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THREE WAYS TO REMOVE VARNISH

A case study

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Three Ways to Remove Varnish: A Case Study

ABSTRACT

The removal of varnish is a central and often controversial practice in the conservation of easel paintings. While varnish enhances colour saturation and offers protection, aged coatings tend to discolour and obscure the artist's intent. This study explores and compares three distinct varnish removal methods: traditional cotton swabs with solvent, agar gel, and Evolon® CR microfiber cloth. Through a controlled case study on a single oil painting, each method was evaluated for its cleaning efficacy, impact on surface integrity, and practical usability in a conservation context.

A qualitative methodology was applied using standardized variables such as solvent type, exposure time, and application techniques. Evaluation tools included visual inspection, photography under ultraviolet and visible light, and instrumental analysis where appropriate, such as X-ray fluorescence and microscopy. The findings highlight both strengths and limitations of each method: cotton swabs offer precise control but risk mechanical abrasion; agar gel minimizes solvent penetration but is limited by its physical form; Evolon® cloth provides consistent solvent delivery and reduced mechanical stress, though it may cause solvent migration through the canvas.

Ethical concerns related to reversibility, artist intent, and historical patina are also examined, acknowledging the conservator's responsibility to balance preservation with legibility. The study concludes that no universal solution exists; rather, an informed, tailored approach is essential. The comparative insights offered here contribute to the growing discourse on sustainable, safe, and effective varnish removal strategies in contemporary conservation practice.

Illustrations by the author, unless otherwise stated.

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Foreword

I would like to express my sincere thanks to those who supported me throughout the process of writing this study.

First and foremost, thank you to Sebastian Karlsson, my supervisor, for your guidance, encouragement, and support as I learned and navigated the challenges of this work.

And my mom, Ursula Fogelström, for being the one who encouraged the path that led me here and supported me though all my highs and lows.

Content

1. Introduction

1.1 Background

Varnish removal is a recurring part of painting conservation. Varnish is applied to paintings for protection and enhancing the paintings, but with time varnish will often yellow which will obscure the artists original colours. Furthermore, dirt will collect on the varnish surface which also adds to the muting of colours. Removing the varnish and the dirt can reveal the artists original work with the clearer colours and making the motif clearer.

There are many different methods for cleaning and removing varnish from paintings and choosing the right one is essential. A good method should balance efficiency, safety and reversibility while preventing the solvent from migrating through the paint layer and further into the painting and minimizing the mechanical stress. Some paintings are more sensitive than others and there is no one method that suit all objects.

Selecting the appropriate cleaning method is critical, as each painting presents unique challenges and sensitivities. An effective cleaning technique must strike a balance between efficiency, safety, and reversibility. It should minimise both chemical penetration into the paint layers and mechanical stress on the surface. Since no single method is suitable for all paintings, a tailored approach is often required depending on the painting's condition, materials, and previous restorations.

Numerous techniques have been developed over the years for the removal of varnish, generally falling into two main categories, mechanical and chemical cleaning.

Mechanical cleaning involves the physical removal of varnish or dirt using tools or materials that apply friction to the surface, such as scalpels or sponges. Chemical cleaning, on the other hand, utilises solvents or chemical agents that react with the varnish, softening or dissolving it for easier removal.

In this study, three methods are explored and compared: traditional cotton swab cleaning with solvent, agar gel application, and Evolon® microfiber cloth. Each method offers unique advantages and limitations regarding cleaning control, solvent delivery, and physical interaction with the painting surface.

In this case study, all three cleaning techniques will be applied to the same painting under controlled conditions, allowing for direct comparison of their effectiveness, safety, and practicality in the removal of aged varnish.

1.2 Purpose and Goal

The aim of this project is to explore and compare three varnish removal methods through a case study. The goal is to assess which of these methods performs most efficiently with respect to the criteria of efficiency, surface safety, and practical usability in the conservation of this painting.

1.3 Research Questions

The central research questions are:

- How do cotton swabs, agar gel, and Evolon® differ in terms of cleaning efficiency, effect on the painted surface, and ease of application?
- What are the limitations and advantages of each method when applied to this specific painting?

1.4 Methodology

A qualitative case study approach is used. Each method is tested on a section of the painting under controlled conditions. Application time, solvent concentration, and removal techniques are standardised as much as possible to enable a comparative evaluation. The methods are assessed primarily through visual observation, photographic documentation (UV and visible light), and, where possible, XRF and microscopy.

1.5 Limitations

This case study presents several limitations that should be acknowledged when interpreting its findings.

Firstly, only three cleaning techniques are evaluated, cotton swabs, agar gel, and Evolon® microfiber cloth. While these are a varied selection of cleaning methods, the exclusion of other gel formulations, emulsions, and enzyme-based systems limits the results (Khaksar-Baghan, Koochakzaei, & Hamzavi, 2024).

Secondly, only one solvent is used across all methods. This control is beneficial for isolating the variables related to application technique, but the solvent is not adjusted to each cleaning method. The possibility that different solvents could give a differing result is not explored.

Each method is applied using a single application procedure, especially relevant for agar gel, which can be varied in concentration, temperature, and form. The versatility of agar is therefore not fully explored in this study (Scott, 2012).

Another limitation is that only post-cleaning micrographs were recorded. Although written descriptions of the surface before treatment are provided, the absence of corresponding “before” images make direct visual comparison more difficult. This choice was due to practical constraints during documentation.

Finally, the test is conducted on a single oil painting. The specificity of materials, condition, and restoration history in every painting makes generalization difficult. The findings from this case study should therefore be understood as situational rather than universally representative.

1.6 Ethical Questions

Varnish removal is a debated subject. While varnish can be degraded, discoloured, and visually diminishing, it’s also an important part of a painting’s history and possibly its aesthetic intent.

Some conservators argue that yellowed varnish should be preserved as part of the object's material authenticity and historical value. In certain cases, artists were aware of, and may even have intended, the yellowing effect of varnish over time. Removing such layers may risk erasing the artist's vision or damaging original materials (White & Kirby, 2001).

On the other hand, others argue that varnish removal is justified when the visual legibility of the artwork is compromised. Advocates of this view emphasize the role of the conservator in restoring access to the original colours and forms, particularly when obscured by aged, darkened coatings (Bomford, 2021).

Moreover, the principle of reversibility is central to ethical conservation. Varnish removal is not a reversible act, even if re-varnishing is possible. It involves a permanent alteration of the artwork, which must be carefully weighed against the benefits of visual clarity (Phenix et al., 2021). The widely cited principle of "minimal intervention" further complicates this debate. While often presented as a guiding principle in conservation, its practical interpretation varies. As Muños Viñas (2009) argues, “minimal intervention” cannot be strictly defined or objectively measured, every intervention involves a subjective judgment about acceptable loss, risk, or aesthetic change. He proposes that the concept should be reframed as minimizing the loss of the object's potential meanings, rather than simply minimizing physical change. This reframing better captures the ethical dilemma at the core of conservation: balancing material preservation with interpretive and visual accessibility.

2. Literature review

2.1 Removal of varnish

The removal of aged or discoloured varnish is a fundamental conservation practice aimed at restoring the legibility and aesthetic integrity of artworks. However, solvent-based cleaning methods pose significant risks to oil paint films, including mechanical and chemical alterations. Swelling and leaching of binding media are primary concerns, particularly when solvents such as ethanol extract soluble components like fatty acids, which can lead to embrittlement and porosity (Phenix & Sutherland, 2001). Mixed solvents may exacerbate these effects compared to single solvents, challenging previous assumptions about the stabilising effects of so-called restrainers (Graham, as cited in Phenix & Sutherland, 2001, p. 48).

Solvent testing is generally approached in a careful, stepwise manner to balance cleaning effectiveness with preservation of original materials. The process begins with the least aggressive solvent likely to achieve the desired effect, often chosen based on theoretical considerations such as solubility parameters and the known properties of the varnish. A small amount of the solvent is then applied to a discreet test area, typically using a cotton swab, and the reaction of both the varnish and underlying paint layer is observed (Phenix et al., 2021).

Solvents are often described along a scale of relative “strength” or aggressiveness toward the paint film. At the milder end are polar alcohols such as ethanol and isopropanol, which can dissolve many natural resin varnishes while generally posing lower risks of swelling or leaching binding oils (Phenix & Sutherland, 2001). According to Stavroudis & Blank (1989), solvents vary in their relative polarity, hydrogen bonding, and dispersion forces, with classes such as alcohols, ketones, aromatics, and chlorinated hydrocarbons occupying different positions on the solubility parameter scale. These differences help explain why some solvents act more aggressively toward varnishes and paint films than others. Thus, a “mild” solvent is one that achieves varnish solubility with minimal impact on the underlying paint, while a “strong” solvent is more likely to cause unwanted alteration or damage. Within this framework, ethanol is frequently selected as a starting point in cleaning tests.

Varnishes are typically composed of either natural resins, synthetic resins, or blends of the two. Common natural resins include dammar and mastic, both derived from tree exudates and valued for their clarity and gloss when freshly applied, though they tend to yellow and become brittle with age (Horie, 2010; Phenix & Townsend, 2021). Other natural options, such as shellac, have been used historically but are less common for easel paintings. Synthetic varnishes, introduced in the 20th century, include ketone resins (e.g., MS2A), acrylic resins (e.g., Paraloid B-72), and aldehyde resins (Goltz et al., 2021; Horie, 2010). These materials are generally more stable and less prone to yellowing than natural resins, but they can exhibit other aging behaviours such as surface dulling. Some varnish layers may also be mixtures of natural and synthetic components, complicating their solubility and response to cleaning. Understanding the likely composition of a varnish layer is important, as it influences both its appearance over time and the choice of an appropriate solvent or cleaning method (Phenix et al., 2021; Phenix & Townsend, 2021).

Hedley (1986) highlighted the ethical dilemma between aesthetic restoration and the preservation of the artwork’s historical authenticity. He questioned whether interventions aimed at improving visual clarity might compromise the original intent or material integrity of the work. This tension remains central to conservation debates, as practitioners weigh the risks of material loss against the cultural imperative to make artworks legible and meaningful to present day audiences. Similar concerns have been echoed by Bomford (2021) who argued that cleaning practices must be guided not only by scientific evidence but also by a critical awareness of their aesthetic and historical consequences.

Additionally, solvents can cause blanching, localised, cloudy white patches, which arises from micro-structural changes in the paint or varnish films that scatter light (Phenix & Sutherland, 2001).

Blanching is most often linked to the use of polar solvents, which penetrate semi-hydrophilic paint layers and disturb their integrity (Horie, 2010). Prolonged solvent exposure, excessive solvent loading, or poor evaporation control further increases the risk of this irreversible optical disturbance. Although temporary blanching may be reversed using non-polar solvents such as aliphatic hydrocarbons, persistent blanching often indicates deeper micro-cracks or permanent changes to the varnish or paint layer.

As a result, meticulous selection of solvents and application methods is essential to minimise the risks and ensure that treatments remain as reversible and non-invasive as possible (Baij et al., 2021; Vergeer et al., 2019)

One tool frequently used to visualise and compare solvent properties in conservation is the Teas diagram. A Teas diagram is a ternary plot used in conservation to visualise the fractional solubility parameters of solvents, dispersion forces (fd), polar forces (fp), and hydrogen bonding (fh). By normalising these three components to sum to 100%, solvents can be plotted as points within a triangular diagram, allowing conservators to compare their relative solvency behaviours. In practice, Teas diagrams are often used to map the “solubility region” of a particular material, such as a natural resin varnish, and to plan solvent testing so that chosen solvents or mixtures fall within that target region while avoiding areas associated with unwanted effects, like the peak swelling zone for oil paints. This makes them a valuable tool for narrowing down which solvents are most likely to dissolve or soften a given varnish type without damaging underlying paint. However, Teas diagrams have limitations as they’re based on solvent properties alone, do not fully capture solvent–solute interaction or non-ideal behaviour in mixtures, and calculated values can vary across datasets. While they can guide the selection of solvents likely to affect a varnish, confirming the varnish type and its solubility still requires practical testing and observation under controlled conditions, rather than relying solely on diagram predictions (McGlinchey, 2002; Phenix et al., 2021).

2.2 Cleaning methods

Over the past several decades, a wide range of cleaning methods have been developed in response to the growing understanding of the complexities involved in varnish removal. No single technique is universally suitable for all paintings due to variations in paint composition, surface condition, degradation processes, and prior restoration interventions. Consequently, conservators must tailor their approach to the specific needs of each object.

Traditional methods, such as cleaning with cotton swabs soaked in solvent, are valued for their simplicity and the high degree of control they offer. However, they can also introduce significant risks, such as mechanical abrasion, solvent overexposure, and pigment disruption, especially on sensitive or deteriorated surfaces (Phenix & Sutherland, 2001; Vergeer et al., 2019). The need to mitigate such risks has led to the development of alternative systems that offer more controlled solvent release and reduced mechanical stress.

One of the driving factors behind the evolution of cleaning techniques is the desire to localize solvent action and prevent deep penetration into the paint or ground layers. Organic solvents can interact with the oil binder in complex and sometimes damaging ways, including swelling, softening, and leaching of soluble components (Phenix & Sutherland, 2001). These concerns have spurred the development of gels, emulsions, and microfibre-based systems that retain solvents within a controlled matrix and release them gradually at the surface (Baij et al., 2021; Khaksar-Baghan et al., 2024). The field has also been greatly influenced by the extensive study and development of gel systems such as those compiled by (Angelova et al., 2017) and by the emerging focus on conservation-specific materials for modern oil paints (Berg, 2020).

The increasing use of scientific tools and imaging technologies has also revealed that even minute residues or changes in paint surface morphology can accumulate over time, further highlighting the importance of non-invasive, residue-minimizing techniques. Gels such as agar, for instance, allow conservators to target specific areas with precision and minimal solvent migration, while Evolon® cloths combine absorbency and flexibility to reduce the need for swabbing (Baij et al., 2021; Scott, 2012).

Another key reason for the diversification of cleaning methods is the shift in conservation ethics. Modern approaches emphasize reversibility, minimal intervention, and the long-term stability of treatments. This ethical framework favours cleaning systems that are safer for both the object and the conservator, eco-friendly, and adaptable to a range of surfaces and solvent types (Hedley, 1986; Stoner & Rushfield, 2012, p. 731-739). The development of new materials and methods thus reflects a balance between scientific advancement, ethical responsibility, and practical necessity in conservation practice.

2.2.1 Agar gel

Agar gel is a rigid hydrocolloid derived from red algae, used in conservation as a solvent delivery system. When dissolved in hot water and cooled, it forms a semi-solid gel that can hold aqueous or polar organic solvents like ethanol. Agar has the ability to localize solvent application, thereby reducing the risk of penetration into lower paint layers and minimizing solvent evaporation into the studio environment (Scott, 2012). These advantages have been consistently demonstrated and expanded upon in major practical studies of gels for art conservation (Angelova et al., 2017, p. 132-137).

Agar offers high control over solvent contact and minimizes mechanical stress, making it ideal for sensitive surfaces or areas with vulnerable paint layers. Because it is applied as a gel sheet, it reduces the need for mechanical action such as rubbing, which is beneficial for fragile surfaces. The gel’s structure allows it to act as a molecular sponge, absorbing solubilized varnish and dirt while preventing the transfer of these materials back onto the painting (Angelova et al., 2017, p. 11-14; Khaksar-Baghan et al., 2024; Scott, 2012)

Despite its advantages, agar does have drawbacks. It requires careful preparation, and its cleaning capacity is influenced by concentration, temperature, and solvent compatibility. Agar’s rigidity can make it less suitable for highly textured or uneven surfaces, as full contact with the paint layer may be difficult to achieve (Scott, 2012).

2.2.2 Evolon®

Alternative materials such as Evolon® have also been studied for their potential as safer, low-residue cleaning systems for oil paintings (Berg, 2020). Evolon® is a non-woven microfibre textile made of polyester and polyamide, specifically adapted for conservation cleaning. It has been increasingly used for the removal of varnish from oil paintings due to its solvent retention capacity and low abrasiveness. The cloth can be pre-saturated with a solvent such as ethanol and gently placed on the painting's surface to soften and absorb the varnish layer (Baij et al., 2021; Vergeer et al., 2019).

Evolon® allows for a soft, even distribution of solvent without the need for rubbing, which reduces both mechanical abrasion and solvent consumption. Its microstructure provides a uniform release of solvent and retains dirt and dissolved varnish within the fabric. The material is also reusable, lint-free, and conforms more easily to textured surfaces than rigid gels (Baij et al., 2021; Vergeer et al., 2019).

However, Evolon® is not without its drawbacks. If left in contact with a surface for too long or overly saturated, it may lead to unwanted solvent migration into deeper layers. Furthermore, Evolon® may contribute to the extraction of materials such as saturated fatty acids from the paint layer into the textile during cleaning (Baij et al., 2021). Its cleaning efficacy is also lower in comparison to more aggressive techniques and might be insufficient for thick or highly oxidized varnish layers.

2.2.3 Cotton Swab

Cotton swabs are among the oldest and most commonly used tools in varnish removal. Typically, they consist of cotton wrapped around a wooden or plastic stick and are rolled across the surface using a selected solvent. This technique offers high tactile control and visual feedback, allowing the conservator to respond to subtle changes in the paint surface during cleaning (Stoner & Rushfield, 2012).

The main strength of cotton swabs lies in their simplicity, adaptability, and precision. They are especially useful for detailed or localized cleaning and can be adjusted in solvent strength, pressure, and motion. Conservators often rely on this method when dealing with varied varnish thicknesses or retouching layers, as the process can be carefully monitored in real-time.

Despite its versatility, swab cleaning is also the most mechanically aggressive method among the three. Repeated rolling and rubbing of the swab may cause abrasion or disturb loose pigment. This abrasiveness can, in some cases, lead to unintended polishing of the surface, potentially altering the painting’s original gloss or texture in a way that is not reversible. Furthermore, solvents delivered through swabs are often less controlled, increasing the risk of penetration into the paint and ground layers, potentially leading to long-term damage such as leaching or swelling of the oil binder (Khaksar-Baghan et al., 2024; Phenix & Sutherland, 2001). Cotton fibres can also leave residues on the surface, which may interfere with subsequent treatments.

2.3 Analytic methods

In conservation science, the need for precise, non-destructive evaluation tools has driven the development of a wide range of analytical techniques. These methods serve to document the condition of an artwork, assess the effects of treatments, and detect any unintended consequences of cleaning. Given the complexity and variability of historical materials, no single method can provide a complete picture. As such, conservators rely on a combination of complementary techniques that vary in resolution, depth of penetration, specificity, and invasiveness (Stuart, 2007).

The removal of varnish, in particular, requires careful monitoring. While surface changes may be visible to the naked eye, microscopic or chemical alterations often go unnoticed without analytical assistance. Some methods, such as ultraviolet (UV) fluorescence, highlight surface residues or changes in varnish coverage. Others, like microscopy, allow close visual inspection of paint layers and the effects of mechanical action. More advanced techniques, such as X-ray fluorescence (XRF), offer elemental analysis to detect whether original pigments or binding media have been unintentionally removed. The issues of solvent retention and residue detection have been a critical focus in solvent gel research (Stulik et al., 2004, p. 12-16). Microscopy has long been regarded as a fundamental tool for conservators (ICOM Committee for Conservation. 1, 1996).

The rationale for this diversity is both practical and ethical. Conservation interventions are ideally minimal and reversible, and analysis must adhere to the same principles. This has prompted a shift toward non-invasive, portable, and high-resolution tools that can be used in situ, without the need for sampling. As conservation goals become more precise, such as distinguishing between original material and later additions, or verifying the presence of treatment residues, analytical techniques must evolve to meet these challenges (Musílek et al., 2024).

Ultimately, the development of varied analysis methods reflects the need for nuanced, interdisciplinary approaches in conservation. They support informed decision-making, validate treatment efficacy, and uphold the professional standards of care, documentation, and ethical responsibility in the preservation of cultural heritage.

2.3.1 UV-light

Ultraviolet (UV) light examination is a widely used non-invasive method in conservation. When a painting is illuminated with UV light, certain materials, especially natural resins and varnishes, fluoresce, revealing surface features that are not visible under normal light. This fluorescence can help distinguish between original materials and later additions, such as overpaint or retouching, as well as detect residues from cleaning agents or incomplete varnish removal (Stuart, 2007).

UV examination is quick, inexpensive, and highly informative. It is especially effective at visualizing old varnishes, which typically fluoresce yellow-green, and distinguishing them from newer synthetic materials that often fluoresce differently or not at all. It is also useful for checking the evenness of varnish removal and for spotting cleaning residues that may not be visible under normal light (Stoner & Rushfield, 2012, p. 306-308; Stuart, 2007).

UV light cannot penetrate below the surface, so it provides no information about subsurface features or structural changes within the paint layers. Its diagnostic power is limited to materials that fluoresce, non-fluorescent or degraded substances may go undetected. Additionally, fluorescence intensity can vary with age, composition, and environmental exposure, making interpretation somewhat subjective and dependent on the experience of the conservator (Stuart, 2007).

