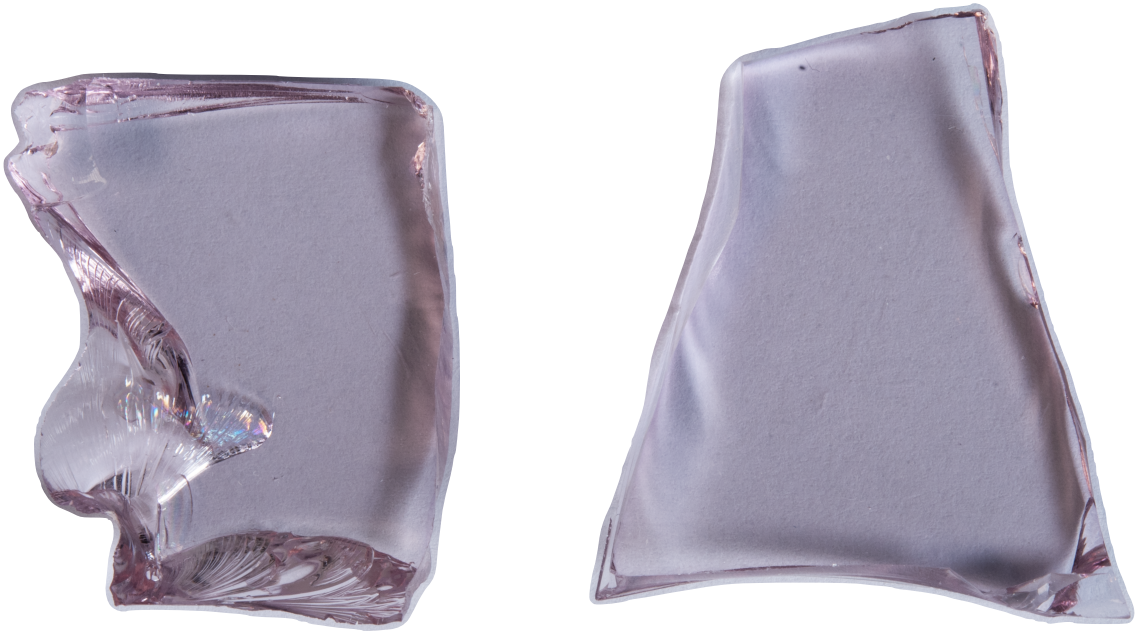
Conservation and Restoration of Cultural Heritage | Glass and Ceramics

Solarisation in Historical Manganese-Containing Glass

Investigating UV Radiation Effects and Conservation Implications

MSc Thesis



Two artificially solarised glass samples (Photo: Joris Nagtegaal)

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Summary

This research investigates solarisation, a colour change in glass, containing manganese as a decolourant, caused by UV radiation. The study aimed to determine the parameters of solarisation by exposing three glass objects to various UV sources and measuring colour changes, to prevent solarisation in museum and non-museum environments. Results showed that solarisation susceptibility varied with UV type and the minor elements in the glass composition, particularly arsenic and chlorine.

Abstract

This research investigates the phenomenon of solarisation of manganese-containing historical glass. Solarisation is the process where UV radiation causes colour changes in glass. This occurs because the manganese in the glass oxidises due to the UV exposure, resulting in a purple or pink hue, leading to conservation concerns for museums and collectors trying to balance displaying and conserving their objects. The research focuses on identifying what parameters — like UV radiation and chemical glass composition — are required for solarisation to occur.

A literature review was conducted concerning manganese as a decolourant in glass production, principles of solarisation, previously conducted experiments, and investigation of lighting standards for museums.

Additionally, three manganese-containing glass objects, spanning the late 18th to the 19th century—including one Early American Pressed Glass (EAPG) and two wheel-engraved European glasses —were available for (destructive) experimentation. These underwent compositional analysis via handheld X-ray fluorescence (pXRF) and scanning electron microscopy with dispersive X-ray spectroscopy (SEM-EDX), which gave a general overview of the glass composition and confirmed the presence of manganese in all objects. The EAPG glass was a soda-lime-silica glass, while the other two were potassium glasses. This made it possible to investigate the influence of varying glass compositions on the solarisation process.

A total of 42 samples were exposed to four different electromagnetic radiation sources: (1) UVA, (2) a combination of UVA and UVB, (3) a sunlight-through-glass simulation — with and without UV blocking filter — and (4) outdoor sunlight. Control samples of all case study objects were kept in the dark, to measure potential colour changes in the absence of electromagnetic radiation exposure. The colour of all samples was regularly measured using a Konica Minolta CM-2600d spectrophotometer and for all measures a CIE ΔE_{00} standard was calculated to detect potential changes in colour over time.

Only samples of the EAPG and one of the European glasses showed both visible and measurable changes in colour after exposure to UVB-containing radiation. Traces of chlorine were detected in these glasses, but not in the glass that did not solarise, suggesting this might have affected the discolouration. In addition, the EAPG glass visually solarised after exposure to UVA alone and a sunlight-through-glass simulation without UV blocking filter, but this change in colour was not measurable. The other two glasses did not show signs of solarisation in any of the other irradiation conditions. The chemical analysis showed that only the EAPG glass contained a significant amount of arsenic, which is known to increase susceptibility to solarisation.

Overall, this study confirms the susceptibility of historical manganese-containing glass to solarisation, especially when exposed to high levels of UVB radiation. To further understand how solarisation may affect museum or private collections and to eventually compose general guidelines to prevent this, more research is needed.

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20 June 2025



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Introduction

This thesis aims to investigate the solarisation of historical manganese-containing glass in museum and private collections. Solarisation is the process in which ultraviolet (UV) radiation causes colour changes in glass. Although the process can occur in glasses with varying compositions, solarisation of clear glass that contains manganese as a decolourant is one of the most common and well described forms. In this case, the clear glass turns purple or pink due to the UV-induced oxidation of manganese.

Although solarisation has been researched over a prolonged period of time, the precise conditions and thresholds that may affect glass in museum and private collections are not well described. This research focusses on the parameters for solarisation of manganese-containing glass through a literature review and controlled experiments in an attempt to determine the specific requirements for a manganese-containing glass to solarise. The main research question is: *How do historical manufacturing practices using manganese as a decolourant, the intrinsic solarisation behaviour of manganese-containing glass, and the UV lighting conditions in museum and non-museum collections combine to determine the susceptibility of historical glass artefacts to solarisation?*

To answer this question, this thesis is built up into two sections: a literature research and the description of the experiments that were conducted to determine the different parameters of solarisation.

Relevance and aim of research

Solarisation is a phenomenon in which glass objects undergo intentional or unintentional changes in colour as a result of prolonged exposure to high energetic electromagnetic waves, such as Ultraviolet (UV) light. When exposed to either artificial or natural UV light, the oxidation states of ions in the glass matrix can change, possibly resulting in a change in colour. As museums wish to present their collection to the audience and at the same time aim for the best possible conservation of their collection, they must balance the level of light in the exhibition rooms. Similarly, private collectors who possess historic glass items face the dilemma of how to appreciate and exhibit these artefacts without risking their solarisation.

The primary aim of this research was to determine the conditions under which manganese-containing glass becomes susceptible to solarisation, with a particular focus on what dose and type of UV is needed for solarisation to occur. This was related to typical museum lighting conditions to generalise the results. In addition, by using samples from three different case study objects, the role of variations in glass compositions — such as the presence or absence of certain metal oxides or impurities — was explored to see what influence this would have on the solarisation of the different glasses. A secondary aim based on this — which was not realised in this study — would be the possible development of general guidelines facilitate determination of objects at risk of solarisation based on their composition.

Through controlled experiments in different lighting conditions and comparative colour analysis of the three case study objects, the aim was to establish a more detailed understanding of how compositional variables would influence the rate and severity of solarisation under defined lighting conditions.

By pinpointing the critical UV dose levels and identifying compositional factors that may influence solarisation, this research hoped to enable both museums and individual collectors to safely display their works of glass. In addition, this research aimed to promote awareness of potential solarisation of vessel glasses in collections, as this seems to be a possible deterioration factor that is often overlooked.

Section I: Literature Research

1. Introduction

This first section contextualises the second and provides a basis for the used experimental methodology. This is done in five chapters; (1) An explanation is given of the underlying chemical mechanisms behind decolouration and solarisation of manganese-containing glass; (2) The historical context of manganese as a decolourant is described, with the goal of identifying glass collections from certain time periods — in which manganese was predominantly used as a decolourant — as potentially at risk of solarisation; (3) An overview is provided of previously conducted experiments ranging from the late 19th century up to 2022; (4) An overview of solarisation as discussed in contemporary conservation literature is provided; (5) An overview of historical and contemporary museum lighting standards is given, which provides insight in whether glass collections are currently exposed to lighting conditions that might eventually lead to solarisation.

2. State of the art — Chemical aspects

To better understand the chemical mechanisms behind solarisation in manganese-containing glass, it is important to note that soda-lime glasses almost always contain iron oxide impurities, which can result in a green hue in the glass.[1] To counteract this, manganese, an important element in the process of solarisation, was often added to the glass melt as a decolourant.[2] This paragraph will explore the interplay between iron and manganese and highlight their role in decolouration as well as solarisation.

Before delving into the details, it is crucial to understand the composition of glass. Glass is made up of three main parts: (1) a network former, (2) fluxes, and (3) stabilisers. In general, the network former, is silica (SiO_2), sourced from sand or ground quartz stone. It forms the three-dimensional structure of the glass. Fluxes are the second component, which are alkali oxides necessary to lower the melting temperature of silica. In its pure form, silica has a melting point of over 1000°C. Finally, stabilisers, such as calcium oxide (CaO) or magnesium oxides (MgO), are also present. They prevent crystallisation as the glass cools and improve its chemical stability. Up until 1000 CE, sodium oxide was primarily used as a flux in the form of soda crystals (Na_2CO_3) or sodium nitrate ($NaNO_3$). From 1000 CE onwards, potash (potassium, K) has also been used as a flux. The silica content of regular glass ranges between 60% and 75%, while the fluxes make up about 15%. The remaining 10% of a glass is made up of stabilisers.[3]

[1] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 31. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[2] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23.

[3] Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 73-75, 177.

2.1 How manganese acts as a decolourant

Sand almost entirely consists of pure quartz (silica, SiO_2), but when sourced from a marine source it often contains calcium. Furthermore, almost all sands contain small percentages of impurities, such as iron or magnesium. When iron is present, this gives the glass a green colour if no decolourant is used. Because pure sand, without iron impurities, is costly and rare, manufacturers often used slightly contaminated sand, adding manganese to the glass melt to neutralise the green hue.[4] Although there are a number of explanations of how manganese functions as a decolourant, these have been found to be contradictory.

For example, in 1985, Rick Baldwin, member of the Ohio Bottle Club, stated that decolouration using manganese could be achieved in two steps. In the first step, an oxidising agent like potassium nitrate (KNO_3) or red lead (Pb_3O_4) was added to the glass melt, to initialise the oxidation of blueish-green Fe^{2+} to Fe^{3+}, which has a much weaker yellow-green colour. Secondly, pyrolusite (manganese dioxide, MnO_2) would be added to aide to fully oxidise all Fe^{2+} into Fe^{3+}, while simultaneously oxidising the Mn^{4+} to Mn^{7+}, the highest oxidation state of manganese. This oxidation state of manganese absorbs electromagnetic radiation in the green region of the visible spectrum and transmits or reflects blue and red, causing it to have a lavender colour which is complimentary to the yellow-green colour of the Fe^{3+} present in the glass. Therefore, according to Baldwin, the combination of Fe^{3+} and Mn^{7+} results in a clear glass.[5]

While both Sandra Davison (2011), a glass conservator, and Ramadan Abd-Allah (2022), professor at the Faculty of Archaeology of the Cairo University, have agreed with Baldwin that Fe^{2+} gives a blueish-green colour and Fe^{3+} gives a yellow-green colour, the oxidation state in which manganese occurs as a decolourant is different. According to both authors, the neutralisation of the glass colour results from an equilibrium between Mn^{2+} and Mn^{3+}, instead of Mn^{4+} and Mn^{7+} as Baldwin claimed. In this case, the manganese would have a pink colour complimentary to the green colour of the iron impurities, resulting in a colourless glass.[6]

Abd-Allah added an important comment that the presence of manganese and iron in the glass mix are not solely responsible for the colour of the glass; numerous other elements can also affect the final colour. For example, Fe^{3+} will be colourless when both fluorine (F) and phosphor (P) are present in the glass melt, while a combination of Fe^{2+} and zinc (Zn) oxides will result in an intense blue colour of the glass. However, Abd-Allah does not provide any exact weight percentages.[7] According to Baldwin, the final colour of manganese-containing glass is influenced by additional components like lead, barium, soda, and potash. However, he doesn't specify their exact influence.[8] Davison does not write about how other elements in the glass mix can influence the decolourising properties of manganese.

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[4] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 31. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[5] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23.

[6] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 33. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025. ; Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 7.

[7] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 35. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[8] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23.

2.2 The chemical mechanisms behind solarisation

Manganese has over six different oxidation states (e.g. Mn^{2+}, Mn^{3+}, Mn^{4+}, Mn^{5+}, Mn^{6+}, Mn^{7+}) each with a distinctly different colour. Respectively resulting in colourless, pink, brown, blue, green and purple hues.[9] In 1985, Rick Baldwin stated, without further specification, that a small amount of the manganese could later be oxidised to purple Mn^{7+} to counteract the yellow hue. The remaining manganese would stay in the glass in a reduced state.[10]

While under strong oxidising conditions in the manufacturing process pyrolusite can be used to purposely create deep-purple glass, discolouration to purple can also occur at a later stage due to solarisation.[11] This is the process by which the oxidation state of ions within the glass composition changes due to high-energy electromagnetic radiation, such as UV, also referred to as photo-oxidation.[12]

In early research in 1867, J.T. Pelouze — a French chemist, as cited by Woldemar A. Weyl in 1951 — compared intentionally produced purple glass containing a high concentration of pyrolusite and solarised purple glass. He observed differences in oxidation states between purposely coloured glasses and glasses that were produced as clear and later turned purple due to solarisation.[13] He found that solarised glass contained $Mn^{3+}{}_2O^{2-}{}_3$ in combination with $Fe^{2+}O^{2-}$, while purposely coloured glass did not contain any $Fe^{2+}O^{2-}$. Instead, in these glasses all of the iron is oxidised to $Fe^{3+}{}_2O^{2-}{}_3$.[14] In 1984, Bamford confirmed that the manganese that is present in soda-lime glass is most often Mn^{2+} or Mn^{3+}, where Mn^{2+} seems susceptible to photo-oxidation to Mn^{3+} which gives the glass a purple hue.[15]

Based on the findings of Pelouze, Weyl explained the process of photo-oxidation in two steps. First, electromagnetic energy removes an electron from the Mn^{2+} cation, forming Mn^{3+}. Then, the free electron is trapped in the glass structure and eventually binds to iron Fe^{3+} cations that serve as electron acceptors, forming Fe^{2+}. Amal Paul (1937-1990), professor of Materials Science Indian Institute of Technology Kharagpur, agreed that in solarisation, an oxidation from Mn^{2+} to Mn^{3+} and a reduction of Fe^{3+} to Fe^{2+} takes place under UV radiation.[16] Weyl explained this process by arguing that the iron ions may sometimes serve as electron donors, under the assumption that not all ions of one certain type are equally willing to accept electrons. This competition for electrons appears to result in a decreased UV transmission through the glass, possibly explaining

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[9] Kolb, Doris. 'Oxidation States of Manganese'. *Journal of Chemical Education* 65, no. 11 (1988): 1004. https://doi.org/10.1021/ed065p1004.2.

[10] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23.

[11] *Ibidem*, 23.

[12] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (2022): 34. https://doi.org/10.21608/arcs.2022.135911.1025.

[13] Woldemar A. Weyl was head of the department of glass technology at the Kaiser Wilhelm Institute from 1932 until 1936. Pennstate Material Science Institute. 'Weyl: Wondemar Weyl'. Accessed 27 February 2025. https://www.mri.psu.edu/mri/newsmedia/pioneers-materials-gallery/weyl-wondemar-weyl.

[14] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 500.

[15] Bamford, C. R., *Colour Generation and Control in Glass*, 1. ed., 2. impression, Glass Science and Technology 2 (Amsterdam: Elsevier, 1984), 51-52.

[16] Paul, A. *Chemistry of Glasses*. 2nd ed. London ; New York: Chapman and Hall, 1990, 332.

the differences in the colour produced by a solarised glass and glass produced under oxidising melting conditions.[17] Furthermore, Weyl stated that glasses containing both manganese and arsenic (As) are especially susceptible to solarisation.[18] Paul explained that in the process of solarisation, As^{5+} ions in the glass accept photo-electrons to reduce to As^{3+}. He argued that this reduction of arsenic results in the oxidation from Mn^{2+} to Mn^{3+}.[19]

Even though it is now established that solarised manganese-containing glass has a purple hue, the exact shade and intensity of the colour can vary depending on the conditions. According to Bamford, the specific colour and its intensity do not only seem to be determined by the equilibrium of Mn^{2+} and Mn^{3+} present in the glass, but also its thickness may influence the distribution and intensity of colour — with decreasing intensity from the surface into the body of the glass.[20] In addition, Baldwin stated that the length of UV exposure and whether or not the glass was placed behind a window may also affect the colour intensity. When placed behind a window, manganese-containing glasses appeared to solarise less than when directly exposed to UV radiation. Given that UVB does not transmit through window glass, this suggests that not only UVA — which is partly transmitted through window glass — but also UVB radiation may play an important role in the process of solarisation.[21]

Baldwin mentioned the use of intense UV lamps, or even UVC containing germicidal lamps, to purposely solarise glasses.[22] The corresponding wavelengths of the types of electromagnetic radiation can be seen in figure 2.1.1.[23] That glass collectors purposely

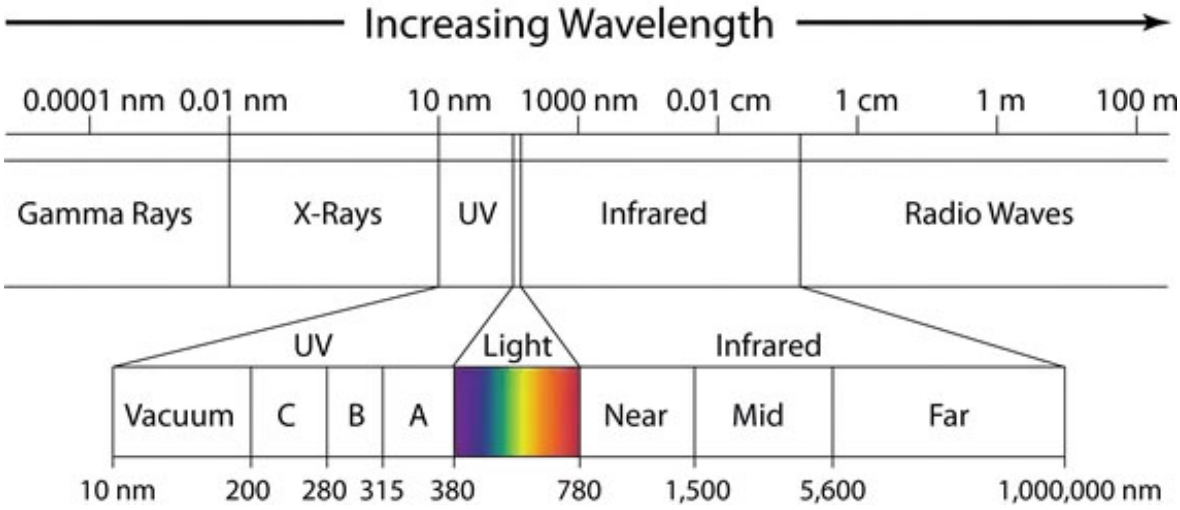


Figure 2.1.1: Overview of wavelengths of the electromagnetic spectrum. (Source: apniPhysics.com, 2023)

[17] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 501.

[18] *Ibidem*, 129.

[19] Paul, A. *Chemistry of Glasses*. 2nd ed. London ; New York: Chapman and Hall, 1990, 332.

[20] Bamford, C. R., *Colour Generation and Control in Glass*, 1. ed., 2. impression, Glass Science and Technology 2 (Amsterdam: Elsevier, 1984), 51-52.

[21] Michalski, Stefan. 'Agent of Deterioration: Light, Ultaviolet and Infrared'. Canada Conservation Institute, 17 May 2018. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html. Accessed 5 June 2025.

[22] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23.

[23] Kumar, Sushil. *Electromagnetic Spectrum | Electromagnetic Wave Spectrum*. 7 October 2023. https://apniphysics.com/electromagnetic-spectrum/. Accessed 1 August 2025.

expose glass to radiation sources to make it discolour was also described by Elaine Henderson, a collector of Early American Pattern Glass, a type of glass that is known to often solarise. In 2005, Henderson wrote in the magazine of the West Virginia Museum of American Glass that glass dealers intentionally turned 19th century American glasses purple. This was done to (mis)lead buyers to believe the glass was older than it actually was. Initially, the discolouration was achieved using UV radiation, but since this process could take up to a month and the light amethyst colour was not considered deep enough, UV radiation was replaced by X-ray to speed up the process and deepen the final colour of the glass.[24] Other authors, such as Lokay, another glass collector, also mentioned that X-ray was used for this purpose.[25] However, neither of the authors gave any evidence supporting the claim that X-ray has been used to purposely solarise glass. It is important to mention that when X-ray is used for analytical purposes, the exposure time generally is very short.

2.3 Discussion

Although all above discussed authors seem to agree that both decolouration and solarisation depend largely on the interplay between manganese and iron, there seems to be some disagreement about the oxidation states in which the manganese occurs. While Baldwin suggested that manganese oxidises from Mn^{4+} to purple Mn^{7+}, Pelouze, Weyl, Bamford, Davison and Abd-Allah all seem to have identified the oxidation of manganese from Mn^{2+} to Mn^{3+}, in combination with blueish-green Fe^{2+}. The balance between manganese and iron oxide ions seems to be the base of both decolouration and solarisation. Given that Fe^{2+} is blueish-green and Mn^{3+} has a pink coloured hue, it makes sense that the glass emits a purple hue after solarisation. Since multiple authors over a long period of time seem to agree about the role of Mn^{2+} and Mn^{3+} in these processes, this scenario seems most likely.

The chemical complexity of decolourisation and solarisation is emphasised even further when looking at other elements that possibly play a role in these processes. For example, Weyl highlighted that arsenic in combination with manganese may increase susceptibility to solarisation.[26] Paul agreed and explained that the photo-induced reduction of As facilitates the oxidation reaction of Mn.[27] In addition, Abd-Allah pointed out fluorine, phosphorus, and zinc oxides as possible elements that influence the glass colour, through interaction with iron ions. Furthermore, Baldwin stated that the final colour of manganese-containing glass is influenced by additional elements, such as lead, barium, soda, and potash.

This shows that it is unclear what exact influence different glass compositions have on the final colour and the solarisation process. Moreover, Baldwin's statement about varying UV radiation conditions raises the question of whether external factors and glass compositions affect each other during solarisation, giving relevance to this study, in which three case study objects with different compositions have been exposed to varying conditions.

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[24] Henderson, Elaine. 'Shedding Light on "Sun Purple" Glass'. All About Glass: The Magazine of the West Virginia Museum of American Glass, 2005.

[25] Lokay, J.D. '"Sun-Purpled" Glass'. *Heisey News*, October 1999.

[26] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 129;

[27] Paul, A. *Chemistry of Glasses*. 2nd ed. London ; New York: Chapman and Hall, 1990, 332.

3. State of the art — Historical context of manganese as decolourant

After gaining a better understanding of the chemistry behind solarisation and the role of decolourisation therein, it is important to also explore the historical context in which this latter process has been used and researched. This places this research within a broader context and highlights the current state of knowledge as well as the areas that remain less thoroughly researched. In addition, hopefully this will help identifying specific collections —from certain periods of time and/or production locations — that potentially have a higher risk to be susceptible to solarisation.

3.1 Historical use of manganese as a decolourant for glass

There are three ways to overcome unwanted colour in glass, resulting from impurities in the glass mix. In the first place, glass makers could use very pure sand with minimal levels of iron for the glass melt. Secondly, oxidising firing conditions could be used to reduce the colour. However, often this does not result in perfectly clear glass. The third option is to add a complementary colour to counteract the colour of the impurities in the glass mix.[28] Because high quality sand without impurities is very expensive, a decolourising agent is often used as an affordable alternative.[29] As was mentioned in the previous chapter, manganese dioxide was a common decolourant in the case of green glass caused by iron impurities.

Manganese has been found in Egyptian glass dating back to 1400 BCE, but there is no evidence that it was intentionally added as a decolourant.[30] In 2022, Abd-Allah stated that manganese dioxide was first used as a decolourant in the second century BCE. For example, Roman glass often contained 0.5-1% manganese oxide.[31] According to Davison, manganese has been increasingly used as a decolourant since the first century CE.[32] It was probably introduced as a mineral called pyrolusite, as was also mentioned in the previous chapter. In the first century CE, Pliny the Elder (23-79 CE), as cited by Abd-Allah, mentioned that sand from the river Volturno produced remarkably clear glass. According to Abd-Allah, this specific sand contained 0,5% manganese.[33] Pliny the Elder, as cited by Biser, described the use of manganese as “To the materials of glass they

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[28] Lockhart, Bill. ‘The Color Purple: Dating Solarized Amethyst Container Glass’, Historical Archaeology, 40, no. 2 (2006): 46.

[29] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 31. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[30] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 122.

[31] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 39. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[32] Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 78.

[33] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 32. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

begin to add the magnetic stone".[34] The "magnetic stone" mentioned here is likely pyrolusite. According to Abd-Allah, until the 9th century, Islamic glasses were predominately decoloured with antimony (Sb) or an antimony/manganese mixture.[35] From the 9th century, the use of antimony declined and the manganese content in the glass mixture increased.[36]

One of the earliest publications found to date was written by Christopher Merret in 1662. In his comments at the end of his translation of *The Art of Glass* by Antonio Neri, Merret specifically mentioned the use of manganese as a decolourant. On page 282 of this translation, he writes that

> "*Manganese … is the most universal material used in glass, not onely to purge off the natural Greenish Blewish colour so call'd by Vergil 4. Georg.*"[37]

In the translation of the original text by Neri, originally from 1612, the use of manganese as a decolourant was not mentioned. According to Merret's translation, Neri only wrote about using manganese to colour glass.[38] This suggests that somewhere between 1612 and 1662, it became more widely known that manganese could be used as a decolourant to counteract the green-blue natural hue of iron impurities in glass.

Since the 19th century, manganese has been used as a decolourant on a large scale for industrial glass in the United States. According to Bill Lockhart, a professor emeritus of New Mexico State University, colourless glass especially gained importance for use in windows and tableware, before being more generally used for containers.[39] In 2006, he conducted a study to determine the exact period in which the decolourising agent was used. Two factors made it difficult to pinpoint an exact date; the process and the terminology for glass making. For example, not all producers of glass in the United States would have changed their production process at the same time. In addition, the terminology creates difficulties, because the term "colourless" did not always refer to the same meaning as "clear", "white", "flint" or "crystal". Furthermore, these terms were not consistently used. Not only for colour there was variation in terminology, also when referring to the glass composition there were inconsistencies. For example, in first place the term "flint" was used to describe lead glass, but later on the same term could be used to describe glass made from pure sand or glass for which a decolourant was used to make it clear.[40]

Lockhart came up with three possible options that could be seen as the start of the industrial use of manganese as a decolourant in the United States. In the first place, he suggests 1870, because this seems the earliest known year in which the use of manganese as a decolourant is mentioned by the glass producer Whitall Tatum & Co.

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[34] Biser, Benjamin Franklin. *Elements of Glass Making*. Pittsburgh: Glass and pottery Publishing Company, 1899, 43.

[35] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 33. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[36] *Ibidem,* 31.

[37] Neri, Antonio. *The Art of Glass*. Translated by Christopher Merret. 1662, 282. Archive.org. https://archive.org/details/TheArtOfGlassWhereinAreShownTheWayesToMakeAndColourGlass/neri-a-art-1662-RTL014704-LowRes/. Accessed 8 June 2025.

[38] *Ibidem,* 28.

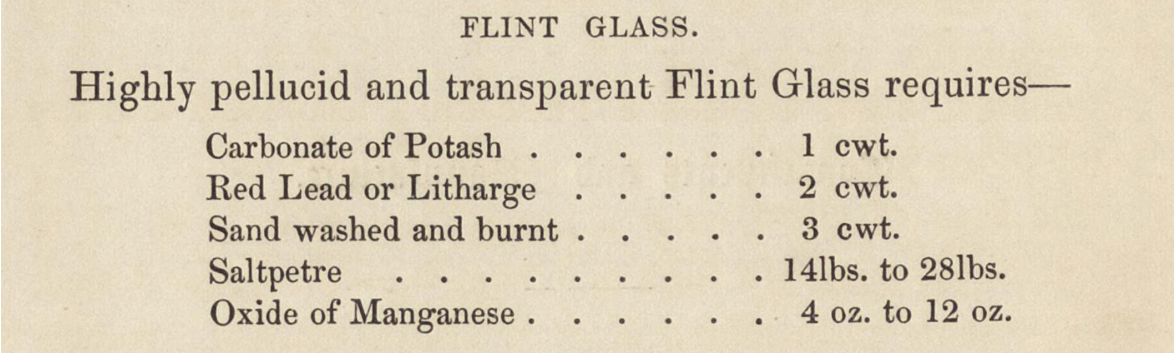
[39] Lockhart, Bill. 'The Color Purple: Dating Solarized Amethyst Container Glass', Historical Archaeology, 40, no. 2 (2006): 46.

[40] *Ibidem,* 50-51.

