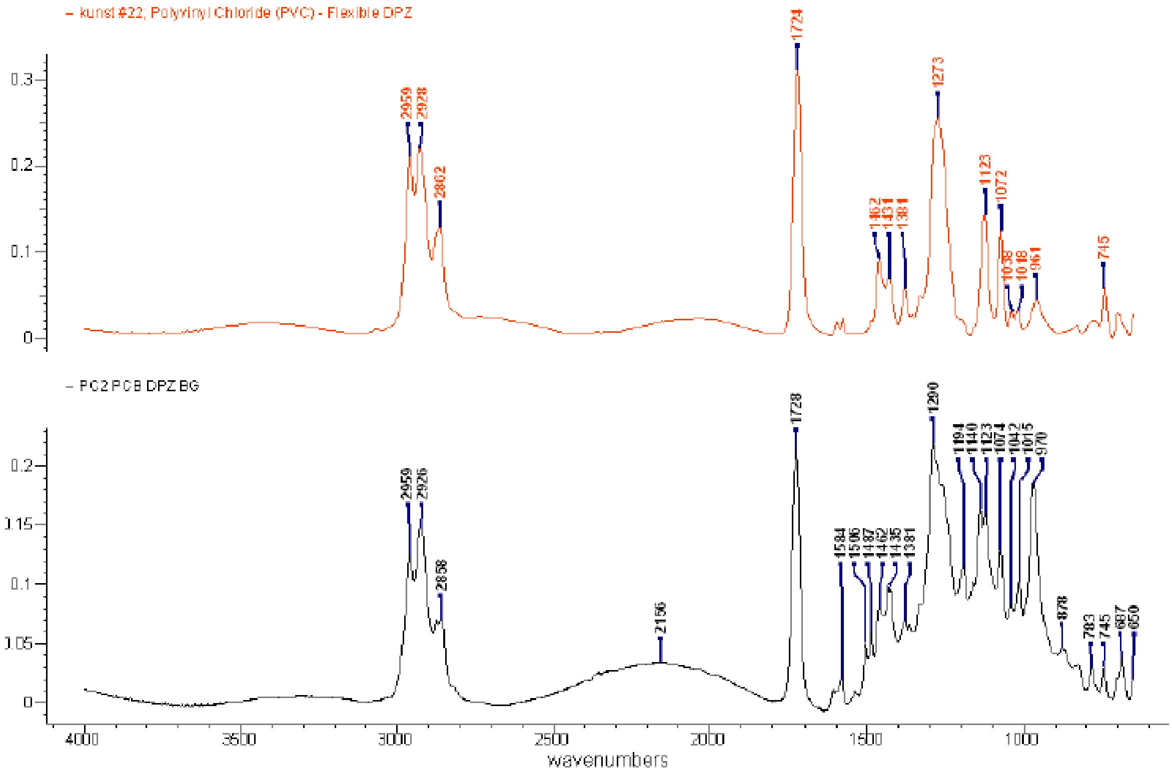
Sample	Location	Identification
PC1 Power cable	Edge of the power cable	Polyvinyl chloride (PVC) plasticized with phthalates
PC2 Red cable in the power cable	Edge of the power cable	Polyvinyl chloride (PVC) plasticized with phthalates
PC3 Black cable in the power cable	Edge of the power cable	Polyvinyl chloride (PVC) plasticized with phthalates

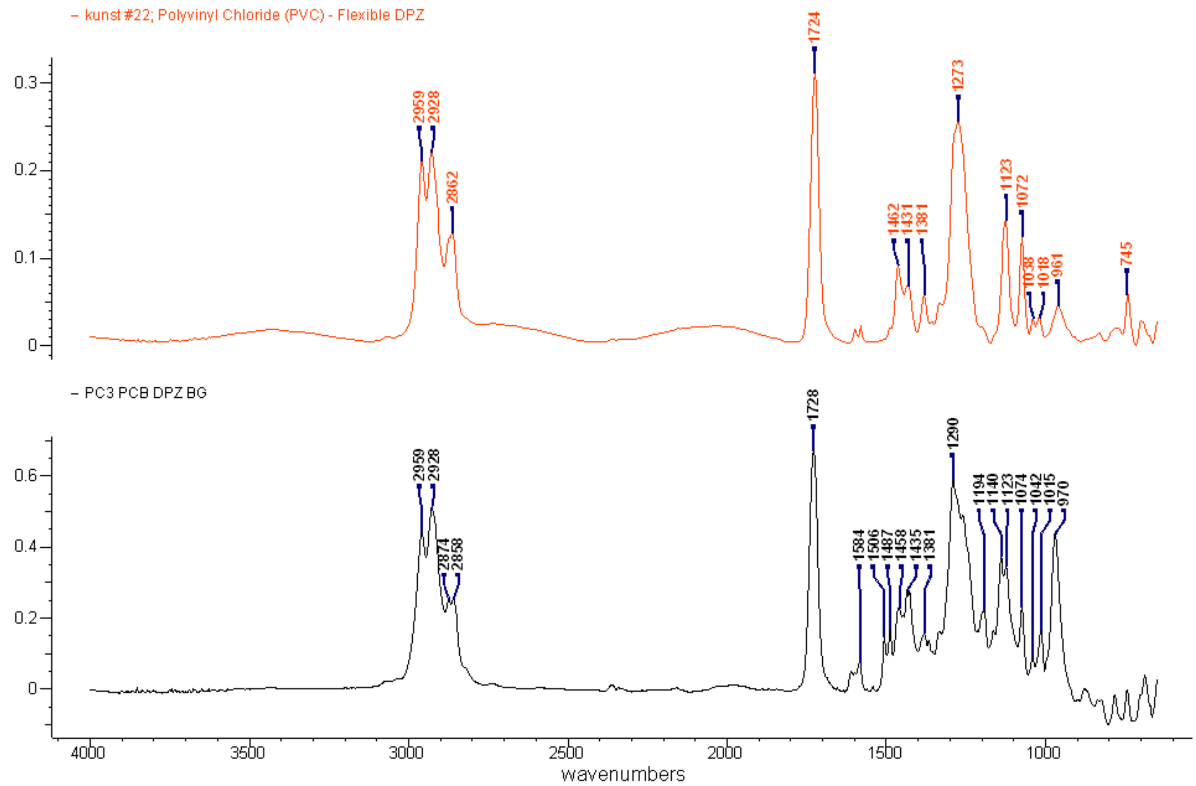
Table 9 : Description of the samples collected on the power cable ©HE Arc CR, A.L