2.3.2 Microscope

Microscopy, particularly optical microscopy, is a foundational tool in conservation for magnified visual examination. Conservators use microscopes to inspect surfaces before and after cleaning, identify tool marks or abrasions, assess pigment particle size, and monitor fine cracks, residues, or fibre fragments. Both reflected light and transmitted light microscopes are used depending on the material and purpose of the analysis (Caple, 2012; Stuart, 2007).

Microscopy offers high-resolution visual data at a microstructural level, allowing for the identification of minute surface changes caused by mechanical cleaning, such as abrasion or pigment disruption. It is especially helpful in assessing whether cleaning methods have caused physical damage or left residues (Caple, 2012). It can also be used during treatment to guide cleaning in delicate areas.

Microscopy is surface-focused and cannot provide chemical information unless combined with other techniques like SEM-EDS. It also requires stable lighting, precise focus, and often static objects, which can make it less suitable for large-scale or in situ works unless portable microscopes are used. Furthermore, it is labour-intensive and typically requires expert interpretation to assess subtle differences in surface morphology (Stuart, 2007).

2.3.3 XRF

X-ray fluorescence (XRF) is a non-destructive method used to analyse the elemental composition of materials. The technique works by directing a beam of primary X-rays onto the surface of an object. When these X-rays interact with the atoms in the material, they cause the atoms to emit secondary X-rays, also called fluorescent X-rays. Each chemical element emits X-rays at specific energy levels, which can be measured by a detector to identify which elements are present (Moradi et al., 2015; Musílek et al., 2024). XRF has been widely used in the study of cultural heritage objects, including historical paintings, as it allows conservators to examine materials without taking physical samples.

XRF is especially useful for detecting elements with higher atomic numbers, such as lead, zinc, iron, or copper, which are commonly found in historical pigments and materials. It allows for non-invasive analysis of objects without requiring physical samples and can be applied in the study of cultural heritage objects, including paintings (Stuart, 2007).

However, XRF provides only elemental information and cannot detect organic materials such as resins or varnishes. Its analysis is generally limited to the surface or near-surface layers of an object. In addition, spectral overlaps between certain elements can make interpretation difficult, and the technique can be influenced by surface roughness or unevenness (Musílek et al., 2024).

XRF analysis often reveals elements such as lead (Pb), calcium (Ca), iron (Fe), zinc (Zn), and sulphur

(S) on painted surfaces. These elements are characteristic of traditional pigments, such as lead white, iron oxides, and zinc white, commonly used in 19th-century oil paintings. However, they are also prevalent in airborne pollution, particularly in historical emissions from coal combustion and industrial processes. According to (Nalbandian, 2012) coal-burning releases fine particulate matter enriched with trace metals including Pb, Zn, Fe, and S, which can settle on exposed varnish layers over time. This environmental deposition complicates the interpretation of XRF data, as superficial contaminants can mimic the elemental profile of underlying pigments. Consequently, distinguishing between genuine pigment residues and surface dirt requires careful consideration of both cleaning method impact and environmental exposure history.

3. Method

Prior to the experiment, preliminary testing was carried out to determine the most suitable solvent. It had been decided that the same solvent was to be used to each cleaning method to more easily compare the methods. A solvent that could dissolve the varnish without visible damage to the paint-layer was needed.

Both ethanol and isopropanol were tested using cotton swabs for application. In each case, the solvent was rubbed on the surface slightly longer than would be typical in an actual cleaning procedure, continuing even after the varnish appeared to be removed. This was done to better assess the solvent's potential effect on the paint layer. The effects were assessed visually under normal lighting conditions.

The decision to begin testing with ethanol was based on its widespread reputation in conservation as one of the mildest effective solvents for varnish removal. In both tests, no colour changes were observed beyond the removal of the yellowed varnish, and there were no signs of damage such as pigment lift, blanching or dissolved paint. Based on these results, either solvent would have been suitable, but ethanol was ultimately chosen as ethanol is generally considered the milder of the two in conservation practice. Ethanol was selected as the test solvent because, as noted in the literature review, it is generally regarded as one of the milder effective solvents in conservation practice, reducing risk to paint films while still capable of dissolving natural resin varnishes.

AI-based tools were used to assist with grammar correction and language refinement during the writing process.

3.1 Material

- Ethanol
- Agar powder
- Evolon®
- Cotton

3.2 Preparation of agar gel

Two types of agar gel were prepared for the experiment: one where ethanol was mixed into the gel before solidification, and another where the gel was soaked in ethanol after hardening. This choice was made due to both practical and methodological considerations. A previous study involving tape removal used agar gel mixed with 20% ethanol, which initially guided the decision to replicate that formulation. However, since it was possible that some of the ethanol may have evaporated during the preparation of the heated gel, it was considered relevant to also test a version where the gel was soaked in ethanol after setting, to ensure sufficient solvent presence. As both approaches were feasible, it was decided to prepare and compare both.

The proportions used for the "agar gel with ethanol" a 3% agar gel prepared in deionized water with 20% ethanol incorporated into the mixture, were taken from the method described in *Borttagning av tryckkänslig tejp på papper* (Nyagake Mwita, 2023), which in turn reproduces the recipe from Scott (2012) in *The Use of Agar as a Solvent Gel in Objects Conservation*. Because agar gel has rarely been applied for the cleaning of paintings and no established standard exists, this published recipe was used as a practical starting point. It provided a tested concentration range that could be transferred to the present study, avoiding the need for having to experiment with different concentrations beforehand of agar formulations, which would have constituted a separate investigation in itself. The "agar gel soaked in ethanol" approach was included to compare its cleaning effectiveness with the pre-mixed gel, since in this case the ethanol enters the gel through diffusion into its pore system, while keeping the same agar-to-liquid ratio as in the previous recipe but replacing the ethanol with water during the initial gel formation. Diffusion refers to the natural movement of ethanol molecules from the surrounding solution, where their concentration is higher, into the gel matrix, where their concentration is lower, until a balance is reached. This ensured that both gels had the same stiffness and viscosity, so any differences observed in cleaning performance could be attributed to the method of ethanol incorporation rather than to variations in gel firmness. While the original reference provided the proportions, it did not address the issue of ethanol's binding or retention within the gel matrix, and this potential limitation is considered further in the discussion of results.

Agar Gel with Ethanol

This version was prepared by mixing 80 ml of deionized water with 3 grams of agar powder (creating a 3% agar gel with 20% ethanol). The mixture was heated in a water bath to at least 85°C. After cooling to room temperature (20-22°C), it was reheated to 85°C to increase porosity (Scott, 2012). Once reheated, the mixture was cooled to below 78°C, just under ethanol's boiling point, to prevent evaporation. At this point, 20 ml of ethanol was added. The final mixture was poured into flat-bottom containers and left to harden overnight.

Agar Gel Soaked in Ethanol

For this version, 100 ml of deionized water was mixed with 3 grams of agar powder (creating a 3% agar gel) and heated to 85°C. It was cooled to room temperature, reheated to 85°C, and then poured into a flat-bottom container. After cooling again, it was covered and refrigerated overnight. The next day, the hardened gel was cut into 3x3 cm squares and soaked in ethanol for one hour before immediate use.

3.3 Case study: Cleaning of ship painting

3.3.1 Condition assessment

The artwork selected for this case study is an oil painting of ships at sea by Johan Jacob Bennetter (see Figure 3), dated April 28, 1860, as confirmed by the artist's signature (see Figure 1). The painting was owned by Gothenburg Museum of Art and is numbered as number 226, marked on the back of the painting (see Figure 4). It has since been donated to the University of Gothenburg, where it now resides as part of the university's collection.

Figure 1. Close up on signature.

The painting remains structurally stable, but it shows significant evidence of prior interventions and damage. Notably, a large section on the left side of the canvas is filled with putty, indicating substantial paint loss in this area. The painting has been partially cleaned with big areas where varnish has been removed and other large areas where varnish has been left. The varnish is clearly visible under normal light due to the clear yellowing of the varnish. The varnish has also a clear fluorescence under UV-light. Some patches of varnish seem to come from previous testing as they do not have the same colour under visible light and is immensely different under UV-light (see Figure 2).

On the paint layer there are numerous small abrasions and scuffs across the surface, particularly around the perimeter and raised texture areas. Despite the noted damage and losses, the overall paint layer and canvas support remain secure and capable of withstanding careful cleaning trials.

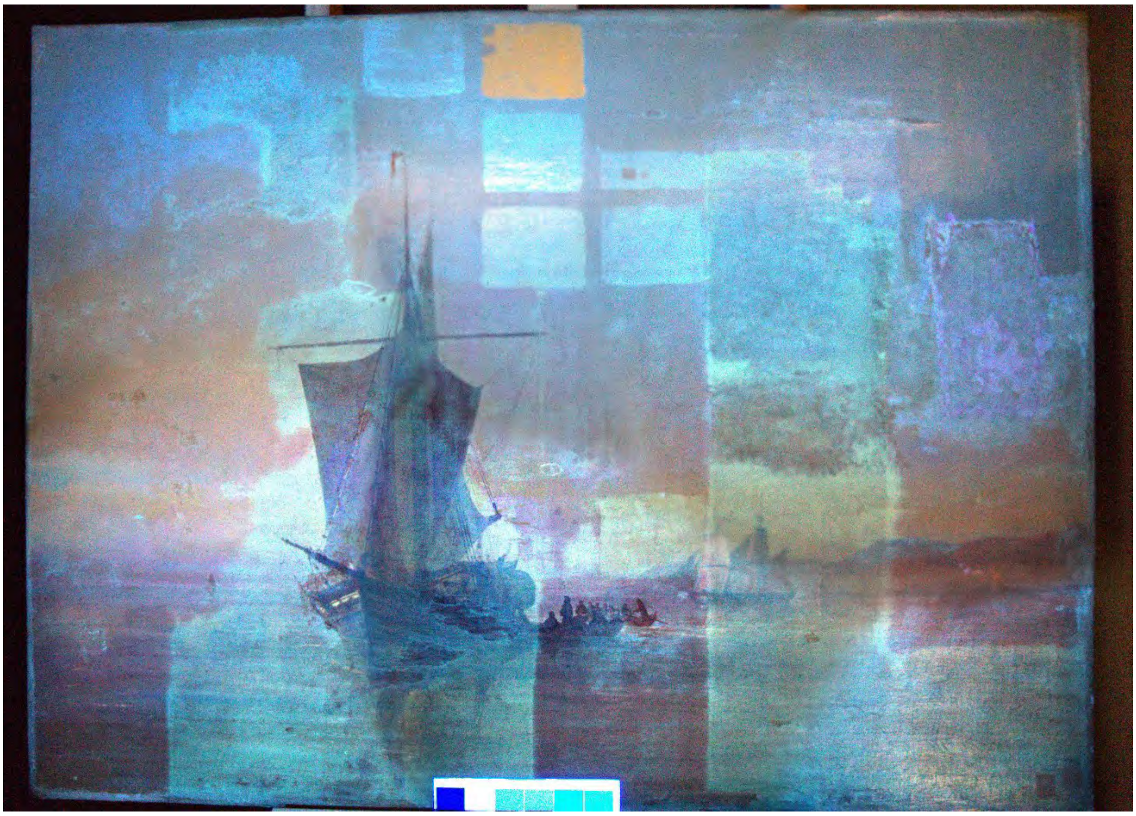


Figure 2. Paintings front under UV-light. The small squares in the upper middle part of the painting are believed to be previous tests of different varnishes.

Figure 3. Paintings front before testing.

Figure 4. Paintings backside before testing.

3.3.2 Cleaning of the painting

3.3.2.1 Evolon®

For the preparation of the Evolon® micro fibre cloth, it was cut into 3x3 cm pieces.

Evolon®, a microfiber textile composed of polyester and polyamide, was tested as an alternative varnish removal tool due to its high absorbency and low abrasiveness. Its non-woven structure allows for even solvent distribution and controlled application, minimizing the mechanical stress typically caused by cotton swabs. The cloth was cut into standardized 3x3 cm patches to ensure consistency across tests.

Each Evolon® patch was soaked with approximately 15 drops of ethanol. The patches were then applied to designated sections of the painting surface for durations of 30, 60, and 90 seconds. The patches were patted down to ensure even coverage and then covered with plastic wrap during application to minimize evaporation.

After the Evolon® was removed, a dry cotton swab was used to mechanically remove any softened varnish that remained on the surface and had not adhered to the Evolon®.

The method was repeated twice for each duration to assess repeatability and to observe any differences in cleaning effectiveness or unintended surface changes. The performance was documented visually and instrumentally under UV light and magnification for comparison with the other methods.

3.3.2.2 Agar

For the agar mixed with ethanol, the gel was applied to the painting surface in standardized 3x3 cm pieces. Three separate tests were conducted, with the gel left in place for 30 seconds, 60 seconds, and 90 seconds respectively. After each interval, the agar was removed, and a dry cotton swab was immediately used to lift any varnish dissolved by the gel.

The same procedure was followed for a second type of agar gel, which had been soaked in ethanol for one hour before application. The gel was cut into 3x3 cm pieces, soaked in ethanol for 60 minutes, then applied to the painting in three separate tests for 30, 60, and 90 seconds respectively. As before, a dry cotton swab was used directly after each application to remove any softened varnish.

Each type of agar gel was tested twice for each duration to ensure consistency and repeatability.

3.3.2.3 Cotton swab

The cotton swab was dipped into ethanol just enough to dampen the cotton tip without allowing any excess solvent to drip. The swab was then gently rubbed over a 3x3 cm area of the painting surface. Rubbing was chosen instead of the more conventional rolling technique because the paint layer was observed to be stable enough to withstand this action, and I wished to test the most mechanically demanding method for comparison. The approach also reflects a technique I had encountered during my internship, where it was used in professional practice. This cleaning action was performed for three separate time intervals, 30 seconds, 60 seconds, and 90 seconds. For each time interval, a fresh swab was used to avoid solvent overload and ensure consistent application. The entire procedure was repeated twice to verify the results and minimize experimental variability.

4. Results

4.1 Photo documentation

Each test was carefully documented through photography, showing both the condition before and after cleaning. These images serve to visually support the assessment of varnish removal efficiency and surface changes. Areas cleaned using different methods and time intervals were clearly marked to maintain consistency across comparative analysis.

The test cleaning patches was named according to the system as can be seen in Table 1. Each test was done twice, separating each test into two rows.

Table 1

Meaning of abbreviated names of the cleaning test

Name	Meaning
AiE30	Agar soaked in ethanol 30 second patch
AiE60	Agar soaked in ethanol 60 second patch
AiE90	Agar soaked in ethanol 90 second patch
AmE30	Agar mixed in ethanol 30 second patch
AmE60	Agar mixed in ethanol 60 second patch
AmE90	Agar mixed in ethanol 90 second patch
EB30	Evolon® 30 second patch
EB60	Evolon® 60 second patch
EB90	Evolon® 90 second patch
B30	Cotton swab 30 second patch
B60	Cotton swab 60 second patch
B90	Cotton swab 90 second patch

Figure 5. Image showing layout for test cleaning patches

Figure 5 display the overall layout of the experimental cleaning tests applied to the painting. The layout identifies the designated 3 × 3 cm test areas for each cleaning method (agar gel mixed with ethanol, agar gel soaked in ethanol, Evolon® microfiber cloth, and cotton swab), applied at three different exposure times (30, 60, and 90 seconds).

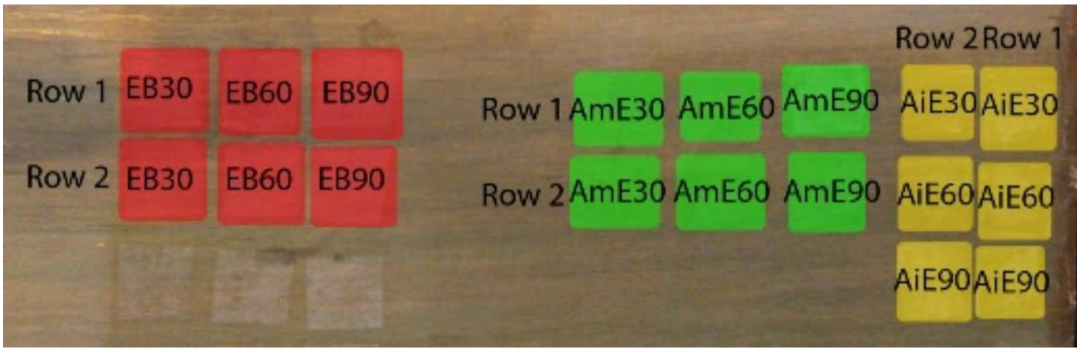


Figure 6. Closeup at layout of Evolon and agar test cleaning patches.

Figure 6 shows a close-up view of the upper portion of the test grid where the Evolon® and both agar gel variants were applied. Test areas are labelled according to cleaning method and contact time.

Figure 7. Closeup of agar mixed with ethanol cleaning tests.

Figure 8. Closeup of agar soaked in ethanol cleaning tests.

Figure 9. Closeup of Evolon® and agar cleaning tests.

Figures 7, 8 and 9 displays detailed images of the Evolon®, agar mixed with ethanol and agar soaked in ethanol test patches taken under normal light conditions. The visual differences in surface appearance after cleaning can be observed, including the incomplete varnish removal of the agar gels and the slightly more uniform, though patchy, cleaning achieved by Evolon®.

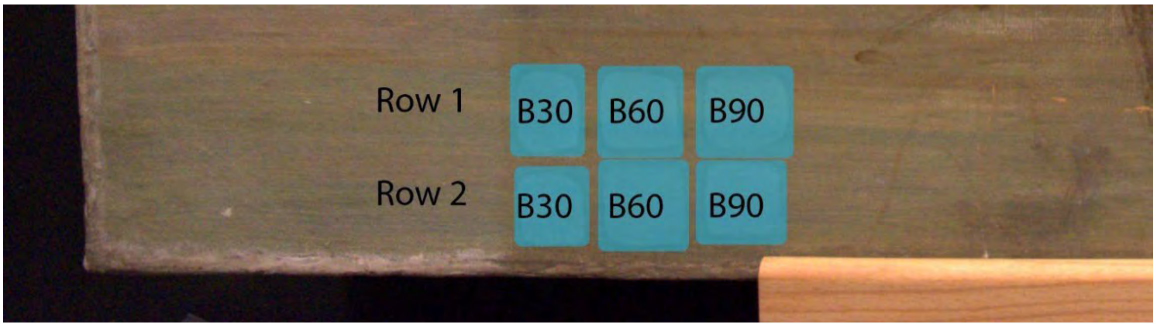


Figure 10. Closeup at layout of cotton swab cleaning tests.

Figure 10 is a close-up image of the cotton swab test areas. Test patches are clearly marked with corresponding time intervals (30, 60, 90 seconds).

Figure 11. Closeup of cotton swab cleaning patches.

Figure 11 is a close-up of the cotton swab test patches after cleaning. The image shows the varnish removal achieved by this method across all durations. Minor micro-abrasions and slight textural flattening can be seen in some areas, particularly at 90 seconds.

Figure 12. Paintings front after testing.

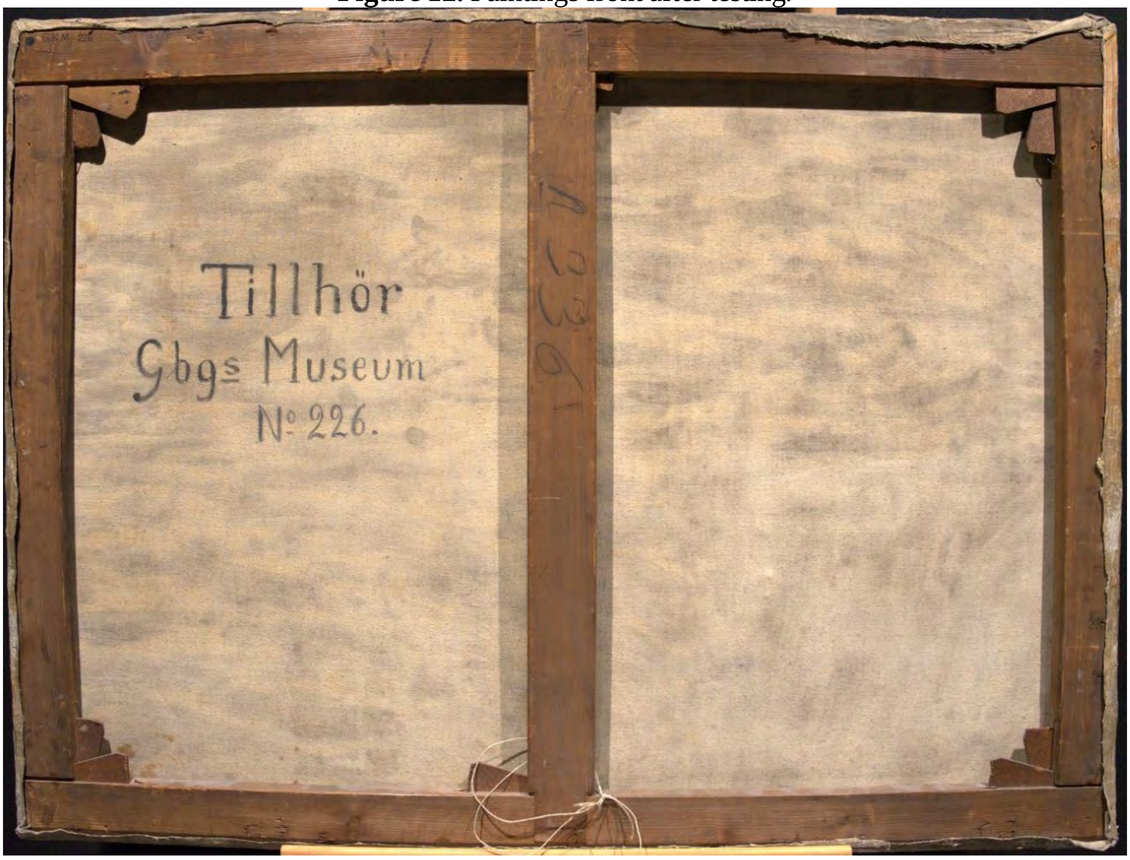


Figure 13. Paintings backside after testing.