Secondly, although it was mentioned before, from the late 1880s onwards manganese seemed to become more generally used. Finally, Lockhart suggested to use different starting dates for different types of glass objects, since manganese has been used as a decolourant in drug store bottles from 1870, milk bottles from the mid 1880s and soft drink bottles from the mid 1890s.[41]

3.2 Glass recipes with manganese as a decolourant

Although a comprehensive research of historic recipes was outside the remit of this research, one recipe has been found that is interesting, because it emphasises manganese specifically as a decolourant. This recipe was written by Apsley Pellatt (1793-1863), English glassware manufacturer and politician, son of glassware maker also called Aplsey Pellatt of the company Pellatt and Green. The recipe was published in his book *Curiosities of Glass Making* in 1849, which describes the family's manufacturing techniques.[42] Pellatt provides a 'base recipe' to make a batch of clear glass, which can be seen in figure 3.2.1. This recipe consists of Carbonate of Potash (potassium carbonate, K_2CO_3), Red Lead (Pb_3O_4) or Litharge (PbO), Sand (washed and burnt, possibly to remove organic contaminants and impurities), Saltpetre (potassium nitrate, KNO_3) and Oxide of Manganese (pyrolusite, MnO_2).[43]



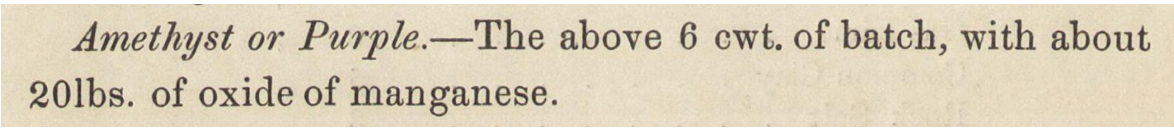
FLINT GLASS.

Highly pellucid and transparent Flint Glass requires—

Carbonate of Potash	1 cwt.
Red Lead or Litharge	2 cwt.
Sand washed and burnt	3 cwt.
Saltpetre	14lbs. to 28lbs.
Oxide of Manganese	4 oz. to 12 oz.

Figure 3.2.1: The base recipe Pellatt gives to produce clear glass. (Pellatt, 1849, page 34)

Furthermore, Pellatt provided several options to adjust this batch to produce glass of specific colours, among which is a recipe for amethyst or purple glass. According to Pellatt, this could be achieved by adding a larger amount of manganese oxide, as can be seen in figure 3.2.2.



Amethyst or Purple.—The above 6 cwt. of batch, with about 20lbs. of oxide of manganese.

Figure 3.2.2: Additions suggested by Pellatt to adjust the colour of a base batch of colourless glass. (Pellatt, 1849, page 34)

[41] Lockhart, Bill. 'The Color Purple: Dating Solarized Amethyst Container Glass', Historical Archaeology, 40, no. 2 (2006): 52.

[42] Pellatt, Apsley. *Curiosities of Glass Making*. With Getty Research Institute. D. Bogue, 1849, 34. Getty Research Institute. https://archive.org/details/gri_33125008683704. Accessed 28 October 2024.

[43] Bray, Charles. Dictionary of Glass: Materials and Techniques. 2. ed. A & C Black [u.a.], 2001, 162, 197 and 206.

He also stated that using coal during the melting process creates a smoky, and therefore reduced, environment. As a result, if the glass was previously colourless, it would now have a greenish tint.

Pellatt comments:

> "*… carbon would seem to be a neutralizer of oxygen, and practically a dissipater of the colour, caused by manganese.*"

Furthermore, he mentions that the purple tint of the manganese or the greenish hue from the iron are not only superficial, but throughout the entirety of the glass.[44] As explained in the previous chapter, this might indicate that the sand Pellatt used for his recipes contained iron impurities.

How manganese is used as a decolourant is also discussed by William Gillinder (1823-1871) in 1854, as cited by Weyl in 1951. Gillinder, an English glassmaker, purchased the American glassmaking company Samuel's Bottle Factory in Philadelphia, Pennsylvania, in 1861. This acquisition led to the creation of the Philadelphia Flint Glass Works. Today, Gillinder Glass remains an active glassmaking company.[45] Gillinder suggested that it is better to add slightly too much pyrolusite than too little, possibly resulting in a purple glass. However, he argued that adding too much pyrolusite did not impose significant problems, as it was relatively easy to reduce this colour by blocking oxygen from entering the melt, either by using organic material like wood or by immersing pieces of arsenic in the hot glass. However, as mentioned in chapter 2.3, adding arsenic could result in the glass being more susceptible to solarisation.[46] In 1899, Biser agreed that the purple colour resulting from using too much pyrolusite could be prevented by adding arsenic in the form of arsenous acid (H_3AsO_3). He also suggested that a potato or an apple could be added to the mixture, or that stirring the mixture with a stick of green wood could create a more reduced environment, achieving the same result.[47]

In 1884, William Leighton, a 19th century American glass maker, as cited by Lockhart, created a recipe for clear glass without the use of lead for the glasshouse Hobbs, Brockunier and Co.[48] It is not known whether or not Leighton's recipe contained manganese. However, this recipe did form the basis for another recipe, created by Whitall Tatum, which certainly did contain manganese. This became the most dominant recipe for inexpensive pressed table glass in the United States, because it was cheaper than lead glass and good to press in a mould.[49]

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[44] Pellatt, Apsley. *Curiosities of Glass Making*. With Getty Research Institute. D. Bogue, 1849, 69. Getty Research Institute. https://archive.org/details/gri_33125008683704. Accessed 28 October 2024.

[45] Jansure, Christina. *Gillinder History: The First Century*. 2023. https://www.gillinderglass.com/the-first-century. Accessed 8 August 2025.

[46] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 129.

[47] Biser, Benjamin Franklin. *Elements of Glass Making*. Pittsburgh: Glass and pottery Publishing Company, 1899, 53.

[48] Lockhart, Bill. 'The Color Purple: Dating Solarized Amethyst Container Glass', Historical Archaeology, 40, no. 2 (2006): 51.

[49] Jones, Olive, and Catherine Sullivan. The Parks Canada Glass Glossary for the Description of Containers, Tableware, Flat Glass, and Closures. Rev. ed. Studies in Archaeology, Architecture, and History. Ottawa, Ont: National Historic Parks and Sites, Canadian Parks Service, Environment Canada, 1989, 11.

3.3 Abandonment of manganese as a decolourant

At some point in time manganese was abandoned as a decolourant. However, it is difficult to determine what the exact date and reasons behind it were. Different authors have different opinions about this. For example, in 1899 Biser stated that the use of manganese as a decolourant was largely abandoned in European factories; especially recipes of window glass did not seem to contain manganese anymore.[50] He also mentioned that the experiments on solarisation conducted by Thomas Gaffield in 1863 — that are described in detail in the next chapter — may have played a role in this shift in the recipes.

Other authors estimate the date of the abandonment of manganese later in time. For example, Elaine Henderson stated that manganese was substituted by selenium (Se) as a decolourant in American factories around 1915.[51] While elemental selenium was first extracted in 1817 and used in glassmaking by 1865, it was primarily used as a colourant to create pink glass; almost a century later is was recognised as a decolourant.[52] This was confirmed by Baldwin, who stated that the substitution of manganese for selenium occurred in 1915. According to him, this was due to the outbreak of the first world war, as he claimed that Germany was one of the largest suppliers of manganese to the United States.[53]

However, this claim has been refuted by Lockhart, who found that before the first world war only 2,03% of all manganese imported to the United States was coming from Germany. The majority (58,2%) was imported from British India.[54] Nevertheless, Lockhart still suggested that the use of manganese became significantly less between 1915 and 1930. He appointed this to the introduction of automatic bottle machines, such as the Owen Automatic Bottling Machine. Since it was impossible to create an oxidising environment, which is necessary for manganese to act as a decolourant, in an automatic bottle making machine. Therefore, Lockhart argued, manganese was replaced by selenium, which can also be effective in a more neutral environment.[55]

3.4 Discussion

Over the past centuries, dating back to 1400 BCE, manganese has been found in different types of glass. The exact date from which a manganese-containing substance deliberately was used is difficult to pinpoint, which becomes clear from the literature, where different authors specify varying dates for the deliberate use of manganese as a decolourant, both on a small and large, industrial scale. Where Abd-Allah states that ancient Roman and Islamic glasses already contained manganese as a decolourant, from Merrit's translation it seems that this became more widely known somewhere between 1612 and 1662, but not before (based on Neri's text). According to Lockhart, in the

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[50] Biser, Benjamin Franklin. *Elements of Glass Making*. Pittsburgh: Glass and pottery Publishing Company, 1899, 44.

[51] Henderson, Elaine. 'Shedding Light on "Sun Purple" Glass'. All About Glass: The Magazine of the West Virginia Museum of American Glass, 2005.

[52] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 282.

[53] Baldwin, Rick. 'Decolorizing Glass With Manganese'. *Crown Jewels of the Wire*, July 1985, 23.

[54] Lockhart, Bill. 'The Color Purple: Dating Solarized Amethyst Container Glass', Historical Archaeology, 40, no. 2 (2006): 48.

[55] *Ibidem,* 53.

United States also on a large scale the exact start of the use of manganese as decolourising agent is difficult to determine.

Not only the first use of manganese as a decolourant is difficult to pinpoint, the same holds for the abandonment of its use. Whereas Biser states that the use of manganese was abandoned in 1899, because of increasing knowledge about solarisation, other authors, like Henderson, Baldwin and Lockhart, believe this was between 1915 and 1930, all providing varying reasons for the abandonment or substitution of manganese.

Unfortunately, based on the complex history of the use of manganese as a decolourant, it is difficult to create a clear timeline in which manganese was used as a decolourising agent. As a result, providing a strict guideline to potentially identify collections at risk of solarisation is difficult. However, the only thing that can be said with some certainty is that collections of pressed glass that have been produced in the United States between the last quarter of the 19th century up until the first quarter of the 20th century are likely to contain manganese as a decolourant. Therefore, these collections possibly have a higher risk of solarisation.

4. State of the art — Solarisation experiments

Now that more is known about the chemical mechanisms that drive solarisation, it is important to also determine the external parameters that influence this process, to gain a full understanding of solarisation. For this purpose, three previously conducted experimental studies will be highlighted in this chapter: one historical experiment, one conducted on special, modern optical glasses and one conducted on historical glass. This will provide a foundation for the experiments discussed in section II.

4.1 Thomas Gaffield, 1863

Extensive historic solarisation experiments have been conducted by Thomas Gaffield, and published in the Journal of the Society of Arts. Gaffield was a glass manufacturer and member of the Massachusetts Institute of Technology Corporation.[56] His research on the action of sunlight on glass involved a systematic and thorough methodology to test how various types of glass responded to exposure to sunlight. In 1863, Gaffield exposed 33 different types of plate glass, crown glass and sheet glass to direct sunlight for a period of two years.[57] He included glass from different manufacturers and different countries, namely from France, Germany, England, Belgium and America. These samples included both coloured and (nearly) colourless glasses. Knowing the compositions of the used glasses is difficult, because the terms describing glass were not used consistently, as described by Bill Lockhart (see paragraph 3.1 of section I).[58] Gaffield did not talk about the composition of the glasses he tested in depth. For some glasses, he mentioned they were crystal or lead glass, but for most samples he only discussed the type of glass (plate, crown or sheet) and the country of origin.[59]

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[56] ‘Thomas Gaffield Papers’. Massachusetts Institute of Technology. Libraries. Department of Distinctive Collections. Accessed 30 April 2025. https://archivesspace.mit.edu/repositories/2/resources/685.

[57] Gaffield, Thomas. ‘The Action of Sunlight on Glass’. *American Journal of Science*, 1867, 224–252.

[58] Lockhart, Bill. ‘The Color Purple: Dating Solarized Amethyst Container Glass’, Historical Archaeology, 40, no. 2 (2006): 50.

[59] Gaffield, Thomas. ‘The Action of Sunlight on Glass’. *American Journal of Science*, 1867, 249.

Gaffield prepared the samples by cutting them in pieces of the same size. After this, the samples were fitted horizontally in wooden boxes and placed horizontally on his rough plate-glass roof in Boston to maximise the exposure to direct and reflected sunlight throughout most of the day, of each type of glass he also kept a control sample in the dark. For the winter or periods with bad weather, Gaffield created a special wooden box for his samples, which could be attached to the outside of south-facing windows to make sure snow or severe rainfall would not cover them.[60]

The colour change of the samples was assessed visually by comparing the colour of the exposed glass to that of the non-exposed. He inspected the samples according to a systematic schedule. Initially, he inspected the glass daily, subsequently at weekly, monthly and eventually at longer intervals. During every inspection, he carefully noted down the changes, which allowed him to chart progressive changes over a period of time and the precise moment when visible colour change first occurred. He also researched the depth of the colour change. Samples that had undergone significant colour change were ground down approximately 0,16 centimetres from all sides and re-polished. Gaffield found that the colour change stayed constant throughout the thickness of the glass.[61] This contrasts with Bamford's claim from 1984 that the purple colour caused by solarisation is not evenly distributed throughout the thickness of the glass, but extends with decreasing intensity from the surface into the body of the glass.[62]

Further tests by Gaffield aimed to determine whether seasonal changes affected the amount of solarisation. He conducted several controlled, smaller experiments during different months and seasons. With these experiments he found that solarisation occurred more quickly during the summer and the slowest change occurred in the winter. This lead Gaffield to conclude that during the summer the light of the sun had the highest actinic power — the highest ability to cause a chemical change.[63]

To determine whether the colour change was really due to light, Gaffield also conducted tests with heat and moisture. Samples were put in elevated temperatures, ranging from cooking ovens to a glass stainer's kiln (approximately 650°C). This did not result in any colour changes in the samples.[64] When samples were submerged in hot water in the dark and while exposed to sunlight, the discolouration was the same as when exposed without water. Gaffield concluded that the discolouration was not influenced by temperature, humidity or general atmospheric pressure, but solely due to exposure to sunlight.[65]

Gaffield found that of the 33 samples of glass he exposed, 24 had changed colour and only 9 showed no difference in colour when exposed to sunlight for three months. He conducted another experiment lasting an entire year and found that most of the 9 nine glasses that initially did not change colour, did change colour after a year. Only one piece

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[60] Gaffield, Thomas. 'The Action of Sunlight on Glass'. *American Journal of Science*, 1867, 247.

[61] *Ibidem,* 245.

[62] Bamford, C. R., *Colour Generation and Control in Glass*, 1. ed., 2. impression, Glass Science and Technology 2 (Amsterdam: Elsevier, 1984), 51-52.

[63] 'Actinic, Adj.' In *Oxford English Dictionary*, 3rd ed. Oxford University Press, 2023. Accessed 30 April 2025. https://doi.org/10.1093/OED/1138829715.

[64] Hicks, Carola, Virginia Chieffo Raguin, Nigel J. Morgan, and M. B. Shepard. 'Stained Glass'. In *Oxford Art Online*, by Carola Hicks, Virginia Chieffo Raguin, Nigel J. Morgan, and M. B. Shepard. Oxford University Press, 2003. https://doi.org/10.1093/gao/9781884446054.article.T080866.

[65] Gaffield, Thomas. 'The Action of Sunlight on Glass'. *American Journal of Science*, 1867, 252.

of glass, that Gaffield described as ‘crystal’ or ‘lead’ glass, did not show only discolouration after two years of exposure.[66]

4.2 Ralf Jedamzik, 2022

Ralf Jedamzik is a principal scientist specialised in optical glass at SCHOTT AG, a German multinational glass company specialised in the manufacture of glass and glass-ceramics. He performed solarisation experiments on several types of optical glass.[67] This is a type of glass that is specifically manufactured for lens and prism production.[68] Solarisation is unwanted for these types of glasses, because the discolouration lowers the light transmittance of the glass. According Jedamzik, it was previously believed that solarisation could only occur due to UV light and that the effects of solarisation due to visible light were negligible. However, a specific N-type glass, N-BK7HT, showed strong solarisation effects induced by a high intensity blue laser. According to SCHOTT AG, N-type glasses are environmentally friendly alternatives to conventional lead and arsenic containing glasses.[69] SCHOTT AG does not provide any information about the exact composition of this type of glass, possibly due to trade secrets, so it cannot be said with certainty whether or not the glasses contained manganese. Because of this unexpected solarisation, Jedamzik also started experiments using other N-type glasses such as N-FK51A, N-PK51 and N-LAF33.

For the experiments, Jedamzik used both UV and high-intensity blue light radiation to investigate the formation of colour centres, which act as absorption sites.[70] Colour centres are defined as areas within a lattice where there is a discontinuity. This occurs when a negative ion is replaced by an electron, often as a result of exposure to intense radiation.[71] To induce the colour centres with a UV containing radiation source, Jedamzik used a Philips Mercury high-pressure gas-discharge lamp (type HOK-4/120, 400 W). This lamp predominately emits UVA radiation, but also emits significant amounts of both UVB and UVC. In the article, Jedamzik only mentions the UVA and UVC intensities of the lamp, respectively 151.2 Joule per cm² (J/cm²) per hour and 90 J/cm² per hour, when the lamp was 70 mm away. The samples Jedamzik used ranged in thickness from 0,5 mm to 100 mm and during the experiments the samples were kept at 100 °C (± 5°C).

The samples were irradiated for 96 hours. Jedamzik measured the difference in transmittance of wavelengths between 250 nm and 850 nm before and after irradiation of the sample to determine if a sample had solarised. He measured this difference with a

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[66] Gaffield, Thomas. ‘The Action of Sunlight on Glass’. *American Journal of Science*, 1867, 249–251.

[67] Jedamzik, Ralf, Volker Dietrich, Axel Engel, and Uwe Petzold. ‘Solarization Effects in Optical Glass from UV to Blue’. In *Optical Manufacturing and Testing XIV*, edited by Heidi Ottevaere, Rolf Rascher, Daewook Kim, and Heejoo Choi, 9. San Diego, United States: SPIE, 2022. Accessed 18 October 2024. https://doi.org/10.1117/12.2632359.

[68] Kumar, Nitesh, Niladri Mandal, and Alok Kumar Das. ‘Microelectrochemical Sparks Machining: A Modern Approach for Fabrication of Microcomponents from Nonconductive Materials’. In *Micro Electro-Fabrication*, 277–315. Elsevier, 2021. https://doi.org/10.1016/B978-0-12-820049-0.00012-8.

[69] SCHOTT. ‘N-FK51A’. Manufacturer website, 2025. https://www.schott.com/shop/advanced-optics/en/Optical-Glass/N-FK51A/c/glass-N-FK51A. Accessed 6 June 2025.

[70] Jedamzik, Ralf, Volker Dietrich, Axel Engel, and Uwe Petzold. ‘Solarization Effects in Optical Glass from UV to Blue’. In *Optical Manufacturing and Testing XIV*, edited by Heidi Ottevaere, Rolf Rascher, Daewook Kim, and Heejoo Choi, 9. San Diego, United States: SPIE, 2022. Accessed 18 October 2024. https://doi.org/10.1117/12.2632359.

[71] Saunders, David. *Colour, Colour Measurement and Colour Change*. 1st ed. Science for Conservators. London: Routledge, 2024, 48. https://doi.org/10.4324/9781003397182.

Perkin Elmer Lambda 950 spectral photometer. Jedamzik based his setup on the Japanese JOGIS Standard Setup JOGIS 04-2019. According to this standard, samples measuring 30 mm by 13 mm by 10 mm are irradiated at 30 mm distance by a 100 W mercury lamp for four hours. He deviated slightly from this standard. However, according to him, the 400 W lamp he used gives a comparable intensity at a distance of 70 mm.

4.3 Ramadan Abd-Allah, 2022

Abd-Allah described solarisation experiments in two articles, published in 2009 and 2022. He aimed to provide insights in the mechanisms and causes of solarisation in historical glass and present an overview of the scientific and historical literature about both decolouration and solarisation. For his tests, Abd-Allah specifically chose historic glass samples of which he knew that they contained non-oxidised manganese, these were identified as soda-lime-silica (Na_2O-CaO-SiO_2) glasses. The presence of non-oxidised manganese made it possible to artificially photo-oxidise, and hence solarise, these samples. To examine the effect of glass composition on solarisation, the chemical composition of the samples was determined using Atomic Absorption Spectrophotometry.[72]

For this experiment Abd-Allah used an Atlas UV2000 weathering devise, which emits UVA at a wavelength of 340 nm.[73] Abd-Allah did not mention the intensity of the UV setup he used, making it difficult to compare this with other setups. In general, the Atlas UV2000 has an intensity of 0.072 J/cm² per hour to 0.396 J/cm² per hour at a distance of 70 mm.[74] Therefore, this is assumed to be the intensity of the weathering devise that Abd-Allah used. The samples were irradiated continuously for one month at 70 mm from the light source. During the irradiation, the samples were kept at approximately 90 °C. According to Abd-Allah, five hours of exposure in this setup is similar to one year of natural outdoor UV exposure, without clarifying this any further.[75] However, as will be explained in chapter 6 of section I, average outdoor UV exposure can vary depending on the location.

To measure whether his samples had solarised, Abd-Allah used several methods. He visually analysed the colour of the samples using both optical microscopy and a magnifying lens. He also measured the colour of the samples with a spectral photometer, within a wavelength range of 250 nm to 2500 nm. Abd-Allah found that the glasses that solarised were characterised by a high manganese content with an average of 0.904%.[76]

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[72] Abd-Allah, Ramadan. ‘Solarization Behaviour of Manganese Containing Glass: An Experimental and Analytical Study’. *Mediterranean Archaeology and Achaeometry* 9, no. 1 (2009): 44.

[73] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 30–41. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[74] ‘UV Weather-O-Meter UV 2000’. Central Institute of Road Transport India, 2016. Accessed 30 April 2025. https://www.cirtindia.com/testing_UVWeather.html.

[75] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 38. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[76] *Ibidem*, 38.

4.4 Discussion

The solarisation experiments conducted by Thomas Gaffield, Ralf Jedamzik, and Ramadan Abd-Allah represent diverse research purposes and methodologies. Gaffield's historical research focused on understanding the action of sunlight on various glass types commonly used in the 19th century. This study provided knowledge on solarisation effects in different historical glass compositions. In contrast, Jedamzik's industrial tests aimed to improve the performance of modern optical glasses needed for technological applications where light is transmitted through the glass. The research performed by Abd-Allah is the only one found that specifically focused on historical glass for conservation purposes.

Not only the aims, but also the glass compositions in the described experiments varied. Gaffield's samples included a range of plate, crown, and sheet glasses from multiple countries, of which he only occasionally mentioned whether it was crystal or lead glass. Jedamzik tested environmentally friendly N-type optical glasses, with undisclosed compositions, of which it is not known whether or not they contained manganese, but certainly did not contain arsenic. Abd-Allah's samples were soda-lime-silica glasses, with a known high manganese content, deliberately chosen to study solarisation processes.

Regarding lighting and UV exposure, Gaffield relied solely on natural sunlight, maximising radiation through prolonged outdoor exposure. Jedamzik employed intense artificial UV and blue light sources, notably a 400 W Philips Mercury lamp, exposing samples to UVA and UVC radiation at specific intensities over 96 hours. Abd-Allah used an Atlas UV2000 weathering device emitting UVA at 340 nm, continuously irradiating samples for a month at controlled temperatures.

This variation in light sources, temperatures, exposure durations and detail of compositional descriptions made it difficult to compare the experiments, and draw conclusions about the specific parameters that influence solarisation. This gives relevance to the present research, that aims to explore the effect of varying lighting conditions on the solarisation of manganese-containing glass in a controlled setting, as described in section II.

5. State of the art — Contemporary conservation literature

One of the aims of this research is to hopefully enable both museums and individual collectors to safely display their works of glass, with respect to lighting conditions and solarisation. For this reason, it is relevant to learn what aspects of solarisation have already been discussed in contemporary glass conservation literature. In two commonly-used glass conservation publications — by Stephen P. Koob and Sandra Davison — solarisation was mentioned. However, both Koob and Davison only mention it briefly, indicating that it is not generally considered a major issue.

In 2006, Koob stated that in general glass is not affected at all by bright light, even when it contains UV, except for glasses that were decolourised with manganese.[77] He provided multiple examples of outdoor glasses that solarised throughout recent history. For example, he mentioned solarised streetlight globes in Venice, 18th century windowpanes in the State Hermitage museum in St. Petersburg and 19th century window glass in the British Museum.[78] However, he did not discuss solarisation of vessel glass in collections,

[77] Koob, Stephen P. *Conservation and Care of Glass Objects*. London: Archetype Publ. [u.a.], 2006, 135.

[78] *Ibidem,* 139.

nor does he give indications of how long glass should be exposed to UV light before it will solarise or what type of UV light induces solarisation.

A few years later in 2011, Sandra Davison also gave a brief description of what solarisation is and stated that the process is particularly noticeable in 19th century window glasses.[79] She also mentioned that solarisation can affect collection glass, but in much lesser extent than in situ window glass.[80] However, she did not provide any examples of the solarisation of vessel glass.

5.1 Discussion

The solarisation of manganese-containing glass is briefly mentioned in two commonly used glass conservation texts by Sandra Davison and Stephen P. Koob. This suggests that solarisation is not considered a major hazard for glass collections. Both authors agree that in situ window glass is significantly more at risk of solarisation compared to other types of collection glass. However, neither author provides specific details about the conditions under which solarisation occurs, nor offers solutions to prevent it. Although solarisation may not be considered a major risk for glass collections, it is known to occur in manganese-containing glass. Therefore, learning more about the conditions in which solarisation can occur is relevant in order to prevent it.

6. State of the art — Museum lighting standards

In order to understand the issue of possible solarisation in museum collections, it is important to understand museum lighting standards. The choice of lighting in a museum setting is not only based on which light source is the least damaging to the objects displayed. Another factor that is taken into account is how the human visual system responds to different levels and colour properties of the lighting, including what is deemed to be adequate, comfortable and pleasant. These are the so-called human factors.[81] An important factor for museum lighting is the level of the lighting. In general, visitors prefer higher levels of lighting, as this makes it easier to see small details in object. However, this is contrary to what conservators often advise, as higher levels of lighting may cause more damage to certain objects.[82]

Currently, there are three standard texts to determine proper museum lighting conditions. These include (1) ‘Agents of Deterioration: Light, Ultraviolet and Infrared’ by Stefan Michalski from the Canada Conservation Institute (CCI), (2) ’Museum Lighting: A Guide for Conservators and Curators’ by David Saunders from the British Museum and (3)

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[79] Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 193.

[80] *Ibidem,* 174.

[81] Saunders, David. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles: The Getty Conservation Institute, 2020, 156.

[82] Michalski, Stefan. ‘Agent of Deterioration: Light, Ultaviolet and Infrared’. Canada Conservation Institute, 17 May 2018. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html. Accessed 5 June 2025.

'Light as an Agent of Deterioration' in The National Trust Manual of Housekeeping.[83] While the recommendations of the CCI and British Museum consider the optimal light levels for visitors, The National Trust only focusses on the sensitivity of the materials displayed.[84] This might be due to the fact that The National Trust specifically focuses on historic houses. Within these houses, the options for light control might be limited and generally they have collections of mixed materials on display. The National Trust advises 50 (sometimes 80) lux for sensitive material and 200 lux for less sensitive material.[85] The British Museum largely agrees, but adds that highly sensitive objects are recommended to be lit at 50 lux, only for a proportion, usually 10%, of the year.[86] The CCI argues that this rule-based approach may not be optimal, especially for smaller museums that do not always have the possibility to control museum conditions very precisely. Rather, they recommend a strategy of risk-assessment in which they created a light damage calculator to enable museums to address individual objects, to take action only for highly light sensitive objects.[87]

The recommendations by The National Trust and CCI also specifically state that it is important to minimise the amount of UVA light in display lighting. They both suggest that light sources used in displays should not exceed a UV level of 75 microwatts per lumen. The National Trust also suggests that UV filters applied to windows should allow no more than 20 microwatts per lumen to pass through. In addition, the filters should be replaced when a level of 75 microwatt per lumen is reached. The British Museum suggests stronger filters, which only admit 10 microwatt per lumen, arguing that the former limit of 75 microwatts per lumen was "overly generous".[88] The CCI does not specify a filter strength, but only mentions the 75 microwatt per lumen norm.

The importance of UV filters on windows differs per area. For example, there seem to be large irradiation differences between the Netherlands and the south of the United States of America, where glasses were purposely solarised, as described in chapter 2.2 of section I. These differences show that it is important to consider the geographic location of the object — if it is exposed to sunlight — when assessing its susceptibility for solarisation of glass.

Assuming that in museum environments at most there is a UVA irradiation of 75 microwatts per lumen, and a maximum light level of 200 lux, the yearly UVA the objects would receive would be 15.768 J/cm^2. How this is calculated, can be seen in appendix I. This would be the maximum radiation an object would be able to receive if it was in direct sunlight through a window with a UV filter, when the museum would be open for 8 hours

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[83] Michalski, Stefan. 'Agent of Deterioration: Light, Ultraviolet and Infrared'. Canada Conservation Institute, 17 May 2018. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html. Accessed 5 June 2025; Saunders, David. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles: The Getty Conservation Institute, 2020. ; National Trust, ed. 'Light as an Agent of Deterioration'. In The National Trust Manual of Housekeeping: Care and Conservation of Collections in Historic Houses, Rev. ed., 93–101. Wiltshire: National Trust, 2011.

[84] Saunders, David. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles: The Getty Conservation Institute, 2020, 206.

[85] National Trust, ed. 'Light as an Agent of Deterioration'. In The National Trust Manual of Housekeeping: Care and Conservation of Collections in Historic Houses, Rev. ed., 96. Wiltshire: National Trust, 2011.

[86] Saunders, David. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles: The Getty Conservation Institute, 2020, 202.