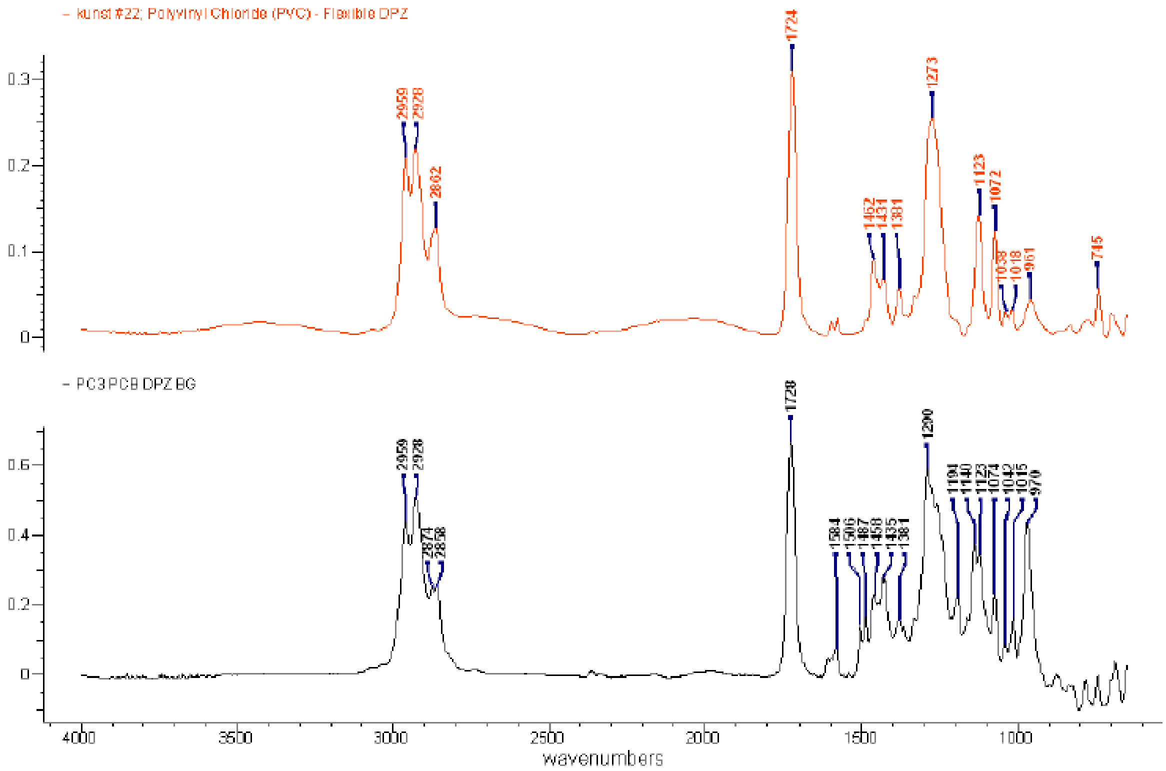
The 3 samples are principally composed of PVC containing phthalates. Other peaks are visible, but they don't refer to PVC, PVC products of degradation or polychlorinated biphenyls (*Picture 115*).

It would be recommended to achieve GC-MS analysis to detect PCB and other products of degradation of PVC.




kunst #22; Polyvinyl Chloride (PVC) - Flexible DPZ
PC2 PCB DPZ BG
wavenumbers

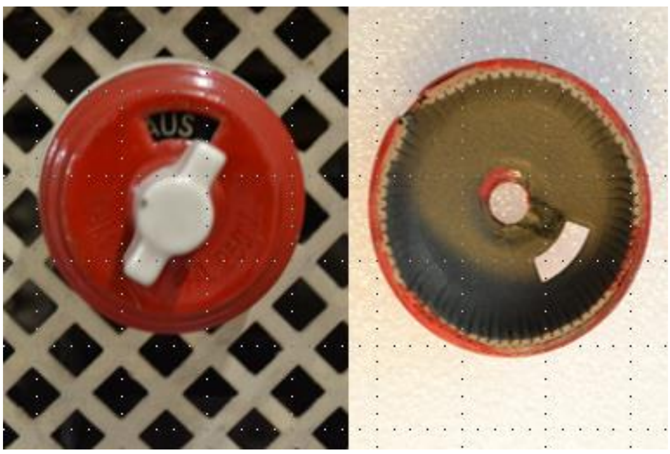

kunst #22; Polyvinyl Chloride (PVC) - Flexible DPZ
PC3 PCB DPZ BG
wavenumbers



Picture 115 : The 3 first FTIR spectra show the presence of PVC and phthalates for samples PC1, PC2 and PC3. The last spectrum show the hexane extraction residue of a piece of PC1 electrical cable (black spectrum) compared to phthalates (red spectrum) ©HE Arc CR, A.L