In Figure 12 a full view of the painting’s front after the completion of all cleaning tests is shown. The area where the cleaning test where applied is visible. The contrasting effects of the different cleaning methods and exposure times on the yellowed varnish layer are visible.

Figure 13 shows a view of the reverse side of the painting following cleaning tests. The image confirms that the canvas remained structurally stable throughout the study, with no visible deformation or damage caused by the solvent applications.

Figure 14. Paintings backside, closeup on backside of Evolon cleaning tests. Image contrast has been enhanced to increase the visibility of solvent migration marks.

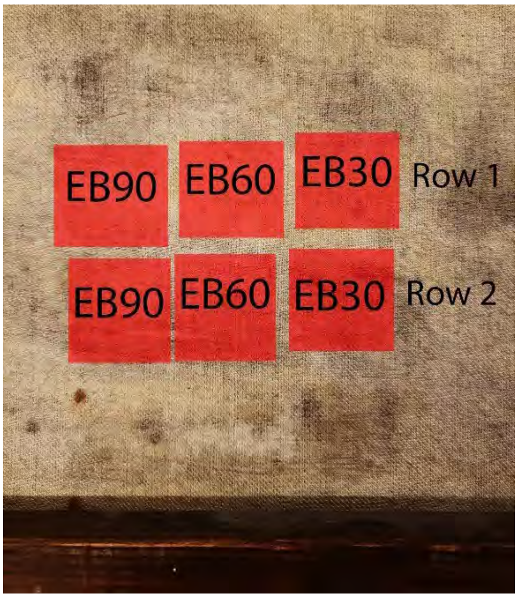


Figure 15. Paintings backside, closeup on layout of backside of Evolon cleaning. Image contrast has been enhanced to increase the visibility of solvent migration marks.

Figure 14 shows a close-up of the reverse side of the painting where the Evolon® cleaning tests were conducted. The image contrast has been digitally enhanced to make solvent migration marks more visible. Faint traces corresponding to the test areas on the front are visible on the reverse, possibly indicating that ethanol migrated through the canvas during cleaning.

Figure 15 is an overview of the layout of the Evolon® cleaning tests on the reverse side of the painting. Contrast has been increased to make subtle changes more discernible. The alignment with test zones on the front suggests that ethanol or moisture have most likely penetrated the canvas during the Evolon® testing.

4.2 Cleaning Results by Method

4.2.1 Agar mixed with ethanol

The agar mixed with ethanol showed minimal cleaning effectiveness across all time intervals. Even at longer application times, most areas retained a visibly yellowed varnish layer, with only negligible reduction. In some cases, a faint outline of the treated area was visible, indicating very light varnish removal. The only notable exception was the 90-second test in row 1, which exhibited significant blanching. Smaller areas of blanching were also observed in the 60-second test of row 1 and the 90-second test of row 2 (see Figure 17).

In Figure 16 is a close-up of the agar gel mixed with ethanol test patches, shown without overlay markings. The image highlights the minimal cleaning effect and widespread retention of the yellowed varnish layer across all application durations.

Figure 16. Close up to test patches of agar mixed with ethanol cleaning test.

Figure 17. Close up to test patches of agar mixed with ethanol cleaning test, blanching marked in green.

4.2.2 Agar soaked in ethanol

Agar soaked in ethanol produced highly uneven results. Some test areas showed localized removal of the varnish, while others remained entirely untouched, even after prolonged contact. The cleaning was patchy and often correlated with the topography of the paint surface, with varnish remaining in recessed areas. Blanching was observed across all test areas. In general, the only areas that did not show blanching were those where the varnish remained intact. Figure 19 highlights the regions affected by blanching, marked in yellow.

Figure 18 shows a close-up of the agar gel soaked in ethanol tests, also shown without markings. The image reveals highly inconsistent cleaning performance, with localized small areas of varnish removal surrounded by extensive patches of unaltered varnish.

Figure 18. Close up to test patches of agar soaked in ethanol cleaning test.

Figure 19. Close up to test patches of agar soaked in ethanol cleaning test, blanching marked in yellow.

4.2.3 Evolon®

Evolon® produced a transparant varnish reduction at shorter exposure times but led to some blanching and disruption of the varnish at longer contact times. In some areas, the cleaning appeared uniform, in others, streaking and uneven patches were recorded.

Figure 20 is a close-up photograph of the Evolon® test areas, taken without overlay markings. Blanching is visible in several of the cleaning tests, indicating surface disruption in certain areas. The extent of blanching has been further highlighted in Figure 21, where affected areas are marked in red.

Faint markings were also observed on the reverse side of the painting, aligning precisely with the Evolon® cleaning test areas (see Figure 14). These marks are most likely caused by the migration of ethanol through the canvas during treatment. While no visible damage was observed on the painted surface, the presence of these marks suggests that the ethanol penetrated the canvas to some extent. This finding supports concerns raised in previous research regarding Evolon®'s potential to deliver solvent more deeply than intended, depending on the volume applied and duration of contact.

Figure 20. Close up to of Evolon® cleaning test.

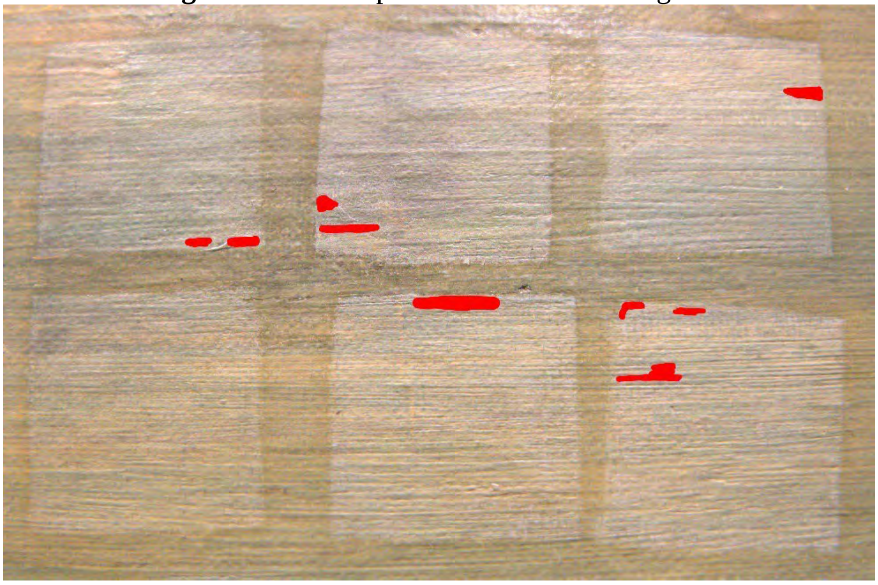


Figure 21. Close up to of Evolon® cleaning test, blanching marked in red.

4.2.4 Cotton swabs with ethanol

The cotton swab method yielded the most efficient varnish removal overall. Most test areas showed uniform removal of varnish with clear colour improvements.

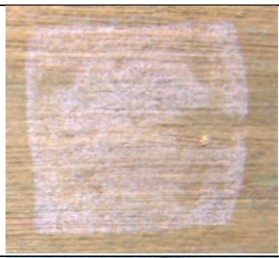
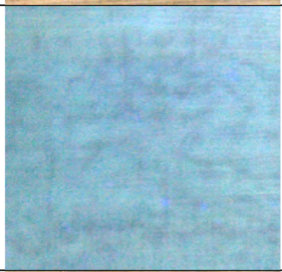
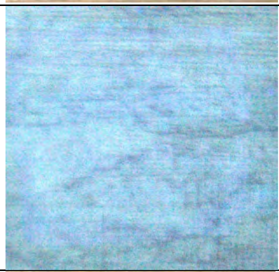
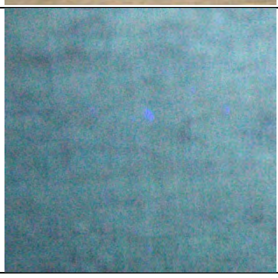
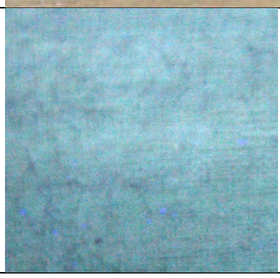
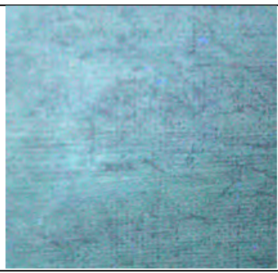
Figure 22 is a close-up of the cotton swab test patches, without markings. This figure illustrates the effectiveness of the cotton swab method, which provided the most complete and uniform varnish removal, though minor signs of mechanical disturbance are apparent under close observation.

Figure 22. Close up to test patches of cotton swab cleaning test.

4.3 UV-Light

Ultraviolet (UV) light examination was employed to assess the extent and uniformity of varnish removal following the application of each cleaning method. The analysis focused on changes in fluorescence patterns, which are highly indicative of residual varnish presence or cleaning agent residues. The results for each cleaning system and time interval are summarized in Table 2 for agar mixed with ethanol, Table 3 for agar soaked in ethanol, Table 4 for Evolon®, and Table 5 for the cotton swab tests.

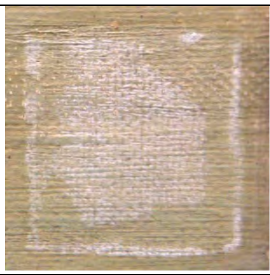
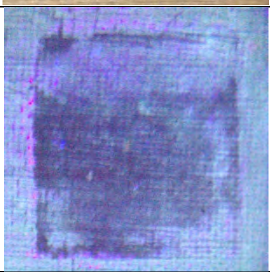
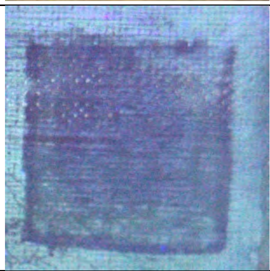
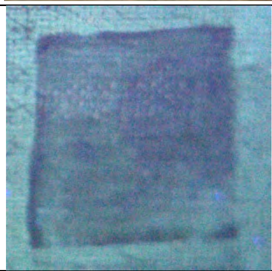
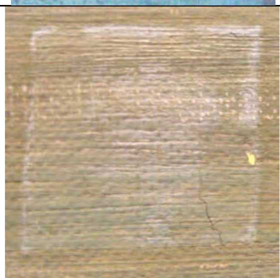
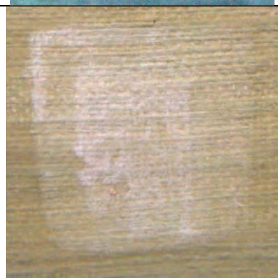
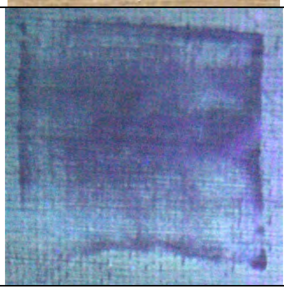
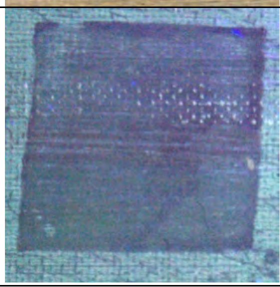
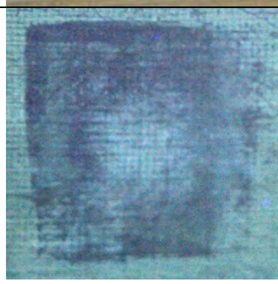
Table 2
Agar mixed with ethanol in normal and UV-light

Agar mixed with ethanol	**30 sec**	**60 sec**	**90 sec**
Row 1 **In normal light**			
Row 1 **In UV-light**			
Row 2 **In normal light**			
Row 2 **In UV-light**			
Comments	No visible change.	Barely visible test area outline; minimal varnish reduction.	Slight improvement: very little varnish removed. Some blanching observed.

The agar mixed with ethanol tests exhibited minimal differences from untreated areas under UV light across all time intervals. The 30-second and 60-second test patches showed almost no discernible change in fluorescence, indicating little or no varnish removal. Even after 90 seconds, only a slight reduction in fluorescence was observed, with the test area boundaries barely visible under UV light. Table 2 presents a side-by-side comparison of the test patches under normal light and ultraviolet (UV) illumination, highlighting the negligible changes in appearance and fluorescence.

Table 3

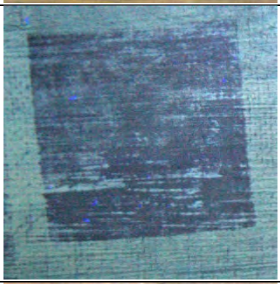
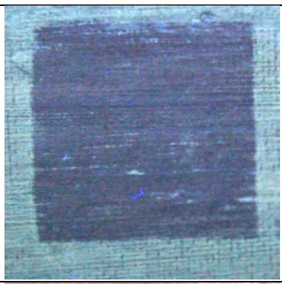
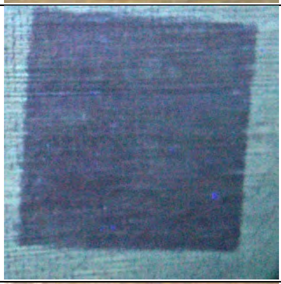
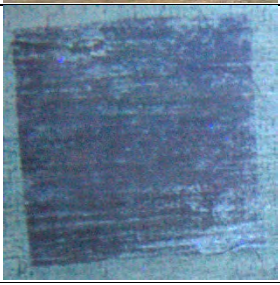
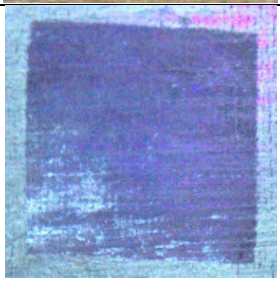
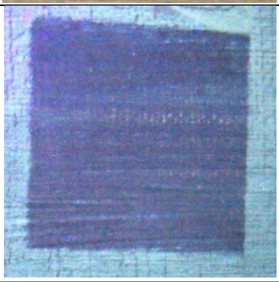
Agar soaked in ethanol in normal and UV-light

Agar soaked in ethanol	**30 sec**	**60 sec**	**90 sec**
Row 1 **In normal light**			
Row 1 **In UV-light**			
Row 2 **In normal light**			
Row 2 **In UV-light**			
Comments	Small areas cleaned; most varnish remains. Blanching present.	More varnish removed, large areas still untouched. Blanching noted.	Slightly more varnish removed. Patchy cleaning and increased blanching.

The agar soaked in ethanol tests showed somewhat greater cleaning action under UV light compared to the mixed agar system. At 30 seconds, small patches of fluorescence reduction were detected, though large areas of varnish remained untouched. After 60 seconds, a more noticeable decrease in fluorescence was observed, with irregular patterns of varnish removal corresponding to the uneven cleaning action seen under the microscope. At 90 seconds, the fluorescence was further reduced, but substantial areas of uneven brightness persisted, confirming incomplete and inconsistent varnish removal (Table 3).

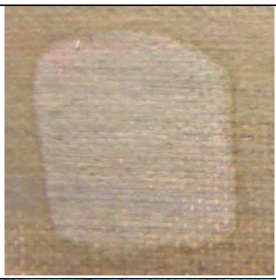
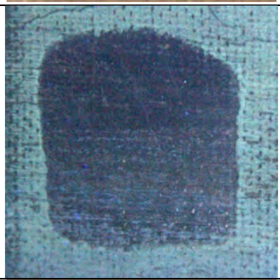
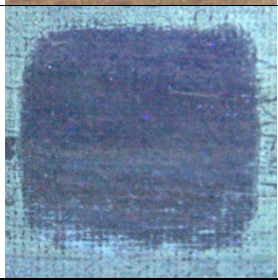
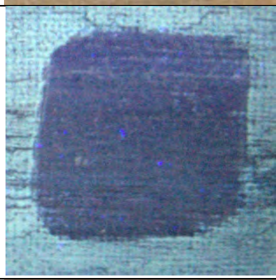
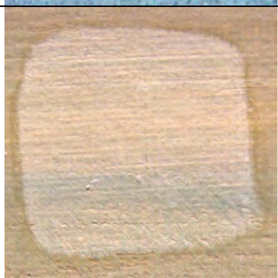
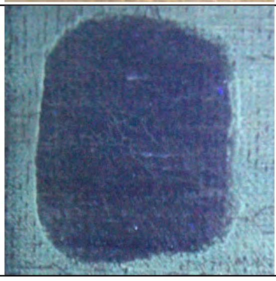
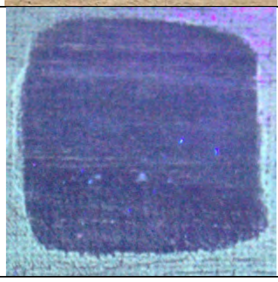
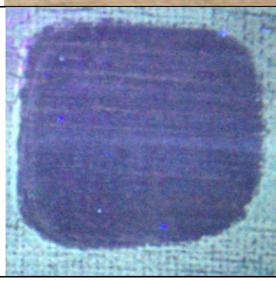
Table 4

Evolon® that was swabbed with cotton swab in normal and UV-light

Evolon® with cotton swab	**30 sec**	**60 sec**	**90 sec**
Row 1 In normal light			
Row 1 In UV-light			
Row 2 In normal light			
Row 2 In UV-light			
Comments	Varnish partially removed; significant areas remain. Small blanching spots in row 2.	Most varnish removed; minor residues remain. Small blanching spots in row 2.	Almost full removal; faint residues remain. Slightly more blanching than shorter times.

For the Evolon® tests, the UV images showed a clear progression of varnish reduction with longer contact times. After 30 seconds, a strong yellow-green fluorescence remained across most of the test area, indicating a substantial retention of varnish. The 60-second samples showed a marked decrease in fluorescence, though small areas of residual varnish were still visible, particularly in recessed regions. By 90 seconds, almost all fluorescence had disappeared, suggesting near-complete removal of the varnish layer, although faint traces were still detectable under UV illumination (Table 4).

Table 5
Cotton swabbed in normal and UV-light

	30 sec	60 sec	90 sec
Row 1 In normal light			
Row 1 In UV-light			
Row 2 In normal light			
Row 2 In UV-light			
Comments	Most varnish removed; minor residues in cracks.	Similar to 30 sec but fewer residues.	Almost all varnish removed, traces in deepest recesses only.

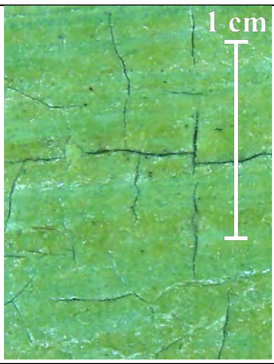
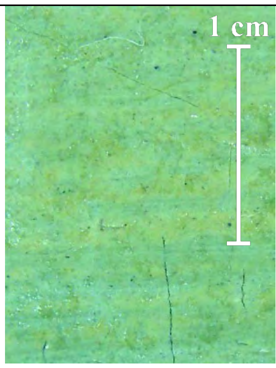
The cotton swab cleaning method produced the most uniform and effective results under UV examination. In the 30-second tests, most of the fluorescence had been eliminated, although small traces of varnish were still visible in cracks and depressions. The 60-second and 90-second tests showed even cleaner surfaces with almost total removal of varnish, and only very faint fluorescence remained detectable in the deepest textured areas. Overall, the cotton swab method consistently demonstrated superior cleaning performance under UV light across all time intervals (Table 5).

In summary, UV-light analysis confirmed the findings of the other examination techniques. The Evolon® and cotton swab methods were the most effective at reducing surface fluorescence associated with aged varnish, with cotton swabs achieving the cleanest results. Both agar gel systems, particularly agar mixed with ethanol, performed poorly under UV analysis, displaying limited varnish reduction and inconsistent fluorescence patterns.