[87] Michalski, Stefan. 'Agent of Deterioration: Light, Ultraviolet and Infrared'. Canada Conservation Institute, 17 May 2018. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html. Accessed 5 June 2025.

[88] Saunders, David. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles: The Getty Conservation Institute, 2020, 287.

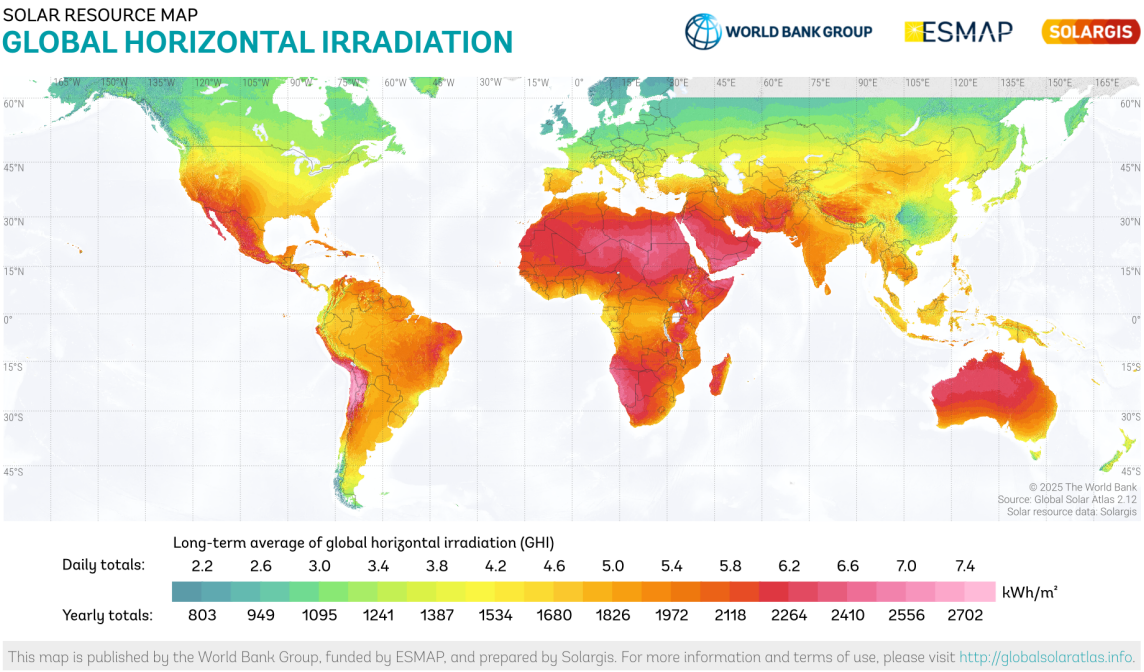


Figure 6.1: A map showing global horizontal UV irradiation in kWh/m^2. (Source: World Bank Group, 2025)

a day, 365 days a year and the lights and blinds would be shut outside of the opening hours. If the object would be displayed in a case, or would not be in the direct light, the UVA dose would be lower. As long as an object is placed inside and there is glass in the windows, the object would not be exposed to UVB, as this will be blocked out by regular window glass.[89] If no protective filter would be used, it is difficult to provide a general statement about the dose of UVA an object would receive. Many factors would influence this, including the object's position relative to the window, the window's direction, and the object's location on earth. Figure 6.1 shows the average annual horizontal irradiation, showing regional differences in kWh/m^2 between different countries.[90]

6.1 Discussion

In two of the most commonly used contemporary standard works, highly sensitive objects are recommended to be lit at 50 lux — although the British Museum added a restriction in which the most sensitive objects can only be displayed for a proportion of the year. The proposed standards by the CCI seem to indicate a shift in thinking about lighting in museum collections. They propose moving beyond the rule-based approach that has been used for years, to motivate smaller museums to identify and conserve at-risk objects. These different approaches might be the result of differences in their focus, as both the British Museum and the CCI seem to balance conservation issues and visitor experience, while The National Trust recommendation is primarily conservation-driven.

[89] Michalski, Stefan. 'Agent of Deterioration: Light, Ultraviolet and Infrared'. Canada Conservation Institute, 17 May 2018. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html. Accessed 5 June 2025.

[90] Global Solar Atlas 2.12, and Solargis. 'Global Horizontal Irradiation'. The World Bank, 2025. https://globalsolaratlas.info/download/world. Accessed 6 June 2025.

Recently, there seems to be a shift in focus from lux to UV. The CCI and The National Trust recommend a maximum UV radiation of 75 microwatts per lumen, while the British Museum suggests an even lower level. All three works stress the importance of placing and maintaining UV filters on windows. Given that UV radiation likely induces solarisation, these guidelines are relevant to asses the potential susceptibility to solarisation of objects in museum environments.

7. Conclusion

Although the process of solarisation was only briefly mentioned in contemporary conservation literature — suggesting that it is generally not considered a major conservation issue — it is known to occur in clear manganese-containing glass. Therefore, learning more about the mechanisms behind it and the conditions in which solarisation can occur is relevant in order to prevent it. This section has highlighted the complexity surrounding the chemical processes and historical context of manganese-based glass decolouration and solarisation.

When manganese was deliberately used as a decolourant is difficult to pinpoint, but it has been found in glasses dating back to 1400 BCE. Mentions of the use of manganese as decolourant have been found in glass making books from the 17th and 18th century. On a large, industrial scale in the United States, it has been used from the 19th up until the first half of the 20th century, meaning that these glasses possibly have a higher risk of solarisation. For this reason, one glass that was produced in the United States in this period was selected as one of the case study objects for the irradiation tests described in section II.

The processes of decolouration and solarisation are likely due to an interplay between Mn^{2+} to Mn^{3+} and iron. Other elements were also mentioned to have an influence on solarisation, such as arsenic, fluorine, phosphorus, zin, lead, barium, soda and potassium. However, among the authors there was no consensus of what exact effect each of these elements has on the colour of the glass or the solarisation process. Therefore, in section II, the chemical compositions of the three different case study objects have been determined, to hopefully identify elements that may affect the solarisation process.

In addition to the composition of the glass, the lighting conditions in which a glass is displayed also seem to influence the solarisation process — different types of UV radiation may give different results. Therefore, in section II, varying irradiation conditions have been examined to identify what influence they had on the solarisation process. These conditions were based on previously conducted solarisation experiments. All of these tested different lighting conditions and types of glass, making it difficult to compare the influence of varying irradiation set-ups across the studies. Therefore, to overcome this problem, the experiments in section II involved similar irradiation set-ups as described in chapter 4, as well as some additional conditions based on non-experimental literature, as described in chapter 2. By using three case study objects in all different conditions, it was possible to not only compare the effect of irradiation in combination with different compositions, but also the effect of varying irradiation conditions on the same glass composition.

Based on contemporary museum lighting standards, it can be estimated that objects on display receive a maximum annual UVA dose of 15.768 J/cm². This estimate enables the comparison between the findings of this study and the museum lighting conditions described in chapter 6, while also providing context for the irradiation doses used in section II.

Section II: Experimental

1. Introduction

As established in section I, there are still several unknown factors involved in solarisation. Both regarding the glass composition and irradiation conditions, authors did not fully agree. To establish further insights on the conditions causing solarisation, a series of solarisation experiments were conducted on the sherds of three historical glass objects which were expected to contain manganese. First, the chemical compositions of the samples were determined. Then, they were exposed to four different electromagnetic radiation sources: UVA, UVB-UVA, a sunlight-through-glass simulation and to outdoor sunlight. To identify possible trends in discolouration of the glasses and attribute the potential solarisation to a specific radiation condition, of each of the case study objects, a set of samples was kept in the dark as reference. The colour of all samples was regularly measured using a spectrophotometer. The detailed methodology and results are described in the following chapters.

2. Methodology

To further investigate the effects of glass compositions and irradiation conditions on solarisation, samples of three manganese-containing historical glass objects were exposed to four different radiation sources. Over a period of 64 days the colour of the samples was regularly measured to examine whether any change in colour had occurred.[91] This chapter will describe the selection procedure of the samples, the types of instrumental analyses that were used to determine the composition of the case study objects, the light sources the samples were exposed to and how the colour of the samples was measured. The three case study objects are shown in figures 2.1.1 to 2.1.3, and will be discussed further in the next paragraph.



Figure 2.1.1: Case study object 1, an EAPG glass. (Photo: Joris Nagtegaal)



Figure 2.1.2: Case study object 2, likely produced in Germany. (Photo: Joris Nagtegaal)



Figure 2.1.3: Case study object 3, likely produced in Germany. (Photo: Joris Nagtegaal)

[91] 64 days was the time available within the time scale of the thesis research.

2.1 Case study objects and sample choice

The first case study object was a late 19th century or early 20th century Early American Pressed Glass (EAPG), acquired by the UvA as case study object specifically for (destructive) analysis (see figure 2.1.1). The glass was imported from the United States from a collector in the United States with the description “Antique 19th Century EAPG Clear Glass Trim Mold Footed Compote 9”2’” and the bowl had a thickness of approximately 4.5 millimetres. This glass was possibly made according to the recipe by Whitall Tatum as described in chapter 3.2 of section I. These types of glasses are known so solarise.

Case study object 2 was an engraved glass with a folded foot and was blown as one object (see figure 2.1.2). In the stem, seven air bubbles are visible. On the chalice, there was a cartouche with an engraved text that says “Vivat de Printz van Orany”. The glass was donated to the UvA for research purposes in 2017 after being declared a total loss by a Dutch museum. It was dated as a 19th century glass, with a thickness of approximately 2 mm. This glass was likely produced in Germany. The glass was broken in 16 sherds, of which 7 were from the foot and 9 from the bowl of the glass. The original position of 3 other sheds was not known.

Case study object 3 was a wheel engraved, blown glass, which was part of the same donation as case study object 2 (see figure 2.1.3). It was dated by the museum as a late 18th century glass. On one side of the bowl, the biblical figures David and Ionathan are engraved while reaching for each other’s hand. On the other side, there is an engraved flower decoration with the text “Glick dese twee bestan, moet onse trowe gaan”. This glass was probably produced in Germany, but engraved in the Netherlands. It had a thickness of approximately 2 mm. This glass was broken in 12 sherds, all from the bowl of the glass.

Of each of the three case study objects, samples were selected for exposure to different light sources. Of each glass, 14 samples were prepared, for a maximum of 7 different irradiation experiments, resulting in a total of 42 samples. Of each sample, the outline was traced on a piece of Melinex® with a permanent marker. A dot was drawn to indicate the position on the sherd where the colour measurements were taken, to increase accuracy across measurements.

For each glass, the samples were chosen based on three aims: (1) all samples of the same glass should have a more or less similar thickness, (2) an as low as possible curvature and (3) have an area larger 3 by 3 mm, as this is the smallest aperture of the Konica Minolta CM-2600d. However, since the case study objects were historical glasses, it was impossible to obtain perfectly flat samples of equal thickness. During the preparation of the samples, the sherds with the smallest curvature and the most similar thicknesses were picked-out to perform the experiments on.

2.2 Chemical analysis

2.2.1 Handheld X-ray Fluorescence (pXRF)

Handheld X-ray Fluorescence (pXRF) was used to determine if the glasses contained manganese and were therefore potentially susceptible to solarisation, and not to determine the quantitative compositional differences between them. Because this method was an easily accessible way to assess the presence or absence of manganese — and thus whether or not the glass could be used for the experiments — this was chosen as the first method of determining the composition. The full range of major elements and the compositional differences between the case study objects were

identified at a later stage using Scanning Electron Microscopy with Energy Dispersive X-ray analysis (SEM-EDX), which will be further explained in paragraph 2.2.2 of section II.

pXRF is a non-destructive semiquantitative analysis method where elements are excited by the absorption of a primary X-ray beam. Subsequently, they emit unique X-rays which makes it possible to identify the specific element.[92] pXRF is able to qualitatively identify elements with an atomic number (Z) greater than oxygen (Z > 8). The response of elements with an atomic number between 8 and 20 is poor.[93] This poses a problem for analysing glass, as some of the major elements, such as calcium (Z = 20), potassium (Z = 19), silicon (Z = 14), and sodium (Z = 11), are difficult to detect with pXRF. Because manganese has an atomic number of 25, this should be detectable with pXRF.

The pXRF measurement was performed using a Bruker Tracer 5i handheld machine, which is an energy-dispersive X-ray fluorescence instrument.[94] The Tracer 5i machine was calibrated with a DualMudrock_Air calibration, which is based on rock-like elements, hence the name Mudrock. It performs two measurements, one at a current of 15 kV and one at 50 kV. This specific calibration provides more accuracy for the elements with atomic numbers below 20. However, even with this calibration, sodium cannot be reliably quantified. For the measurements, the analysis time was set to 70 seconds.

Because case study object 1 was still intact, one measurement was taken of its bowl. For measuring case study object 1, the pXRF was mounted in such a way that it could measure the glass of the bowl of the object. Since the other two case study objects consisted of sherds, the pXRF was mounted facing up and the glass samples were laid down on top of the apparatus for measurement, as can be seen in figure 2.2.1. Of case study object 2, one measurement was taken of the bowl and one of the foot and of case study object 3, two measurements were taken of the bowl.



Figure 2.2.1: pXRF analysis of case study object 3. (Photo: Joris Nagtegaal)

2.2.2 Scanning Electron Microscopy with Energy Dispersive X-ray analysis (SEM-EDX)

To analyse the elements that were too light to quantify with the pXRF, such as sodium, the case study objects were also analysed with Scanning Electron Microscopy with Energy Dispersive X-ray analysis (SEM-EDX). The SEM was used to take back scattered images and the EDX to determine the elemental composition.[95] To analyse a sample of

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[92] Skoog, Douglas A., F. James Holler, and Stanley R. Crouch. *Principles of Instrumental Analysis*. 7. edition. Boston, MA: Cengage Learning, 2018, 287.

[93] Bommel, Maarten van. 'X-Ray Fluorescence Spectroscopy (XRF)'. Lecture, Amsterdam, 19 September 2024.

[94] The analysis was performed by Luc Megens (Heritage Scientist at the Cultural Heritage Agency of the Netherlands) on February 18, 2025. Bruker. 'S1 TITAN / Tracer 5' User Manual'. Accessed 4 June 2025. https://www.geotechenv.com/Manuals/Bruker_Manuals/s1_titan_tracer_5i_user_manual_outdated.pdf.

[95] Bommel, Maarten van. 'Scanning Electron Microscopy - Energy Dispersive X-Ray Spectroscopy (SEM-EDX)'. Lecture, Amsterdam, 20 September 2024.

each of the three glasses, the samples were imbedded in EpoFix Epoxy Resin.[96] The embedded samples were wet-polished using a Stuers LaboPol-21 with silicon carbide paper grit 600, 800, 1000, 2000 and 4000. This was done because the outside layer of glass is always affected by the environment, for example by atmospheric pollution or humidity. To accurately analyse the chemical composition of the glass, the core of the glass was analysed. The SEM analysis was conducted on a JEOL JSM-IT700HR SEM at low vacuum mode of 30 Pa and 20kV and a 10mm working distance (WD). The EDX analysis was conducted using a ThermoFisher Scientific SDD Ultradry detector and NSS (Noran System Seven) software.[97]

The SEM-EDX analysis was conducted twice. One EDX analysis was configured to actively detect both manganese and iron. The second time, it was not configured to detect any specific elements. This analysis was undertaken for comparison.

2.3 Exposure to different lighting conditions

To examine which radiation sources would influence the solarisation of the case study objects, two samples per glass were exposed to six different lighting conditions, and two were kept in the dark as control samples. This resulted in a total sample size of 42 across all conditions. The lighting conditions were chosen based on the findings in section I.

For example, Rick Baldwin suggested that UVA radiation alone would not be sufficient to properly solarise the samples.[98] However, the experimental set-up of Ramadan Abd-Allah only contained a UVA radiation source, which successfully induced solarisation.[99] To see whether UVA radiation alone would be sufficient to solarise the case study objects, two samples of each object were exposed to solely UVA radiation, using a Blak-Ray® UVL-56 lamp. To asses the effect of UVB radiation, two samples of each glass were exposed to UVB fluorescent tubes in an Opsytec Dr. Gröbel UV chamber. To mimic possible lighting conditions in museum and non-museum environments, four samples of each glass were exposed using an Atlas/Ametek Xenotest 440.[100] All set-ups will be discussed in detail in the following paragraphs.

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[96] Struers. ‘EpoFix Resin Safety Data Sheet’, 5 March 2020. https://www.struers.com/-/media/Library/SDS/Canada-English/Mounting/SDS-EPOFIX-RESIN-CA-EN-M0025.pdf. Accessed 4 June 2025.

[97] The analysis was undertaken by Luc Megens (Heritage Scientist at the Cultural Heritage Agency of the Netherlands) on the 11th of June 2025 and by Kate van Lookeren Campagne (Lecturer in conservation of ceramics and glass) on the 1st of May 2025.

[98] Baldwin, Rick, ‘Decolorizing Glass With Manganese’, *Crown Jewels of the Wire*, July 1985, 23.

[99] Abd-Allah, Ramadan. ‘From Decolorization to Solarization of Historical Glass: A Review’. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 30–41. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[100] Four samples of each glass were exposed to natural sunlight on the roof of the Laboratorio Nacional de Engenharia Civil — National Laboratory for Civil Engineering (LNEC) under the supervision of Dr. Silvia Pereira in Lisbon. Six were exposed to sunlight without protection, and six were placed in glass vials to simulate sunlight through a window. Since it was not possible to measure any colour change at the time of writing this thesis, these samples are used for further research, and therefore not discussed here.

2.3.1 Control sample

Two samples from each case study object were kept in the dark, to measure possible colour changes in the dark that are not attributable to solarisation. The samples were put in small, plastic containers which were wrapped in aluminium foil, and left at room temperature.

2.3.2 UVA radiation by the Blak-Ray® UVL-56 lamp

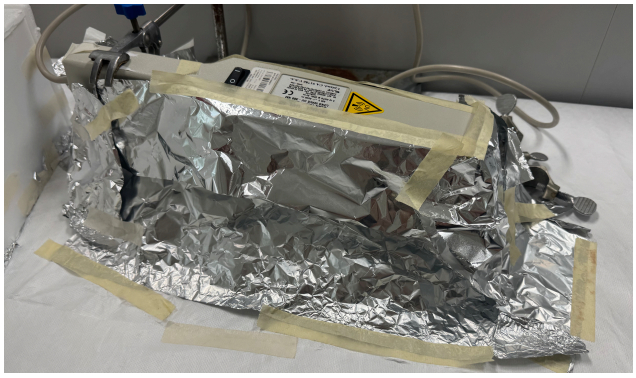


Figure 2.3.2.1: The radiation set-up using a Blak-Ray® UVL-56 lamp. (Photo: Joris Nagtegaal)

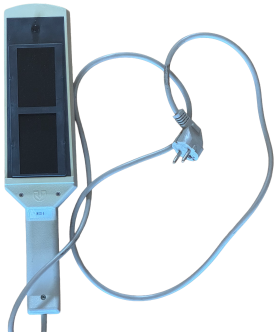


Figure 2.3.2.2: The Blak-Ray® UVL-56 lamp without aluminium foil. (Photo: Joris Nagtegaal)

A second set of samples of each case study object was exposed to UVA radiation, using a set-up with a Blak-Ray® UVL-56 lamp. As can be seen in figure 2.3.2.1, to maximise the amount of UVA radiating the samples, the lamp was enclosed in a 'box' using aluminium foil. Figure 2.3.2.2 shows the lamp without aluminium foil. The samples were positioned over the length of the lamp to minimise the variation in light exposure, at a distance of approximately 20 cm. The position of the samples — also relatively to each other — can be seen in figure 2.3.2.3. The samples were left at room temperature. The UVA emission of this lamp was measured at one time point using an Elsec 764 UV+ Monitor, taken from different positions underneath the lamp to provide an average. This gives its measurements in microwatt per square meter (mW/M^2), which was converted to Joule per hour per square centimetre (see appendix XI).

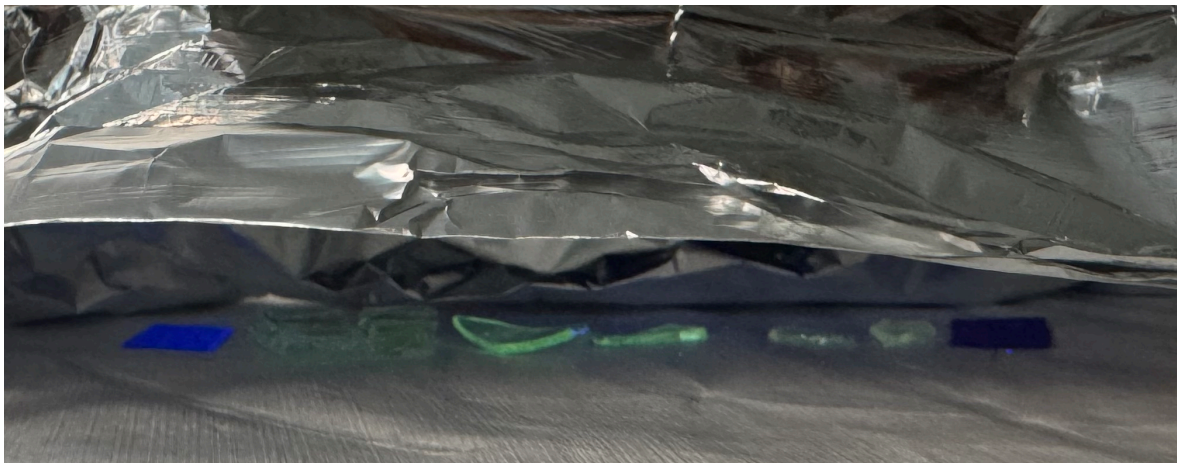


Figure 2.3.2.3: The position of the samples underneath the turned-on Blak-Ray® UVL-56 lamp. The samples were positioned approximately 20 cm from the lamp, at the top of the figure. The two samples on the left were from case study object 1, the two in the middle from case study object 2 and the two on the right from case study object 3. (Photo: Joris Nagtegaal)

2.3.3 Combination of UVA and UVB radiation in the Opsytec Dr. Gröbel UV chamber

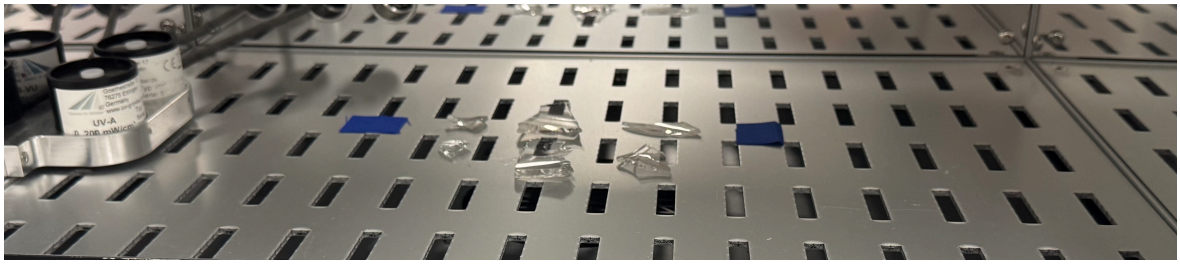


Figure 2.3.3.1: The samples in the Opsytec Dr. Gröbel UV chamber, left glass 2, middle glass 1 and right glass 3. (Photo: Joris Nagtegaal)

Baldwin stated that exposure to UVA radiation alone would be insufficient to properly solarise a glass — he argues that UVB may also play a role. On the other hand, Ramadan used only UVA radiation in his experimental set-up, which resulted in successful solarisation.[101] Since there is no clear consensus of what type of UV radiation is required to induce solarisation, it was deemed useful to examine if exposure to UVB would induce solarisation. Therefore, a third set of samples per case study object was exposed to UV fluorescent tubes in an Opsytec Dr. Gröbel UV chamber. The samples were placed in the middle of the chamber, as can be seen in figure 2.3.3.1. The irradiation chamber had an area of 46 x 32 x 23 centimetres and maintained the samples at a temperature of 25 °C (± 5°C).

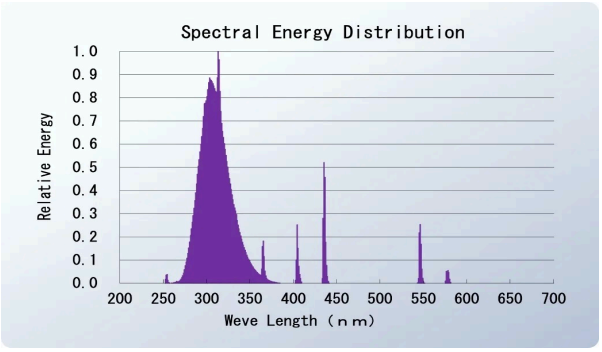


Figure 2.3.3.2: The spectral distribution of the radiation emitted by the Sankyo Denki G15T8E UVB fluorescent tubes. As can be seen, the tubes do not only emit UVB (280-315 nm) but also UVA (315-400 nm) and visible light (400-700 nm) (Source: Sankyo Denki, 2025)

This chamber was specifically developed for exposing samples to a high doses of UV radiation and can be equipped with UVA, UVB and UVC fluorescent tubes.[102] The chamber was fitted with eight Sankyo Denki G15T8E UVB fluorescent tubes, of which the spectral distribution of the radiation can be seen in figure 2.3.3.2.[103] Although the tubes are sold specifically as UVB fluorescent tubes (280-315 nm), they also emit UVA radiation (315-400 nm) and some visible light (400-700 nm).

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[101] Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23. ; Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 30–41. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

[102] Opsytec Dr. Gröbel. 'Opsytec Product Information Irradation Chamber BS-02'. Accessed 3 June 2025. https://www.opsytec.com/fileadmin/user_upload/products/downloads/e_bs02.pdf.

[103] Sankyo Denki. 'UV-B Lamps G15T8E'. Accessed 4 June 2025. https://www.sankyo-denki.co.jp/en/product/g15t8e.

2.3.4 Sunlight through glass simulation in the Atlas/Ametek Xenotest

A fourth set of samples per case study object was exposed to simulated daylight in a Xenotest 440, which is used for the accelerated aging of samples.[104] It simulates daylight through window glass using two 2200-watt xenon lamps. Together, they emit 100.000 lux with a UVA radiation between 40 and 180 W/m^2.[105]

The samples were irradiated according to the ISO 105-B02 standard, which was developed to determine the effect of the colour change in coloured wool when exposed to a light source similar to daylight (CIE D65).[106] To comply to this ISO standard, the xenon lamps in the chamber were fitted in a Xenochrome 320 filter. This filters the wavelengths of the xenon lamps in such a way that the wavelengths reaching the samples are similar to the wavelengths of daylight through glass.[107] This includes a small part of the UVA radiation spectrum, the visible light spectrum and parts of the infrared spectrum.

To mimic museum lighting conditions as described in chapter 6 of section I, two additional samples were placed in the Xenotest 440 behind a UV filter. The other two samples were not placed behind the UV filter, to represent the lighting environment that a glass could be exposed to in private collections.

All samples were kept at a relative humidity of 40%. The Xenotest was programmed to simultaneously maintain a Conjugate Heat Transfer (CHT) temperature of 32 ºC and a Black Standard Temperature (BST) of 49 ºC. The CHT is the air temperature in the chamber, whereas the BST indicates the surface temperature of a sample in the chamber, provided it would absorb all the radiation wavelengths emitted by the lamp. The BST was assessed by placing a black temperature measuring surface in the chamber.[108] This means that the air in the chamber was 32ºC and the temperature of the samples was at most 49ºC, if they would have been black.

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[104] Atlas/Ametek. 'Xenotest 220-440 Brochure'. Atlas Material Testing Solutions, 2023. https://www.atlas-mts.com/products/standard-instruments/xenon-arc-weathering-test/xenotest/440. Accessed 04-06-2025.

[105] Atlas/Ametek. 'Xenochrome 320 Filter System for Xenotest 220/220+/440'. Atlas Material Testing Solutions, 2025. https://store.ametek.co.uk/xenochrome-320-filter-system-for-xenotest-220-220-440/. Accessed 6 June 2025.

[106] 'Colour Fastness to Artificial Light: Xenon Arc Fading Lamp Test', 2014. https://www.iso.org/standard/65209.html. Accessed 6 June 2025.

[107] Atlas/Ametek. 'Xenochrome 320 Filter System for Xenotest 220/220+/440'. Atlas Material Testing Solutions, 2025. https://store.ametek.co.uk/xenochrome-320-filter-system-for-xenotest-220-220-440/. Accessed 6 June 2025.

[108] Atlas/Ametek. 'Xenotest 220-440 Brochure'. Atlas Material Testing Solutions, 2023. https://www.atlas-mts.com/products/standard-instruments/xenon-arc-weathering-test/xenotest/440. Accessed 04-06-2025.

2.4 Photographic documentation

To ensure that the samples could be visually compared over time, photographs of the samples were taken in a controlled environment. All the photographs were taken in the UvA photodocumentation room in the Ateliergebouw of the Rijksmuseum with a Nikon D750 digital camera, using a 60 mm lens with a maximum aperture of f/2.8. The camera was controlled with Camera Control Pro 2 and the photographs were taken with a shutter speed of 1/1.3 seconds, an aperture of f/25, 0 ev exposure compensation, 0 flash compensation and at an ISO sensitivity of 100. Two standing flashlights were used, positioned at the left side and the right side of the samples at a distance of 85 cm at both sides. The left flashlight had a strength of 6.5 and the right had a strength of 8.5. The camera was positioned above the samples to take photos facing down; the distance between the lens of the camera and the samples was kept at 21.5 cm. The photographs were taken whenever a change in colour was suspected after visual inspection of the samples during the measuring of the colour.