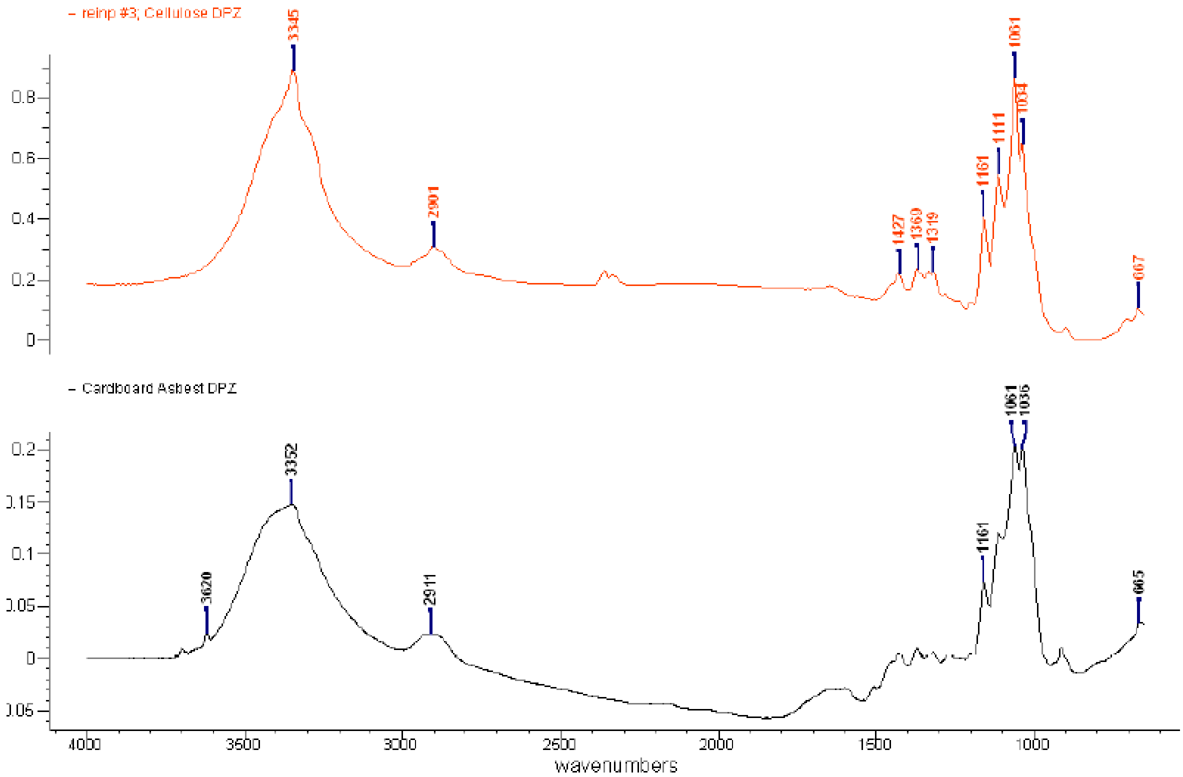
IV.5 Suspicion of asbestos

An insulating cardboard located in the cover of the switch of the transformer is suspected to contain asbestos because of its colour and its fibrous aspect (*Picture 116*). Asbestos was often use in the form of cardboard as insulting pieces, close to light sources or electrical devices. FTIR analysis has been carried on in order to identify the composition of the carboard and if necessary, take safety measures.



Picture 116 : Localisation of the insulating cardboard ©HE Arc CR, A.L

The insulating cardboard is principally constituted of a cellulosic material. It also contains a silicate which could be an ochre for the brown colouration of the cardboard (*Picture 117*).



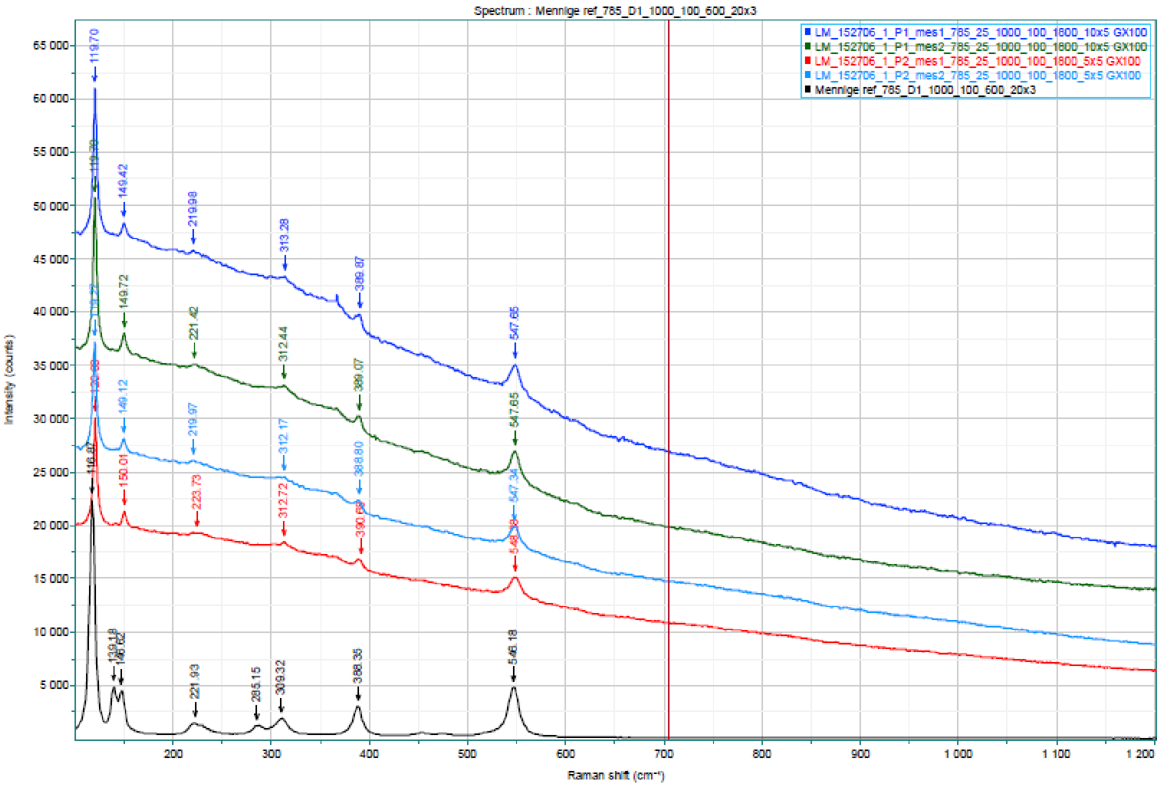
Picture 117 : FTIR spectrum of the insulating cardboard (black) compared to cellulose (red) ©HE Arc CR, A.L