4.4 Microscopic Analysis of the Cleaned Areas

Microscopic examination was conducted to document the surface condition of the painting after cleaning and to assess the presence of any varnish residues or physical surface alterations caused by the different cleaning methods. Each test patch was examined and the results are summarized in Table 6 for agar mixed with ethanol, Table 7 for agar soaked in ethanol, Table 8 for Evolon®, and Table 7 for the cotton swab method. Attachment 4 includes a table with the same microscope images shown in the results section, presented at a larger scale to make it easier to observe surface details. Each microscope image in Tables 7-9 and attachment 4 equals a scale of about 1:65 relative to the full painting width.

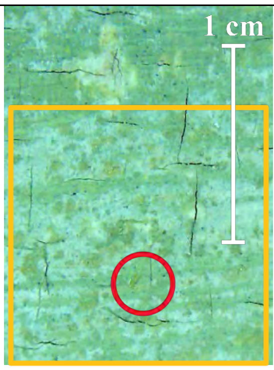
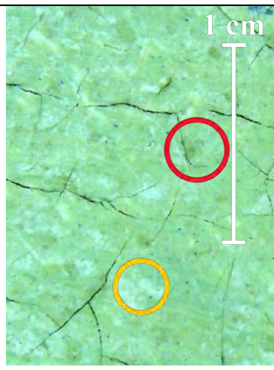
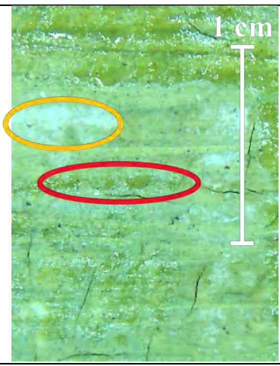
Table 6
Microscope result of agar mixed with ethanol cleaning test

	30 sec	**60 sec**	**90 sec**
Row 1 Image			
Row 1 Description	Varnish fully intact, no removal. Visible as the dark colour remain and still very glossy.	Very limited removal, mostly covered. Area where varnish has been removed is marked with yellow. A spot of varnish is the cleaned area is marked in red.	Slight removal, much varnish remains, blanching present. Cleared area is marked with yellow. A spot of varnish in the cleaned area is marked in red.
Row 2 Image			
Row 2 Description	Varnish fully intact, no removal. Visible as the dark colour remain and still very glossy.	Small top layer removal, mostly intact. Visible by the lighter colour and being less glossy.	Small areas cleared; large areas still covered. A spot where varnish has been removed is marked with yellow.

The agar mixed with ethanol patches demonstrated poor varnish removal at all durations. After both 30 and 60 seconds, the varnish layer remained nearly completely intact across the entire test area, with only slight disturbance visible under magnification. Even at 90 seconds, only minimal removal of the surface layer of varnish was observed, and substantial varnish remained embedded in the valleys and textured areas of the paint layer. Additionally, the agar mixed with ethanol produced noticeable white bloom residues at the surface after treatment, particularly in the 90-second test areas (see Table 6).

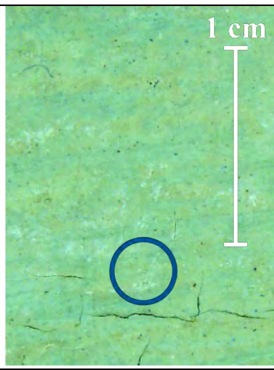
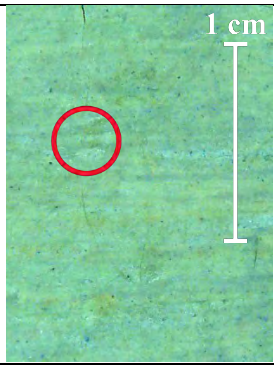
Table 7

Microscope result of agar soaked in ethanol cleaning test

	30 sec	**60 sec**	**90 sec**
Row 1 Image			
Row 1 Description	Some small, cleared spots, mostly covered in uneven layer of varnish. A spot of varnish is marked with red. Area where varnish has been removed is marked with yellow.	Larger cleared areas, residues in paint recesses. A spot of varnish is marked with red. Area where varnish has been removed is marked with yellow.	Uneven cleaning. Big, cleared patches, varnish remains in texture. A spot of varnish is marked with red. A spot where varnish has been removed is marked with yellow.
Row 2 Image			
Row 2 Description	Patches cleared; varnish remains in texture wells. A spot of varnish is marked with red. A spot where varnish has been removed is marked with yellow.	Patches cleared; more varnish removed than at 30 sec. Varnish remain in texture of paint. A spot of varnish is marked with red. A spot where varnish has been removed is marked with yellow.	Similar to Row 1 but slightly more varnish removed. A spot of varnish is marked with red. Area where varnish has been removed is marked with yellow.

The agar soaked in ethanol tests presented more variable results. After 30 seconds, limited removal was observed, with most areas remaining covered by varnish except for small, scattered spots of clearance. The 60-second applications showed greater removal, with reduced varnish levels but still significant residues present, especially in the recesses of the paint structure. At 90 seconds, the removal pattern remained uneven: while large areas showed clean zones, significant patches of varnish remained, and varnish traces were consistently found in the deep crevices of the paint surface (results in Table 7). This test also confirmed the same tendency for uneven action noted in the overall results.

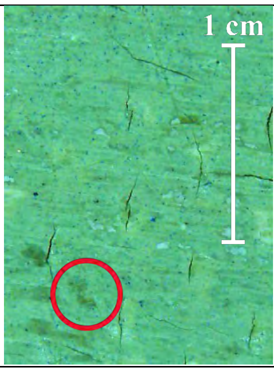
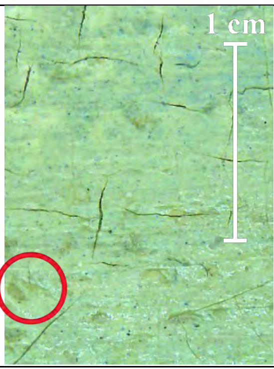
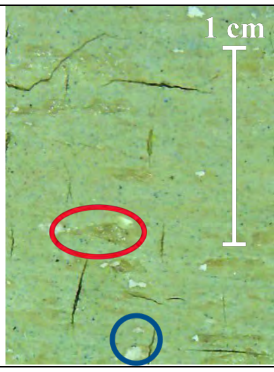
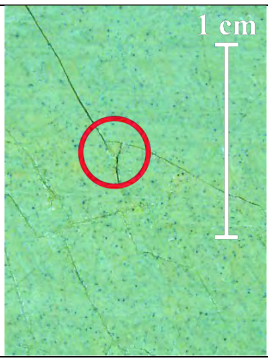
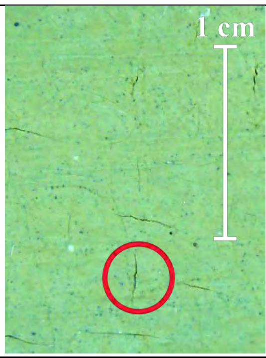
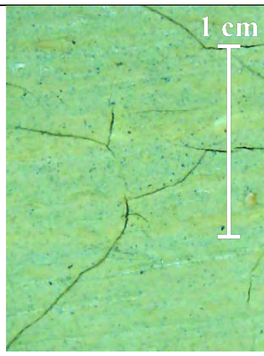
Table 8
Microscope result of Evolon® cleaning test

	30 sec	60 sec	90 sec
Row 1 Image			
Row 1 Description	Thin continuous varnish layer across the area. A prominent varnish spot is marked in red.	Mostly clean; small varnish remains in recesses. Varnish residue marked in red.	No visible varnish: slight surface damage detected and blanching. Blanching spot is marked in blue.
Row 2 Image			
Row 2 Description	Uneven and small varnish spots present. One thicker varnish spot is marked in red.	Almost fully removed; tiny varnish spots remain. Varnish residue is marked with red.	Almost fully removed; minor varnish spots remain. Varnish residue is marked with red.

The Evolon® test patches revealed a progressive improvement in varnish removal with increasing contact time. After 30 seconds, the entire patch remained covered by a thin, continuous film of varnish. In the 60-second tests, only very small spots of varnish were left in the recessed areas of the paint surface, while most of the varnish had been removed. After 90 seconds, the varnish appeared almost completely removed. However, at this duration, the microscope detected minor damage in the form of faint surface abrasions in the high points of the paint texture, as shown in Table 8.

Table 9

Microscope result of cotton swab cleaning test

Cotton swab	**30 sec**	**60 sec**	**90 sec**
Row 1 Image			
Row 1 Description	Small varnish residues around cracks. A spot of varnish is marked in red.	Less varnish than 30 sec. Residues in cracks/wells. A spot of varnish is marked in red.	Minimal varnish in deep wells. Slight paint damage visible. A spot of varnish marked in red circle. A spot of blanching is marked in blue.
Row 2 Image			
Row 2 Description	Small residues around cracks. A spot of varnish is marked in red.	Less varnish than 30 sec; small amounts remain. A spot of varnish is marked in red.	No varnish found.

The cotton swab method proved the most effective in terms of overall varnish removal, as reflected in Table 9. After 30 seconds, some small residues of varnish were still visible, particularly along cracks and within the low areas of the textured paint. The 60-second samples exhibited similar residue patterns but at a reduced level. The 90-second test areas were largely free of varnish under microscopic inspection, though some localized residues remained in the deepest wells of the paint surface. Importantly, slight signs of abrasion were detected on the paint surface at this longest exposure time, suggesting that prolonged or excessive mechanical action can result in micro-damage. Microscopic analysis also revealed minor abrasion and flattening of the texture in areas where excessive pressure had been applied, further highlighting the mechanical sensitivity of the paint surface under swab cleaning.

Overall, the microscope analysis confirmed that both Evolon® and cotton swabs achieved the most consistent varnish removal. Evolon® showed good cleaning performance but left faint varnish residues at shorter contact times and caused minor surface damage at longer durations. Cotton swabs removed more varnish overall but carried the highest risk of mechanical abrasion to the paint surface. In contrast, the agar gel systems showed significantly weaker cleaning action. Of the two, agar soaked in ethanol performed slightly better than the version mixed with ethanol, but both gels left considerable varnish residues, particularly in textured or recessed areas, and caused blanching.

4.5 XRF-analysis

The data from the XRF-analysis of the cleaning materials can be read in Attachment 1 and XRF-analysis of the paintings paint layer can be found in Attachment 2. Attachment 3 contains a series of graphs comparing the elemental spectra from all cleaning tests, visually illustrating the consistency of detected elements across methods. Here is a summary of what was found on the cleaning material.

All collected spectra exhibited high levels of noise, complicating their interpretation. Several detected elements can be attributed to ambient air, such as argon (Ar) or to the X-ray source itself, specifically rhodium (Rh). Other identified elements are likely due to instrumental noise, as they are either extremely rare in nature or not naturally occurring. Examples of these are technetium (Tc), palladium (Pd), ruthenium (Rh) and niobium (Nb) Consequently, these elements will be excluded from further interpretation

X-ray fluorescence (XRF) analysis was conducted to evaluate whether pigment residues or inorganic elements from the painting had been unintentionally removed by the cleaning methods. The analysis first established a baseline by examining the clean, unused cleaning materials. As shown in Table 10, the unused Evolon® cloth contained only titanium (Ti), which may come from titanium white used to make the material appear whiter, although the exact reason for its presence is unclear. These elements were considered inherent to the materials and served as control values for later comparisons.

Table 10
XRF analysis of clean unused materials

Material	Inorganic chemical elements found
Clean Evolon® (Ren Evolon®)	Ti
Clean agar (Ren agar)	--
Clean cotton (Ren bomull)	--

Table 11
XRF analysis of spots on painting

Paint	Inorganic chemical elements found
Clear yellow (Klar gul)	S, Pb, Cl, Ca. Zn, Fe, Cd
Clear yellow 2 (Klar gul 2)	S, Pb, Ca, Zn, Fe,
Dark blue green (Mork Bla Gron)	S, Pb, Cl, As, Ca, Fe, Zn, Cu
Light green (Ljus Gron)	S, Pb, Ca, Zn, Fe,

The summarized results of the XRF analysis from selected spots on the painting's paint layer are presented in Table 11. These measurements were taken in areas where the varnish had been successfully removed. The results reflect the elemental composition of the pigments present in the paint layer. If any of these elements are later found in the cleaning materials, they could originate from pigment residues or from other sources such as dirt or materials present in the varnish. For example, lead was commonly used as a siccative to speed up drying, and calcium, often in the form of chalk, was a typical filler. However, it is important to note that all of the identified elements could also be attributed to airborne pollutants, which may complicate the differentiation between their sources.

In Table 12 is the summary of the XRF analysis of all cleaning materials from each respective row 1.

The Evolon® test patches used during cleaning were analysed after 30, 60, and 90 seconds of application, and in all cases no relevant elements were detected, consistent with the unused control material (see Table 10). The accompanying cotton swabs used to assist varnish removal showed the presence of sulphur (S), calcium (Ca), lead (Pb), iron (Fe), zinc (Zn), and, in the 60-second sample, cobalt (Co). These elements could indicate pigment residues or may originate from dirt or other surface materials.

Table 12
Summary of XRF analysis of cleaning materials

Material	**Inorganic chemical elements found in the 30 second test**	**Inorganic chemical elements found in the 60 second test**	**Inorganic chemical elements found in the 90 second test**
Agar mixed with Ethanol, Row 1 Agar gel	Ru	Ru	Ru
Agar mixed with Ethanol, Row 1 Cotton	Ti	Ti	Ti
Agar soaked in Ethanol, Row 1 Agar gel	Ru	Ru	Zn
Agar soaked in Ethanol, Row 1 Cotton	Ca, Pb, Zn	Ca, S, Pb, Zn, Fe	S, Ca, As, Zn
Evolon®, Row 1 Evolon®	--	--	--
Evolon®, Row 1 Cotton	S, Ca, Pb, Fe, Zn	S, Ca, Pb, Zn, Fe, Co	S, Ca, Pb, Fe, Zn
Cotton swab, Row 1 Cotton	Ca, S, Pb, Zn, Fe	Ca, S, Pb, Zn, Fe	Ca, S, Pb, Zn, Fe

The agar mixed with ethanol test samples showed no evidence of additional elemental residues beyond those recorded in the unused agar control material. Similarly, no detectable pigment residues were found on the cotton swabs used after cleaning with this material, and all detected elements were ruled out as noise, indicating that the agar mixed with ethanol was the least invasive of the tested systems.

In contrast, the agar soaked in ethanol samples revealed variable results across the three time intervals. After 30 seconds, only the control element ruthenium (Ru) was detected in the gel. The 60-second gel sample also contained ruthenium (Ru), while the 90-second gel sample showed zinc (Zn). The cotton swabs used after cleaning with agar soaked in ethanol detected varying combinations of calcium (Ca), sulphur (S), lead (Pb), zinc (Zn), iron (Fe) and arsenic (As). These results could indicate the presence of pigment residues, or alternatively, residues from surface dirt, degraded varnish, or other unrelated material.

Finally, the cotton swabs used as a direct cleaning method showed a consistent presence of calcium (Ca), sulphur (S), lead (Pb), zinc (Zn), and iron (Fe) across all application times.

In summary, the XRF data indicate that Evolon® alone did not remove any detectable surface material, whereas the combination of Evolon® and cotton swabbing did collect inorganic residues. Agar mixed with ethanol was the least reactive system, showing no measurable residue pickup. Agar soaked in ethanol led to slightly more varied results, particularly when followed by cotton swabbing. The cotton swab method alone showed the highest frequency of inorganic elements across all tests. The detected elements could indicate pigment residues or may derive from surface contaminants, degraded varnish, or other materials not directly related to the paint layer.

5. Discussion

The objective of this study was to investigate and compare three different cleaning systems for the removal of aged varnish from an oil painting by Johan Jacob Bennetter. The research was guided by two central questions: How do cotton swabs, agar gel, and Evolon® differ in terms of cleaning efficiency, effect on the painted surface, and ease of application? and What are the limitations and advantages of each method when applied to this specific painting? These questions reflect the core aim of evaluating the effectiveness and safety of the cleaning methods in conservation practice.

Although a Teas diagram was not formally used during solvent selection in this study, positioning the tested solvents within such a diagram helps contextualise the results. Ethanol plots in the more polar region of the diagram, where it is known to dissolve or soften polar varnishes such as shellac and certain spirit varnishes, and to have some effect on resins like sandarac (Phenix et al., 2021). In the 19th century, when the painting was produced, the most common varnishes were dammar and mastic, together with occasional use of shellac, sandarac, or mixed spirit varnishes (Stoner & Rushfield, 2012; Townsend & Phenix, 2021). Since dammar and mastic do not dissolve readily in ethanol alone, their presence can be considered unlikely. The fact that the varnish on the painting was removed effectively with ethanol therefore points instead towards a polar resin such as shellac, sandarac, or a spirit-varnish blend, all of which were available in the period and share solubility parameters consistent with ethanol. While such limited speculation cannot provide definitive identification, when combined with historical knowledge of varnish use and practical solubility testing it offers a way to narrow down the possible varnishes.

To determine which method performed best, a set of criteria was defined. The assessment focused on five primary factors. The first is the degree of varnish removal as observed through visual examination, UV fluorescence, and microscopy. The second is the extent of damage or disturbance to the paint surface, based on microscope and XRF analysis. The third is the presence or absence of cleaning residues. The fourth is consistency of results across multiple trials. The fifth and last is practical aspects such as ease of use and solvent control. The cleaning method that provided the most complete varnish removal with minimal surface damage and residue, and that was most controllable and repeatable, was considered the most successful.

In my tests the varnish generally dissolved quite quickly on contact with ethanol, becoming a low-viscosity liquid that was only slightly thick. The exact consistency was noted to be dependent on how much solvent was present, with more ethanol the varnish was more fluid, while with less it became thicker and tackier. This behaviour directly influenced how effectively the dissolved material could be cleared from the surface. When the varnish became more fluid, absorbent systems such as cotton swabs or Evolon® CR were able to take it up relatively efficiently, leaving little residue behind. In cases where the varnish was more viscous, clearance was less straightforward, and some redeposition was observed, consistent with reports that viscous residues can increase risks of streaking or blanching after treatment (Phenix & Sutherland, 2001). Agar gels were particularly affected by this issue, since the gel itself is not absorbent and therefore could not take up the dissolved varnish, after removing the gel, cotton swabs were required to mechanically lift residues from the paint surface. Similarly, with Evolon® CR some of the dissolved varnish remained on the surface, most likely because the softened material was too viscous to be fully absorbed by the cloth, which didn't contain enough ethanol to make the dissolved varnish a lower viscosity. In both cases, the use of cotton swabs to clear residues introduced an additional step involving mechanical action, and with it an increased risk of abrasion or disruption to fragile paint layers. Overall, the low viscosity of the dissolved varnish facilitated rapid removal but also meant that clearance was strongly dependent on the absorbent capacity and handling of the cleaning system used.

Ethical questions

Varnish removal is an irreversible intervention that must be approached with caution. Even when the visual impact of the aged varnish is significant, the process of removing it can affect the underlying paint layer or the original materials. This echoes concerns highlighted by Phenix and Sutherland (2001), Hedley (1986), and Bomford (2021) about the potential ethical and material risks of solvent-based cleaning. In this study, even though the painting had already undergone partial varnish removal, the tests contributed to further alteration. The occurrence of blanching and pigment residue detection in some methods illustrates that aesthetic gains can come at a cost. This raises the important ethical consideration of whether aesthetic clarity justifies material compromise, and whether the notion of 'minimal intervention' is still applicable when cleaning leads to blanching or mechanical wear. As mentioned by Hedley (1986), and Bomford (2021), subjective intentions around aesthetic restoration frequently challenge the objectivity of conservation practice. Cotton swabs, for instance, may be effective but cannot always be considered a gentle or non-invasive approach.

Mechanical action

In addition to differences in solvent delivery, the cleaning methods varied in the degree and type of mechanical action applied to the paint surface, which likely influenced both their effectiveness and potential risks. The cotton swab method inherently involves a rubbing motion, producing continuous physical contact and slight abrasion that can help dislodge softened varnish but also increases the potential for wear or disturbance of friable paint layers (Phenix & Sutherland, 2001). Evolon® sheets, when lifted after contact, exert minimal lateral force, relying mainly on solvent action and absorption, whereas agar gels generally apply almost no direct mechanical movement beyond initial placement and removal. This means that while rubbing methods like cotton swabs may achieve faster and more uniform varnish removal in cases where the varnish dissolves readily, they are also inherently more aggressive toward the surface. Conversely, static-contact methods may be safer for delicate or textured paint but could require longer contact times or multiple applications to achieve similar cleaning results. The balance between solvent action and mechanical action should therefore be considered when interpreting the differences observed in cleaning outcomes.

XRF

Many of the inorganic elements detected in the cleaning tests, such as sulphur (S), titanium (Ti), lead (Pb), calcium (Ca), iron (Fe), and zinc (Zn), are naturally present in both earth pigments and airborne pollutants. This overlap complicates interpretation. Nonetheless, the elements found in the analysis of the paint layers offer some clues about the materials used. The elements found in the analysis of the paint layers could indicate the use of several pigments. Most of the colours are likely earth-based, as no significant elements linked to yellow or blue pigments were identified, with the exception of cadmium (Cd), which is present in cadmium yellow. However, since cadmium yellow became commercially available in the 1840s (Cadmium Yellow, n.d.), its presence is uncertain, though not impossible given the painting's date. Copper (Cu) and arsenic (As) could indicate an arsenic green pigment, such as Scheele's green.