2.5 Colour spectrometry

To measure any colour change of the glass samples, colour measurements were performed using a Konica Minolta CM-2600d spectrophotometer (see figure 2.5.1).[109] This apparatus had a d/8 geometry. An aperture of 3 mm was used, because this allowed a smaller area to be measured. The colour measurements were taken both including (SCI) and excluding (SCE) the specular component and the UV light was cut out at 400 nm. The light source was a CIE D65 illuminant and the observer was at an angle of 10º of the surface that was measured.

As can be seen in figure 2.5.1, the spectrophotometer was put upside down so the glass samples could be placed on top for measuring. This was done to ensure a piece of non-fluorescent white paper could be pressed onto the glass sample using a plastic bag filled with glass spheres, keeping the paper in contact with the glass. Assuming that the paper would not change colour over time, this way the cumulative colour of the white paper and the glass was measured to see whether the glass colour had changed — as the glass is transparent and cannot be measured by itself.



Figure 2.5.1: The MinoltaKonica Minolta CM-2600d spectrophotometer with the aperture facing up. The glass samples were placed on the grey circle, in which the black circle in the centre shows the aperture of 3 mm. (Photo: Joris Nagtegaal)

[109] Coatech Instruments. ‘CM-2600D Konica Minolta’, 18 May 2022. https://nam39234.tistory.com/1829. Accessed 14 June 2025.

As can be seen in figure 2.5.2, the entire apparatus was covered with a styrofoam box. The inside of the box was covered with aluminium foil to limit the amount of ambient light that could distort the measurements. To measure the colour of the samples, the Konica Minolta CM-2600d was connected to a computer and controlled by SpectraMagix NX2 software, which automatically takes the average of three colour measurements at the same time point, every time that a sample is measured. From every sample, three measurements (adding up to a total of nine measurements per sample) were taken to minimise measurement error. These nine measurements were averaged to obtain one measure per sample at every time the colour was measured. See paragraph 2.6 of section II for more details about the analysis.

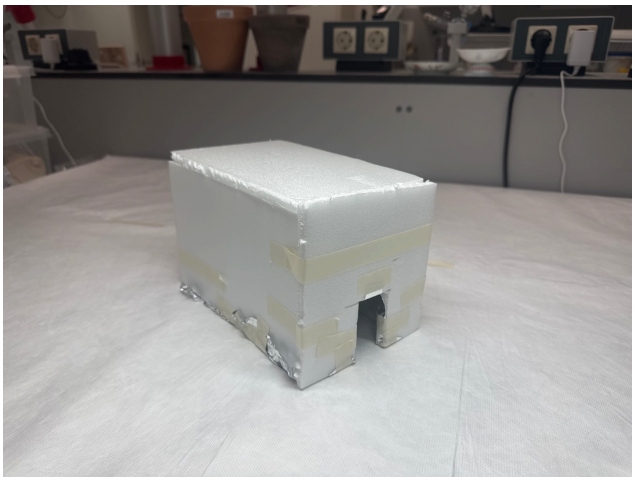


Figure 2.5.2: The outside of the styrofoam box that was used for blocking the ambient environmental light, during colour measurement with a Konica Minolta CM-2600d spectrophotometer (inside the box). (Photo: Joris Nagtegaal)

2.6 Colour change calculation and visualisation

To investigate whether any of the glass samples had observably changed in colour due to solarisation, a CIE ΔE_{00} was calculated for every observation, as described below. Each measurement per sample in a certain condition was compared to the first measurement (baseline measure) of that specific sample in that specific condition. This way, the change in CIE Lab values was measured, which were converted to LCh values to use in the ΔE_{00} equation. This process was repeated for all samples from all conditions, both for the SCI and SCE measurements. All equations that were used to convert Lab values to LCh, as well as the equations to calculate ΔE_{00}, as well as a detailed explanation thereof, can be found in appendix II.

The data were visualised by plotting the ΔE_{00} against either time (for the Xenotest and dark samples) or UV dose (for the UVA and UVB samples). The 95%-confidence intervals were also shown in the graphs. The ΔE_{00} equations were implemented in R (version 4.4.2) with the help of Lodewijn Ubbink (University of Utrecht), see appendix III for the full code.[110]

It is generally accepted that a ΔE_{00} of 1.5 indicates a single just noticeable change. However, different thresholds can be found in the literature, ranging between 1 and 4.[111] When a change in colour was measured, this colour was also visualised by converting the measured CIELAB values to a HEX number with colordesigner.io.[112]

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[110] R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austia: R Foundation for Statistical Computing, 2024. https://www.R-project.org/.

[111] Saunders, David. *Colour, Colour Measurement and Colour Change*. 1st ed. Science for Conservators. London: Routledge, 2024, 94, 190-191. https://doi.org/10.4324/9781003397182.

[112] Banas, Wojciech. 'Convert LAB to HEX'. Online. colordisigner.io, 2025. https://colordesigner.io/convert/labtohex. Accessed 17 June 2025.

3. Results

3.1 Chemical analysis results

3.1.1 pXRF results

The pXRF is a qualitative method to determine the composition of the glass, the results are quantified to semi-quantitative values. The aim of the pXRF analysis was to determine the presence of manganese in the case study objects and have a general idea about the other elements in the glass composition. An overview of the raw pXRF results can be found in appendix IV. As can be seen in table 3.1.1 and figures 3.1.1.1 — 3.1.1.3, in all of the case study objects the presence of both manganese and iron was confirmed. Because for solarisation only a small amount of manganese is needed, these results provided sufficient evidence to use all three glasses as case study objects.[113] It stands out that the spectra for case study object 2 and 3 are very similar, with a high peak of potassium (K), while that of case study object 1 differs — the K peak is not present here, but two peaks of arsenic (As) are visible.

Table 3.1.1: Results from the pXRF analysis of the case study objects. (Analysis by Luc Megens)

Major elements (wt%)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO					
Case Study Object 1	2.8	1.7	*ND**	83.6	*ND**	0.1	0.1	3.3					
Case Study Object 2 — bowl	1.4	0.3	1.1	83.9	0.1	0.3	14.5	5.9					
Case Study Object 2 — foot	1.3	0.3	0.9	73.8	0.1	0.3	12.2	5.1					
Case Study Object 3 — bowl 1	1.2	0.4	0.9	74.5	0.1	0.3	13.0	5.5					
Case Study Object 3 — bowl 2	1.0	0.3	1.1	82.7	0.1	0.3	14.2	5.9					
Minor elements (In ppm)	Cl	Ti	V	Mn	Fe	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
Case Study Object 1	829	197	36	485	273	20	*ND**	8	852	*ND**	32	103	*ND**
Case Study Object 2 — bowl	*ND**	250	55	1448	472	25	27	13	11	145	121	68	*ND**
Case Study Object 2 — foot	*ND**	367	68	1374	601	28	30	15	13	133	112	67	*ND**
Case Study Object 3 — bowl 1	*ND**	249	74	1320	493	25	33	13	12	140	121	65	5
Case Study Object 3 — bowl 2	*ND**	255	70	1346	465	26	27	14	12	140	116	65	5

** An pXRF result of ND indicates that the element was not detected, i.e. not present in the glass composition.*

[113] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 30–41. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025.

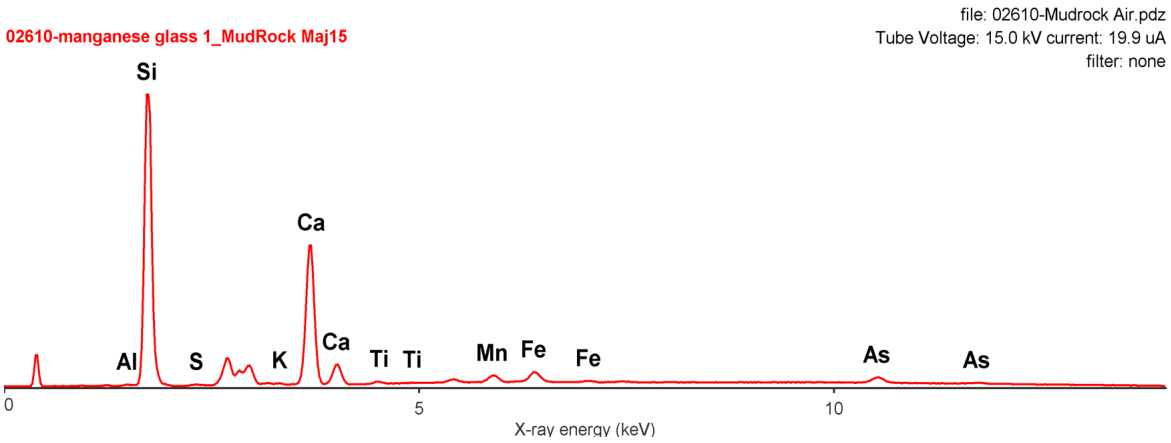


Figure 3.1.1.1: This pXRF spectrum shows the presence of both manganese (Mn) and iron (Fe) in case study object 1. (Analysis by Luc Megens)

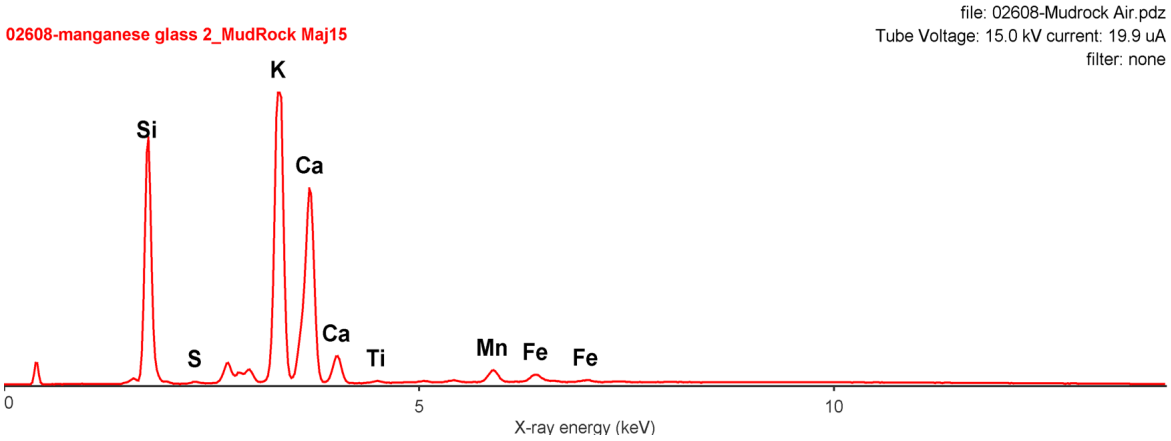


Figure 3.1.1.2: This pXRF spectrum shows the presence of both manganese (Mn) and iron (Fe) in case study object 2. (Analysis by Luc Megens)

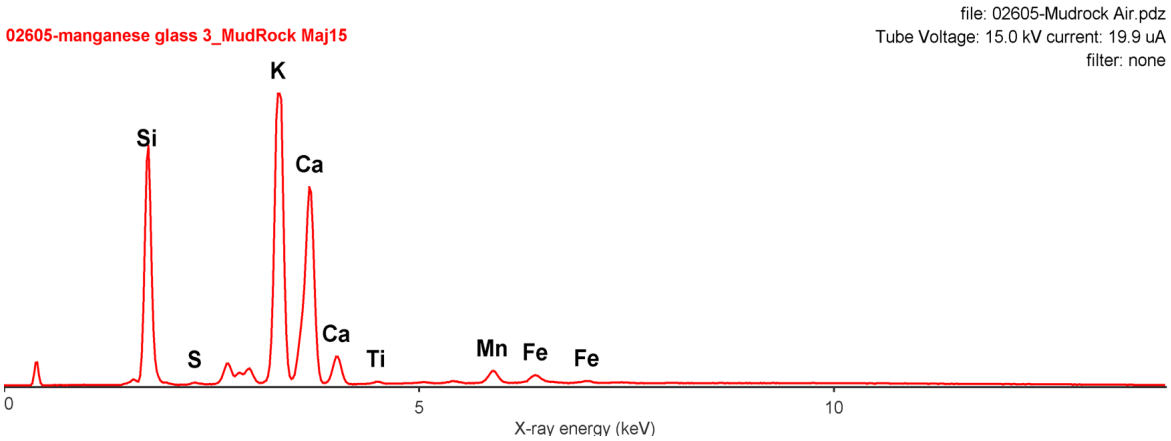


Figure 3.1.1.3: This pXRF spectrum shows the presence of both manganese (Mn) and iron (Fe) in case study object 3. (Analysis by Luc Megens)

3.1.2 SEM-EDX results

The aim of the SEM-EDX analysis was to have a more accurate measurement of the chemical composition of the case study objects. The semi-quantitative results of EDX analysis are presented in tables 3.1.2 and 3.1.3, respectively, for the analysis where Mn and Fe were targeted or not. Figures 3.1.6, 3.1.7 and 3.1.8 show the EDX spectra of case study object 1, 2 and 3, where Mn and Fe were actively identified. A complete overview of the raw data can be found in appendix V and VII. The normalised results in appendix VI (table VI-1 — VI-3) and VIII (table VIII-1 — VIII-3). Because the samples were embedded in epoxy resin, EDX showed a high percentage of carbon (C) present. As this cannot be in the glass composition, the results were normalised by removing the C values and re-calculating the wt% of the other elements.

Table 3.1.2 shows the average wt% of two measurements per case study object, where Mn and Fe were targeted specifically. The percentages in table 3.1.3 show the average wt% of respectively eight, seven and six measurements — without specifically identifying Mn and Fe — of case study objects 1, 2 and 3. After normalisation, the percentages of silica detected by both EDX analyses were close to what is expected for glass, around 75 wt%. There were some interesting differences in the EDX results when analysis was performed with or without specifying the identification of Mn and Fe. Specifically, when the identification of manganese was not specified during EDX analysis, the wt% of manganese was too low to be detected as a major element (table 3.1.3). However, as can be seen in table 3.1.2, small amounts of manganese and iron were found in all case study objects.

When comparing the compositions of the three case study objects, it stands out that case study object 2 and case study object 3 showed minimal differences, while case study object 1 seemed to have a distinct composition (visible in both table 3.1.2 and 3.1.3). For example, the proportion of sodium (Na) and magnesium (Mg) was significantly higher in case study object 1 than in 2 and 3. In addition, both case study objects 2 and 3 consisted mainly of Na_2O, SiO_2, K_2O, CaO, whereas in case study object 1, K_2O was not detected at all.

Although there were a lot of similarities between case study object 2 and 3, the EDX results also show some minor compositional differences, that were especially detected when the analysis was not specifically targeting Mn and Fe (table 3.1.3). For example, case study object 2 contained approximately 1 wt% more K_2O and 0.4 wt% less Na_2O than case study object 3. However, the most noticeable difference was that case study object 3 contained traces of sulphur trioxide (SO_3) and chlorine (Cl). The EDX result of Cl was 0.0, which means that the average wt% was too low to accurately estimate with EDX, but the element was still detected in the glass composition. If the element was not present in the glass composition, the result would have been ‘not detected’ (ND). Chlorine was also found in case study object 1, but was not detected in case study object 2.

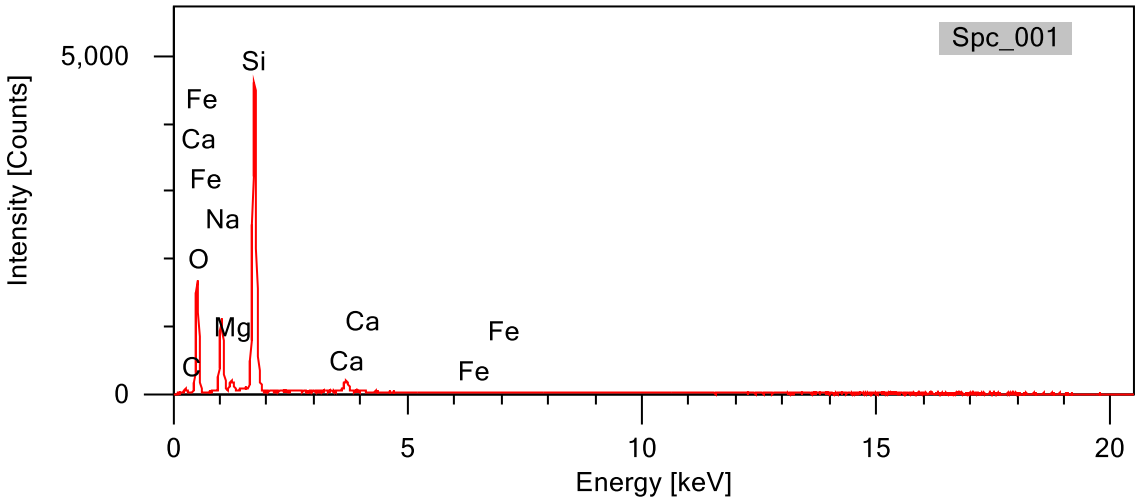


Figure 3.1.6: EDX spectrum the sample from measurement 1 of case study object 1, where Mn and Fe were specifically targeted. (Analysis by Kate van Lookeren Campagne)

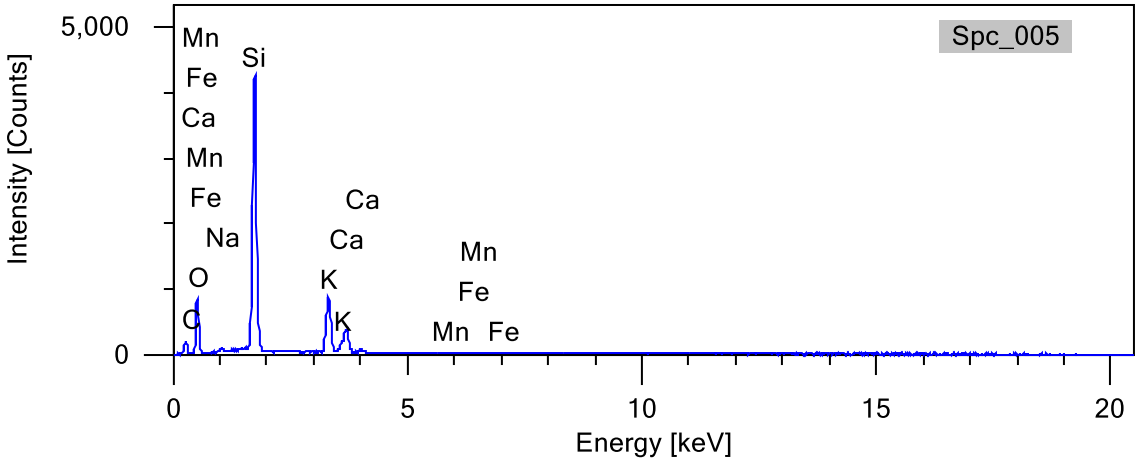


Figure 3.1.7: EDX spectrum the sample from measurement 5 of case study object 2, where Mn and Fe were specifically targeted. (Analysis by Kate van Lookeren Campagne).

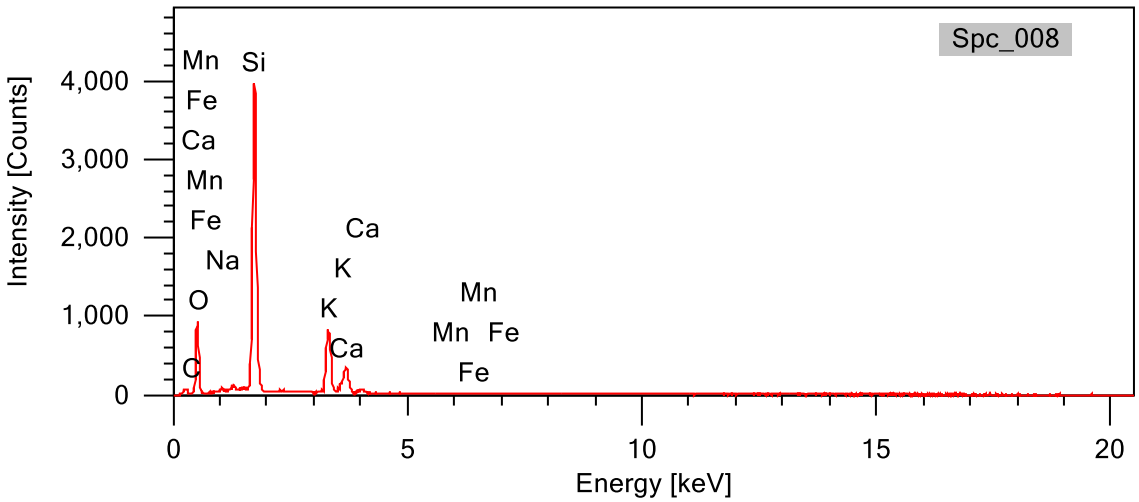


Figure 3.1.8: EDX spectrum the sample from measurement 8 of case study object 2, where Mn and Fe were specifically targeted. (Analysis by Kate van Lookeren Campagne).

Table 3.1.2: The EDX results when the identification of Mn and Fe was specified during analysis (normalised). (Analysis by Kate van Lookeren Campagne)

In average wt%	SiO2	Na2O	MgO	K2O	CaO	MnO	FeO3	Total
Case Study objects 1	**76.9**	**17.3**	**2.2**	**ND****	**3.4**	**0.2**	**0.0***	**100.0**
StDev	*0.1*	*0.4*	*0.0*	*ND*	*0.1*	*0.2*	*0.0*	
Case Study objects 2	**74.6**	**0.9**	**ND****	**15.2**	**9.0**	**0.1**	**0.1**	**100.0**
StDev	0.0	0.1	*ND*	0.2	0.0	0.1	0.0	
Case Study objects 3	**74.9**	**0.7**	**0.0***	**15.7**	**8.5**	**0.2**	**0.1**	**100.1**
StDev	0.1	0.0	0.0	0.0	0.1	0.0	0.1	

Table 3.1.3: The EDX results when the identification of specific elements was not specified during analysis (normalised). (Analysis by Luc Megens)

In average wt%	SiO2	Na2O	MgO	K2O	CaO	Cl	SO3	Total
Case study object 1	**76.9**	**17.3**	**2.4**	**ND****	**3.4**	**0.1**	**ND****	**100.0**
StDev	*0.3*	*0.3*	*0.1*	*ND*	*0.1*	*0.1*	*ND*	
Case study object 2	**74.8**	**1.0**	**ND****	**15.1**	**9.0**	**ND****	**ND****	**100.0**
StDev	*0.2*	*0.1*	*ND*	*0.1*	*1.0*	*ND*	*ND*	
Case study object 3	**74.1**	**0.6**	**ND****	**16.2**	**9.0**	**0.0***	**0.1**	**100.0**
StDev	*0.3*	*0.0*	*ND*	*0.1*	*0.2*	*0.1*	*0.2*	

** An EDX result of 0.0 indicates that the average wt% was too low to accurately estimate, but the element was still present in the glass composition.*

*** An EDX result of ND indicates that the element was not detected, i.e. not present in the glass composition.*

3.2 Results of light exposure tests

In the following sections, the spectrophotometer colour measurements of the samples exposed to different light sources and the photographs will be presented. In appendix IX, an overview can be found of when the colour of each sample was measured. The frequency of the colour measurements depended on when the experiments started — they were not all performed for an equal amount of time. In addition, since the Xenon apparatus was being simultaneously used for other experiments, it could not be opened often to perform colour measurements on set dates.

All the colour measurements presented in this chapter are excluding the specular component (SCE). The full calculations of the ΔE_{00} formula be found in appendix III. The exact thickness of each sample and all the measured CIELAB values can be found in appendix X. As described in paragraph 2.6 of section II, there is no agreement of what exact value of ΔE_{00} should be considered a just noticeable change in colour. In this research, 1.5 is assumed to be a good indicator of a just noticeable change.[114] The ΔE_{00} change for each irradiation condition is visualised in graphs. In these graphs, the red lines represent case study object 1, the green lines represent case study object 2 and the blue lines represent case study object 3. Around the lines, a cloud in the same colour is visible, which indicates the 95% confidence interval.[115] The solid lines represent sample 1 of the case study objects and the dotted lines represent sample 2. The individual measurements are indicated with dots for sample 1 and triangles for sample 2.

[114] Saunders, David. *Colour, Colour Measurement and Colour Change*. 1st ed. Science for Conservators. London: Routledge, 2024, 94. https://doi.org/10.4324/9781003397182.

[115] Confidence interval $= \bar{x} \pm z * \frac{s}{\sqrt{n}}$ where $\bar{x}$ = mean, $z = 1.96$ for a 95% interval, s = standard deviation and n = sample size.

If this experiment would be repeated many times, in 95% of all replications, the interval would contain the true value.

3.2.1 Results of the colour measurements of the control samples

The samples that were kept in the dark were expected to not show any change of colour over time, since UV or shorter wavelength radiation are necessary to induce solarisation.[116] The photographs in figure 3.2.1.3 (day 60) were taken in a different angle than those in 3.2.1.2 (day 1), to make possible changes in colour more clearly visible. When comparing the photographs, the samples did not show any visible colour differences between day 1 and day 60 of the experiment.

However, as can be seen in figure 3.2.1.1 and table 3.2.1.1, the ΔE_{00} was never zero. Almost all calculated ΔE_{00} values were above 2. Even the sample with the lowest ΔE_{00} — sample 2 of case study object 1 — showed values around 1. The largest variation in ΔE_{00} values is found in sample 2 of case study object 2. This ranges from 6.5 at day 2, to 0.67 on day 60. A photograph of this sample can be seen in figure 3.2.1.4. All other samples do show a very consistent ΔE_{00} — the lines in figure 3.2.1.1 are all relatively horizontal.

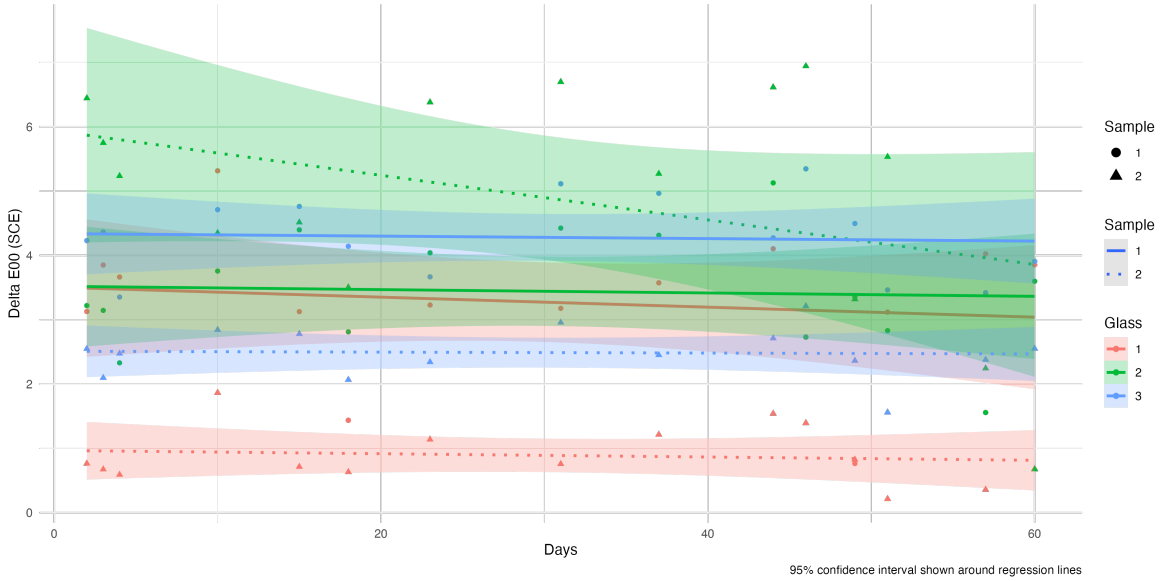


Figure 3.2.1.1: Plot of the ΔE_{00} of the samples kept in the dark with the cloud showing the 95% confidence interval. (Graph: Lodewijn Ubbink)

[116] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 129. ; Bamford, C. R., *Colour Generation and Control in Glass*, 1. ed., 2. impression, Glass Science and Technology 2 (Amsterdam: Elsevier, 1984), 51-52. ; Lokay, J.D. '"Sun-Purpled" Glass'. *Heisey News*, October 1999.