IV.6 Identification of the nature of a painting

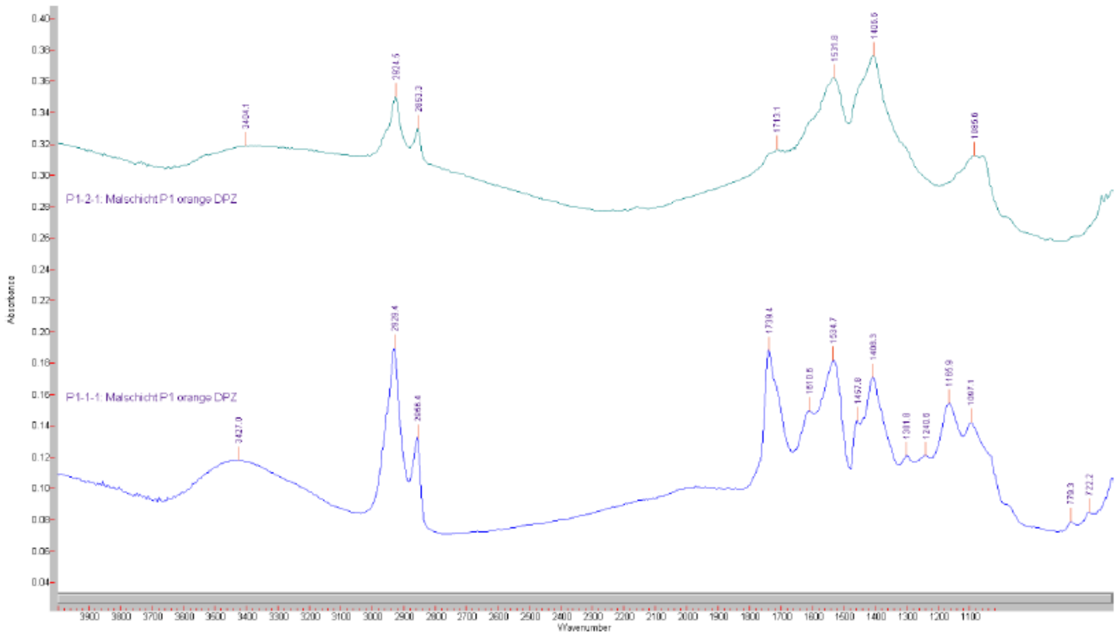
Two similar paintings have been observed at the backdoor of the lantern and inside the chimney of the object. We know that the chimney is not the initial one of the object (*Picture 118*). If the painting is of the same nature on the backdoor, we would know that the backdoor has also been added to the object. Also, as we suspect red lead, preventive conservation measures could be defined thanks to the results of the analysis.

A sample of each paint layer has been collected for Raman spectroscopy analysis. The sample P1 corresponds to the paint of the backdoor of the lantern. The sample P2 corresponds to the sample of the inside of the chimney. Both are composed of red lead (*Picture 119*) and their binding is a drying oil which is partially or completely degraded. The black areas of the painting of the chimney are constituted of PVC containing phthalates (*Picture 120*, *Picture 121*).

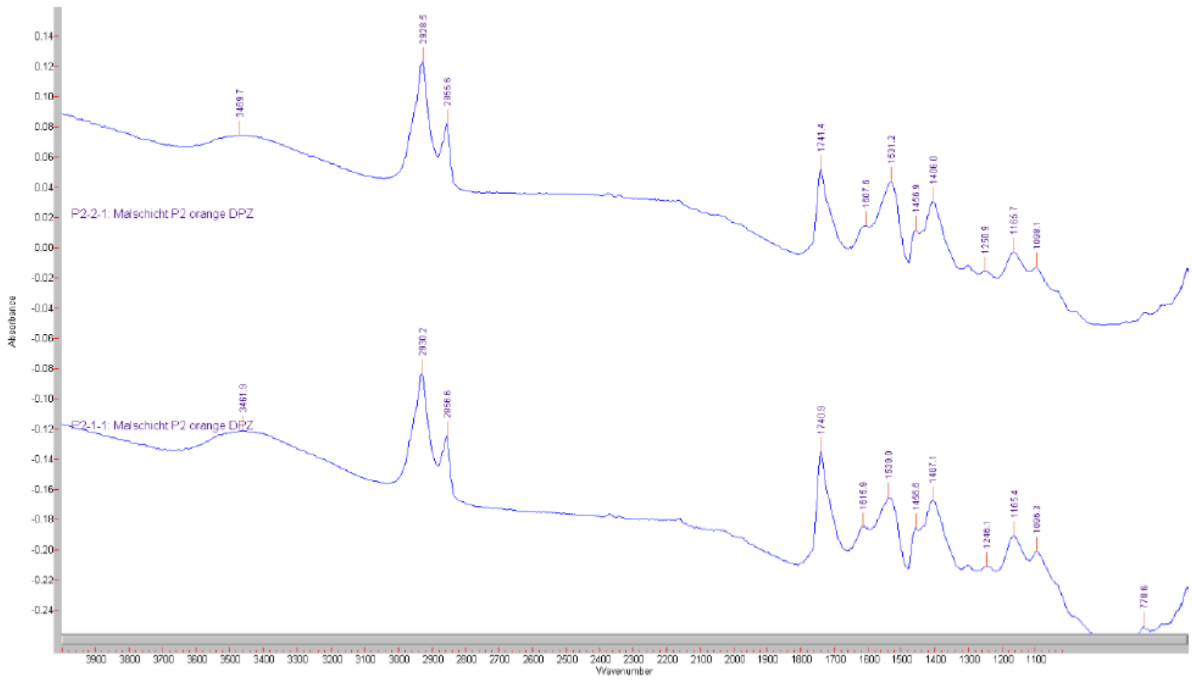
Picture 118 : Localization of the samples ©HE Arc CR, A.L