As outlined by Musílek et al. (2024), XRF's surface sensitivity makes it vulnerable to misattributing surface contaminants to underlying layers, which must be carefully considered in conservation interpretation. It is also worth noting that the overall intensity of the XRF spectra was consistently very low across all samples, much lower than would be expected if actual pigment particles had been removed. Furthermore, when comparing XRF results across all tested materials, including those that removed little or no varnish, such as agar gels, the elemental profiles remain remarkably similar, regardless of cleaning effectiveness. Since these gentler methods did not reach into the paint layer, it is highly unlikely that pigment was affected. This strongly supports the interpretation that the detected elements are surface contaminants, likely from environmental dirt accumulated on the varnish.

Earth pigments, commonly used in 19th-century paintings, contain iron oxides, clay minerals, and trace metals like lead or copper. However, these same elements are prevalent in ambient pollutants from historical sources such as coal-burning and leaded fuels. Their deposition onto varnish layers means they can easily be mistaken for original pigment signals.

Considering both the similarity in elemental spectra between cleaning methods and the known composition of airborne particles, it is far more probable that what we detect is environmental contamination. While we cannot completely rule out pigment transfer due to elemental overlap, the balance of evidence indicates that the materials picked up surface dirt, not pigment, from the painting.

As illustrated in the graphs in Attachment 3, particularly the graph comparing all cotton swabs, the elemental profiles detected across the different cleaning materials exhibit a remarkably consistent pattern, even in cases where varnish removal was minimal or absent (e.g., agar mixed with ethanol). This uniformity in signal distribution, especially the recurring presence of elements such as Ca, Pb, Zn, and Fe, across all samples, including those with very limited contact with the paint layer, strongly suggests that the residues are superficial contaminants rather than originating from the underlying pigment.

In this study, XRF results showed pigment-associated elements on cotton swabs and to some degree on the Evolon® cleaning cloths (via associated swabs). However, the analysis could not definitively distinguish between pigment and contamination. This uncertainty highlights a limitation of the micro-XRF instrument used. Micro-XRF measures very small areas, and do not use helium gas, which would have reduced much of the background noise and made the results easier to interpret. These factors make it more difficult to determine whether detected elements come from deposited particles or from the varnish or paint layers. Nonetheless, this approach presents a compelling avenue for evaluating material removal during cleaning. Further research, including cross-section analysis and FTIR, is needed to confirm material migration or loss and to enhance interpretation of XRF results in this context.

Agar Gel Mixed with Ethanol

The agar gel mixed with ethanol exhibited the weakest cleaning performance of all tested systems. Across all time intervals, UV and microscopic examination (Tables 2 and 6) showed little to no observable varnish removal, and the visual appearance of the patches remained nearly identical to untreated areas. Even after 90 seconds, only very slight disturbance of the surface varnish layer could be observed. Additionally, the test areas showed a tendency to develop white blanching effect, especially in the longest exposures. Scott (2012) describes how the rigid structure and low solvent release of agar gels limit their cleaning efficiency, especially when used with non-aqueous solvents.

The poor cleaning performance can be explained by the structural properties of agar. As a rigid hydrogel, it holds a limited quantity of solvent and releases it slowly, preventing the gel from effectively softening or dissolving the varnish within short application times. Furthermore, its inability to conform to textured or uneven surfaces limits contact and solvent delivery to the painting surface.

This combination of low solvent release and poor surface contact explains the extremely limited cleaning capability of agar mixed with ethanol. These limitations are well-documented in gel-based cleaning literature, including Khaksar-Baghan et al. (2024), who highlight the importance of tailoring gel porosity and concentration to specific surface topographies.

A limitation of the used recipe is that it does not address how ethanol is retained or released within the agar gel matrix. As a result, the effective solvent concentration at the paint surface may not correspond exactly to the 20% ethanol described in the preparation. Depending on the extent of ethanol binding and its rate of diffusion, the solvent action could be weaker or less predictable than expected. This uncertainty may help to explain some of the observed differences between the two agar gel approaches and highlights the need for further research into solvent retention and release in agar-based systems.

Another possibility is that the concentration of the agar gel may have been too low to effectively maintain the ethanol or support mechanical cohesion. Future studies should explore variations in agar concentration, as well as different degrees of gel firmness, to determine whether these parameters could improve cleaning efficiency and surface conformity.

Agar Gel Soaked in Ethanol

The agar soaked in ethanol delivered slightly better results than the mixed version but still failed to achieve thorough varnish removal. UV examination and microscopy (Tables 3 and 7) showed that some varnish was removed, particularly in small patches, but large areas remained untreated, especially in deeper recesses and valleys of the paint surface. The results remained inconsistent and patchy even at longer contact times. Similar to the mixed agar, the soaked gel created blanching that increased with the time duration. Similar effects have been observed in previous studies; for example, Scott (2012) reported that ethanol-soaked agar gels often produced inconsistent cleaning results, particularly on textured surfaces, and noted an increase in blanching with longer contact times.

The improved performance over mixed agar is likely due to the higher ethanol saturation achieved by soaking, allowing slightly better solvent diffusion into the varnish layer. However, the same inherent limitations of rigid structure and poor conformity to textured surfaces were observed. The uneven and incomplete cleaning pattern, combined with the appearance of surface residues, clearly demonstrated that the method is not suitable for highly textured paintings where full varnish removal is required.

An additional variable that was not explored in this study is the absorption time, how long the agar gel was allowed to soak in ethanol before use. It remains unclear how absorption time influences the gel's cleaning performance. Future research should examine the effects of varying absorption times and test gels of different firmness to determine whether these factors can improve varnish removal efficiency and surface contact.

More flexible gel formulations, different solvents, or increased contact times may improve agar's usability, but these modifications were outside the scope of this study.

Evolon®

The Evolon® cleaning trials demonstrated moderate cleaning efficiency, with noticeable improvement at longer contact times. These results align with findings by Baij et al. (2021), who demonstrated that Evolon® CR cloth enables effective varnish removal at longer contact times while minimizing surface abrasion and pigment disturbance. Visual and UV examination (Table 4) showed that varnish was reduced after 60 seconds and almost fully removed at 90 seconds. However, microscopy (Table 8) revealed that while Evolon® left less surface abrasion than cotton swabs at 90 seconds, faint residues of varnish remained in recesses, and very fine micro-abrasions were visible after the longest application times as well as very small spots of blanching. XRF analysis (Table 12) indicated that while inorganic residues were not transferred to the Evolon® itself, they were detected on the accompanying cotton swabs used to wipe the softened varnish. However, as discussed earlier, the similarity in elemental composition across all cleaning methods, including those that did not remove varnish, suggests that these residues most likely originate from surface dirt rather than pigment.

One significant issue observed with Evolon® was the appearance of faint rectangular markings on the back of the canvas, aligning precisely with the cleaned areas on the front. Notably, these marks were visible even at the shortest contact time of 30 seconds. These marks suggest that ethanol had migrated through the canvas during application, something not seen with the other cleaning methods. This is likely due to Evolon®'s relatively high solvent loading capacity combined with prolonged contact time, especially under plastic covering to reduce evaporation. When left in place for extended periods, the cloth may have released more solvent than the painting could safely absorb, allowing ethanol to penetrate beyond the varnish and paint layers into the canvas itself. This kind of solvent penetration not only raises ethical and structural concerns but could also compromise the mechanical integrity of the canvas over time or affect ground layers beneath the paint.

Because these marks were visible from the reverse side and indicate that solvent travelled deeper than intended, this significantly undermines Evolon®'s suitability for this specific painting. While Evolon® is often seen as a gentler, low-abrasion method, in this case it introduced a risk of solvent overexposure, making it a less appropriate option for canvas paintings, especially those with thinner or more absorbent supports.

The moderate mechanical interaction offered by Evolon® is a strength, but its lower flexibility and absorbency compared to swabs may hinder its effectiveness on textured surfaces. Blanching observed during longer exposures suggests prolonged solvent retention at the interface, potentially inducing temporary structural changes in the paint or varnish layer. Additionally, Evolon® requires more handling steps and may be perceived as less intuitive during repeated applications. These limitations affect its usability in routine practice.

The reason for Evolon®'s limited performance at shorter times likely lies in its mode of action, as a non-woven textile, Evolon® acts through solvent release and absorption rather than mechanical action. While it reduces physical stress on the surface, it does not reach well into the textured areas of the painting, leading to uneven cleaning. Its performance also depends heavily on solvent concentration, contact time, and pressure, making the method less controllable than expected.

Cotton Swab

The cotton swab method consistently delivered the most efficient varnish removal across all examination methods. This is consistent with traditional cleaning literature, where cotton swabs with controlled solvent application remain a benchmark method for varnish removal (Stoner & Rushfield, 2021). Both visible light and UV photography showed near-total removal of varnish after 90 seconds. Microscopy confirmed almost complete cleaning of the surface, with only tiny traces of varnish in deep recesses (Table 9). However, the results also clearly showed that surface damage occurred after 90 seconds of application, whereas the 60-second application resulted in no observable damage. This highlights 60 seconds as the most effective and safest interval tested in this study.

Although small residues of varnish were still visible after 60 seconds, they were so minor that they could only be detected using UV light and microscopy. These remnants pose no known risk to the painting's stability and do not affect visual perception in normal light. Given this, the 60-second interval can be recommended as the optimal balance between cleaning effectiveness and safety. Future studies may explore more granular intervals, such as 65, 70, or 75 seconds, to identify whether even more precise optimization is possible, but these were beyond the scope of the current investigation.

The decision to remove the varnish in this case was primarily driven by visual considerations. The existing varnish, though not structurally harmful to the paint layer, obscured the painting's original colour balance and clarity. Enhancing the visibility of the artwork justified the removal. Leaving behind trace amounts of varnish that are undetectable without special equipment is ethically acceptable when the main goal is to improve legibility without compromising the object's integrity.

Although XRF analysis showed elements consistent with pigments on the cotton swabs, this is most likely not evidence of pigment loss. As discussed earlier, similar elemental profiles were found even in methods that failed to remove any varnish. This strongly suggests that the detected signals stem from surface dirt rather than from the paint layer itself.

The success of cotton swabbing can be explained by its combined chemical and mechanical action. The ethanol solvent softens the varnish, while the gentle rolling of the swab physically lifts it away. This dual mechanism is extremely effective but difficult to fully control. The risk of micro-abrasion increases with the number of swabbing passes and solvent exposure, particularly on fragile or textured surfaces.

Future refinement might involve reducing contact time or alternating swab materials to lower friction. While efficient, swabs should be used cautiously on sensitive or matte surfaces.

Blanching

Blanching was observed in both Evolon® and agar gel cleaning tests but not in the cotton swab tests. The phenomenon appeared as temporary white, hazy areas after the cleaning trials, and reappeared after evaporation when aliphatic naphtha was applied and then allowed to dry. The absence of blanching in the swab tests, despite the use of the same solvent (ethanol), suggests that blanching is not caused by the solvent itself but by prolonged solvent contact between the cleaning material and the paint surface. This supports earlier findings by Phenix and Sutherland (2001), who noted that extended solvent contact can lead to localised swelling and optical changes in paint films.

One possible explanation is that prolonged solvent exposure may extract soluble material from the varnish or paint surface, leading to subtle micro-porosity or roughness that scatters light. Another hypothesis is that swelling and contraction during drying could trap tiny voids or micro-bubbles of air, again producing localized scattering. In the case of agar gel, its high water content may also introduce additional swelling or phase disruption in the varnish layer. Prolonged solvent contact through either solvent-induced extraction or solvent-plus-water swelling Evolon® and agar gels both promote prolonged solvent retention at the interface with the paint layer due to their high absorbency and slow solvent release characteristics. In the case of agar gel, its high water content may also contribute to blanching, as added moisture could enhance swelling or affect the varnish layer differently. This could explain why blanching was especially pronounced after agar gel cleaning. In contrast, cotton swabbing applies solvent quickly and removes it immediately, minimizing solvent exposure time and avoiding the formation of such light-scattering changes. Therefore, blanching appears to be a contact-time dependent phenomenon associated with diffusion-driven solvent retention.

Whether this blanching leads to long-term structural changes is not yet known and should be the focus of further monitoring. The ethical and aesthetic implications are significant, especially when treated areas appear altered due to optical disturbance. Applying a varnish layer may conceal blanching, but if the varnish is not a good match with the altered surface, the blanching can reappear through it with time. The damage itself is permanent, varnish can only mask the effect, not reverse the underlying change.

Summary

In comparing the three methods, the cotton swab technique at 30-60 seconds provided the most effective varnish removal and most consistent results. However, as Vergeer et al. (2019) emphasize, such manual methods carry higher risks of abrasion and rely heavily on operator skill, making them less suitable for fragile or modern paint surfaces. However, while longer application times (90 seconds) resulted in micro-abrasion, the 60-second interval achieved strong results without visible damage. Evolon® offered a safer alternative in terms of mechanical action but left residues in textured areas and exhibited blanching due to prolonged solvent contact. The agar gels, while offering excellent solvent control and minimal surface stress, proved too weak in cleaning capability and presented similar blanching effects as Evolon® when applied for longer periods.

Although XRF analysis initially suggested possible pigment presence in the cleaning residues, the consistent elemental findings across all cleaning methods, including those that failed to remove varnish, strongly suggest that the residues originate from surface dirt rather than actual pigment loss.

6. Conclusion

The aim of this study was to explore and compare the effectiveness, safety, and usability of three conservation methods for varnish removal: cotton swabs with ethanol, Evolon® microfiber cloth with ethanol, and agar gel with ethanol. The evaluation was conducted on a single oil painting, under controlled conditions, using microscopy, UV imaging, and XRF analysis to assess the results.

The findings show that cotton swab cleaning remains the most effective method for thorough varnish removal on this painting. It allowed for good control and cleaning efficiency, successfully restoring the original colours and surface clarity. In particular, cotton swabs achieved the same cleaning result in 30-60 seconds as Evolon® did in 90 seconds, making it the most time-efficient option.

Additionally, cotton swabs are inexpensive and require no preparatory steps, whereas Evolon® involves a two-step process and incurs a higher material cost. However, tests showed that cotton swab cleaning applied for 90 seconds led to noticeable surface damage, indicating that prolonged use beyond 60 seconds should be avoided. The mechanical action of swabbing still introduced light damage to the paint layer in textured areas, underlining the technique’s trade-off between cleaning efficiency and risk of abrasion.

The Evolon® method offered the advantage of reduced mechanical action and decent varnish removal, particularly when used for 90 seconds. However, it was more labour-intensive compared to cotton swabbing and required more careful handling and preparation, reducing its overall practicality as a routine method. This increased labour refers to the two-step process required, first applying the ethanol-loaded Evolon® cloth with a plastic sheet to soften the varnish, followed by a second step using a cotton swab to remove the dissolved layer. Additionally, Evolon® did cause some surface damage, with small spots of blanching. More concerningly, Evolon® left faint marks on the reverse of the canvas, evidence of ethanol bleed-through not observed with the other methods. This unintended solvent migration raises serious concerns about Evolon®’s viability, particularly for structurally sensitive paintings where controlled solvent exposure is essential.

The agar gel method was tested in two variants, agar mixed with ethanol and agar soaked in ethanol. Both versions were the least effective and had visible limitations. Agar mixed with ethanol showed almost no cleaning effect. Agar soaked in ethanol performed somewhat better but was still insufficient. In both cases, the rigid structure of the gel may have reduced its ability to make contact with the textured paint surface. There is also reason to suspect that ethanol may have evaporated during the preparation phase, particularly in the mixed variant, reducing its cleaning potential. While these limitations may be partly methodological, they raise important concerns about agar gel’s effectiveness under the conditions used here.

Blanching was observed in both agar and Evolon® methods, but not in the cotton swab tests. This likely results from prolonged solvent exposure at the paint interface and may indicate temporary microstructural changes, such as swelling or void formation, which cause localized light scattering. Although not structurally damaging in the short term, blanching affects surface appearance and must be considered when evaluating treatment ethics.

This study also raises ethical considerations regarding varnish removal. Although the varnish on the tested painting had already been partially removed before the study, further intervention still constitutes irreversible change. The decision to clean should consider both visual clarity and the potential impact on material stability. While cotton swabbing offered the clearest visual results, it also introduced the greatest surface risk. Evolon® and agar, although safer in theory, introduced unintended effects such as blanching and left significant varnish residues. These findings reinforce the idea that minimal intervention must be critically evaluated in the context of each object and treatment goal.

Future research could build on this study by refining the parameters within each cleaning method. For agar mixed with ethanol, it would be valuable to test different ethanol concentrations and gel consistencies to determine whether improved solvent retention and varnish solubility can be achieved. Regarding agar soaked in ethanol, further work could focus on optimizing soaking time and gel firmness to reduce solvent evaporation and improve surface contact. For Evolon®, studies could investigate whether different loading techniques or application durations affect cleaning efficiency and solvent penetration. While cotton swabs proved highly effective in removing varnish, they also posed the greatest risk of solvent diffusion and mechanical stress, future experiments could explore shorter or more varied application intervals to better control these risks and potentially reduce solvent exposure. Continued research on these method-specific variables would help develop safer and more precise cleaning strategies in conservation practice.

In conclusion, cotton swabs with ethanol proved the most effective and practical for varnish removal in this specific context. However, their abrasive potential and risk of pigment movement limit their suitability for more delicate surfaces. Evolon®, despite initial promise, showed insufficient cleaning performance and introduced critical risks due to solvent migration, rendering it unsuitable for general use. Agar gel in its tested forms did not perform sufficiently. The study underlines the need for method selection to be guided by the specific conservation scenario and supports further investigation into low-risk, controlled cleaning systems.

7. Sources

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Figure- and Table Description

Figures

1. **Close-up on signature -** Detail of Johan Jacob Bennetter's signature, confirming the artwork's date and authenticity.
2. **Painting's front under UV-light -** Shows previous varnish tests as fluorescing patches, indicating different varnish compositions.
3. **Painting's front before testing -** Overview showing general condition and yellowed varnish layer.
4. **Painting's backside before testing -** Initial condition of the canvas reverse, showing previous labels and minor structural wear.
5. **Layout for test cleaning patches -** Overall schematic view of cleaning test zones, indicating cleaning method and timing distribution.
6. **Close-up of Evolon® and agar test patch layout -** Top portion of the test grid showing patches cleaned with Evolon® and agar gels.
7. **Closeup of Agar mixed with ethanol cleaning tests -** Normal light images showing limited varnish removal and test patch outlines.
8. **Closeup of Agar soaked in ethanol cleaning tests -** Normal light images with inconsistent cleaning and surface irregularities.
9. **Closeup of Evolon® and agar cleaning results -** Comparative image of Evolon® and agar test zones, highlighting cleaning quality and patchiness.
10. **Closeup of cotton swab cleaning patch layout -** Patch grid for swab-applied ethanol, annotated with timing.
11. **Closeup of cotton swab cleaning patches -** Post-cleaning image showing effective varnish removal and some abrasion.
12. **Painting front after testing -** Overview of final condition, visual contrast between cleaned and uncleaned varnish.
13. **Painting backside after testing -** Confirms structural stability, no solvent damage visible.
14. **Paintings backside, closeup on backside of Evolon cleaning tests. Contrast has been increased -** Enhanced contrast reveals solvent migration patterns through canvas.
15. **Paintings backside, closeup on layout of backside of Evolon cleaning. Contrast has been increased -** Mapping of front-to-back alignment of test areas.
16. **Close up to test patches of agar mixed with ethanol cleaning test -** Unmarked view highlighting limited varnish removal.
17. **Close up to test patches of agar mixed with ethanol cleaning test, blanching marked in green -** Marked areas indicating blanching zones.
18. **Close up to test patches of agar soaked in ethanol cleaning test -** Shows uneven and localized cleaning performance.
19. **Close up to test patches of agar soaked in ethanol cleaning test, blanching marked in yellow -** Highlights blanching regions.
20. **Close up to of Evolon® cleaning test -** Shows test performance and extent of varnish removal.
21. **Close up to of Evolon® cleaning test, blanching marked in red -** Blanching damage highlighted.
22. **Close up to test patches of cotton swab cleaning test -** Effective varnish removal and minor texture flattening.