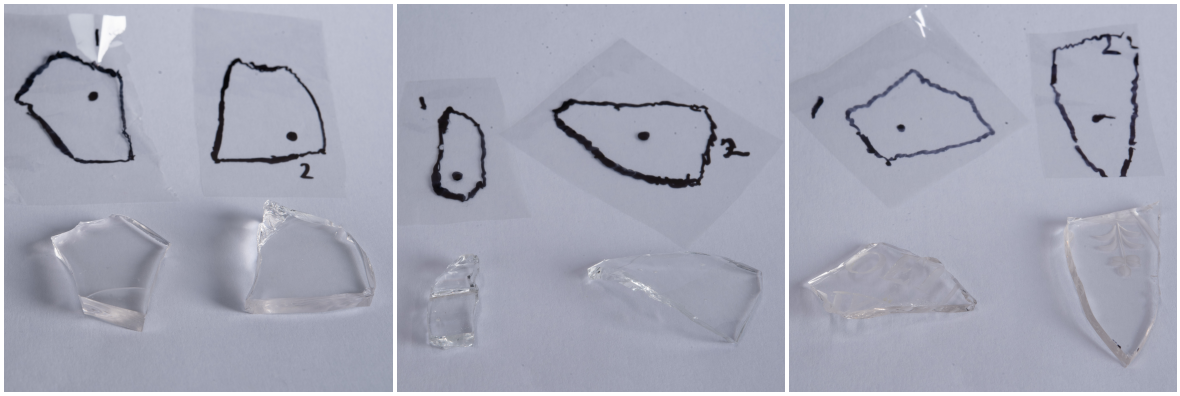


Figure 3.2.1.2: The samples kept in the dark, photographed at day 1. Samples from case study object 1 are on the left, 2 in the middle and 3 on the right. Above, the traced outlines on Melinex® are shown, the number indicates the sample number and the dot shows the location of the colour measurements. (Photo: Joris Nagtegaal)

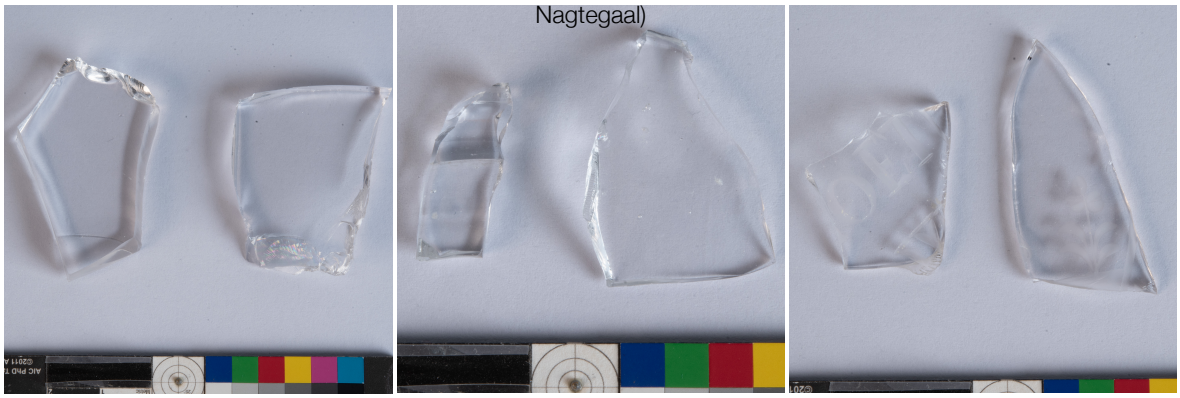
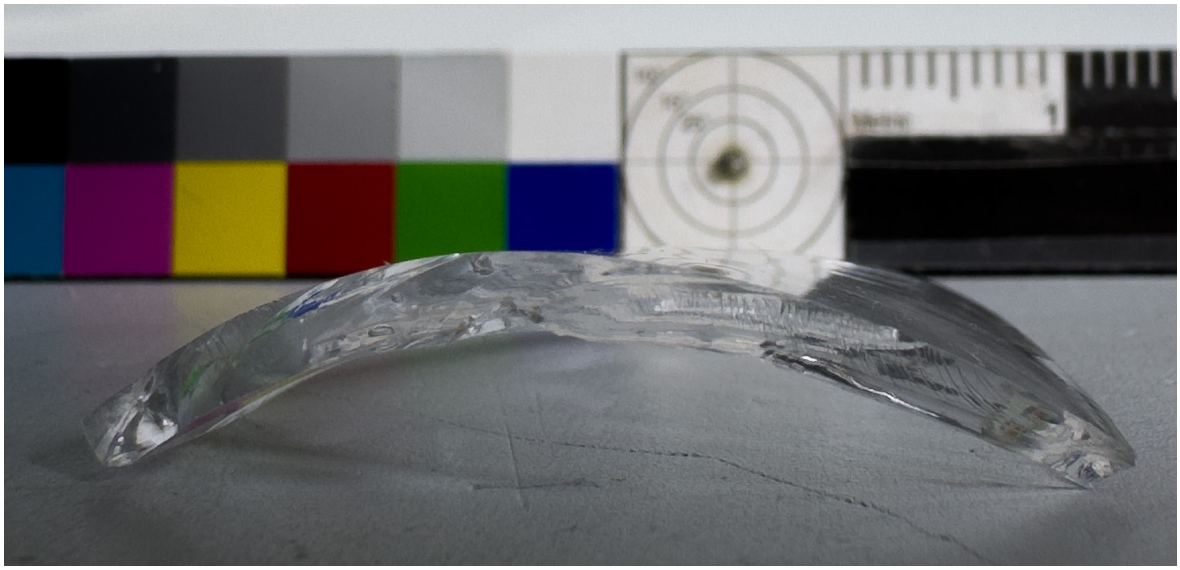


Figure 3.2.1.3: The samples kept in the dark, in the same order as in figure 3.2.1.2, after 60 days. (Photo: Joris Nagtegaal)



3.2.1.4: The large curvature of sample 2 of case study object 2. (Photo: Joris Nagtegaal)

Table 3.2.1.1: All ΔE00 values for the samples kept in the dark. For the calculation see appendix III.

Time (in days)	ΔE_{00} Glass 1-1	ΔE_{00} Glass 1-2	ΔE_{00} Glass 2-1	ΔE_{00} Glass 2-2	ΔE_{00} Glass 3-1	ΔE_{00} Glass 3-2
2	3.13	0.76	3.22	6.45	4.23	2.55
3	3.85	0.67	3.14	5.75	4.36	2.10
4	3.66	0.59	2.33	5.24	3.35	2.47
10	5.32	1.86	3.76	4.35	4.71	2.84
15	3.13	0.71	4.40	4.51	4.76	2.78
18	1.44	0.63	2.81	3.51	4.14	2.07
23	3.23	1.14	4.04	6.38	3.67	2.34
31	3.18	0.76	4.42	6.70	5.11	2.96
37	3.57	1.21	4.31	5.27	4.97	2.45
44	4.10	1.54	5.13	6.62	4.27	2.71
46	2.73	1.39	2.73	6.95	5.35	3.21
49	0.76	0.83	3.36	3.32	4.50	2.36
51	3.12	0.21	2.83	5.53	3.46	1.56
57	4.02	0.36	1.56	2.24	3.42	2.38
60	3.85	0.68	3.60	0.67	3.91	2.55

3.2.2 Samples exposed to UVA, under the Blak-Ray® UVL-56 lamp

When comparing the samples exposed to UVA radiation using a Blak-Ray® UVL-56 lamp from day 1 and day 60 (figures 3.2.2.1 and 3.2.2.2, respectively), the samples from case study object 1 and 3 are clearly seen to have turned slightly purple. This visual change occurred after an exposure of 1826.59 J/cm² of UVA. However, when looking at the Lab values of these objects, and the visualisation thereof (figure 3.2.2.3), there was no increase in colour change. The average UVA radiation of the lamp in Joule per hour per cm² can be seen in table 3.2.2.1. The standard deviation was found to be high. The cumulative Joule per cm² of UVA the samples were exposed to can be found in table 3.2.2.2.

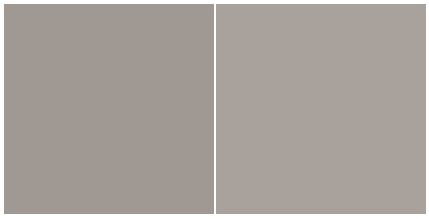


Figure 3.2.2.3: The change in colour over time as represented by the measured CIELAB values of day 1 (HEX # 9F9893) and day 60 (HEX #A9A29C) (from left to right) of case study object 1, sample 1.

When looking at the ΔE_{00} (figure 3.2.2.4 and table 3.2.2.3), different trends are visible in different case study objects. For example, in both samples of case study object 2 and sample 2 of case study object 3 the lines are going up. The lines of case study object 1 and sample 1 of case study object 3 remain either relatively horizontal or go down. However, based on the 95% confidence intervals, it might also be possible that all of the lines could in fact be horizontal.

The highest ΔE_{00} value of all the measurements was seen in case study object 1, sample 1. This ΔE_{00} value was measured on the 15th day of the experiment, after the sample was exposed to 470 Joule per cm² of UVA radiation (see table 3.2.2.2). In the following measurements, the ΔE_{00} value decreased.

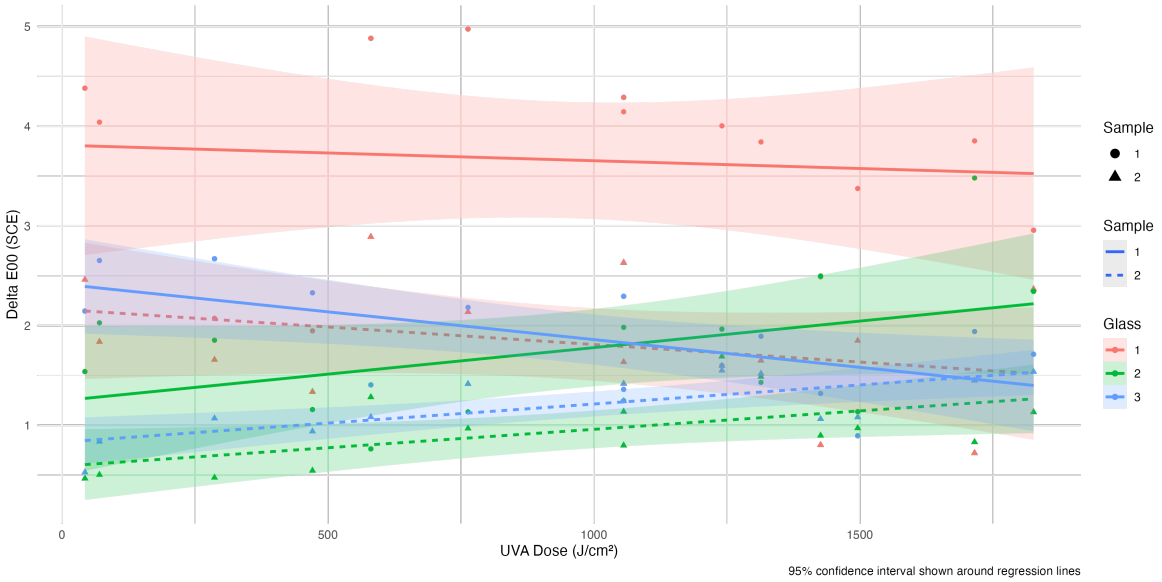


Figure 3.2.2.4: Plot of the ΔE_{00} of the samples exposed to UVA measured excluding the specular component. (Graph: Lodewijn Ubbink)

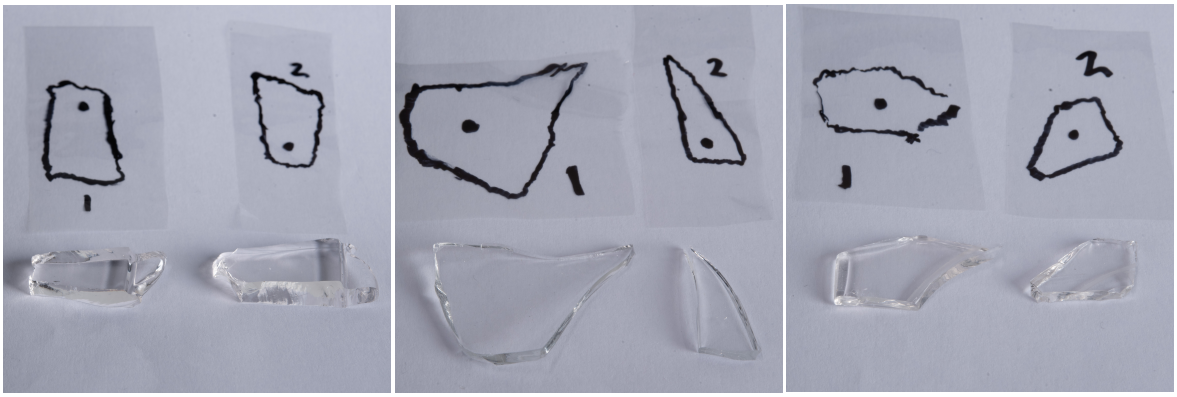


Figure 3.2.2.1: The samples exposed to UVA with the Blak-Ray® UVL-56 lamp, photographed at day 1. Samples from case study object 1 on the left, 2 in the middle and 3 on the right. Above, the traced outlines on Melinex® are shown, the number indicates the sample number and the dot shows the location of the colour measurements. (Photo: Joris Nagtegaal)



Figure 3.2.2.2: Photographs of the samples exposed to UVA in the same order as figure 3.2.2.1 show that the samples from case study object 1 (left) and case study object 2 (right) experienced a slight change in colour, looking more purple after 60 days of exposure. (Photo: Joris Nagtegaal)

Table 3.2.2.1: The measured and average of the Blak-Ray® UVL-56 lamp

Measurement	UV in mW/M2
1	1463
2	5119
3	3846
4	2179
5	4830
6	3505
7	2642
8	7780
9	9173
10	2072
11	4096
Average	**4246**
Standard deviation	**2407**

Table 3.2.2.2: Overview of sample exposure with the Blak-Ray® UVL-56 Lamp.

Date	Measurement	UVA dose until measurement (in $\frac{J}{cm^2}$)	Cumulative UVA dose (in $\frac{J}{cm^2}$)	Hours exposed to UVA at time of measurement	Cumulative hours of exposure
1 April	1	0.00	0.00	0h 0m	0h 0m
3 April	2	43.18	43.18	29h 15m	29h 15m
4 April	3	27.25	70.43	17h 50m	47h 5m
10 April	4	216.29	286.72	141h 30m	188h 35m
15 April	5	184.19	470.91	120h 30m	309h 5m
18 April	6	109.80	580.71	71h 50m	380h 54m
23 April	7	182.66	763.37	119h 30m	500h 24m
1 May	8	292.60	1055.97	191h 25m	691h 50m
		LAMP STOPPED WORKING			
9 May,	9	**ISSUES RESOLVED**			
14 May	10	184.70	1240.67	120h 50m	812h 39m
16 May	11	73.49	1314.16	48h 5m	860h 44m
19 May	12	112.09	1426.25	73h 20m	934h 4m
21 May	13	69.79	1496.04	45h 40m	979h 44m
27 May	14	219.73	1715.77	143h 45m	1123h 29m
30 May	15	110.82	1826.59	72h 30m	1195h 59m
Total:		**1826.59**	**1826.59**	**2391h 57m**	**1195h 59m**

Table 3.2.2.3: All ΔE00 values for the samples exposed in the Blak-Ray® UVL-56 lamp. For the calculation see appendix III.

UV Dose in J/cm²	ΔE_{00} Sample 1-1	ΔE_{00} Sample 1-2	ΔE_{00} Sample 2-1	ΔE_{00} Sample 2-2	ΔE_{00} Sample 3-1	ΔE_{00} Sample 3-2
43.18	4.38	2.46	1.54	0.47	2.15	0.53
70.43	4.04	1.84	2.03	0.50	2.65	0.84
286.72	2.07	1.66	1.85	0.48	2.67	1.07
470.91	1.95	1.34	1.16	0.55	2.33	0.94
580.71	4.88	2.89	0.76	1.28	1.41	1.08
763.37	4.97	2.14	1.13	0.97	2.18	1.42
1055.97	4.14	1.64	1.25	0.80	1.36	1.24
1055.97	4.29	2.63	1.98	1.14	2.29	1.42
1240.67	4.00	1.60	1.96	1.69	1.60	1.55
1314.16	3.84	1.65	1.43	1.49	1.89	1.52
1426.25	2.49	0.80	2.50	0.90	1.32	1.06
1496.04	3.37	1.85	1.14	0.97	0.90	1.08
1715.77	3.85	0.72	3.48	0.83	1.94	1.45
1826.59	2.96	2.37	2.34	1.13	1.71	1.54

3.2.3 Samples exposed to a combination of UVA and UVB radiation in the Opsytec Dr. Gröbel UV chamber

When comparing the samples exposed to UVA and UVB radiation from day 1, day 31 and day 60 (figures 3.2.3.5, 3.2.3.6 and 3.2.3.7, respectively), a clear visual difference in colour was observed in case study objects 1 and 3, but not in case study object 2. The colour changes of case study object 1 and 3 are visualised in figures 3.2.3.2 and 3.2.3.4. The colour difference in these two objects occurred after exposure to 8325 J/cm^2 of UVB and 2113 J/cm^2 of UVA radiation. After the same exposure, case study object 2 did not show any changes of colour, as is represented in figure 3.2.3.3 An overview of the total UVB and UVA dose per measurement and cumulative radiation time can be seen in table 3.2.3.1.

The colour changes of case study objects 1 and 3 were also reflected by the ΔE_{00} results (see table 3.2.3.2 and figure 3.2.3.1). The ΔE_{00} values for sample 1 and 2 of case study object 1 increased from 1.41 to 4.44 and from 1.12 to 5, respectively. Even when the 95% confidence interval was taken into account, there was a distinct increase in the ΔE_{00} value for both samples of case study object 1. For sample 1 and 2 of case study object 3, the ΔE_{00} value increased from 0.66 to 3.98 and 1.1 to 5.29, respectively. The variation in the results of case study object 3 was larger (as reflected in the wider 95% confidence intervals) and the change of colour was visually less distinctive than that of case study object 1. However, the increase in ΔE_{00} of both samples of object 3 was still significant. In both case study objects there was a consistent change in colour over time. As can be seen in figure 3.2.3.1 and table 3.2.3.2, although there was a slight increase in ΔE_{00} values of case study object 2, they remained relatively similar throughout the experiments — especially when taking the wide 95% confidence intervals into account.

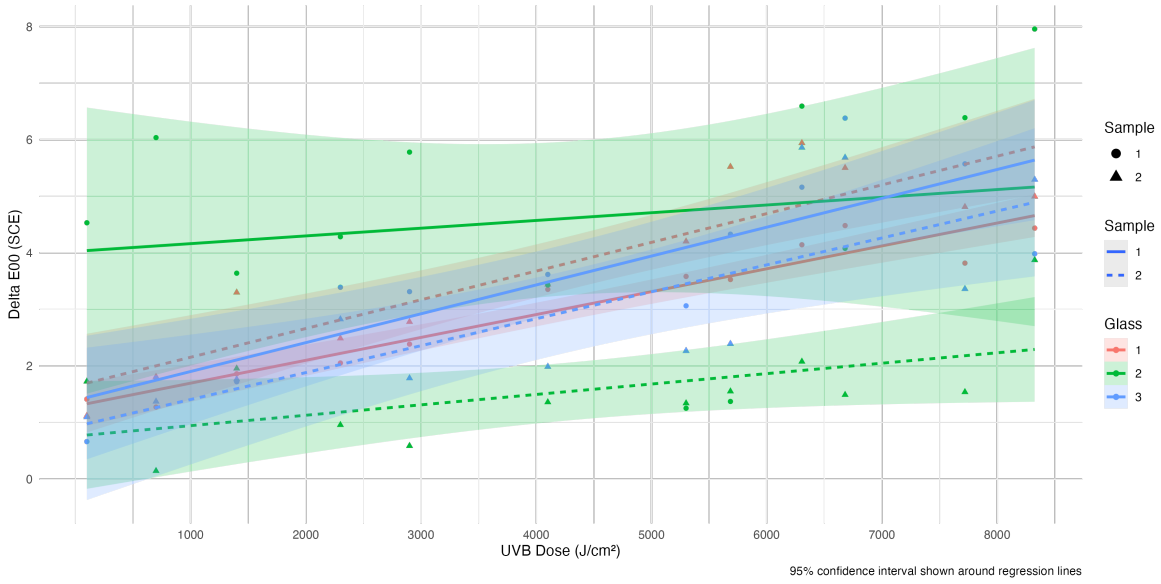


FIgure 3.2.3.1: Plot of the ΔE_{00} of the samples exposed to Opsytec Dr. Gröbel UV chamber measured excluding the specular component. (Graph: Lodewijn Ubbink)



Figure 3.2.3.2: The change in colour over time as represented by the measured CIELAB values at an exposure of 0 J/cm^2 (HEX # B0ACA9), 2900 J/cm^2 (HEX # B3A9A5) and 8325 J/cm^2 (HEX #AEA3A4) (from left to right) of sample 1, case study object 1.



Figure 3.2.3.3: The change in colour over time as represented by the measured CIELAB values at an exposure of 0 J/cm^2 (HEX # ADA7A2), 2900 J/cm^2 (HEX # 9C958F) and 8325 J/cm^2 (HEX # 958F8A) (from left to right) of sample 1, case study object 2.

Figure 3.2.3.4: The change in colour over time as represented by the measured CIELAB values at an exposure of 0 J/cm^2 (HEX # B0ACA9), 2900 J/cm^2 (HEX # B3A9A5) and 8325 J/cm^2 (HEX #AEA3A4) (from left to right) of sample 1, case study object 3.

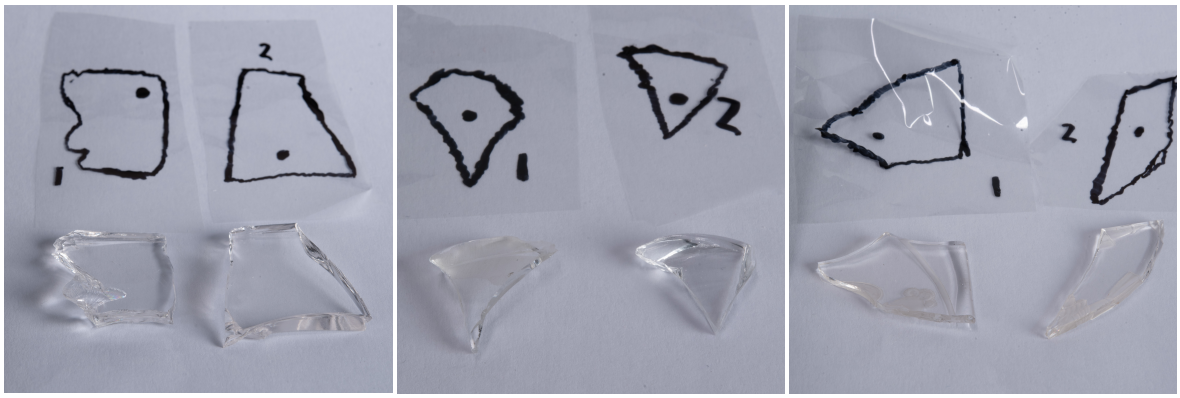


Figure 3.2.3.5: The samples exposed to UVA and UVB in the Opsytec Dr. Gröbel UV chamber, photographed at day 1. Samples from case study object 1 are on the left, 2 in the middle and 3 on the right. Above, the traced outlines on Melinex® are shown, the number indicates the sample number and the dot shows the location of the colour measurements. (Photo: Joris Nagtegaal)

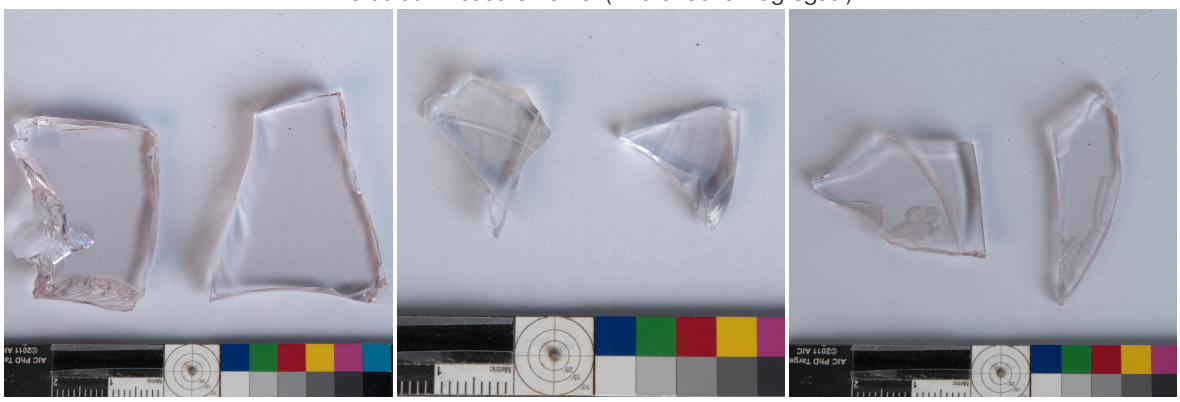


Figure 3.2.3.6: Photographs of the samples exposed to UVA and UVB in the same order as figure 3.2.3.4 show that the samples from case study object 1 (left) experienced a clear change in colour and the samples from case study object 3 (right) a slight change of colour after 2900 J/cm^2 of UVB and 792 J/cm^2 of UVA exposure. (Photo: Joris Nagtegaal)

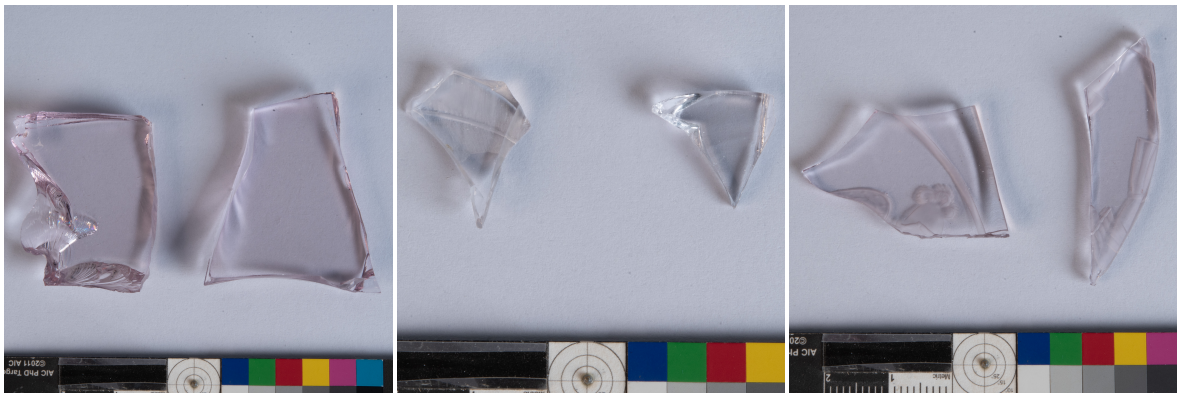


Figure 3.2.3.7: Photographs of the samples exposed to UVA and UVB in the same order as figure 3.2.3.4 show that the samples from case study object 1 (left) and case study object 2 (right) turned clearly more purple after 8325 J/cm^2 of UVB and 2113 J/cm^2 of UVA exposure. (Photo: Joris Nagtegaal)

Table 3.2.3.1: Overview of UVB dose within the Opsytec Dr. Gröbel UV chamber.

Date	Measurement	UVB dose until measurement (in $\frac{J}{cm^2}$)	Cumulative UVB dose (in $\frac{J}{cm^2}$)	UVA dose until measurement (in $\frac{J}{cm^2}$)	Cumulative UVA dose (in $\frac{J}{cm^2}$)	Minutes irradiated until measurement	Minutes irradiated in total.	Hours irradiated in total.
2 April 2025	1	0	0	0	0	0	0	0:00
14 April 2025	2	100	100	27	27	665	665	11:05
18 April 2025	3	600	700	164	191	4028	4693	78:13
23 April 2025	4	700	1400	191	382	4720	9413	156:53
28 April 2025	5	900	2300	246	628	5765	15178	252:58
1 May 2025	6	600	2900	164	792	4056	19234	320:34
7 May 2025	7	1200	4100	329	1121	8201	27435	457:15
14 May 2025	8	1200	5300	329	1450	8203	35638	593:58
16 May 2025	9	385	5685	105	1555	2598	38236	637:16
19 May 2025	10	620	6305	170	1725	4260	42496	708:16
21 May 2025	11	375	6680	103	1828	2527	45023	750:23
27 May 2025	12	1040	7720	285	2113	7196	52219	870:19
30 May 2025	13	605	8325	166	2279	4173	56392	939:52
Total:	**13**	**8325**	**8325**	**2279**	**2279**	**56392**	**56392**	**939:52**

Table 3.2.3.2: All ΔE00 values for the samples exposed in the Opsytec Dr. Gröbel UV chamber. For the calculation see Appendix III.

UV Dose in J/cm²	ΔE_{00} Glass 1-1	ΔE_{00} Glass 1-2	ΔE_{00} Glass 2-1	ΔE_{00} Glass 2-2	ΔE_{00} Glass 3-1	ΔE_{00} Glass 3-2
100	1.41	1.12	4.53	1.73	0.66	1.10
700	1.27	1.81	6.04	0.15	1.79	1.37
1400	1.86	3.30	3.64	1.96	1.72	1.77
2300	2.05	2.49	4.28	0.96	3.39	2.83
2900	2.39	2.78	5.78	0.59	3.31	1.78
4100	3.35	3.44	3.43	1.36	3.62	1.99
5300	3.58	4.20	1.25	1.34	3.06	2.27
5685	3.53	5.52	1.37	1.55	4.33	2.39
6305	4.14	5.94	6.59	2.08	5.16	5.86
6680	4.48	5.50	4.08	1.49	6.38	5.68
7720	3.82	4.81	6.39	1.54	5.57	3.36
8325	4.44	5.00	7.96	3.87	3.98	5.29

3.2.4 Samples exposed to the sunlight-through-glass simulation

In the Xenotest, two experiments were run simultaneously, each with a separate set of samples. These samples were exposed to a sunlight-through-glass simulation, both with and without a UV filter. Figures 3.2.4.4 and 3.2.4.5 show the samples without a filter and figures 3.2.4.6 and 3.2.4.7 show the samples with a filter. The total emitted UVA (300 – 400 nm) and the cumulative exposure time can be seen in table 3.2.4.1.

All the ΔE_{00} values of the samples with and without a UV filter can be seen in tables 3.2.4.2 and 3.2.4.3 and in figures 3.2.4.2 and 3.2.4.3, respectively. The variation in these plots for all case study objects was very wide (as reflected by the 95% confidence intervals), ranging from below zero to 10. When looking at table 3.2.4.2 and 3.2.4.3 there was also no clear increase in ΔE_{00}. This contrasted with the visual inspection of figures 3.2.4.1, 3.2.4.6 and 3.2.4.7, where a small change in colour seemed visible for the samples of case study object 1 when exposed to the sunlight-through-glass simulation without a UV filter.