Picture 119 : Raman spectra of the paint samples compared with the spectrum of minimum ©HE Arc Cr, A.L



Picture 120 : IRTF spectra of the sample P1, showing drying oil at 2924, 2854, 1739, 1240, 1165, 1097 cm-1 and carboxylates at 1713, 1531 and 1406 cm-1 ©HE Arc CR, A.L



Picture 121 : IRTF spectra of the sample P2, showing oil at 2924, 2854, 1739, 1240, 1165, 1097 cm-1 and carboxylates at 1713, 1531 and 1406 cm-1 ©HE Arc CR, A.L

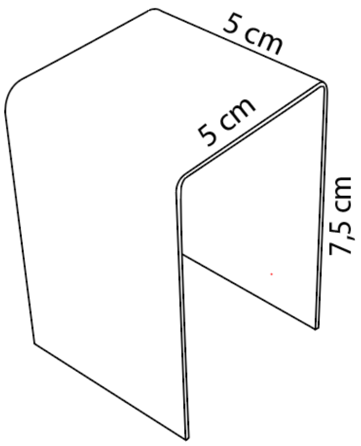
V. Preparation of the metallic coupons

V.1 Selection of the alloy

In order to properly test the treatments of corrosion removal and coloured protection of the blued steel sheets, it has been decided to create metallic coupons replicating the composition of the steel alloy, the surface treatment and their corrosion products.
X-ray fluorescence has been achieved on the surface of the steel sheets for the purposes of identifying the composition of the alloy. Blue and naked steel surfaces of the object were represented to distinguish a difference of composition.
The ST-37 steel alloy has been chosen for its composition close to the composition of the studied material, as well as for its manufacturing technique (hot-rolled).

V.2 Manufacturing parameters of the coupons

The dimensions of the coupons have been selected from an article from Christian Degrigny[88] but adapted in order to represent the different orientations of the steel sheets as well as the folding angles of the object. Sheets of a thickness 2 millimetres and dimensions of 20 cm has been folded twice in order to obtain a "U" shape coupon. Surfaces of 75 x 50 mm and 50 x 50 mm are large enough to limit edge effects on the corrosion process[89].



Picture 122 : Shape and dimension of the coupons ©HE Arc, A.L

[88] Degrigny, Christian, 2010, p.368

[89] Degrigny, Christian, 2010, p.368

Considering the large number of coupons, they have been sanded electrically with abrasive paper of different granulometry : 80, 120, 180 and 320 with a Festool ETS EC 150 eccentric sander and SIA abrasive disks. Then, they have been degreased twice with cotton swabs and ethanol and blued thermically at a temperature of 300°C for 100 minutes in a Memmert UF 450 universal proofer, with the following parameters, according to the behaviour of a test coupon :

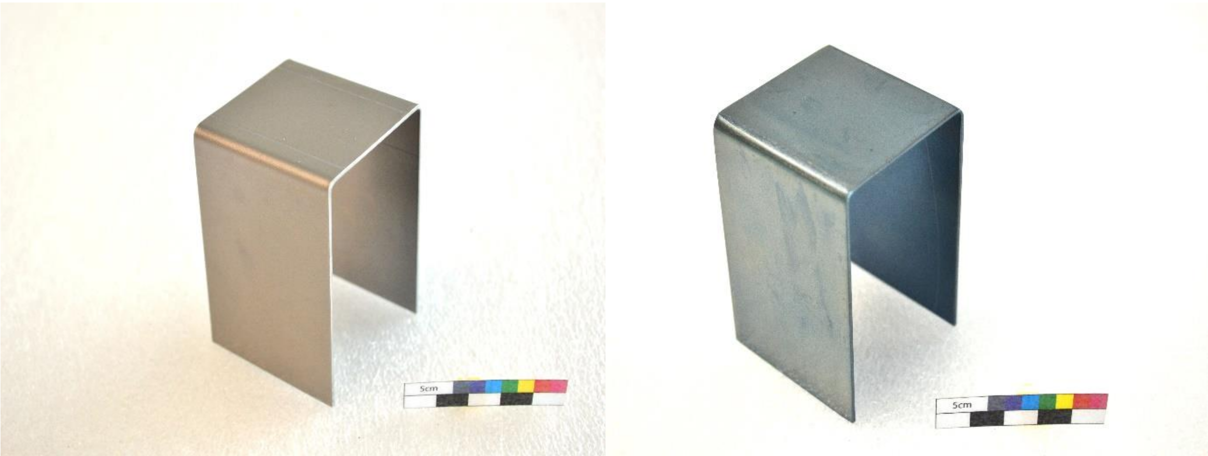
- Fan : 90% for 50 minutes, then reduced to 50% for 20 minutes, and to 30% for 30 minutes;
- Flap : 40%.