Tables

Attachment 1

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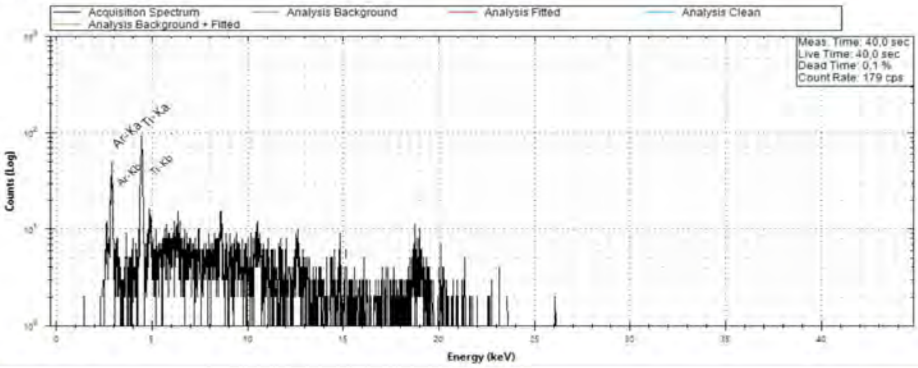

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Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

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E oanvand

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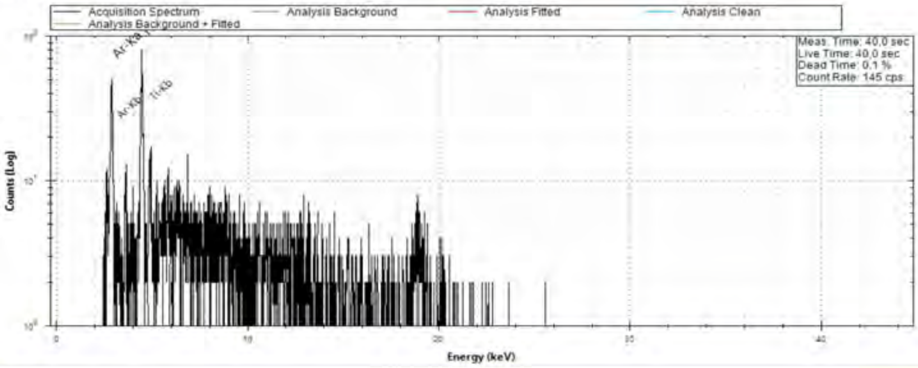

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Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

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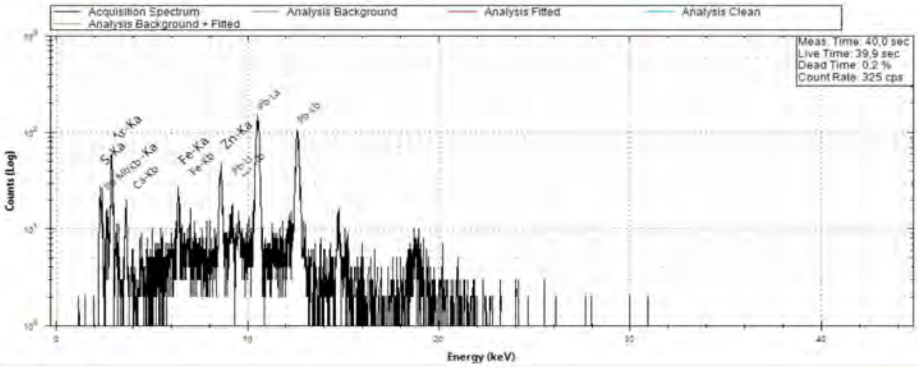

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Excluded Elements for FP Analysis:
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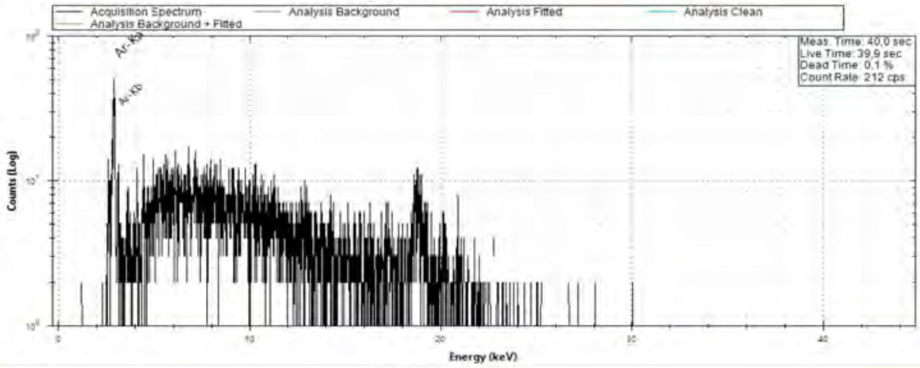

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Excluded Elements for FP Analysis:
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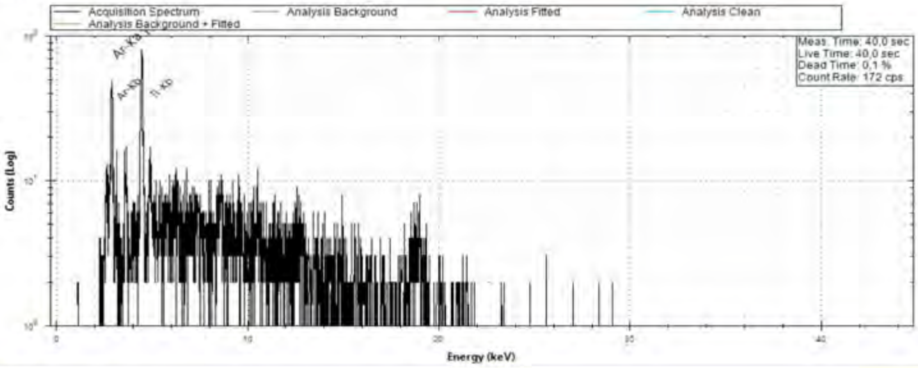

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EB60 bomull

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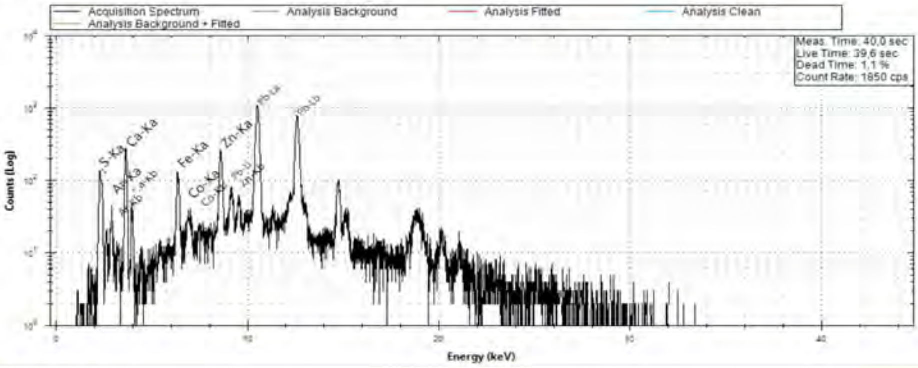

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Excluded Elements for FP Analysis:
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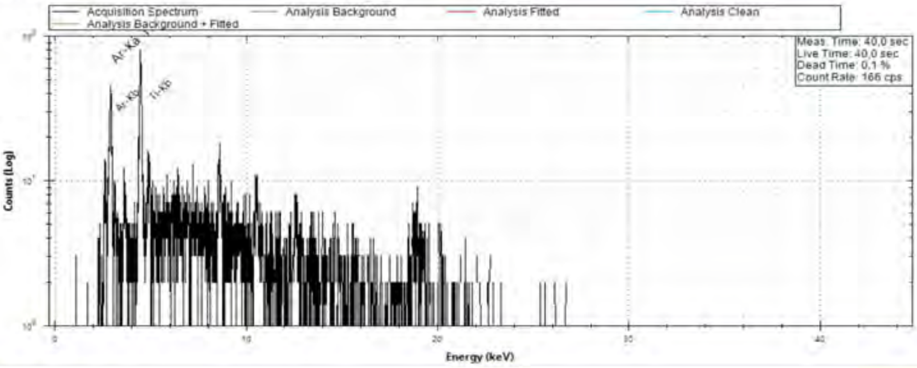

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H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

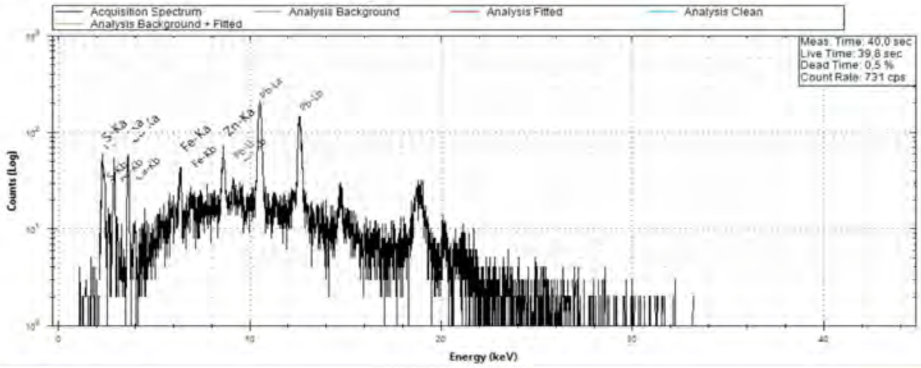
Project File: Kerstin 7

EB90 bomull

5/2/2025 1:28:54 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	65,91%	±5,74%
Ca	22,96%	±4,43%
Pb	8,95%	±1,78%
Fe	1,2%	±5,41%
Zn	0,98%	±4,13%

Analysis Date and Time: 5/2/2025 1:28:36 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

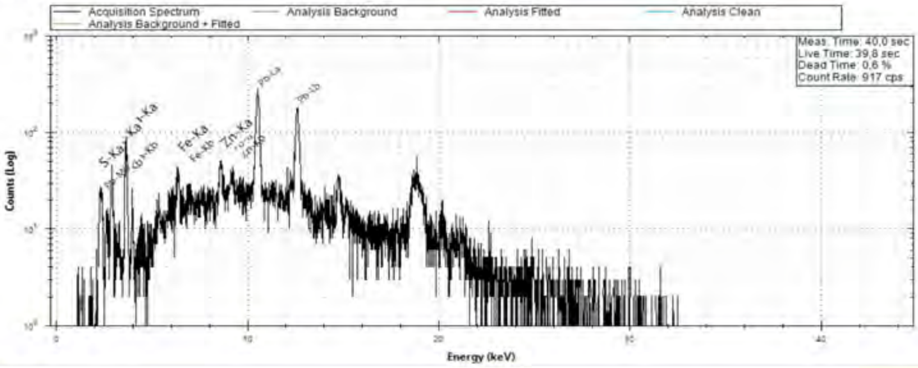
Project File: Kerstin 8

B30

5/2/2025 1:31:38 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ca	40,94%	±3,85%
S	36,61%	±11,91%
Pb	19,18%	±1,65%
Fe	2,3%	±5,05%
Zn	0,98%	±5,43%

Analysis Date and Time: 5/2/2025 1:31:04 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

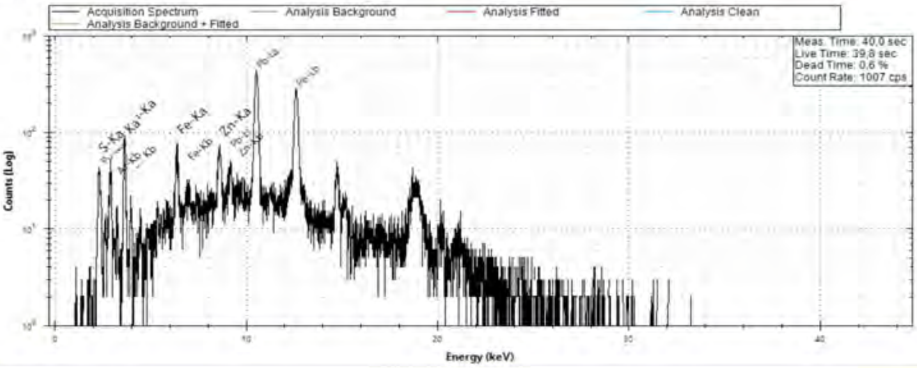
Project File: Kerstin 9

B60

5/2/2025 1:34:02 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ca	35,63%	±3,59%
S	35,49%	±7,87%
Pb	24,97%	±1,25%
Fe	2,6%	±3,99%
Zn	1,31%	±3,95%

Analysis Date and Time: 5/2/2025 1:33:02 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

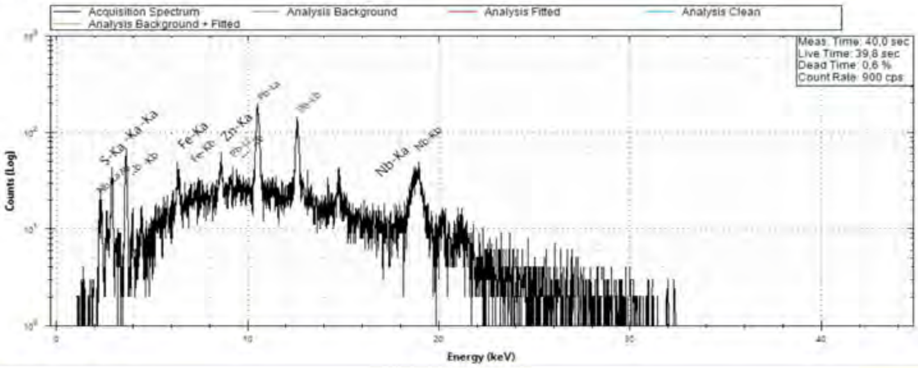
Notes:

B90

5/2/2025 1:35:13 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	46,19%	±10,39%
Ca	38,31%	±4,18%
Pb	12,71%	±2,04%
Fe	1,82%	±5,9%
Zn	0,88%	±5,92%
Nb	0,1%	±7,89%

Analysis Date and Time: 5/2/2025 1:34:53 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

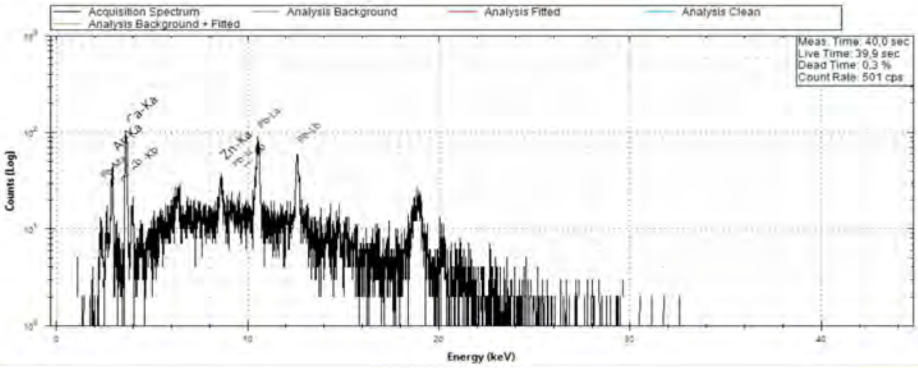
Notes:

AiE30 bomull

5/2/2025 1:38:51 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ca	83,3%	±3,27%
Pb	14,85%	±2,92%
Zn	1,85%	±6,27%

Analysis Date and Time: 5/2/2025 1:38:25 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

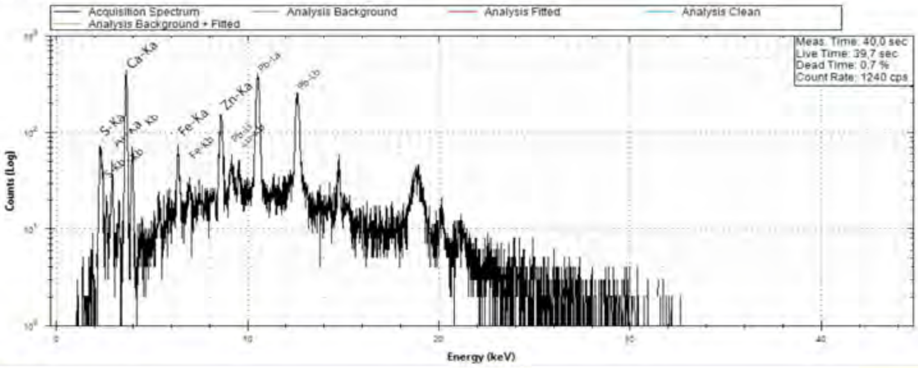
Project File: Kerstin 12

AiE60 bomull

5/2/2025 1:40:42 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ca	57,46%	±1,61%
S	30,59%	±5,1%
Pb	9,16%	±1,27%
Zn	1,58%	±2,36%
Fe	1,2%	±3,88%

Analysis Date and Time: 5/2/2025 1:40:22 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

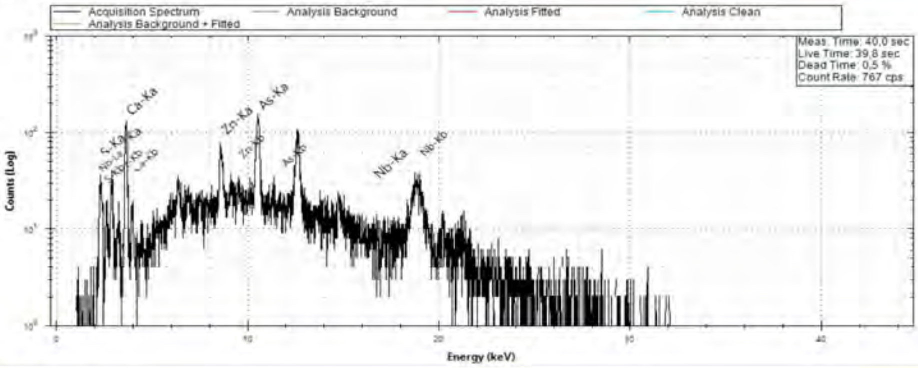
Project File: Kerstin 13

AiE90 bomull

5/2/2025 1:43:26 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	64,11%	±5,23%
Ca	33,28%	±2,92%
As	1,75%	±2,21%
Zn	0,83%	±3,76%
Nb	0,03%	±6,84%

Analysis Date and Time: 5/2/2025 1:42:17 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

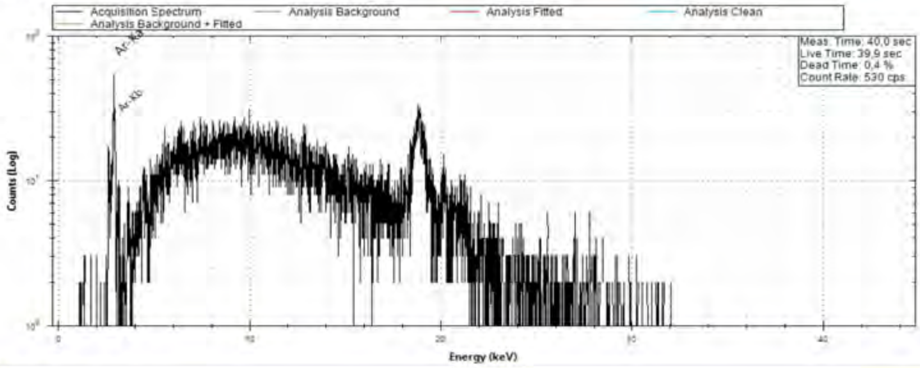
Project File: Kerstin

A30 bomull

5/2/2025 1:46:18 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA

Analysis Date and Time: 5/2/2025 1:46:04 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

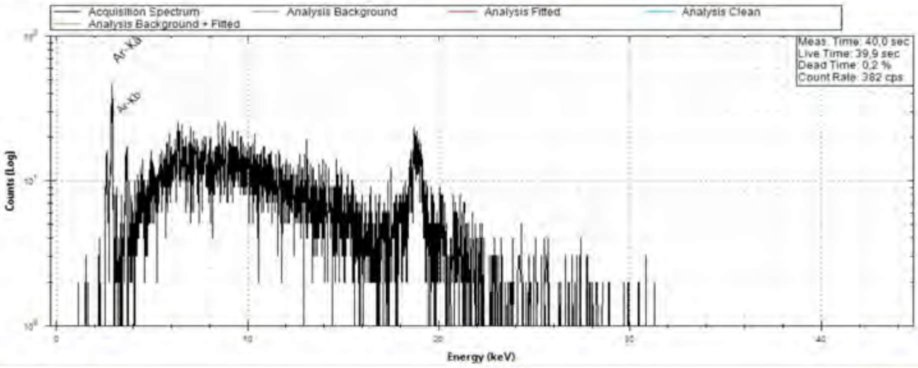
Project File: Kerstin 15

A60 bomull

5/2/2025 1:48:18 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA

Analysis Date and Time: 5/2/2025 1:47:59 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

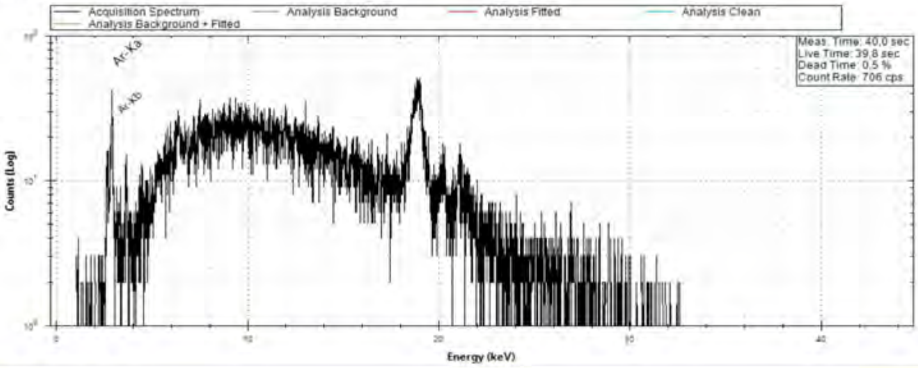
Project File: Kerstin 16

A90 bomull

5/2/2025 1:50:15 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA

Analysis Date and Time: 5/2/2025 1:49:50 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