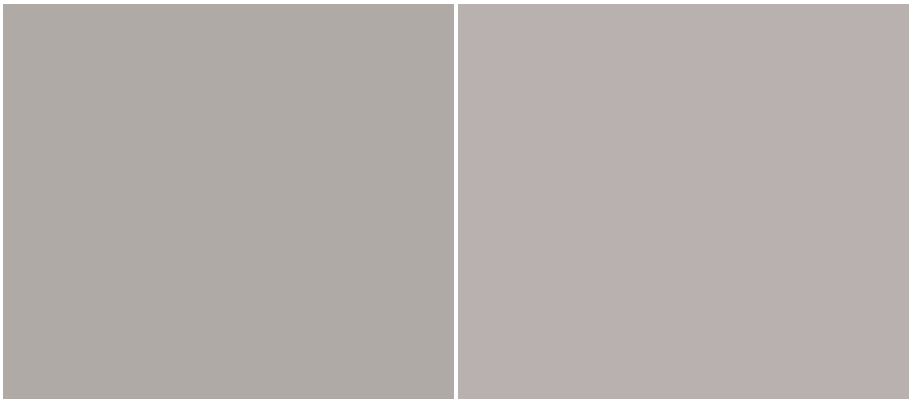


Figure 3.2.4.1: The change in colour over time as represented by the measured CIELAB values after 0 hours of exposure (HEX # AFAAA6) and 732 hours of exposure (HEX #B8B1AF) (from left to right) of sample 1, case study object 1 exposed without a UV filter.

Table 3.2.4.1: Overview of UVA dose within the Altas/Ametek Xenotest 440.

Date	Measurement	UVA dose (300-400 nm) until this stop (in $\frac{J}{m^2}$)	UVA dose (300-400 nm) until this stop (in $\frac{J}{cm^2}$)	UVA dose in total	Hours until measurement	Hours in total
1 April 2025	1	0	0.00	0.00	0:00	0:00
15 April 2025	2	13606	1.36	1.36	90:00	90:00
28 April 2025	3	16631	1.66	3.02	110:00	200:00
8 May 2025	4	30238	3.02	6.05	200:00	400:00
3 June 2025	5	50177	5.02	11.07	332:00	732:00
Total:	**5**	**110,652**	**11.07**	**11.07**	**732:00**	**732:00**

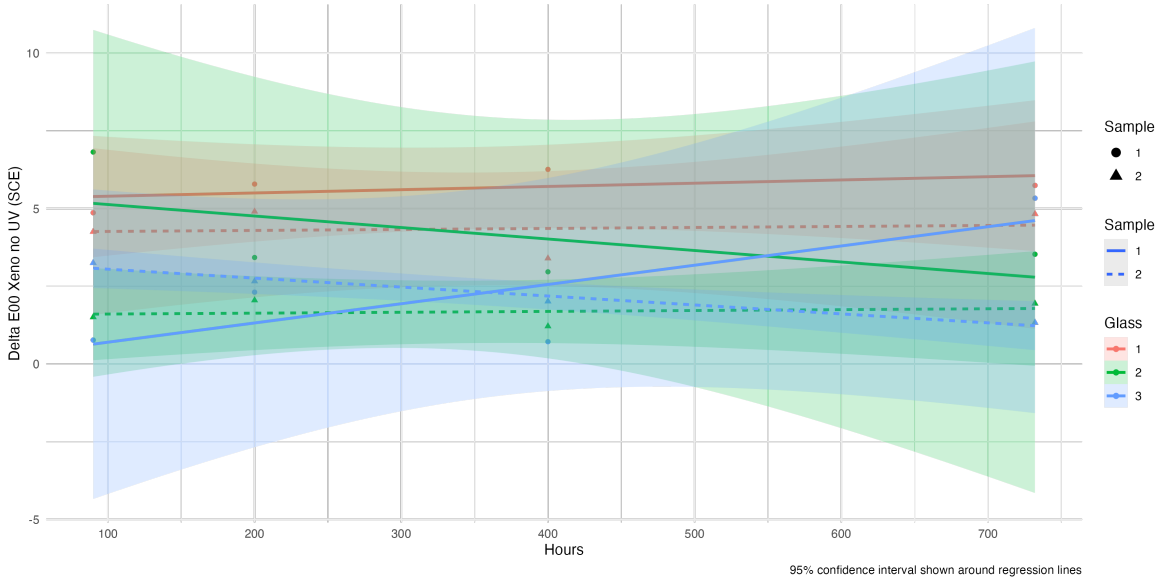


Figure 3.2.4.2: Plot of the ΔE_{00} of the samples exposed to the Xenotest with a UV filter. (Graph: Lodewijn Ubbink)

Table 3.2.4.2: All ΔE00 values for the samples exposed in the Xenotest with a UV filter. For the calculations see appendix III-1

Time (in hours)	ΔE_{00} Glass 1-1	ΔE_{00} Glass 1-2	ΔE_{00} Glass 2-1	ΔE_{00} Glass 2-2	ΔE_{00} Glass 3-1	ΔE_{00} Glass 3-2
90	4.86	4.25	6.82	1.51	0.77	3.25
200	5.79	4.90	3.42	2.05	2.31	2.66
400	6.26	3.40	2.96	1.21	0.72	2.01
732	5.74	4.82	3.53	1.94	5.33	1.33

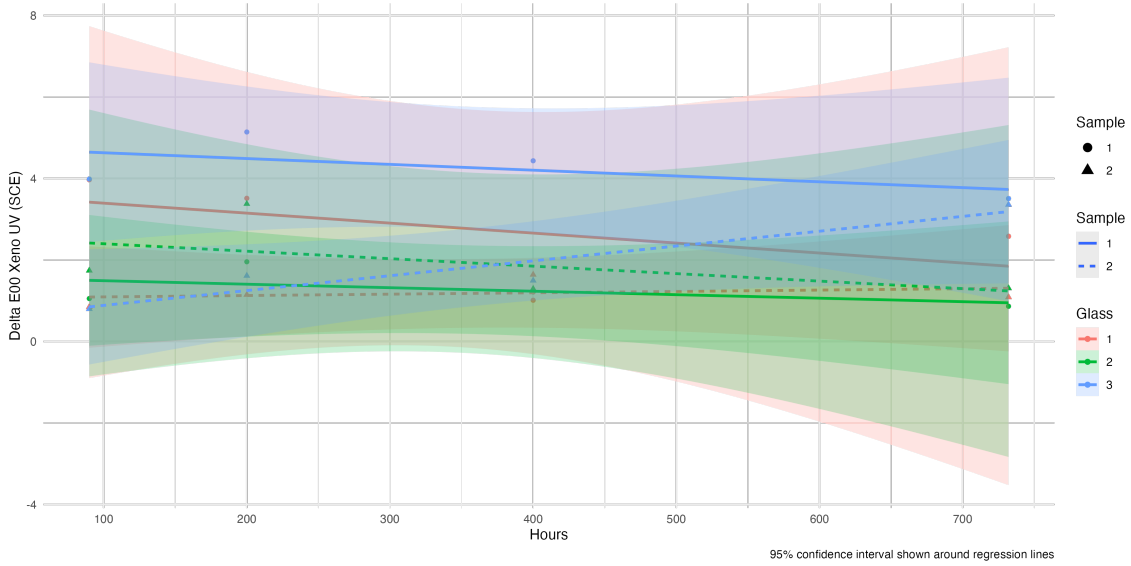


Figure 3.2.4.3: Plot of the ΔE_{00} of the samples exposed to the Xenotest without a UV filter. (Graph: Lodewijn Ubbink)

Table 3.2.4.3: All ΔE00 values for the samples exposed in the Xenotest without a UV filter. For the calculations see appendix III-1

Time (in	ΔE_{00} Glass	ΔE_{00} Glass	ΔE_{00} Glass	ΔE_{00} Glass	ΔE_{00} Glass	ΔE_{00} Glass
90	3.97	0.84	1.05	1.74	3.99	0.80
200	3.51	1.15	1.96	3.38	5.14	1.61
400	1.01	1.64	1.22	1.29	4.43	1.50
732	2.58	1.09	0.86	1.31	3.51	3.36

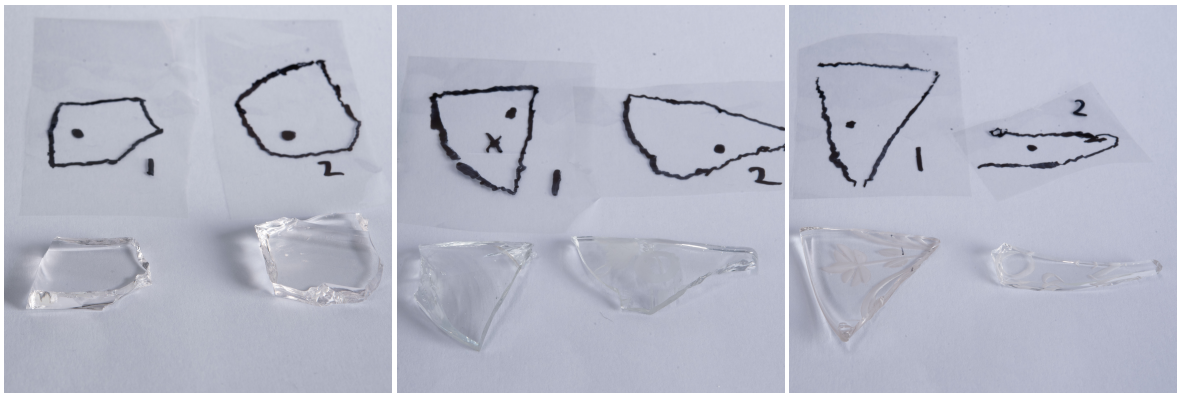


Figure 3.2.4.4: The samples exposed in the Xenotest with UV filter, photographed after 0 hours of exposure. Samples from case study object 1 on the left, 2 in the middle and 3 on the right. Above, the traced outlines on Melinex® are shown, the number indicates the sample number and the dot shows the location of the colour measurements. (Photo: Joris Nagtegaal)



Figure 3.2.4.5: Photographs of the samples exposed in the Xenotest with UV filter in the same order as figure 3.2.4.4, shows no changes of colour after 732 hours of exposure. (Photo: Joris Nagtegaal)



Figure 3.2.4.6: The samples exposed in the Xenotest without UV filter, photographed after 0 hours of exposure. Samples from case study object 1 on the left, 2 in the middle and 3 on the right. Above, the traced outlines on Melinex® are shown, the number indicates the sample number and the dot shows the location of the colour measurements. (Photo: Joris Nagtegaal)



Figure 3.2.4.7: Photographs of the samples exposed in the Xenotest without UV filter in the same order as figure 3.2.4.6, expect for the samples of case study object 1, on the left now shows sample 1 and on the right sample 2, show that the samples from case study object 1 (left) a slight change of colour after 732 hours of exposure. (Photo: Joris Nagtegaal)

4. Discussion

Although all glasses were confirmed to contain manganese — suggesting they were all potentially susceptible to solarisation — only case study glasses 1 and 3 exhibited a clear change in colour after some types of irradiation, while case study glass 2 did not show any discolouration at all. These visual colour changes were confirmed by the CIELAB values measured with the spectrophotometer. However, this was only the case when the colour changes were very prominent, such as in the samples of case study object 1 and 3 that were primarily exposed to UVB radiation. Only for these samples there was a significant increase in ΔE_{00} values over time. While a visual change was also seen in both samples of case study glass 1 when exposed in the Xenotest without a UV filter, and in lesser extent in the samples of the same glass when exposed to UVA radiation, these changes were not reflected by the ΔE_{00} values. The large differences in discolouration between the case study glasses was not expected, as they all contained manganese and iron, which were assumed to be the main elements responsible for solarisation.

The first question that arose, was whether or not all glasses contained similar amounts of these two important elements. SEM-EDX showed that all case study glasses only contained small percentages of MnO (0.1 — 0.2 wt%) and FeO_3 (ca. 0.1 wt%). As these percentages were consistent across all glasses, it was still surprising that they did not solarise similarly. Another possible explanation may be that there were other compositional differences. EDX analysis showed that case study glasses 2 and 3 had very similar chemical compositions, while that of glass 1 differed significantly. For example, case study glasses 2 and 3 were found to contain a significant amount of potassium, while this was not the case for glass 1. In contrast, the amount of Na_2O and MgO detected by EDX was significantly higher in case study glass 1 than in the other two glasses. This suggests that case study glass 1 was a soda-lime-silica glass (Na_2O-MgO-SiO_2), while case study objects 2 and 3 were potassium (K_2O) glasses. This may explain why case study glass 1 exhibited solarisation in more irradiation conditions than the other two glasses. However, this does not explain the observation that case study glass 1 and 3 discoloured in the UVA/UVB condition, whereas case study glass 2 did not. When looking at minor compositional elements, the only significant difference between the case study glasses was that 1 and 3 contained traces of chlorine (Cl), while this was absent in case study glass 2. Furthermore, it was found that case study glass 1 contained significantly more arsenic than case study glasses 2 and 3.

Although these compositional differences might — at least partly — explain the observed differences in solarisation between the case study glasses, physical properties of the samples may also have affected the measurements. For example, differences in the thickness of the glass samples may have influenced the observed colour. The samples of case study glass 1 were significantly thicker (on average 4.1 mm) compared to those of case study glasses 2 (on average 2.1 mm) and 3 (on average 1.8 mm). See appendix X for the thickness of each individual sample. The visually observed colour intensity of the samples of case study glass 1, particularly in the Xenotest without filter and UVA condition, might appear greater because it had double the thickness of the samples of the other case study objects. However, this does not explain why these visually observed colour changes in case study glass 1 were not reflected by the ΔE_{00} values — which stayed relatively constant over time, while an increase was expected given the change of colour.

This discrepancy may not be related to the colour change itself, but rather to the colour measurement. Although each measurement was taken from roughly the same spot, the results showed high variability, as reflected by high standard deviations and wide 95% confidence intervals. The issues with the colour measurements became even more apparent when visualising the Lab values, by converting them to HEX colours. Even when a clear change of colour was visually observed in the Xenotest without filter and UVA

condition, the corresponding HEX colours of case study glass 1 were only minimally different. Given that both the HEX colours and the ΔE_{00} were derived from the same Lab values, it is likely that this measurement process was flawed. The most likely cause is the curvature of the glass samples. This was especially apparent in control sample 2 of case study glass 2, which had the largest curvature of all samples. Here, the ΔE_{00} values fluctuated significantly between measurements, even though no colour change — and thus a ΔE_{00} that remained zero over time — was expected in a control sample kept in the dark. Given that the fluctuations in ΔE_{00} were present in the control samples, it is reasonable to assume that this also applies to the samples exposed to other radiation conditions. These findings suggest that the physical properties of the samples, especially their curvature, likely resulted in significant variability in the measurements.

In addition to curvature, the limited number of measurements is also likely to have influenced the accuracy the colour measurements. This is most notable when comparing the results from the samples exposed in the Xenotest with those exposed to UVA and the control samples. While the samples in exposed to UVA and the control samples were measured 15 and 16 times, respectively, the samples in the Xenotest were only measured 5 times. This was reflected by the standard deviations and 95% confidence intervals, as those resulting from the Xenotest were significantly higher than those of the other two conditions. This implies that if more measurements could have been taken at closer intervals, this would likely have resulted in more clearly visible trends in the colour changes and smaller standard deviations, improving the reliability of the measurements.

Although all irradiation conditions were affected by the measurement errors described above, only in the UVB condition the extent of solarisation was sufficient to be clearly detectable both visually and through the ΔE_{00} values (in case study glasses 1 and 3). Initially, the aim was to expose samples to UVB radiation alone in the Opsytec Dr. Gröbel UV chamber, to investigate its influence on solarisation. However, it only became clear later during the experiment that the radiation sources that were presented as UVB fluorescent tubes in fact also emitted radiation in the visible and UVA region of the electromagnetic spectrum. Theoretically, the UVA dose emitted from these UVB tubes was higher than that of the Blak-Ray® UVL-56 lamp, although it was not possible to determine the exact emission of the latter. Ideally, the dose emitted by the Blak-Ray® UVL-56 lamp should have been monitored continuously, as was the case in the UV chamber. Since this was not possible, the average of the measurements taken with the Elsec 764 UV+ Monitor were used to calculate the cumulative UVA dose the samples were exposed to throughout the experiment. The cumulative dose of UVA in the Opsytec Dr. Gröbel UV chamber was similar to the UVA dose from the Blak-Ray® UVL-56 lamp. Therefore, it is impossible to attribute the change in colour to UVB radiation alone. These results suggest that a combination of UVA and UVB may be necessary for solarisation to occur in potassium glasses — as case study glass 3 only discoloured in this condition, but not in the other ones. Given that UVA alone seems to have induced solarisation in case study glass 1, the presence of UVB may have only accelerated the solarisation in soda-lime-silica glasses. However, if the potassium glass samples were left for long enough, UVA from the Blak-Ray® UVL-56 lamp might also have induced solarisation in these samples, so further research is needed to examine the role of different types of UV radiation in solarisation.

5. Conclusion

Based on the experiments described in section II, it appears that the presence of manganese and iron alone does not guarantee that a glass will solarise under irradiation. Although all case study glasses contained both elements, only two of the three exhibited a clear colour change, and only in certain conditions. The most significant and the only measurable discolouration occurred in the samples of case study glasses 1 and 3 when they were exposed to UVB-containing radiation. In addition, given the limitations of the colour measurements, it was difficult to extract definitive conclusions based on the ΔE_{00} values, so visual assessment might be an important tool to identify solarisation.

Surprisingly, differences in base composition did not seem to affect the solarisation process. While both case study glass 1 (a soda-lime-silica glass) and case study glass 3 (a potassium glass) were solarised, case study glass 2 (another potassium glass) was not. This suggests that minor elements within the glass composition may play an important role, as the two solarised glasses both contained traces of chlorine, whereas case study glass 2 did not. Furthermore, case study glass 1 contained significantly more arsenic than case study glasses 2 and 3.

With respect to the irradiation conditions, it seemed that only the UVB-containing radiation measurably induced solarisation. However, no definite conclusion can be drawn about the exact influence of UVB on solarisation, as the supposed UVB condition and the UVA-only condition were found to contain similar UVA doses. In addition, other conditions — such as the Xenotest without a UV filter and the UVA condition — did visibly cause discolouration in case study glass 1, although this was not reflected in the ΔE_{00} values. This may suggest that soda-lime-silica glass is more susceptible to UVA-induced solarisation than potassium glass, which may need a combination of UVA and UVB (or UVB alone) to solarise. However, with the rather limited number of case study objects of each glass type, to conclude this with certainty, more research is needed.

Overall, the results of section II show that solarisation is a complex process, being influenced not only by the general glass composition and the presence of manganese and iron, but also by minor compositional differences and the type of UV irradiation the glass is exposed to.

Section III: Discussion, Conclusion & Recommendations for Further Research

1. Discussion

The literature research in section I showed that Abd-Allah, Baldwin, Bamford, Davison, Paul, Pelouze and Weyl all agreed that both manganese and iron play a significant role in the process of solarisation.[117] Since their presence was confirmed in all case study objects in section II, in theory they all should have been susceptible to solarisation. Surprisingly, only case study glasses 1 and 3 showed signs of solarisation in the UVB-containing condition, and only case study glass 1 visually discoloured in the Xenotest without a filter and in the UVA only condition.

When looking at the quantitative composition of each case study glass, it is interesting to note that case study glass 1 was found to be a soda-lime-silica glass, while case study glasses 2 and 3 both were potassium glasses. This implies that — at least when UVB was present — the general composition of the glass may not be the main explanation for the observed variation in solarisation. In section I, the only previous research describing a solarisation experiment on historical glass was conducted by Ramadan Abd-Allah, who only focused on soda-lime-silica glasses, and UVA radiation.[118] Therefore, it is difficult to compare the solarisation of case study glass 3, under UVB-containing radiation, with what was found in the literature.

However, it stands out that the glasses described by Abd-Allah contained significantly more manganese than all case study glasses described in section II of this study According to Abd-Allah, in order to solarise glasses should contain approximately 0.9 wt% manganese.[119] This is significantly higher than the percentages found in the case study glasses in this research, which only contained about 0.1 wt%. The weight percentages of manganese in the case study glasses was more in line with the recipe by Apsley Pellatt in 1849 for producing colourless glass.[120] This makes sense, as all case study glasses were likely produced around this period. Based on Abd-Allah's suggested manganese wt% threshold for solarisation under UVA radiation, the fact that some case study glasses did show signs of solarisation is interesting.

The other minor elements in the glass composition that may influence solarisation were not discussed thoroughly by the authors mentioned in section I. Only Abd-Allah and Weyl specifically mentioned elements that could potentially influence the solarisation process. According to Abd-Allah, the presence of both fluorine and phosphorus could play a role

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[117] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 33. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025; Baldwin, Rick, 'Decolorizing Glass With Manganese', *Crown Jewels of the Wire*, July 1985, 23; Bamford, C. R., *Colour Generation and Control in Glass*, 1. ed., 2. impression, Glass Science and Technology 2 (Amsterdam: Elsevier, 1984), 51-52; Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 7; Paul, A. *Chemistry of Glasses*. 2nd ed. London ; New York: Chapman and Hall, 1990, 332: Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 500-501.

[118] Abd-Allah, Ramadan. 'Solarization Behaviour of Manganese Containing Glass: An Experimental and Analytical Study'. *Mediterranean Archaeology and Achaeometry* 9, no. 1 (2009): 44.

[119] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review', Advanced Research in Conservation Science 3, no. 1 (25 June 2022): 38, https://doi.org/10.21608/arcs.2022.135911.1025.

[120] Pellatt, Apsley. *Curiosities of Glass Making*. Getty Research Institute. D. Bogue, 1849, 69. Getty Research Institute. https://archive.org/details/gri_33125008683704. Accessed 28 October 2024.

in this process.[121] However, neither of these was detected in the case study glasses that were examined in this research, so this could not be tested. Weyl suggested that glasses containing both manganese and arsenic are especially susceptible to solarisation.[122] This is in line with what was found during the experiments conducted in section II. Here, case study glass 1 — the only glass that contained a significant amount of arsenic — showed the most significant solarisation and was the only glass that solarised in different irradiation conditions. Therefore, the presence of arsenic might explain why case study glass 1 was the only glass that solarised under UVA radiation, even though the wt% of manganese was too low, according to Abd-Allah's threshold.

The interplay between the major and minor elements within the glass composition makes it difficult to draw conclusions. That case study glass 1 showed the most prominent solarisation is evident, but whether that is due to the presence of arsenic, or that this is related to the fact that this was the only soda-lime-silica glass, remains unclear. Since the wt% of manganese and iron were similar in all case study objects, it seems these factors did not play a role in the differences in solarisation observed.

When aiming to explain why only case study glasses 1 and 3 solarised under UVB-containing radiation, it may be interesting to highlight a minor element that was not described in the literature in section I. The chemical analysis in section II showed that the two solarised glasses both contained traces of chlorine, while case study glass 2 did not. Whether and how chlorine plays a role in the solarisation process demands further research.

It is important to note that there were some methodological differences between the experiments conducted in section II of this research and the ones described in section I. The most significant difference between the experimental set-up in this research and the earlier conducted solarisation experiments, is that for this research, the samples were not actively heated. In the previous experiments the samples were kept at a temperature between 90 and 100 ˚C.[123] It was chosen to perform the experiments described in section II at room temperature, because the aim was to identify the parameters that influence solarisation for both museum and non-museum collections, which, are generally kept at room temperature.

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[121] Abd-Allah, Ramadan, 'From Decolorization to Solarization of Historical Glass: A Review', Advanced Research in Conservation Science 3, no. 1 (25 June 2022): 35, https://doi.org/10.21608/arcs.2022.135911.1025.

[122] Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 129.

[123] Abd-Allah, Ramadan. 'From Decolorization to Solarization of Historical Glass: A Review'. *Advanced Research in Conservation Science* 3, no. 1 (25 June 2022): 38. Accessed 18 October 2024. https://doi.org/10.21608/arcs.2022.135911.1025. ; Jedamzik, Ralf, Volker Dietrich, Axel Engel, and Uwe Petzold. 'Solarization Effects in Optical Glass from UV to Blue'. In *Optical Manufacturing and Testing XIV*, edited by Heidi Ottevaere, Rolf Rascher, Daewook Kim, and Heejoo Choi, 9. San Diego, United States: SPIE, 2022. Accessed 18 October 2024. https://doi.org/10.1117/12.2632359.

2. Conclusion

The main research question of this thesis was "*How do historical manufacturing practices using manganese as a decolourant, the intrinsic solarisation behaviour of manganese-containing glass, and the UV lighting conditions in museum and non-museum collections combine to determine the susceptibility of historical glass artefacts to solarisation?"* Answering this question has proven to be complicated. The information obtained from the literature and the results of experimental research are ambiguous and presenting definitive explanations for the outcomes has not been possible. Despite the relatively short time period of the research, it was possible to induce solarisation in some of the case study glasses.

The percentage of manganese found in the case study glasses was very low (ca. 0.1 wt%). In addition, there were clear differences in chemical composition between case study object 1 and case study objects 2 and 3. However, the fact that case study objects 2 and 3 were potassium glasses while case study object 1 was a soda-lime-silica glass was not reflected in the colour changes that were observed. This might be attributed to the fact that both case study glasses that solarised contained traces of chlorine, whereas case study glass 2 did not. This was not the only minor element that may have influenced the process, as arsenic might have played a role in the discolouration of glass 1.

Objects that are in an indoor environment will in general only be exposed to UVA lighting because all of the UVB will be blocked out by window glass. In most museum environments, objects will also be exposed to less UVA radiation, due to the use of UV filters on the windows, which was mimicked in this study in the Xenotest with filter. Since glass is considered to have a low sensitivity to light, based on contemporary museum standards the case study objects would be advised to be exposed to a maximum UVA dose of 75 microwatts per lumen, and a maximum illumination of 200 lux. This corresponds to a maximum yearly UVA dose of 15.768 J/cm^2. Since the Blak-Ray® UVL-56 lamp exposed the samples to a total of 1826.59 J/cm^2 of UVA, this would be equivalent to exposure of 115 years and ten months. Although this did not cause any measurable changes of colour, the samples of case study glass 1 did discolour visually. This was not the case for the samples exposed in the Xenotest with a UV filter, the condition that should specifically mimic museum conditions. However, the samples of case study glass 1 exposed in the Xenotest without a UV filter, mimicking non-museum conditions, did solarise visually. That the samples with a filter did not solarise is likely due to the fact that they were not exposed to an equal dose of UV as the samples exposed to UVA. Furthermore, samples from both case study glasses 1 and 3 did measurably discolour after exposure to UVB-containing radiation. This suggests that collections displayed outdoors, and thus also exposed to UVB, have an even greater risk of solarisation.

It cannot be assumed that in a museum environment, for glasses with a similar composition to case study object 1, there would be no risk of solarisation within a 115 year time frame. Even when the UV filters would be replaced regularly to block out UV radiation above 75 microwatts per lumen, the chance of solarisation would be present. Furthermore, after 64 days of exposure to different radiation sources, only the samples of case study glass 1 and 3 that had been exposed to UVB-containing radiation were found to have both visible and measurable discolouration. This suggests that glass that is displayed outdoors, with similar compositions as case study objects 1 and 3, is at risk of solarisation, as this is exposed to UVB radiation.

The fact that even very small compositional differences, such as traces of chlorine, between case study glass 2 and 3, might have a significant influence on their discolouration, highlights the complexity of the process of solarisation. The exact parameters for a glass to be susceptible to solarisation remain largely unknown. Therefore, it remains difficult to provide proper guidelines for conservators to know whether or not their glass collections are at risk of solarisation.

3. Recommendations for further research

In this chapter, several possibilities for further research will be explained. These are based on the findings and limitations of this research.

3.1 Alternative analytical techniques

In this research the case study objects have been analysed using pXRF and SEM-EDX. These techniques showed that case study object 2 and case study object 3 had a very similar composition. However, after exposure to electromagnetic radiation containing UVB, case study object 3 exhibited a change in colour, while case study object 2 did not. This suggests that there must be a significant difference in chemical composition between the two of them. To find out if there are compositional differences — other than the traces of chlorine that were found in case study object 3 — it is suggested to analyse the glasses with a more sensitive and precise analytical technique, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This technique is able to accurately quantify weight percentages of major, minor and trace elements.[124]

In addition, it would be useful to determine the oxidation states of the manganese and the iron present in the case study objects. This could give an explanation why two very similar glasses did not show similar solarisation effects and simultaneously provide a deeper understanding of the solarisation process. This could be done using Electron Spin Resonance Spectroscopy, which determines the oxidation state of ions by recording the spin of electrons in a magnetic field.[125] This technique was also suggested by Sandra Davison to determine the oxidation state of elements within a glass composition.[126]

3.2 Influence of chlorine and arsenic

To better understand the process of solarisation and identify glasses that are potentially at risk, it would be useful to further research the effects of chlorine and arsenic on the solarisation process. Paul and Weyl described theoretically — but not experimentally — that the presence of arsenic might make a manganese-containing glass more susceptible to solarisation.[127] The possible influence of chlorine on solarisation was not described in the literature presented in section I of this research. However, since this element was present in both solarised case study objects, it would be very interesting to research if this is also present in other solarised glasses. Therefore, it would be useful to chemically analyse (naturally) solarised glasses to find out whether the presence of chlorine and/or arsenic is common in them.

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[124] Skoog, Douglas A., F. James Holler, and Stanley R. Crouch. Principles of Instrumental Analysis. 7. edition. Boston, MA: Cengage Learning, 2018, 263.

[125] *Ibidem,* 123.

[126] Davison, Sandra. *Conservation and Restoration of Glass*. Second Edition [Digital Print]. London & New York: Routledge, 2011, 239.

[127] Paul, A. *Chemistry of Glasses*. 2nd ed. London ; New York: Chapman and Hall, 1990, 332; Weyl, W A. *Coloured Glasses*. Sheffield: Society of Glass Technology, 1951, 129.