A high ventilation has been chosen at the beginning of the heating process to provide a good contact between oxygen and steel, in order to obtain a successful blueing[90]. It has then been progressively reduced to reproduce the near airtight conditions used in a second step in the traditional process[91].

Picture 123 : Universal proofer used to blue the coupons ©HE Arc CR, A.L

[90] Kraus, Hugo, 1951, p.100

[91] Société des Ingénieurs Civils, 1889, [Online], p. 717



Picture 124 : Comparison between a paper sanded coupon and a blued coupon @HE Arc CR, A.L

This blueing method is the closest we could get from the original, as it was not possible to use charcoal for safety and equipment reasons. The use of charcoal would have concentrated the heat at the surface of the metal and we would have probably obtained a darker grey blueing surface.

V.3 Corrosion protocol of the coupons

V.3.1 Initial protocol

The corrosion of the blued steel coupons has initially been thought with a climate chamber. Three resources from the literature have been compared in order to define the protocol of corrosion of the coupons. Therefore, these resources concern the testing of surface protections on iron-based alloys and not the corrosion of a metal covered with an oxide coating.

Christian Degrigny, defined the following parameters for the PROMET project[92] :

- A duration of 28 days (4 weeks);
- A manual changing between the cycles;
- A phase at ambient temperature : 20-25°C, 50-60% relative humidity during 8 hours;
- A hot and humid phase : 35°C, 90% relative humidity during 16 hours.

Janine Meyer defined the following parameters for the testing of surface protections on Keris[93] :

- A duration of 6 weeks;
- The time of transition between the two phases is of 30 minutes and changes automatically;
- A cold and dry phase : 18°C, 40% relative humidity;
- A hot and humid phase : 34°C, 90% relative humidity.

[92] Degrigny, Christian, 2010, p.369

[93] Meyer, Janine, 2020, p.80

The DIN 50017 norm defined the following parameters[94] :

- A phase at ambient temperature : 18-22°C and 40% relative humidity during 16 hours;
- A hot and humid phase at 40°C and 100% relative humidity.

After a consultation of the literature, and having in mind that the corrosion of a non-protected metal takes 2 weeks, the parameters below have been defined with Christian Degrigny :

- A duration of 4 weeks;
- The time of transition between the two phases is of 4 hours and changes automatically;
- A dry phase : 20-25°C, 50-60% relative humidity;
- A humid phase : 35°C, 90% relative humidity.

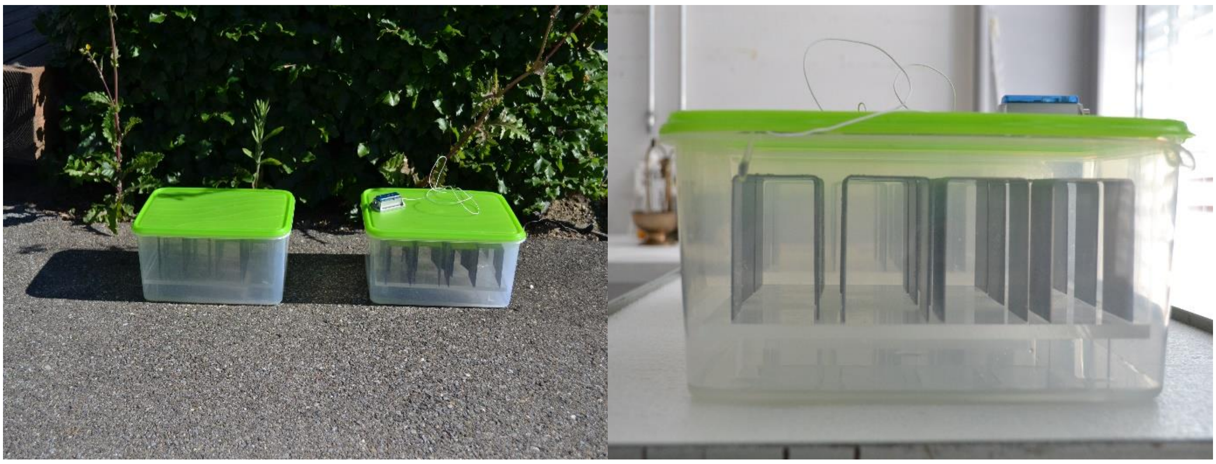
Unfortunately, despite the several requests for the use of a climate chamber which have been done with the support of Christian Degrigny, none was available in the surroundings. Consequently, another protocol has then been defined in order to corrode the coupons.

V.3.2 Applied protocol

The blued surface of each coupons has then been damaged with the blade of a scalpel and punctually with glass beads at a dosage of 0.5 and a pressure of 0.5 for 4 seconds, in order to reproduce the flaws of the blued layer and generate corrosion. The scratches have been made with a scalpel and the halos with a sandblaster, to allow the reproducibility of the tests on all the surfaces of the coupons.

The cycles applied to corrode the coupons are the following (*Picture 125*):

- A hot and humid phase where the coupons are exposed outside for 8 hours;
- A dry phase : inside the Collection Centre for 16 hours.