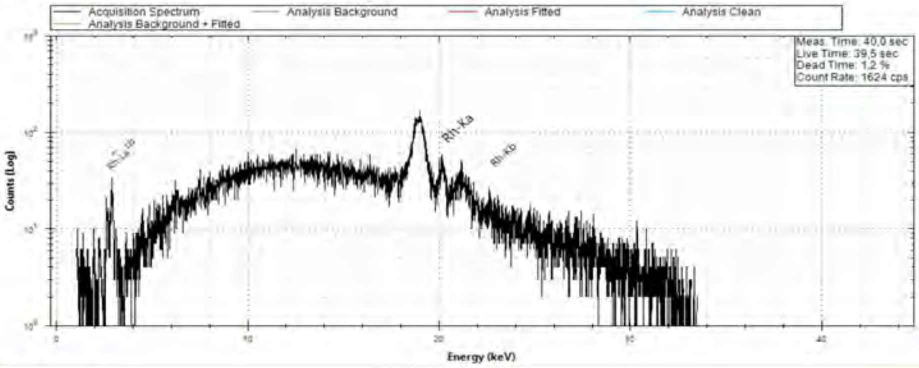
Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

AiE30
5/2/2025 1:54:04 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Tc	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 1:52:23 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

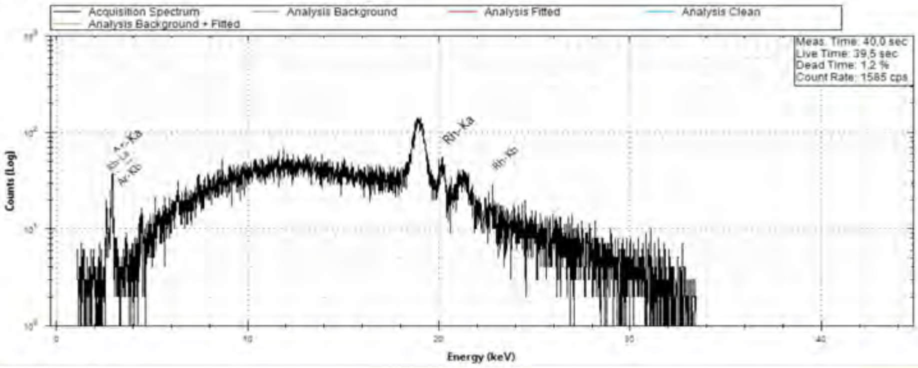
Notes:

Project File: Kerstin 18

AiE60
5/2/2025 1:55:15 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 1:54:58 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

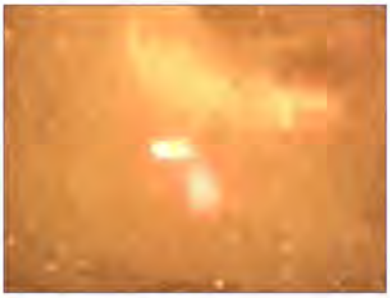
Notes:

Project File: Kerstin 19

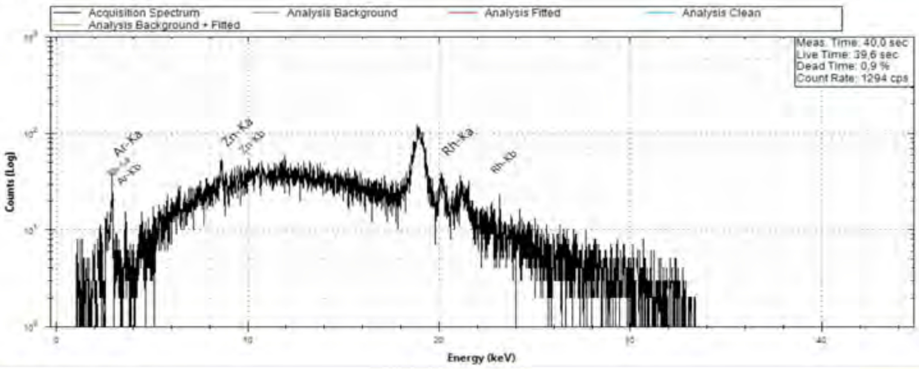
AiE90

5/2/2025 1:58:07 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air



Spectrum:



Analysis Results:

Element	Concentration	Error
Zn	100%	±7,02%

Analysis Date and Time: 5/2/2025 1:56:33 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

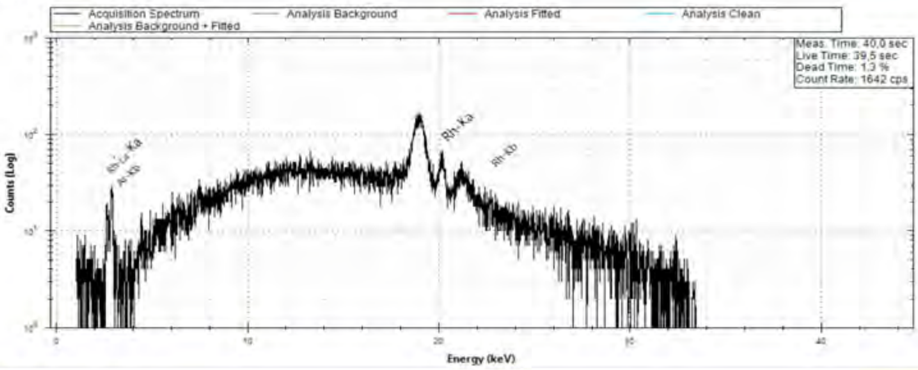
Notes:

Project File: Kerstin 20

Ren agar utan etanol
5/2/2025 1:59:21 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA
Tc	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 1:58:52 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

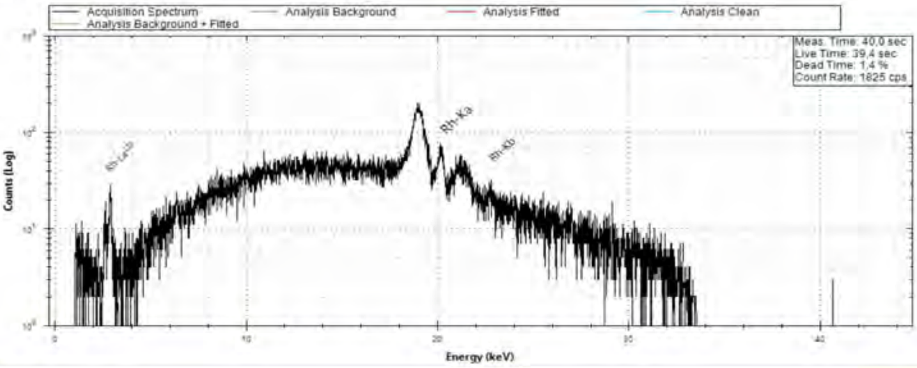
Project File: Kerstin 21

A30

5/2/2025 2:01:14 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Tc	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 2:00:59 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

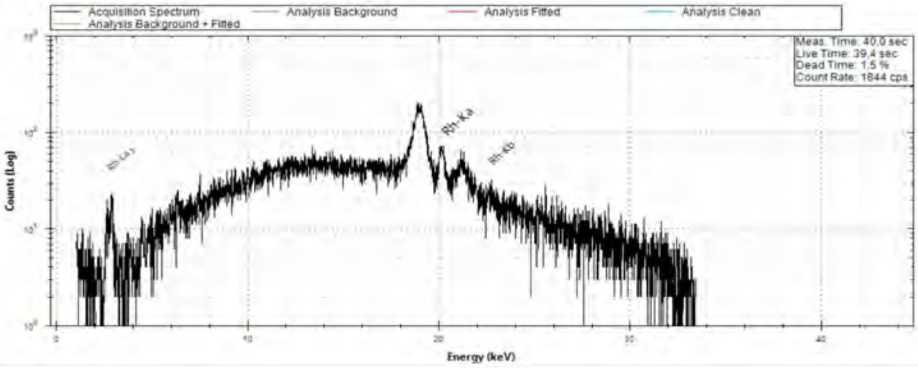
Project File: Kerstin 22

A60

5/2/2025 2:02:49 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Tc	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 2:02:29 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

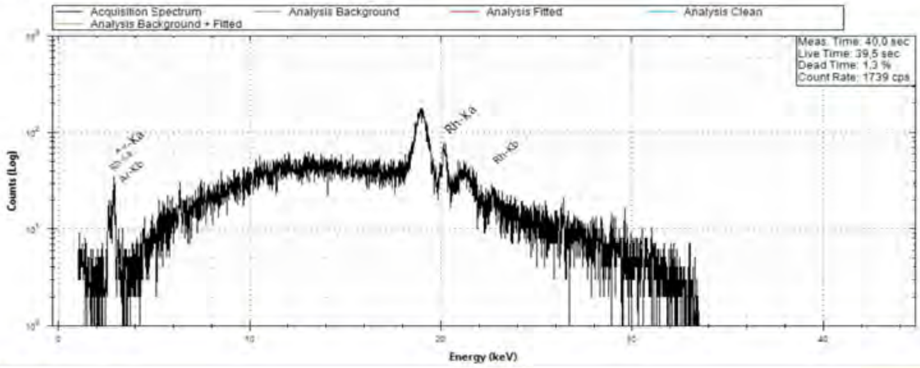
Project File: Kerstin 23

A90

5/2/2025 2:04:17 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
Ar	NA	NA
Tc	NA	NA
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 2:03:54 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

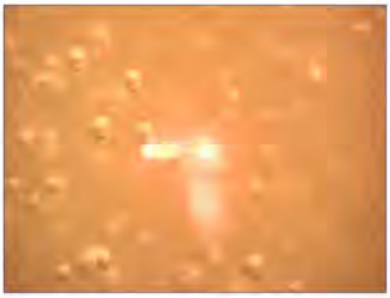
Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

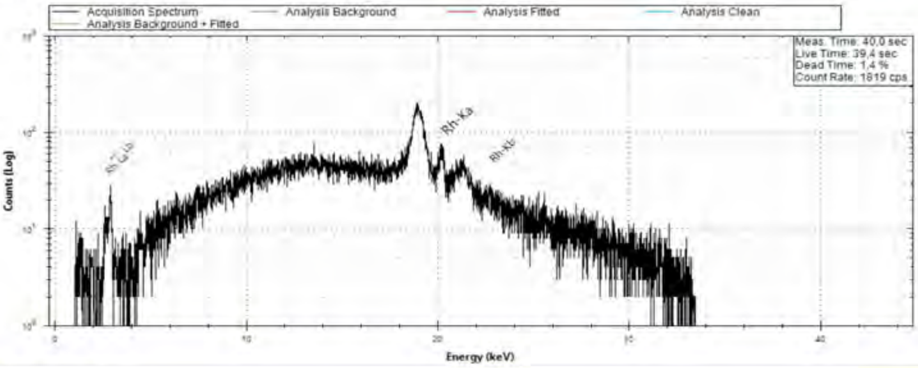
Ren agar med etanol 20

5/2/2025 2:06:03 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air



Spectrum:



Analysis Results:

Element	Concentration	Error
Ru	NA	NA
Rh	NA	NA
Pd	NA	NA

Analysis Date and Time: 5/2/2025 2:05:45 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

Project File: Kerstin 25

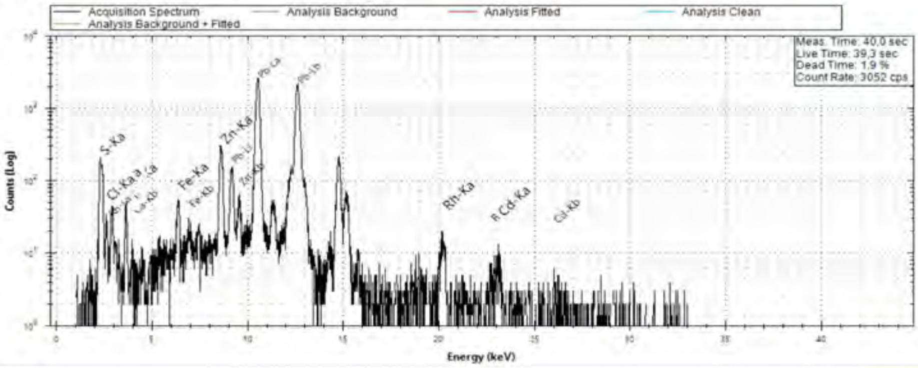
Attachment 2

Klar gul

5/2/2025 3:33:22 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	43,35%	±3,77%
Pb	34,41%	±0,52%
Cl	15,56%	±7,54%
Ca	4,41%	±5,75%
Zn	1,45%	±1,76%
Fe	0,44%	±4,59%
Cd	0,38%	±8,88%

Analysis Date and Time: 5/2/2025 3:32:26 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

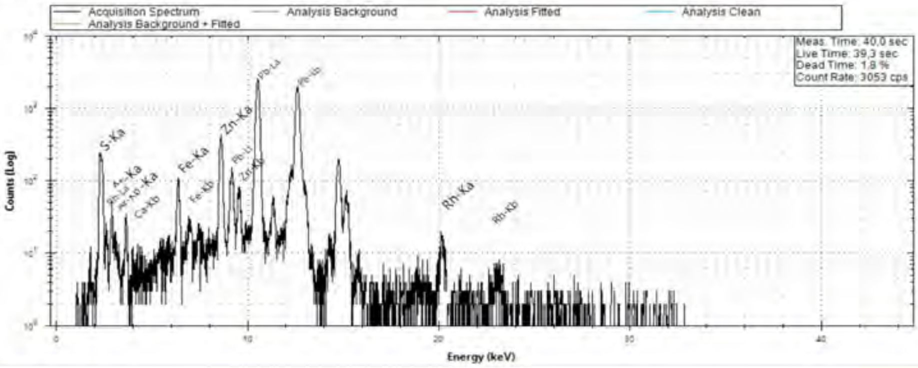
Project File: Tavlan 1

Klar gul 2

5/2/2025 3:35:48 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	58,41%	±2,99%
Pb	35,66%	±0,51%
Ca	2,96%	±6,93%
Zn	2,09%	±1,45%
Fe	0,89%	±3,19%

Analysis Date and Time: 5/2/2025 3:35:01 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

Notes:

Project File: Tavlan

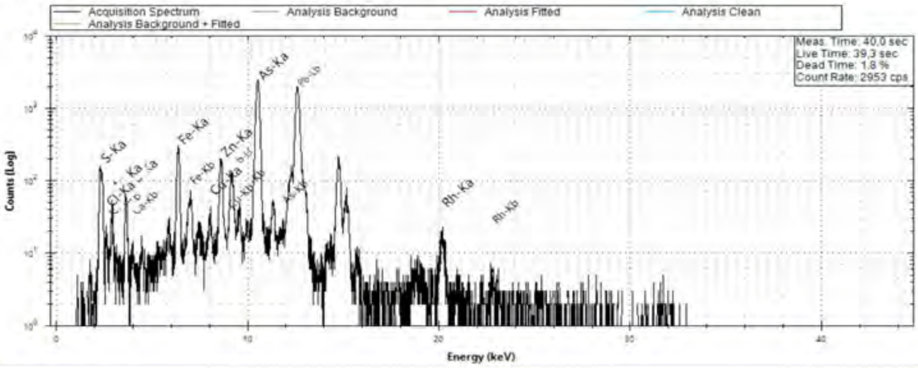
Mork Bla Gron

5/2/2025 3:40:16 PM

BRUKER

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	44,21%	±4,08%
Pb	17,98%	±0,5%
Cl	16,33%	±7,68%
As	8,87%	±0,68%
Ca	8%	±4,11%
Fe	3,34%	±1,64%
Zn	1,17%	±1,98%
Cu	0,1%	±7,21%

Analysis Date and Time: 5/2/2025 3:41:24 PM
Analysis Type: Advanced
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

Selected Elements for Analysis:
Cl, As, S, Pb (K,L lines), Zn, Cu, Fe, Ca

Included Elements for Fitting Analysis:
Ar, Cl, As, S, Pb, Zn, Cu, Rh, Fe, Ca

Notes:

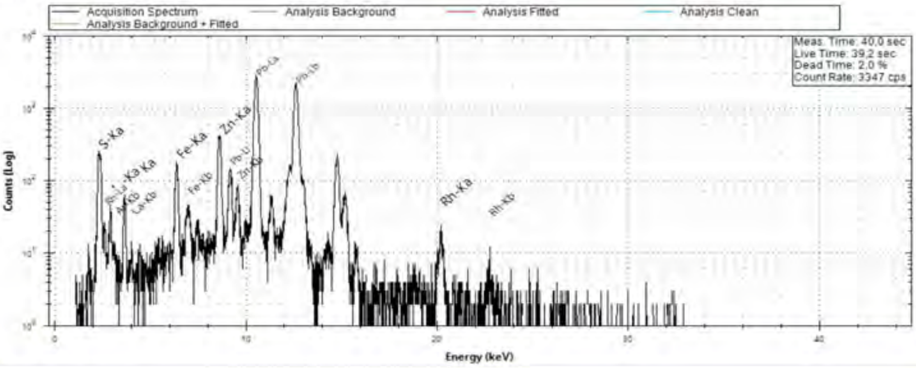
Project File: Tavlan 3

Ljus gron

5/2/2025 3:44:54 PM

Measurement Time: 40,0 s
Tube Voltage: 40 kV
Tube Current: 20 µA
Tube Target Material: Rh
ELIO Device: SN1253
Device Mode: HeadMotor
Acquisition Mode: Manual
Acquisition Channels: 4096
Sample to Detector Material: Air

Spectrum:



Analysis Results:

Element	Concentration	Error
S	53,1%	±3,25%
Pb	36,96%	±0,47%
Ca	6,1%	±4,42%
Zn	2,24%	±1,32%
Fe	1,6%	±2,21%

Analysis Date and Time: 5/2/2025 3:44:12 PM
Analysis Type: Automatic
Spectrum Left Cut: 1 keV
Spectrum Right Cut: 50 keV
Spectrum Upper Limit: 50 keV
Use M Line: True
Super Impose Peak Areas: True

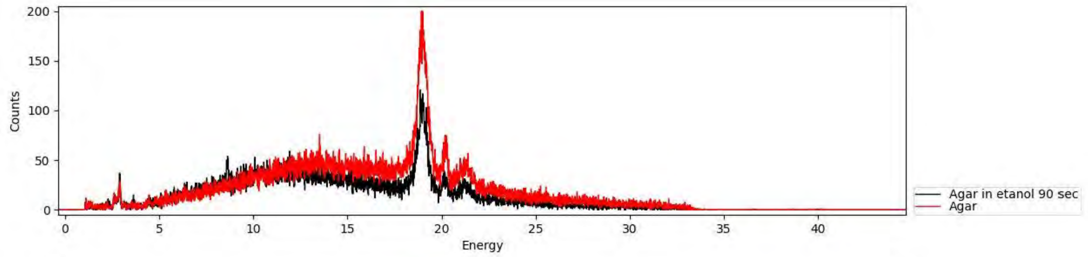
Excluded Elements for Fitting Analysis:
H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Kr, Xe, Rn, At, Po, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr, Pd, Tc, Ru

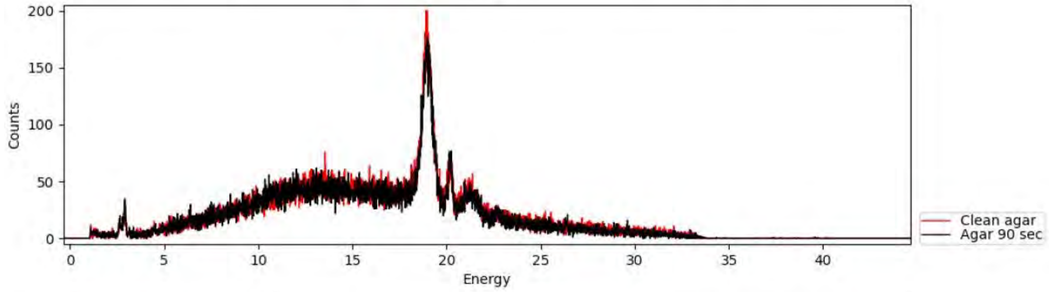
Excluded Elements for FP Analysis:
Rh, Ar, Ag:L, Nb:L, Mo:L, Cd:L, In:L, Sn:L, Sb:L, Pb:M, Bi:M, Tl:M, Hg:M, Au:M, Pt:M, Ir:M, Os:M, Re:M, W:M, Ta:M, Hf:M, La:M