3.3 Solarisation of soda-lime-silica and potassium glasses

During this research, it was surprisingly found that both a soda-lime-silica and a potassium glass solarised, even though the literature only references to solarisation of historic soda-lime-silica glass. Therefore, it would be interesting to further investigate whether these two types of glass have similar solarisation properties, and whether or not solarisation is dependent on the major elements in the glass composition, or rather on the minor elements.

3.4 Improving the accuracy of the colour measurements

The colour measurements in this research showed high standard deviations and large fluctuations, which is believed to be due to inaccuracies caused by the curvature of the glass samples. To improve this, it is suggested to use flat samples. This can be achieved in two ways, either by producing artificial samples with a composition reflecting that of glasses known to be sensitive to solarisation, although this is very difficult to achieve. Another way to achieve this, is by grinding down and polishing the historic glass samples until they all have the same thickness and are flat, which is also very difficult to do.

3.5 Alternative lighting conditions

The UVB fluorescent tubes used in this research were found to also emit UVA radiation. Therefore, it was not certain that the discolouration of some of the sample was solely caused by UVB radiation. It would be good to expose the samples to a source emitting only UVB, to see whether or not they would solarise to the same extent. This cannot be achieved using fluorescent tubes, because they always also emit UVA light, but it might be possible to build an apparatus made of UVB emitting LED lights, such as those from AP Technologies. Their TUD99F1B LED emits radiation between 280 and 315 nanometers, which corresponds to UVB radiation alone.[128]

[128] AP Technologies. ‘Deep UV LED - 295nm’. Product Information Sheet, 25 June 2019. https://www.aptechnologies.co.uk/images/Data/SETi/DS_TUD99F1B_r4_25Jun19.pdf. Accessed 13 June 2025.

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Section IV: Appendices

Appendix I: Calculation yearly UVA dose museum environment

To calculate the yearly UVA dose of an object in a museum environment and to be able to compare this with the conducted experiments, the given 75 µW/lumen needs to be converted to Joule per square centimetre, per year. This is done according to the following steps:

Step 1
Convert µW/lumen to µW/m²

UV irradiance $= 75\ \mu W/$lumen $\times\ 200$ lumen/m$^2 = 15{,}000\ \mu W/m^2$

Step 2
Convert µW to W

$15{,}000\ \mu W/m^2 = 0.015\ W/m^2$

Step 3
Convert W to Joule per second

$$0.015 W/m^2 = 0.015 \frac{J/s}{m^2}$$

Step 4
Calculate total exposure seconds per year

Second during opening hours per year $= 365$ days $x\ 8$ hours per day x 60 minutes per hour $x\ 60$ seconds per minute $=\ 10{,}512{,}000$ seconds per year

Step 5
Calculate UV dose per square meter per year

$$0.015 \frac{J/s}{m^2}\ x\ 10{,}512{,}000\ =\ 157{,}680\ \frac{J/year}{m^2}$$

Step 6
Convert Joule per square meter to Joule per square centimetre

$$1m^2 = 10{,}000 cm^2$$

$$157{,}680\ \frac{J}{m^2} = \frac{156{,}680}{10{,}000} \frac{J}{cm^2} = 15.768 \text{ Joule per } cm^2 \text{ per year}$$

Appendix II conversion of Lab to LCh and Calculating ΔE_{00}

$$C' = \sqrt{a^{*2} + b^{*2}}$$

$$h' = \tan^{-1}\left(\frac{b'}{a'}\right)$$

Of which

$$a' = a * (1 + G)$$

And

$$b' = b *$$

Where

$$G = 0.5\sqrt{\frac{\bar{C}^{*7}_{ab}}{\bar{C}^{*7}_{ab} + 25^7}}$$

$\bar{C}^{*}_{ab}$ is the arithmetic mean of C^{*}_{ab}, so the mean of C* of measurement 1 (a) and measurement 2 (b).

Calculating ΔE_{00}

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

(Equation 2.6.1)

$$\Delta L = L'_1 - L'_2$$ (Equation 2.6.2)

This equation calculates the difference in lightness between colour 1 and colour 2.

$$\Delta C' = C'_1 - C'_2$$ (Equation 2.6.3)

This equation calculates the difference in chroma between colour 1 and colour 2.

$$\Delta H' = 2\sqrt{C'_1 * C'_2}\sin\frac{\Delta h'}{2}$$ (Equation 2.6.4)

This equation shows the difference in hue, the colour in an angle around the centre of the colour wheel, because it is an angle, the use of sin is needed to compare the angles of h'$_1$ and h'$_2$, the square root in the first part of the equation is to compensate for the fact that hue differences do not matter much when a colour is almost grey, so has a very low C'.

$$\Delta h' = h'_1 - h'_2$$ (Equation 2.6.5)

This equation gives the numerical difference between the hue of colour 1 and colour 2. To make this usable, it is needed to wrap it around 360° because the hue is an angle in the colour wheel, this is done in equation 3.2.12. Calculating h' is explained in equations 3.2.3 until 3.2.5.

Equations 3.2.14, 3.2.15 and 3.2.16 are to weight respectively the Lightness, Chroma and Hue. In these equation sometimes there is a *bar* ($\bar{x}$) above parts of the equation, this stands for the mean of that part, so $\bar{x} = (x_1 + x_2)/2$.

$$S_L = 1 + \frac{0.015(\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}}$$ (Equation 2.6.6)

This equation adjusts how much the difference in lightness counts in the final ΔE_{00} equation. This is necessary because human eyes are especially sensitive to lightness changes in the middle regions, so around L' = 50, and less sensitive to changes in very light or very dark regions.

$$S_C = 1 + 0.045\bar{C}'$$ (Equation 2.6.7)

This equation adjusts for the fact that small changes in chroma become noticeable when the average chroma is relatively high.

$$S_H = 1 + 0.015\bar{C}'T$$ (Equation 2.6.8)

This equation adjusts the weight of hue difference. This depends on the average chrome and on a factor T, described in equation 3.2.18. This is necessary because human sensitivity to hue changes is not equal around the colour wheel. A small change in a certain region of the colour wheel could be noticed worst than the same change in another area. The factor T accounts for those regional differences.

$$R_T = -\sin(2\Delta\theta)R_C$$ (Equation 2.6.9)

This equation makes corrections that tweak the combined effects of ΔC' and ΔH' in certain regions of the colour wheel, particularly within the blue region. This is necessary because in those areas human perception of chroma and hue differences does not interact in an additive way, R_T tweaks the changes in these areas so they correspond better with human perception.

$$T = 1 - 0.17\cos(\bar{h}' - 30°) + 0.24\cos(2\bar{h}') + 0.32\cos(3\bar{h}' + 6°) - 0.20\cos(4\bar{h}' - 63°)$$
(Equation 2.6.10)

This equation gives the factor T. Factor T is necessary to adjust the final outcome of the ΔE_{00} equation to the different sensitivities human perception has to certain parts of the colour circle. Each cos adjusts T depending on which sector of the colour circle $\bar{h}'$ falls into.

$$\Delta\theta = 30\,e^{-\left(\frac{\bar{h}' - 275°}{25}\right)^2}$$ (Equation 2.6.11)

This equation creates a small angle shift for R_T (equation 3.2.14). This angle shift is basically zero for most hue angles, but grows up to 30 degrees when $\bar{h}'$ is near 275 degrees, which is the blue area of the colour circle. This is needed because the interaction between the chroma and the hue in this region is most pronounced.

$$R_C = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}}$$ (Equation 2.6.12)

This equation scales the size of the R_T correction according to how intense the colours are. When the difference in chroma is small, this equation will be almost 0, resulting in R_T also becoming almost 0. With a large chroma difference this equation can be 2 at most, giving R_T its maximal effect.

Appendix III: ΔE00 calculation and visualisations

UV Manganese Colours

Joris Nagtegaal & Lodewijn Ubbink 2025-06-20

```r
# Load required libraries
library(readxl)
library(dplyr)
library(ggplot2)
```

```r
# Read in data and remove the first two rows (not relevant)
data_glas1 <- read_excel("UV_Manganese_Colour_2_final.xlsx", sheet = "Glass 1")
data_glas1 <- data_glas1[-(1:2),]

data_glas2 <- read_excel("UV_Manganese_Colour_2_final.xlsx", sheet = "Glass 2")
data_glas2 <- data_glas2[-(1:2),]

data_glas3 <- read_excel("UV_Manganese_Colour_2_final.xlsx", sheet = "Glass 3")
data_glas3 <- data_glas3[-(1:2),]

data_wool <- read_excel("UV_Manganese_Colour_2_final.xlsx",
                        sheet = "Blue Wool Measurements")
data_wool <- data_wool[-(1:2),]

# Combine data sets for glass 1-3 into one large dataset
data <- rbind(data_glas1, data_glas2, data_glas3)
data <- rbind(data, data_glas3)

# The data were not numeric, so we made sure R saw the numbers as numbers
data <- data %>%
  mutate(across(
    .cols = -c(`SCI / SCE`, CIELAB, Measurement),  # all columns except SCI/
                                                   # SCE and CIELAB
    .fns = ~ round(as.numeric(.),2) # change to numeric and round to 2 decimals
  ))
```

```r
# Create data set containing only delta (Δ) measures
data_delta <- data[data$Measurement == "Δ",]

# Split SCI and SCE data set
# Specular Component Included - with gloss
data_SCI <- data_delta[data_delta$`SCI / SCE` == "SCI",]

# Specular Component Excluded - without gloss
data_SCE <- data_delta[data_delta$`SCI / SCE` == "SCE",]
```

```
# Change 0.00 values into "not available" NAs
# so R knows there is no measurement here
data_SCE <- data_SCE %>%
  mutate(across(
    where(is.numeric), # only the columns that contain numbers
    ~ na_if(., 0.00) # change 0.00 to NA
  ))

data_SCI <- data_SCI %>%
  mutate(across(
    where(is.numeric), # only the columns that contain numbers
    ~ na_if(., 0.00) # change 0.00 to NA
  ))
```

Cie2000 function

```
cie2000 <- function(L1, a1, b1, L2, a2, b2, K_L = 1, K_C = 1, K_H = 1) {

  # Calculate C' and C_bar (mean) based on a* and b*
  C1 <- sqrt(a1^2 + b1^2)
   C2 <- sqrt(a2^2 + b2^2)
   C_bar <- (C1 + C2) / 2

  # Calculate G correction factor
  G <- 0.5 * (1 - sqrt((C_bar^7) / (C_bar^7 + 25^7)))

  # Calculate adjusted a' values with correction G
  a1_prime <- (1 + G) * a1
  a2_prime <- (1 + G) * a2

  # Recalculate C' with adjusted a'
  C1_prime <- sqrt(a1_prime^2 + b1^2)
  C2_prime <- sqrt(a2_prime^2 + b2^2)
  C_bar_prime <- (C1_prime + C2_prime) / 2

  # Calculate h'
  h1_prime <- atan2(b1, a1_prime)
  h2_prime <- atan2(b2, a2_prime)

  # Calculate delta L', C', and H'
  delta_L_prime <- L2 - L1 # Equation 2.6.2
  delta_C_prime <- C2_prime - C1_prime # Equation 2.6.3

  delta_h_prime <- h2_prime - h1_prime # Equation 2.6.5

  delta_H_prime <- 2 * sqrt(C1_prime * C2_prime) * sin((delta_h_prime) / 2)
  # Equation 2.6.4# Calculate mean L_bar and H_bar
  L_bar <- (L1 + L2) / 2
```

```
  h_bar_prime <- (h1_prime + h2_prime) / 2

  # Calculate T
  # Equation 2.6.10
  t <- 1
  t <- t - 0.17 * cos(h_bar_prime - 30 * pi / 180)
  t <- t + 0.24 * cos(2 * h_bar_prime)
  t <- t + 0.32 * cos(3 * h_bar_prime + 6 * pi / 180)
  t <- t - 0.20 * cos(4 * h_bar_prime - 63 * pi / 180)

  # Calculate S_L, S_C and S_H
  S_L <- 1 + ((0.015 * (L_bar - 50)^2) / sqrt(20 + (L_bar - 50)^2))
  # Equation 2.6.6
  S_C <- 1 + 0.045 * C_bar_prime # Equation 2.6.7
  S_H <- 1 + 0.015 * C_bar_prime * t # Equation 2.6.8

  # Calculate delta_theta
  delta_theta <- 30 * exp(-((h_bar_prime - 275 * pi / 180) / 25)^2)
  # Equation 2.6.11

  # Calculate R_C
  R_C <- 2 * sqrt((C_bar_prime^7) / (C_bar_prime^7 + 25^7)) # Equation 2.6.12

  # Calculate R_T
  R_T <- -1 * sin(2 * delta_theta) * R_C # Equation 2.6.9

  # Step 11: Combine all into delta_E00
  delta_E00 <- sqrt(
    (delta_L_prime / (K_L * S_L))^2 +
    (delta_C_prime / (K_C * S_C))^2 +
    (delta_H_prime / (K_H * S_H))^2 +
    R_T * (delta_C_prime / (K_C * S_C)) * (delta_H_prime / (K_H * S_H))
  )

  return(delta_E00)
}
```

Dark SCE

```
# Select only the Dark condition as dataset
Dark <- data_SCE |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Dark_1, Dark_2)

# Change one measurement that was 0 to 0.001 so R doesn't
# view this as a missing value
Dark$Dark_2[Dark$Day == 37 & Dark$CIELAB == "a" & is.na(Dark$Dark_2)] <- 0.001

# Delete all other NA values
Dark <- na.omit(Dark)

# Remove extra rows that are there for some reason
```

```
Dark <- Dark[1:144,]

# Split the dark
Dark_g1 <- Dark |>
  filter(Glass ==1)

Dark_g2 <- Dark |>
  filter(Glass ==2)

Dark_g3 <- Dark |>
  filter(Glass ==3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Dark_l <- data |> filter(CIELAB == "l")
  Dark_a <- data |> filter(CIELAB == "a")
  Dark_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- Dark_l[[column_name]][1]
  a1 <- Dark_a[[column_name]][1]
  b1 <- Dark_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Dark_l[[column_name]][-1], Dark_a[[column_name]][-1],
  Dark_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Dark_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Dark_g1, glass2 = Dark_g2, glass3 = Dark_g3)
columns <- c("Dark_1", "Dark_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

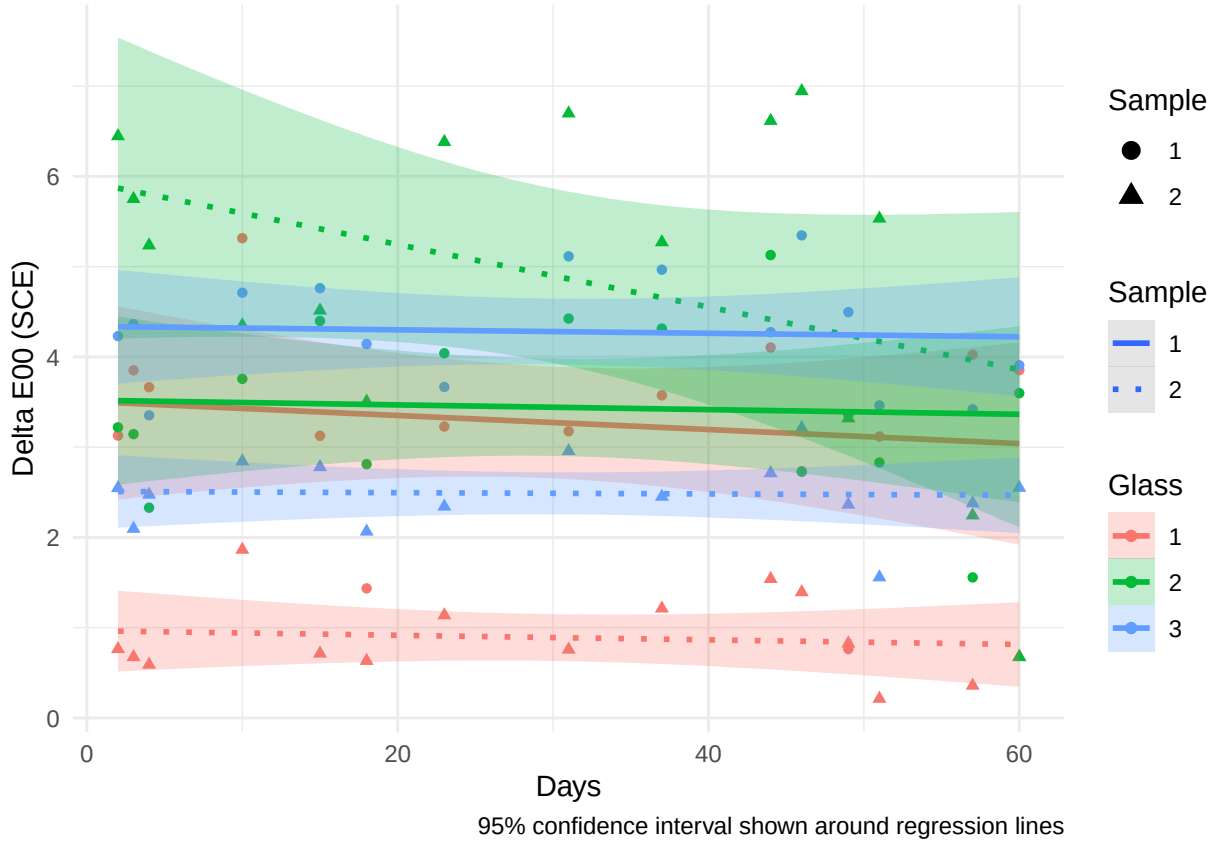
# Create data frame with delta E00 for Dark
deltaE_Dark <- data.frame(glass = rep(c(1,2,3), each = 30),
                          day = rep(unique(Dark$Day)[2:16], 6),
                          dark = rep(c(1,2), each = 15, 3),
```

```
                          deltaE00 = c(results$glass1_Dark_1$delta_E00,
                                       results$glass1_Dark_2$delta_E00,
                                       results$glass2_Dark_1$delta_E00,
                                       results$glass2_Dark_2$delta_E00,
                                       results$glass3_Dark_1$delta_E00,
                                       results$glass3_Dark_2$delta_E00))

# Plot delta E00 as a function of days
Dark_plot <- ggplot(deltaE_Dark,
                    aes(x=day, y=deltaE00,
                        color = factor(glass),
                        linetype = factor(dark),
                        fill = factor(glass),
                        shape = factor(dark))) +
  geom_point() +
  geom_smooth(method = "lm",
              se = TRUE,
              alpha = 0.25) + scale_linetype_manual(values = c( "solid",
                                                                "dotted")) +
  theme_minimal() + labs(x = "Days", y = "Delta E00 (SCE)") + labs(
    color = "Glass",
    fill = "Glass",
    shape = "Sample ",
    linetype = "Sample",
    caption = "95% confidence interval shown around regression lines"
  ) +
  guides(
    shape = guide_legend(order = 1, override.aes = list(size = 3)),
    linetype = guide_legend(order = 1)
  )

Dark_plot
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



UVB tl SCE

```
# Select only the UVB_tl condition as dataset
UVB_tl <- data_SCE |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, UVB_tl_1, UVB_tl_2)

# Delete all NA values
UVB_tl <- na.omit(UVB_tl)

# Remove extra rows that are there for some reason
UVB_tl <- UVB_tl[1:117,]

# Split UVB_tl dataset into three separate ones for all glasses
UVB_tl_g1 <- UVB_tl |>
  filter(Glass ==1)

UVB_tl_g2 <- UVB_tl |>
  filter(Glass ==2)

UVB_tl_g3 <- UVB_tl |>
  filter(Glass ==3)

# Define helper function to compute delta_E00 for a single glass & condition
```

```
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  UVB_tl_l <- data |> filter(CIELAB == "l")
  UVB_tl_a <- data |> filter(CIELAB == "a")
  UVB_tl_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- UVB_tl_l[[column_name]][1]
  a1 <- UVB_tl_a[[column_name]][1]
  b1 <- UVB_tl_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, UVB_tl_l[[column_name]][-1], UVB_tl_a[[column_name]][-1],
  UVB_tl_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(UVB_tl_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = UVB_tl_g1, glass2 = UVB_tl_g2, glass3 = UVB_tl_g3)
columns <- c("UVB_tl_1", "UVB_tl_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

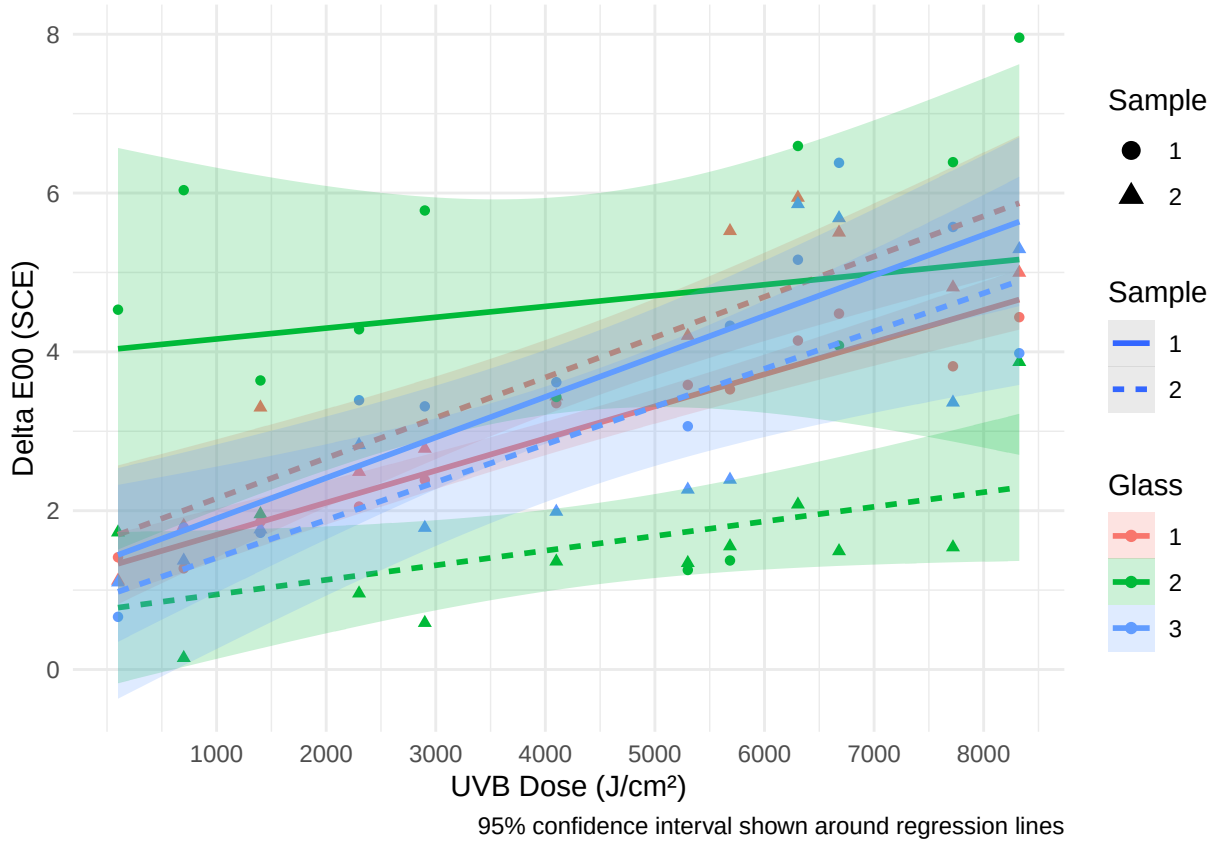
# Create data frame with delta E00 for UVB tl
deltaE_UVB_tl <- data.frame(glass = rep(c(1,2,3), each = 24),
                            uvb_tl = rep(c(1,2), each = 12, 3),
                            dose = rep(c(100,
                                         700,
                                         1400,
                                         2300,
                                         2900,
                                         4100,
                                         5300,
                                         5685,
                                         6305,
                                         6680,
                                         7720,
                                         8325),6),
                            deltaE00 = c(results$glass1_UVB_tl_1$delta_E00,
                                         results$glass1_UVB_tl_2$delta_E00,
```

```
                                    results$glass2_UVB_tl_1$delta_E00,
                                    results$glass2_UVB_tl_2$delta_E00,
                                    results$glass3_UVB_tl_1$delta_E00,
                                    results$glass3_UVB_tl_2$delta_E00))


# Plot delta E00 as a function of dose
UVB_tl_plot_dose <- ggplot(deltaE_UVB_tl,
                    aes(x=dose, y=deltaE00,
                        color = factor(glass),
                        linetype = factor(uvb_tl),
                        fill = factor(glass),
                        shape = factor(uvb_tl))) +
  geom_point() +
  geom_smooth(method = "lm",
              se = TRUE,
              alpha = 0.2) +
  theme_minimal() +
  labs(x = "UVB Dose (J/cm²)", y = "Delta E00 (SCE)") +
  scale_x_continuous(breaks = c(1000, 2000, 3000, 4000, 5000, 6000,
                                7000, 8000)) +
  labs(
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    shape = "Sample ",
    caption = "95% confidence interval shown around regression lines"
  )+ guides(
    shape = guide_legend(order = 1, override.aes = list(size = 3)),
    linetype = guide_legend(order = 1)
)

UVB_tl_plot_dose
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



UVA los SCE

```
### UVA los
# Select only the UVA_los condition as dataset
UVA_los <- data_SCE |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, UVA_los_1, UVA_los_2)

# Delete all NA values
UVA_los <- na.omit(UVA_los)

# Remove extra rows that are there for some reason
UVA_los <- UVA_los[1:135,]

# Split UVA_los dataset into three separate ones for all glasses
UVA_los_g1 <- UVA_los |> filter(Glass == 1)
UVA_los_g2 <- UVA_los |> filter(Glass == 2)
UVA_los_g3 <- UVA_los |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  UVA_los_l <- data |> filter(CIELAB == "l")
  UVA_los_a <- data |> filter(CIELAB == "a")
```

```
  UVA_los_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- UVA_los_l[[column_name]][1]
  a1 <- UVA_los_a[[column_name]][1]
  b1 <- UVA_los_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, UVA_los_l[[column_name]][-1], UVA_los_a[[column_name]][-1],
  UVA_los_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(UVA_los_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = UVA_los_g1, glass2 = UVA_los_g2, glass3 = UVA_los_g3)
columns <- c("UVA_los_1", "UVA_los_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

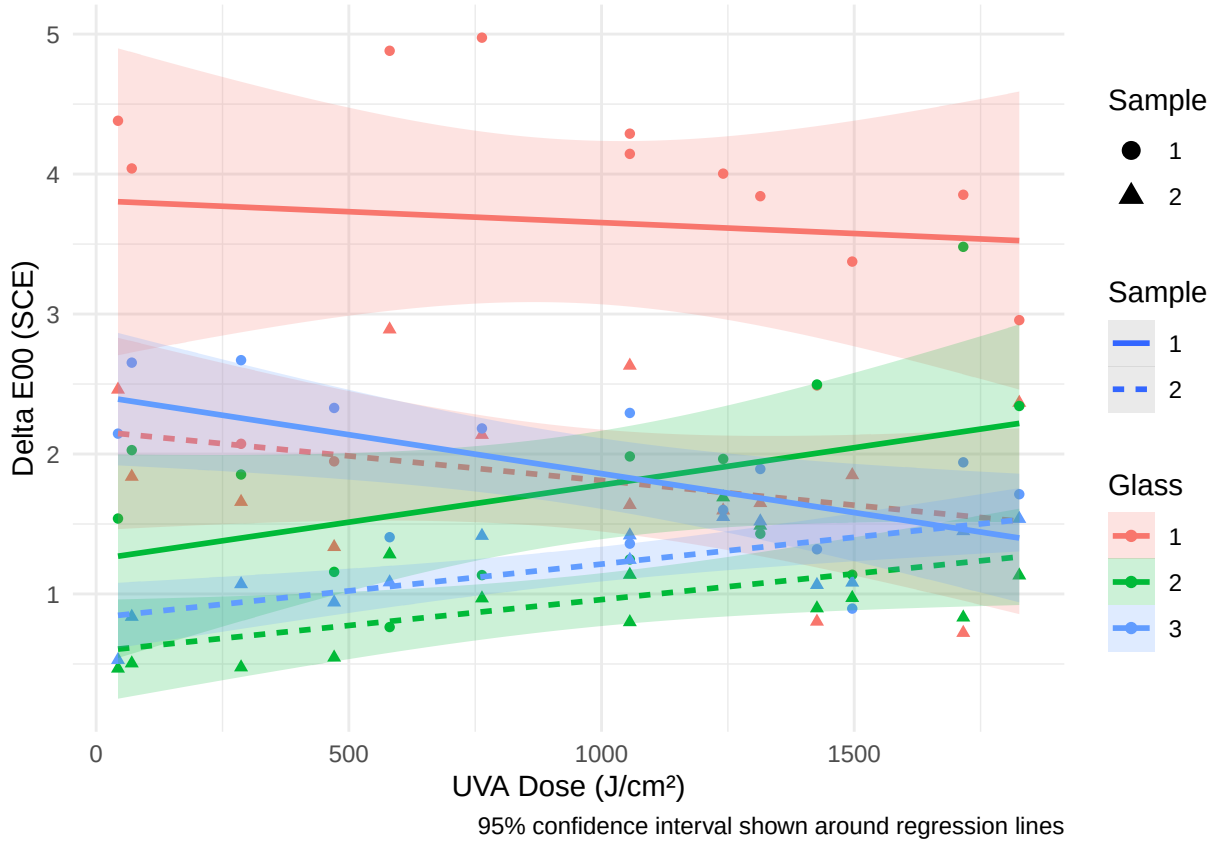
# Create data frame with delta E00 for UVA los
deltaE_UVA_los <- data.frame(
  glass = rep(c(1, 2, 3), each = 28),
  uva_los = rep(c(1, 2), each = 14, 3),
  dose = rep(c(43.18,
               70.43,
               286.72,
               470.91,
               580.71,
               763.37,
               1055.97,
               1055.97, # replicated because there was no
                        # dose measurement at this point
               1240.67,
               1314.16,
               1426.25,
               1496.04,
               1715.77,
               1826.59), 6),
  deltaE00 = c(
    results$glass1_UVA_los_1$delta_E00,
```

```
    results$glass1_UVA_los_2$delta_E00,
    results$glass2_UVA_los_1$delta_E00,
    results$glass2_UVA_los_2$delta_E00,
    results$glass3_UVA_los_1$delta_E00,
    results$glass3_UVA_los_2$delta_E00
  )
)


# Plot delta E00 as a function of dose
UVA_los_plot_dose <- ggplot(deltaE_UVA_los,
                     aes(x = dose, y = deltaE00,
                         color = factor(glass),
                         linetype = factor(uva_los),
                         fill = factor(glass),
                         shape = factor(uva_los))) +
  geom_point() +
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "UVA Dose (J/cm²)",
    y = "Delta E00 (SCE)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    shape = "Sample ",
    caption = "95% confidence interval shown around regression lines"
  ) +
  theme_minimal() + guides(
    shape = guide_legend(order = 1, override.aes = list(size = 3)),
    linetype = guide_legend(order = 1)
)

UVA_los_plot_dose
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Xeno UV SCE