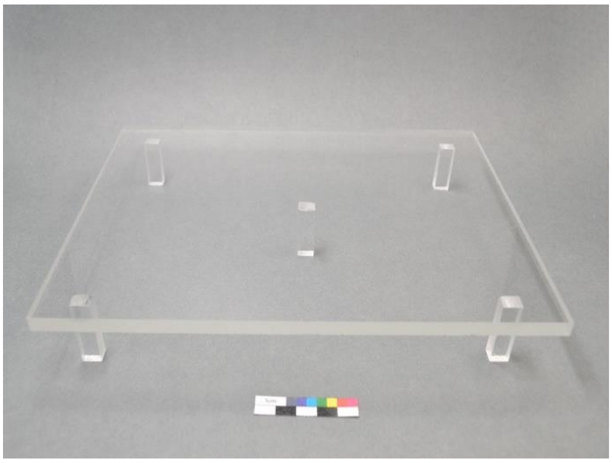


Picture 125 : Coupons exposed to a hot and humid phase (left) and a dry phase (right) ©HE Arc CR, A.L

The norm EN ISO 9227[95] describing salt fog standardized tests to evaluate the corrosion resistance of metallic materials inspired the corrosion protocol of the coupons. As akageneite, a corrosion product formed with the presence of chlorides has been identified on the blued sheets of the object, the choice of using salt fog has been made. We are aware of the non-reproducibility of the protocol that will describe in the next paragraph, as all the parameters, mainly temperature, can't be controlled. Also, as the resistance to corrosion in salt fog is different from the corrosion resistance in other environments[96]. However, this method is mainly used here to corrode coupons.

A saturated solution of NaCl has been prepared in order to activate the corrosion process. We opted for a saturated solution of NaCl instead of a 5% solution of sodium chloride because to allow the corrosion process in the not vacuumed boxes. A saturated solution of NaCl allows a humidity around 78%. The solution has been prepared at ambient temperature by referring to the solubility of NaCl at 80°C (380.5 g/L^{-1}) to allow more solubility when the temperature rises during the hot and humid phase.

20 blued coupons and 4 coupons blued with a chemical modern product have been disposed at equal distance on a Plexiglas stand of 26cm long, 19cm wide and 3cm height in order to fit two polyethylene box of 8 litres. The volume of deionised water necessary to saturate the closed environment is located in the bottom of the box, under the Plexiglas stand (*Picture 126*) and is about 250cL. Two coupons covered with the "Gun Blue" chemical blueing product have been added in each box to test their resistance to corrosion. A MSR 145 datalogger sensor has been inserted in a small insert cut at the top of the box, to control relative humidity and temperature variations.



Picture 126 : Plexiglas stand made to carry the coupons ©HE Arc CR, A.L

V.3.3 Monitoring of the corrosion process of the coupons

The coupons have been corroded :

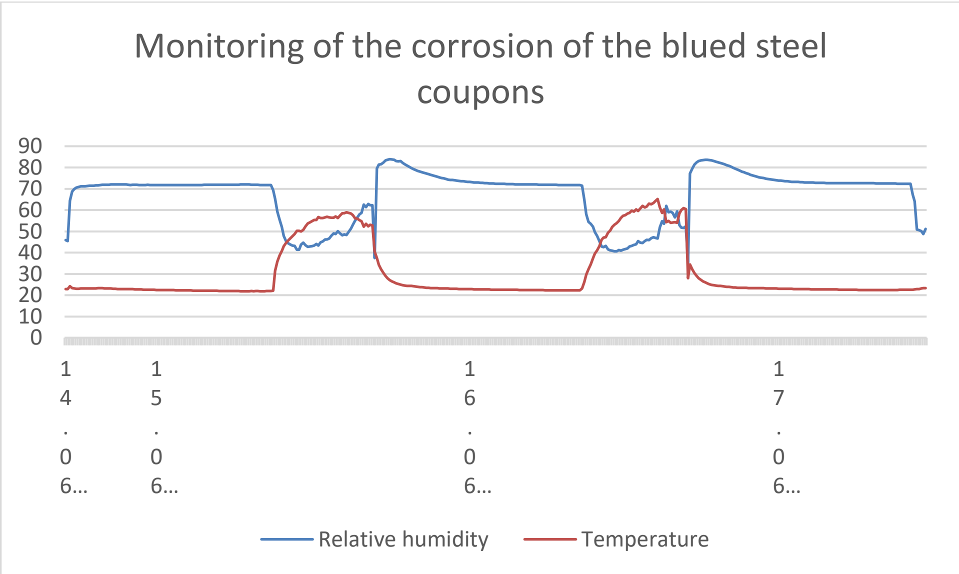
14.06.2021 : starting of the corrosion process at 5:00 P.M, then dry phase at 5.00 P.M for 16 hours

15.06.2021 : hot and humid phase from 9:00 A.M to 5.00 P.M, then dry phase at 5.00 P.M for 16 hours

16.06.2021 : hot and humid phase from 9.00 A.M to 5.00 P.M, then dry phase at 5.00 P.M for 16 hours

17.06.2021 : end of the corrosion process

The state of corrosion of the coupons have been observed and documented during the process every day at 5.00 P.M. The sides and top of the coupons have also been sprayed with a saturated solution of NaCl at every switch from the hot and humid phase to the dry phase.



Picture 127 : Monitoring of the corrosion of the blued steel coupons ©HE Arc CR, A.L

The succession of the different phases is visible on *Picture 127*.

V.3.4 Results

Corrosion products have been obtained after 3 days of altering the corrosion cycles. They are thicker than those of the blued layer but allowed a first selection of treatments. The stratigraphy of the corrosion on the corroded coupons is very similar to those of the object. Filiform corrosion, pitting corrosion and extensive filiform corrosion are visible.

VI. Survey

A survey dealing with the retouching and protection of blued steel objects after the removal of corrosion has been carried out in order to gather information about the current practices around the world. 14 institution and independent conservators have been contacted.

The following questions have been addressed :
- Do you use bluing solutions (as Perma Blue, Super Blue) to retouch blued losses on armours, weapons or other objetcs ?
- If yes, which product?
- What is your preferred method of application?
- What is your opinion about the aesthetic result?
- Have you observed its durability through time?
- Do you use another method for the reintegration of losses?