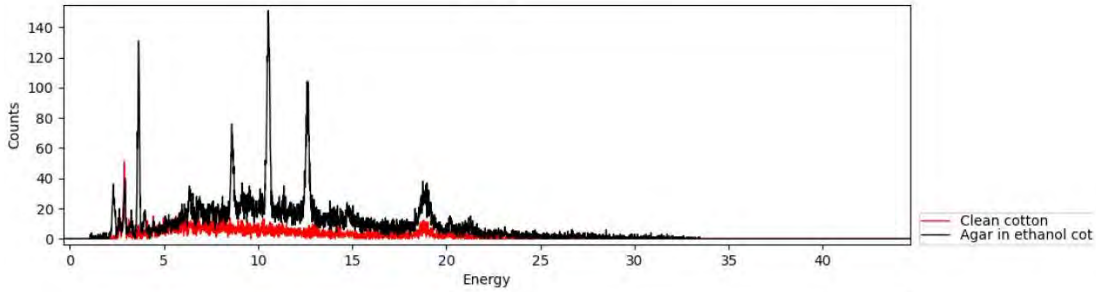
Notes:

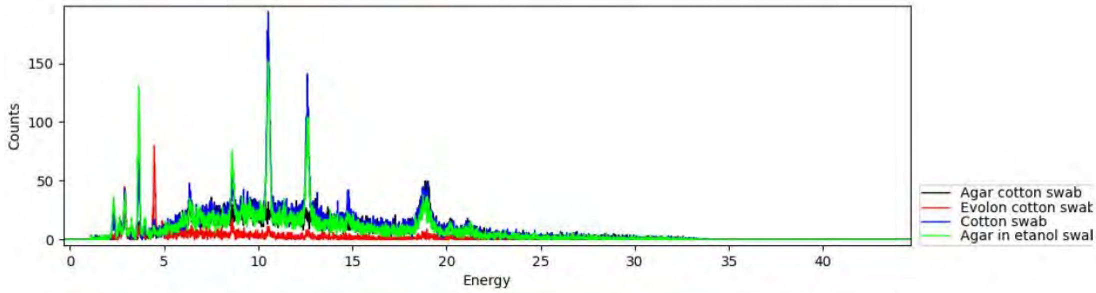
Project File: Tavlan 4

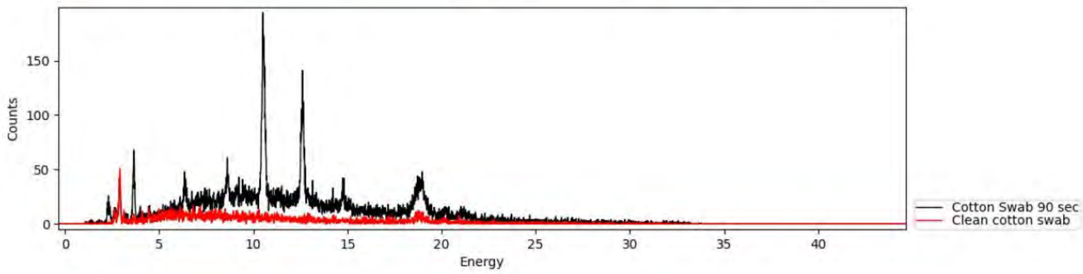
Attachment 3

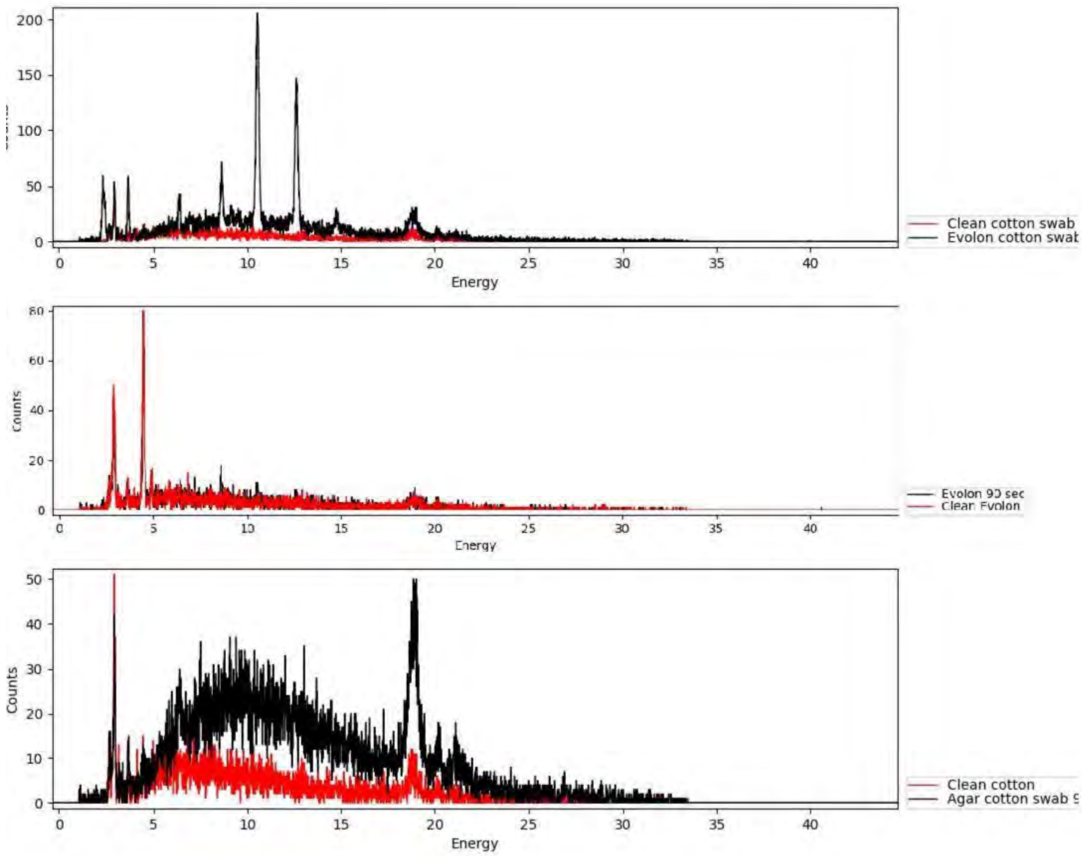






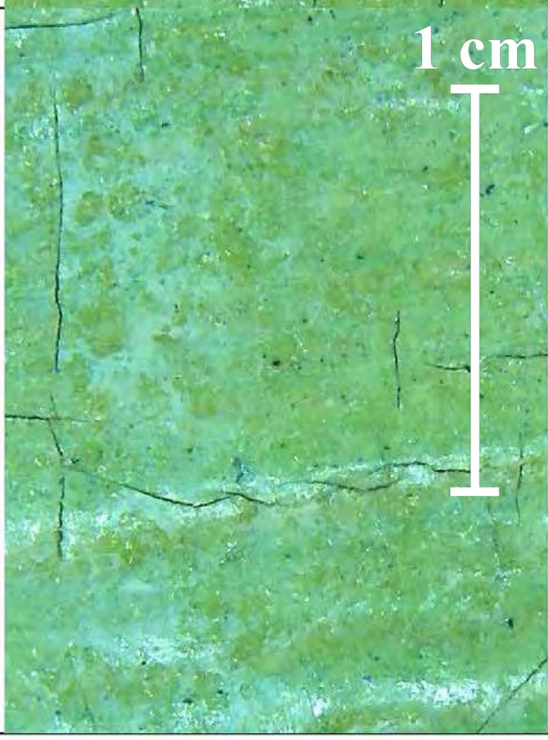





Energy
Clean cotton swab
Evolon cotton swa
Counts
Energy
Evolon 90 sec
Clean Evolon
Counts
Energy
Clean cotton
Agar cotton swab

Attachment 4

Agar mixed with ethanol cleaning test
Row 1

30 seconds	
60 seconds	

90 seconds	

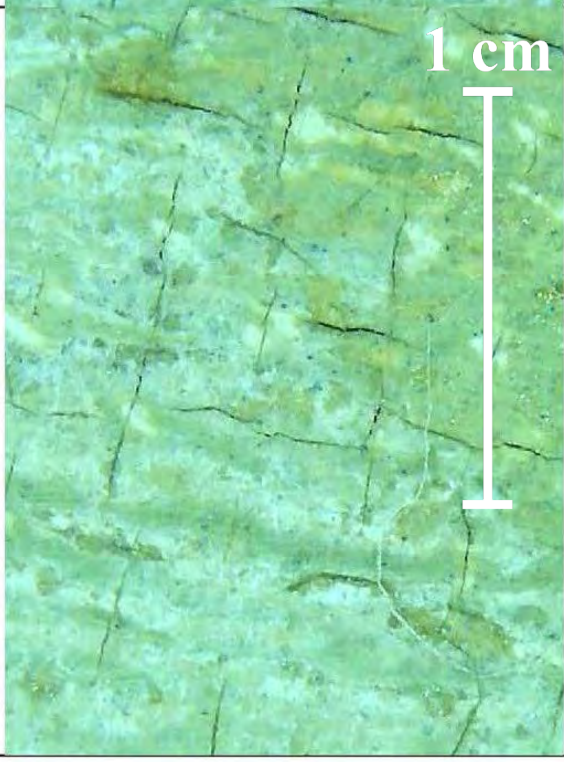
Agar mixed with ethanol cleaning test
Row 2

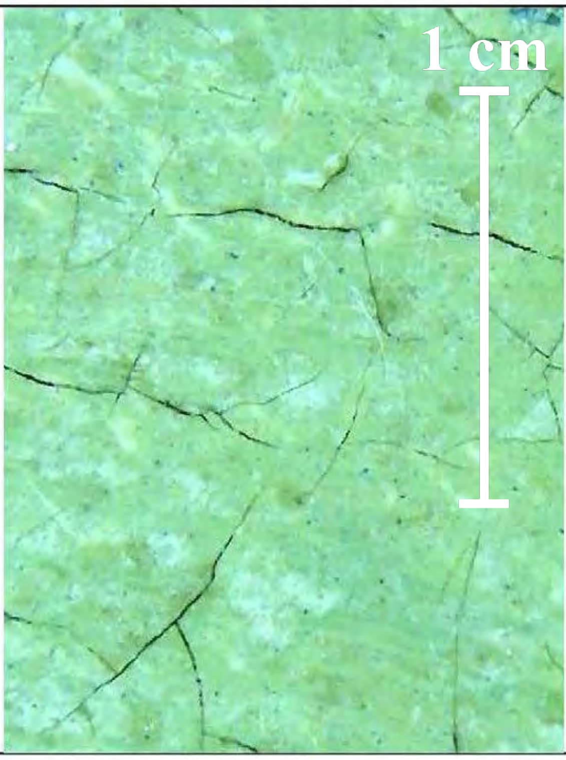
30 seconds	

60 seconds		
90 seconds		

Agar soaked in ethanol cleaning test

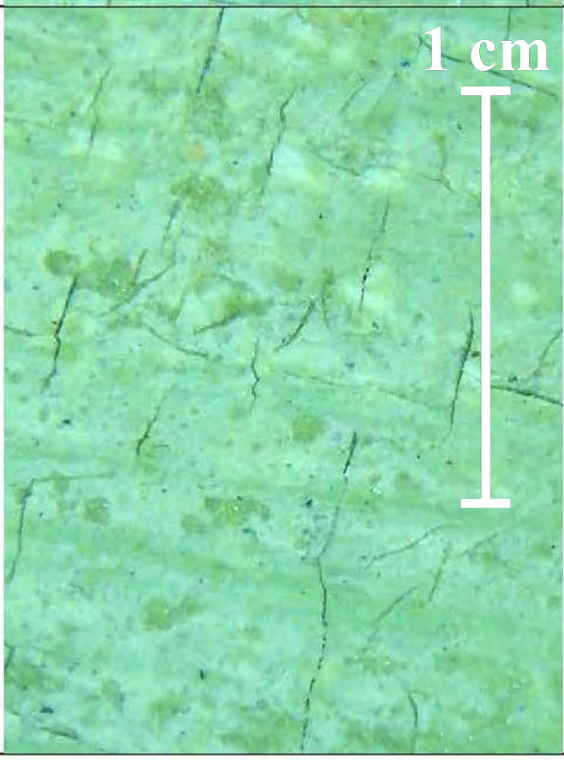
Row 1

30 seconds	
60 seconds	

90 seconds		

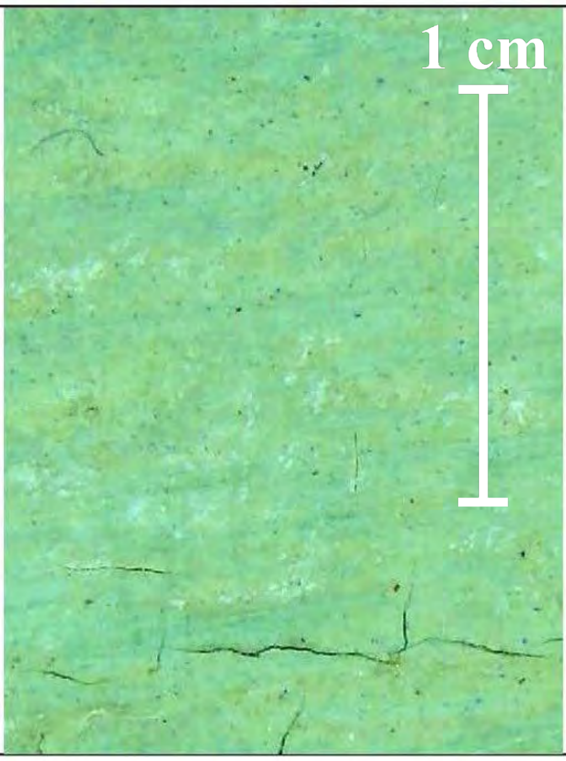
Agar soaked in ethanol cleaning test
Row 2

30 seconds		

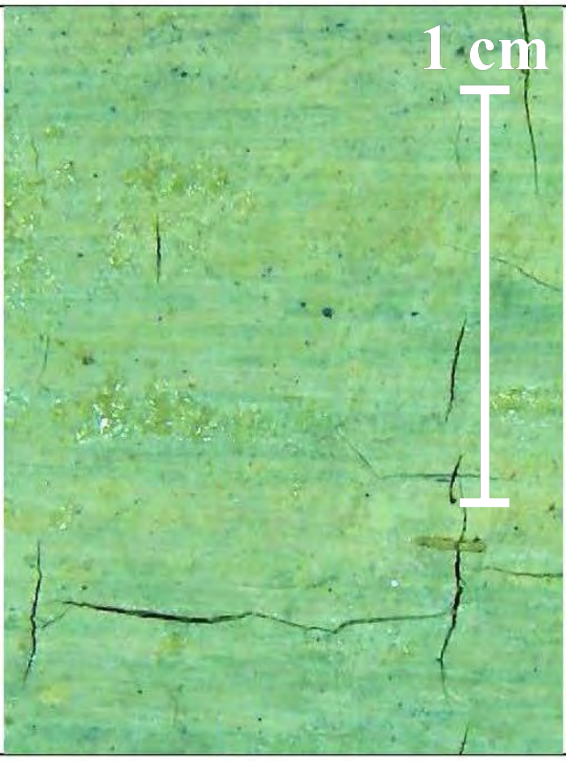
60 seconds	
90 seconds	

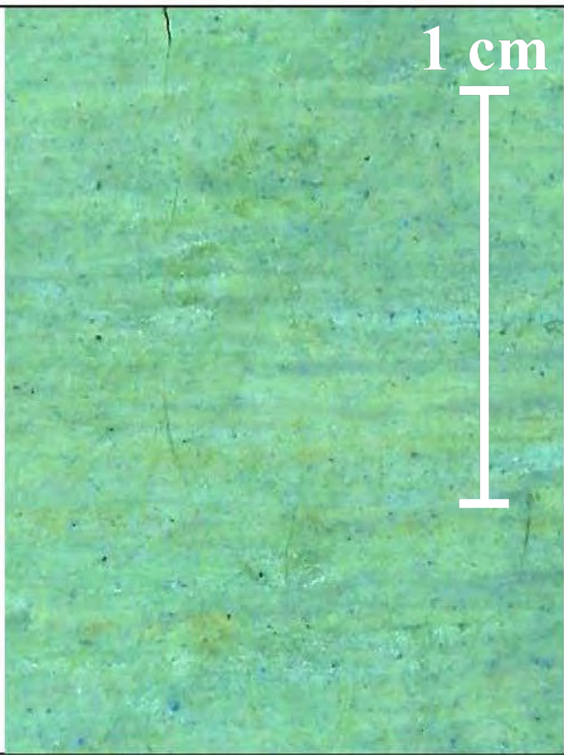
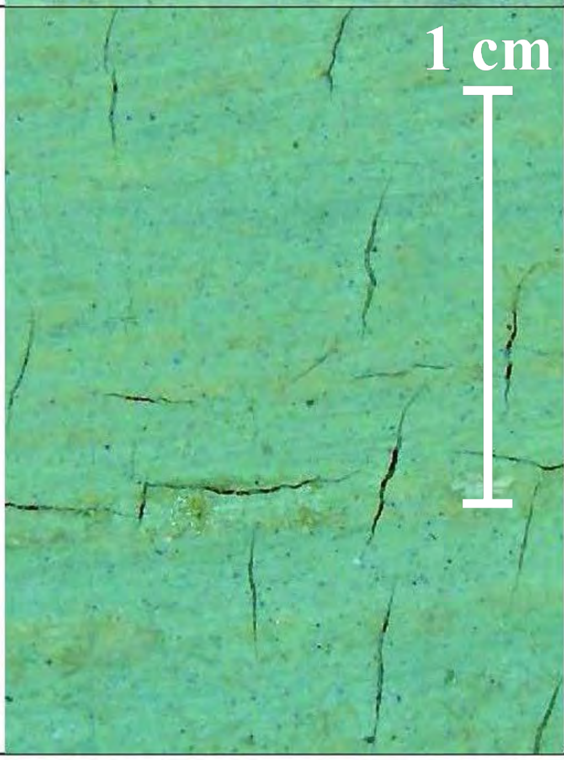
Evolon® cleaning test
Row 1

30 seconds		
60 seconds		

90 seconds		

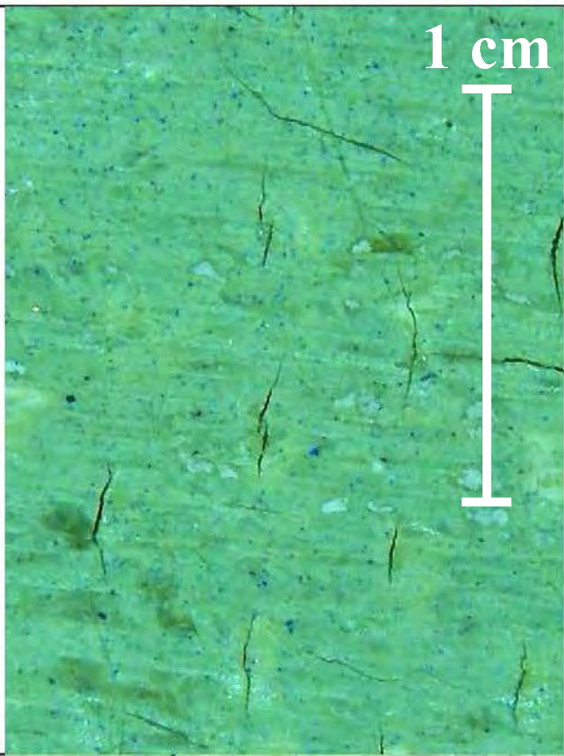
Evolon® cleaning test
Row 2

30 seconds		

60 seconds		
90 seconds		

Cotton swab cleaning test

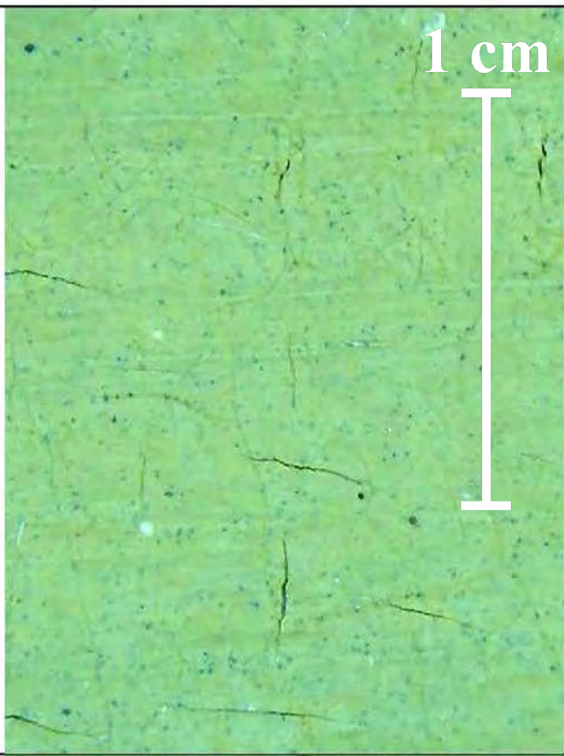
Row 1

30 seconds		
60 seconds		

90 seconds		

Cotton swab cleaning test
Row 2

30 seconds		

60 seconds		
90 seconds