Five professionals answered. Blueing by heating has been mentioned for small objects, as screws, or a complete re-blueing. Chemical blueing with a modern commercial product as Gun Blue is used for local retouching, as well as oil painting, waxing and pigments, shellac retouch or metal-inlay. Non-intervention has also been mentioned.

VII. List of pictures and photographic credits

VIII. List of tables

IX. List of diagrams

X. Glossary

Cast iron : "Alloy composed of iron and carbon (2 to 4%) which can also contain silicium (1 to 3%) and other elements modifying its properties"[97].

Coke : "Combustible obtained from carbonization or the distillation of coal"[98].

Galvanic corrosion : "Accelerated corrosion of a metal put in electrical contact with a nobler metal in an electrolyte"[99].

Lantern slide : "Transparency of a positive photograph on glass. It is viewed either by projection or by transmitted light. These images can be made using albumen, collodion or gelatin. To view lantern slides, a magic lantern was used." They have been invented by Christian Huygens (1829-1895) and used from 1850 to 1950[100].

Molted cast iron : "Cast iron constituted of a mixture in variable proportions of white cast iron and grey cast iron, giving its break the speckled appearance of a trout's coat (disseminated graphite creating dark spots)"[101].

Oxide : "Component resulting of the combination of a simple body, an organic molecule or a radical"[102].

Quench : "Cool rapidly, generally by soaking a body in a cold liquid"[103].

Rust : " Red-brown corrosion products, principally composed of iron hydroxides and oxides), found on iron metals"[104].

[97] Selwyn, Lyndsie, 2004, p.216

[98] L'Internaute, 2021, [Online]

[99] Selwyn, Lyndsie, 2004, p.212

[100] Library and Archives Canada, undated, [Online], p.8

[101] CNRTL, a, 2012, [Online]

[102] CNTRL, 2012, b, [Online]

[103] Selwyn, Lyndsie, 2004, p.221

Scoria : "Solid residue from metal ore processing operation or from the refining of several metals, usually supernatant in molten metal"[105].

Shellac : "Shellac is a resinous product obtained from the secretion of the female "lac bug" (Kerria lacca) on trees, mostly in the forests of India and Thailand. The dry flake processed shellac is dissolved in ethanol to obtain liquid shellac, which is used as a brush-on colorant, food glaze, and wood finish'[106].

White cast iron : "Cast iron whose carbon content is mainly in the form of cementite : the freshly exposed surface is white[107]."

XI. Acronyms and abbreviations

CFST : Commission fédérale de coordination pour la sécurité au travail (*Federal Coordination Commission for Occupational Safety*)

FTIR : Fourier transformed infrared spectroscopy

PVC : poly vinyl chloride

OFEV : Office Fédéral de l'Environnement (*Federal Office for the Environment)*

XII. Corrigendum

On 2021, Thursday 30th, the following modifications and additions have been achieved. What figures in bold constitutes an addition.

Page 108, the chapter **II.4 Retouching of the wooden losses** has been added.

Page 125, the chapter **III.4. Retouching of the wooden losses** has been added.

[104] Selwyn, Lyndsie, 2004, p.220
[105] CNTRL, 2012, c, [Online]
[106] Science Direct, 2021, [Online]
[107] Selwyn, Lyndsie, 2004, p. 216

Page 140-141 on chapter IV. Identification of plastic and research of polychlorinated biphenyls, the following text has been added : **A strong smell coming from the power cable of the object has been detected. As the modifications brought to the object have been estimated between the 1940s and the 1960s, the presence of bitumen and polychlorinated biphenyls is questioned as they were often use in cables for their insulating properties.**
Three samples have been collected for FTIR analysis and dissolved in hexane and analysed. They are introduced in Table 9.
The 3 samples are principally composed of PVC containing phthalates. Other peaks are visible, but they don't refer to PVC, PVC products of degradation or polychlorinated biphenyls (*Picture 115*).
It would be recommended to achieve GC-MS analysis to detect PCB and other products of degradation of PVC.

Page 140, **picture 114** has been added.

Pages 141-142-143, **picture 115** has been added.

Page 143, in chapter IV.5 Suspicion of asbestos, picture 116 has been added as well as the following text : **An insulating cardboard located in the cover of the switch of the transformer is suspected to contain asbestos because of its colour and its fibrous aspect (*Picture 116*). Asbestos was often use in the form of cardboard as insulting pieces, close to light sources or electrical devices. FTIR analysis has been carried on in order to identify the composition of the carboard and if necessary, take safety measures.**

Page 144, **picture 117** has been added as well as the following text : **The insulating cardboard is principally constituted of a cellulosic material. It also contains a silicate which could be an ochre for the brown colouration of the cardboard (*Picture 117*).**

Page 144, the following paragraph has been added to the chapter IV.6 Identification of the nature of the painting : **The sample P2 corresponds to the sample of the inside of the chimney. Both are composed of red lead and their binding is a drying oil which is partially or completely degraded. The black areas of the painting of the chimney are constituted of PVC containing phthalates ;** as well as this caption to Picture 118**: "Localization of the samples ©HE Arc CR, A.L".**

Pages 145-146, the **pictures 119, 120 and 121 have been added.**

Page 152, **picture 127** has been added with the following sentence : "**The succession of the different phases is visible on Picture 127**".

Page 152, the sentence '**The stratigraphy of the corrosion on the corroded coupons is very similar to those of the object. Filiform corrosion, pitting corrosion and extensive filiform corrosion are visible.'** has been added to the chapter V.4.3 Results.

Page 153, the chapter **VI. Survey** has been added.

Pages 158-159, the following words have been added to chapter X. Glossary : **rust, scoria, coke, quench, cast iron, oxide, galvanic corrosion**.