```
# Select only the Xeno_UV condition as dataset
Xeno_UV <- data_SCE |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Xeno_UV_1, Xeno_UV_2)

# Delete all NA values
Xeno_UV <- na.omit(Xeno_UV)

# Remove extra rows that are there for some reason
Xeno_UV <- Xeno_UV[1:45,]

# Split Xeno_UV dataset into three separate ones for all glasses
Xeno_UV_g1 <- Xeno_UV |> filter(Glass == 1)
Xeno_UV_g2 <- Xeno_UV |> filter(Glass == 2)
Xeno_UV_g3 <- Xeno_UV |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Xeno_UV_l <- data |> filter(CIELAB == "l")
  Xeno_UV_a <- data |> filter(CIELAB == "a")
  Xeno_UV_b <- data |> filter(CIELAB == "b")
```

```r
  # Reference values (first row)
  L1 <- Xeno_UV_l[[column_name]][1]
  a1 <- Xeno_UV_a[[column_name]][1]
  b1 <- Xeno_UV_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Xeno_UV_l[[column_name]][-1], Xeno_UV_a[[column_name]][-1],
  Xeno_UV_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Xeno_UV_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Xeno_UV_g1, glass2 = Xeno_UV_g2, glass3 = Xeno_UV_g3)
columns <- c("Xeno_UV_1", "Xeno_UV_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

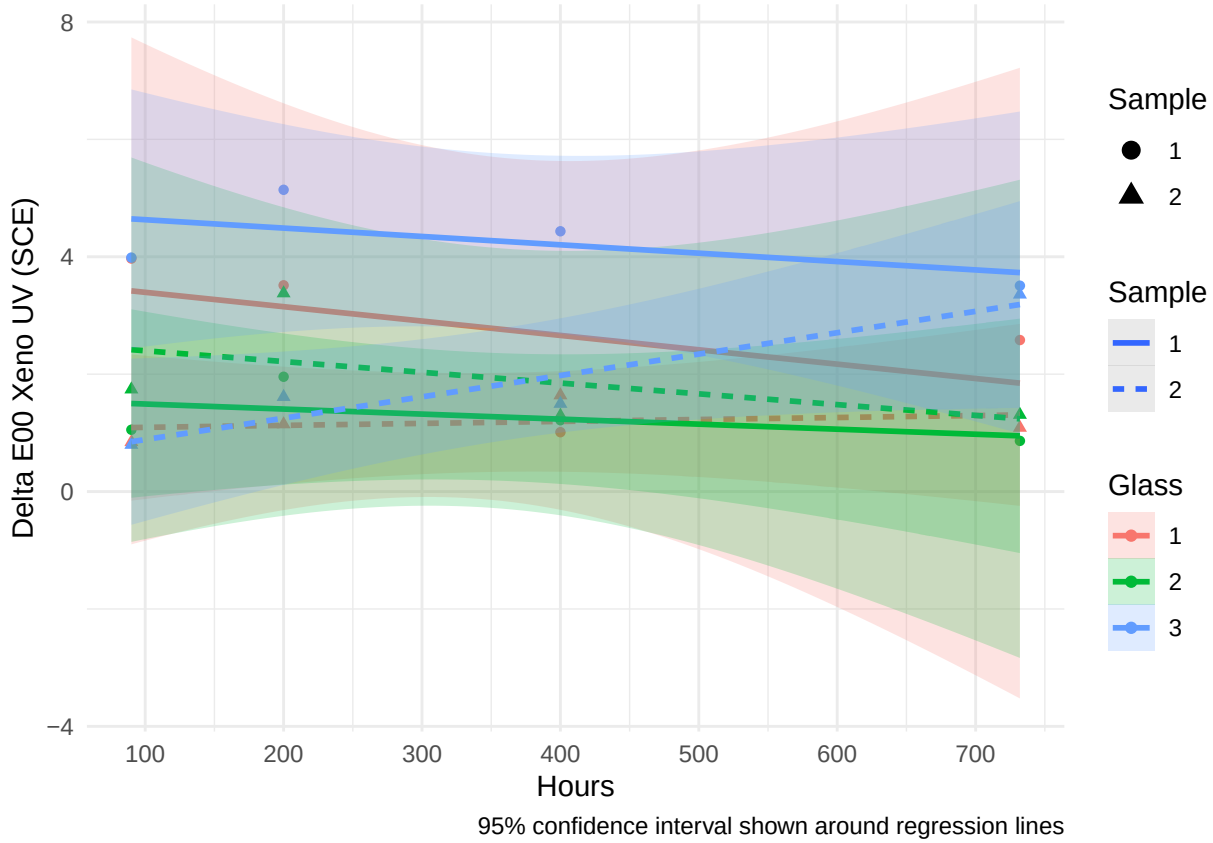
# Create data frame with delta E00 for Xeno UV
deltaE_Xeno_UV <- data.frame(
  glass = rep(c(1, 2, 3), each = 8),
  xeno_uv = rep(c(1, 2), each = 4, 3),
  hours = rep(c(90, 200, 400, 732), 6),
  deltaE00 = c(
    results$glass1_Xeno_UV_1$delta_E00,
    results$glass1_Xeno_UV_2$delta_E00,
    results$glass2_Xeno_UV_1$delta_E00,
    results$glass2_Xeno_UV_2$delta_E00,
    results$glass3_Xeno_UV_1$delta_E00,
    results$glass3_Xeno_UV_2$delta_E00
  )
)

# Plot delta E00 as a function of dose
Xeno_UV_plot <- ggplot(deltaE_Xeno_UV,
                    aes(x = hours, y = deltaE00,
                        color = factor(glass),
                        linetype = factor(xeno_uv),
                        fill = factor(glass),
                        shape = factor(xeno_uv))) +
  geom_point() +
```

```
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "Hours",
    y = "Delta E00 Xeno UV (SCE)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    shape = "Sample ",
    caption = "95% confidence interval shown around regression lines"
  ) + scale_x_continuous(breaks = c(100, 200, 300, 400, 500, 600, 700)) +
  theme_minimal() + guides(
    shape = guide_legend(order = 1, override.aes = list(size = 3)),
    linetype = guide_legend(order = 1)
)

Xeno_UV_plot
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Xeno no UV SCE

```r
# Select only the Xeno_noUV condition as dataset
Xeno_noUV <- data_SCE |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Xeno_noUV_1,
         Xeno_noUV_2)

# Delete all NA values
Xeno_noUV <- na.omit(Xeno_noUV)

# Remove extra rows that are there for some reason
Xeno_noUV <- Xeno_noUV[1:45,]

# Split Xeno_noUV dataset into three separate ones for all glasses
Xeno_noUV_g1 <- Xeno_noUV |> filter(Glass == 1)
Xeno_noUV_g2 <- Xeno_noUV |> filter(Glass == 2)
Xeno_noUV_g3 <- Xeno_noUV |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Xeno_noUV_l <- data |> filter(CIELAB == "l")
  Xeno_noUV_a <- data |> filter(CIELAB == "a")
  Xeno_noUV_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- Xeno_noUV_l[[column_name]][1]
  a1 <- Xeno_noUV_a[[column_name]][1]
  b1 <- Xeno_noUV_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Xeno_noUV_l[[column_name]][-1], Xeno_noUV_a[[column_name]][-1],
  Xeno_noUV_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Xeno_noUV_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Xeno_noUV_g1, glass2 = Xeno_noUV_g2,
                glass3 = Xeno_noUV_g3)
columns <- c("Xeno_noUV_1", "Xeno_noUV_2")

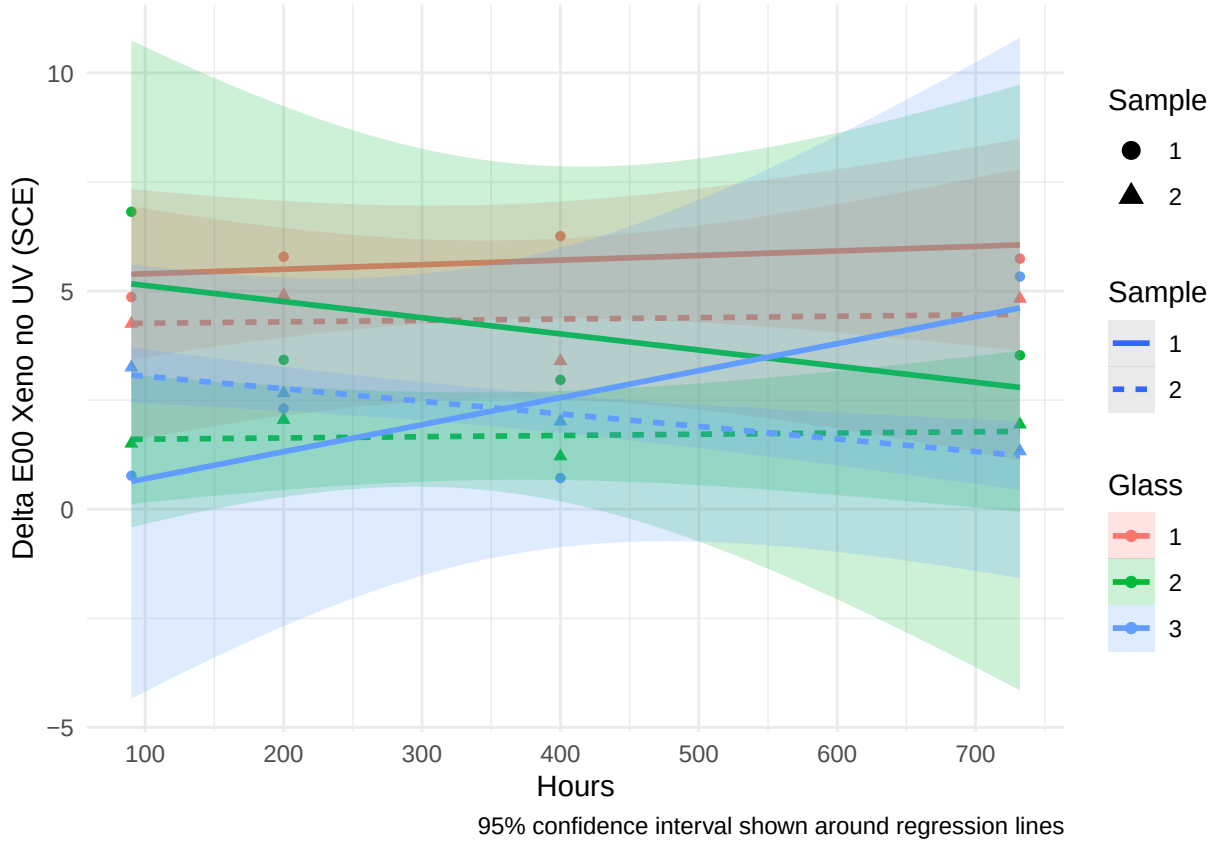
# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}
```

```r
# Create data frame with delta E00 for Xeno noUV
deltaE_Xeno_noUV <- data.frame(
  glass = rep(c(1, 2, 3), each = 8),
  xeno_noUV = rep(c(1, 2), each = 4, 3),
  hours = rep(c(90, 200, 400, 732), 6),
  deltaE00 = c(
    results$glass1_Xeno_noUV_1$delta_E00,
    results$glass1_Xeno_noUV_2$delta_E00,
    results$glass2_Xeno_noUV_1$delta_E00,
    results$glass2_Xeno_noUV_2$delta_E00,
    results$glass3_Xeno_noUV_1$delta_E00,
    results$glass3_Xeno_noUV_2$delta_E00
  )
)

# Plot delta E00 as a function of hours
Xeno_noUV_plot <- ggplot(deltaE_Xeno_noUV,
                    aes(x = hours, y = deltaE00,
                        color = factor(glass),
                        linetype = factor(xeno_noUV),
                        fill = factor(glass),
                        shape = factor(xeno_noUV))) +
  geom_point() +
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "Hours",
    y = "Delta E00 Xeno no UV (SCE)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    shape = "Sample ",
    caption = "95% confidence interval shown around regression lines"
  ) + scale_x_continuous(breaks = c(100, 200, 300, 400, 500, 600, 700)) +
  theme_minimal() + guides(
    shape = guide_legend(order = 1, override.aes = list(size = 3)),
    linetype = guide_legend(order = 1)
)

Xeno_noUV_plot
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Dark SCI

```
# Select only the Dark condition as dataset
Dark_SCI <- data_SCI |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Dark_1, Dark_2)

# Delete all other NA values
Dark_SCI <- na.omit(Dark_SCI)

# Remove extra rows that are there for some reason
Dark_SCI <- Dark_SCI[1:144,]

# Split the dark
Dark_g1_SCI <- Dark_SCI |>
  filter(Glass ==1)

Dark_g2_SCI <- Dark_SCI |>
  filter(Glass ==2)

Dark_g3_SCI <- Dark_SCI |>
  filter(Glass ==3)
```

```r
# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Dark_l <- data |> filter(CIELAB == "l")
  Dark_a <- data |> filter(CIELAB == "a")
  Dark_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- Dark_l[[column_name]][1]
  a1 <- Dark_a[[column_name]][1]
  b1 <- Dark_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Dark_l[[column_name]][-1], Dark_a[[column_name]][-1],
  Dark_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Dark_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Dark_g1_SCI, glass2 = Dark_g2_SCI,
                glass3 = Dark_g3_SCI)
columns <- c("Dark_1", "Dark_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

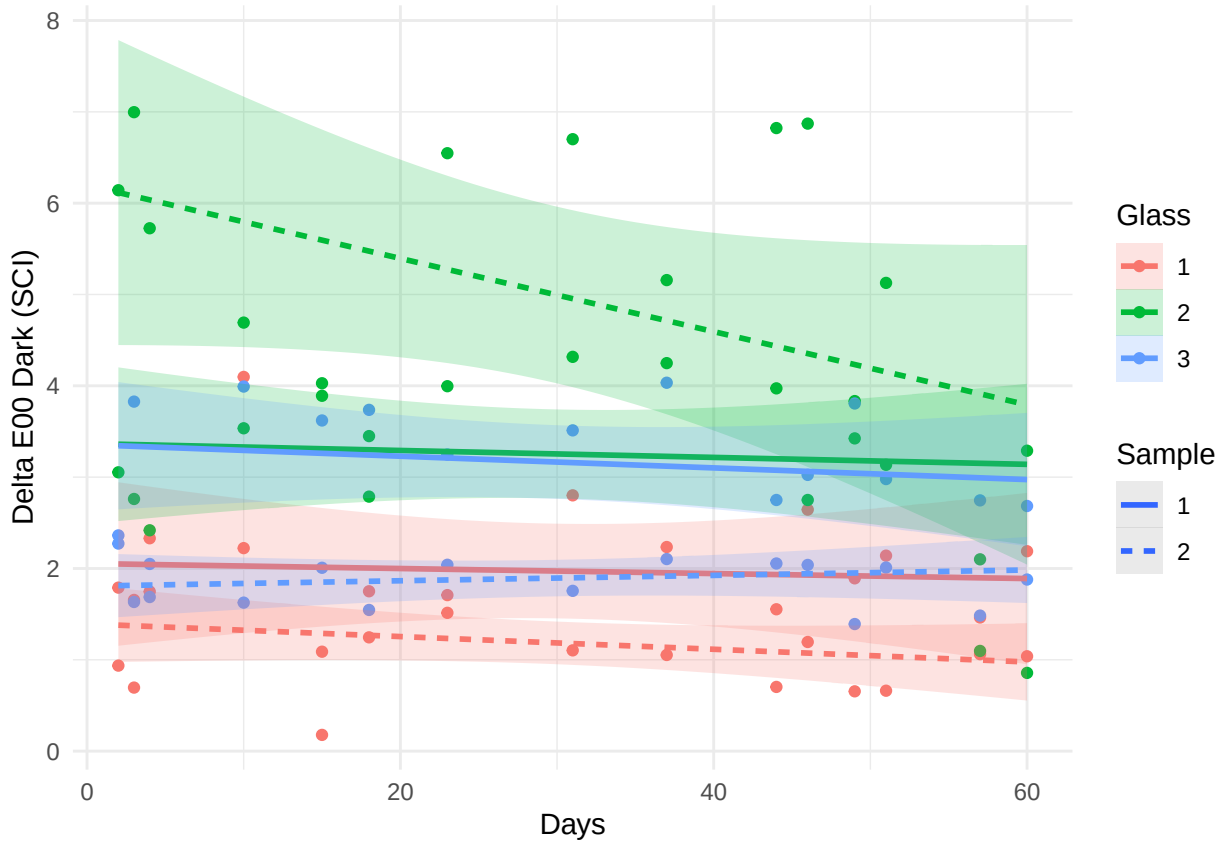
# Create data frame with delta E00 for Dark
deltaE_Dark_SCI <- data.frame(glass = rep(c(1,2,3), each = 30),
                          day = rep(unique(Dark$Day)[2:16], 6),
                          dark = rep(c(1,2), each = 15, 3),
                          deltaE00 = c(results$glass1_Dark_1$delta_E00,
                                       results$glass1_Dark_2$delta_E00,
                                       results$glass2_Dark_1$delta_E00,
                                       results$glass2_Dark_2$delta_E00,
                                       results$glass3_Dark_1$delta_E00,
                                       results$glass3_Dark_2$delta_E00))

# Plot delta E00 as a function of days
Dark_plot_SCI <- ggplot(deltaE_Dark_SCI,
                    aes(x=day, y=deltaE00,
                        color = factor(glass),
```

```
                       linetype = factor(dark),
                       fill = factor(glass))) +
  geom_point() +
  geom_smooth(method = "lm",
              se = TRUE,
              alpha = 0.2) +
  theme_minimal() + labs(x = "Days", y = "Delta E00 Dark (SCI)") + labs(
    color = "Glass",
    fill = "Glass",
    linetype = "Sample"
  )

Dark_plot_SCI
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



UVB tl SCI

```
# Select only the UVB_tl condition as dataset
UVB_tl_SCI <- data_SCI |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, UVB_tl_1, UVB_tl_2)
```

```r
# Delete all NA values
UVB_tl_SCI <- na.omit(UVB_tl_SCI)

# Remove extra rows that are there for some reason
UVB_tl_SCI <- UVB_tl_SCI[1:117,]

# Split UVB_tl_SCI dataset into three separate ones for all glasses
UVB_tl_g1_SCI <- UVB_tl_SCI |>
  filter(Glass ==1)

UVB_tl_g2_SCI <- UVB_tl_SCI |>
  filter(Glass ==2)

UVB_tl_g3_SCI <- UVB_tl_SCI |>
  filter(Glass ==3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  UVB_tl_l <- data |> filter(CIELAB == "l")
  UVB_tl_a <- data |> filter(CIELAB == "a")
  UVB_tl_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- UVB_tl_l[[column_name]][1]
  a1 <- UVB_tl_a[[column_name]][1]
  b1 <- UVB_tl_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, UVB_tl_l[[column_name]][-1], UVB_tl_a[[column_name]][-1],
  UVB_tl_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(UVB_tl_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = UVB_tl_g1_SCI, glass2 = UVB_tl_g2_SCI,
                glass3 = UVB_tl_g3_SCI)
columns <- c("UVB_tl_1", "UVB_tl_2")

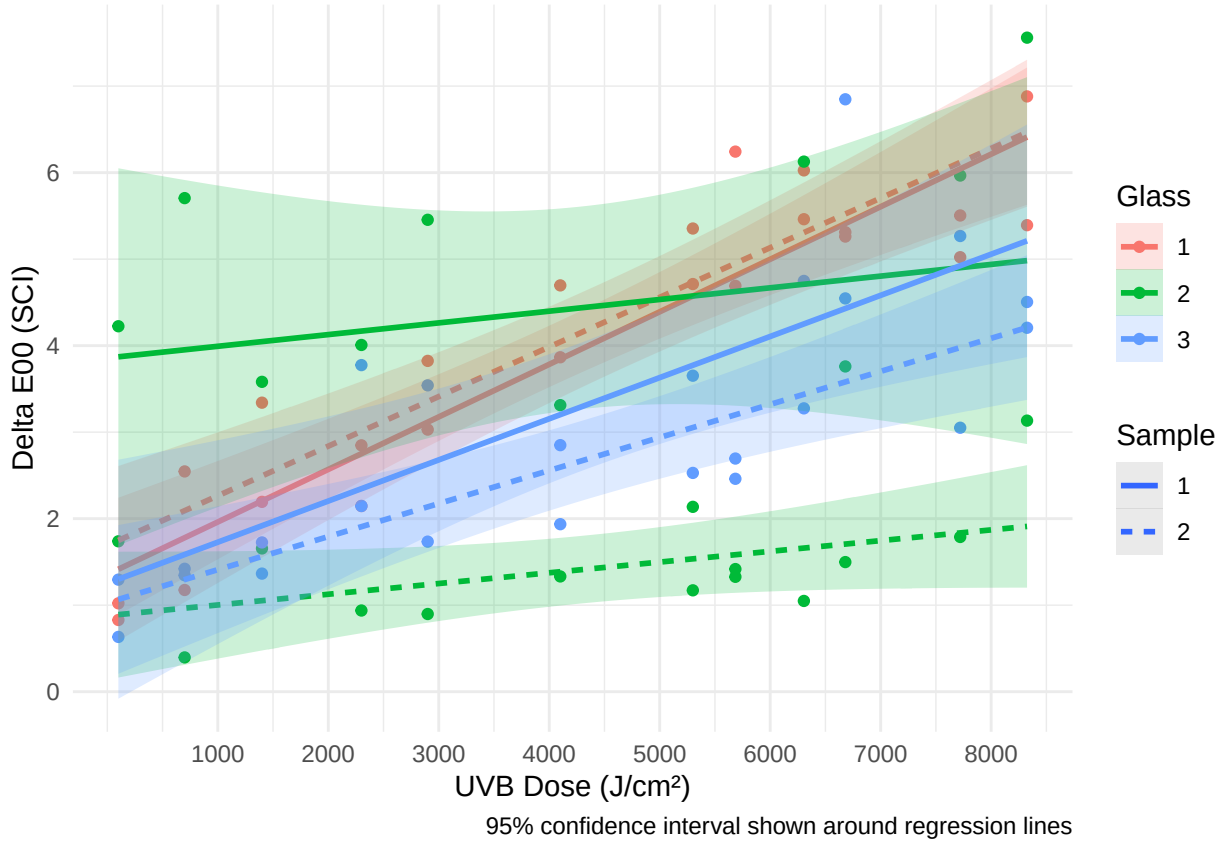
# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}
```

```r
# Create data frame with delta E00 for UVB tl
deltaE_UVB_tl_SCI <- data.frame(glass = rep(c(1,2,3), each = 24),
                          uvb_tl = rep(c(1,2), each = 12, 3),
                          dose = rep(c(100,
                                       700,
                                       1400,
                                       2300,
                                       2900,
                                       4100,
                                       5300,
                                       5685,
                                       6305,
                                       6680,
                                       7720,
                                       8325),6),
                          deltaE00 = c(results$glass1_UVB_tl_1$delta_E00,
                                       results$glass1_UVB_tl_2$delta_E00,
                                       results$glass2_UVB_tl_1$delta_E00,
                                       results$glass2_UVB_tl_2$delta_E00,
                                       results$glass3_UVB_tl_1$delta_E00,
                                       results$glass3_UVB_tl_2$delta_E00))


# Plot delta E00 as a function of dose
UVB_tl_plot_dose_SCI <- ggplot(deltaE_UVB_tl_SCI,
                     aes(x=dose, y=deltaE00,
                         color = factor(glass),
                         linetype = factor(uvb_tl),
                         fill = factor(glass))) +
  geom_point() +
  geom_smooth(method = "lm",
              se = TRUE,
              alpha = 0.2) +
  theme_minimal() +
  labs(x = "UVB Dose (J/cm²)", y = "Delta E00 (SCI)") +
  scale_x_continuous(breaks = c(1000, 2000, 3000, 4000, 5000, 6000,
                                7000, 8000)) +
  labs(
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    caption = "95% confidence interval shown around regression lines"
  )

UVB_tl_plot_dose_SCI
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



UVA los SCI

```
### UVA los
# Select only the UVA_los condition as dataset
UVA_los_SCI <- data_SCI |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, UVA_los_1, UVA_los_2)

# Delete all NA values
UVA_los_SCI <- na.omit(UVA_los_SCI)

# Remove extra rows that are there for some reason
UVA_los_SCI <- UVA_los_SCI[1:135,]

# Split UVA_los dataset into three separate ones for all glasses
UVA_los_g1_SCI <- UVA_los_SCI |> filter(Glass == 1)
UVA_los_g2_SCI <- UVA_los_SCI |> filter(Glass == 2)
UVA_los_g3_SCI <- UVA_los_SCI |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  UVA_los_l <- data |> filter(CIELAB == "l")
  UVA_los_a <- data |> filter(CIELAB == "a")
```

```
  UVA_los_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- UVA_los_l[[column_name]][1]
  a1 <- UVA_los_a[[column_name]][1]
  b1 <- UVA_los_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, UVA_los_l[[column_name]][-1], UVA_los_a[[column_name]][-1],
  UVA_los_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(UVA_los_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = UVA_los_g1_SCI, glass2 = UVA_los_g2_SCI,
                glass3 = UVA_los_g3_SCI)
columns <- c("UVA_los_1", "UVA_los_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

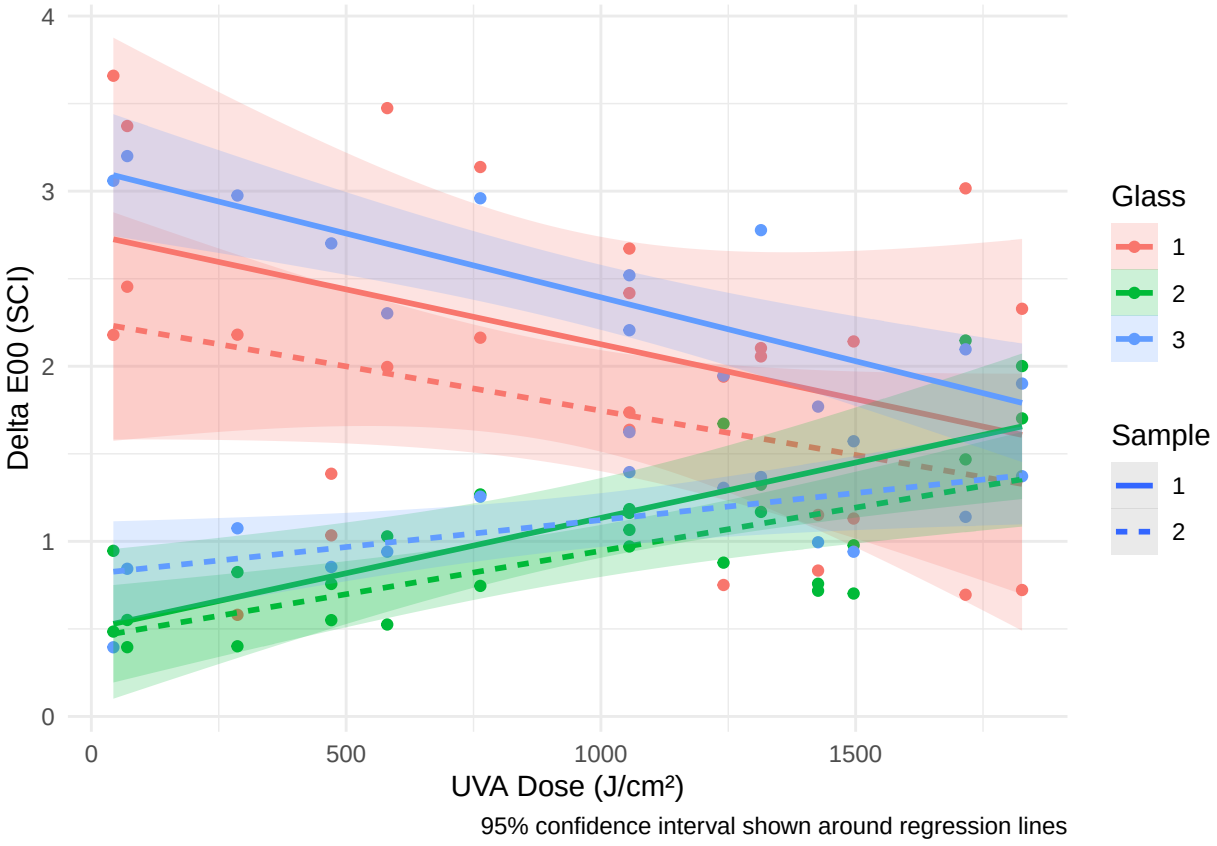
# Create data frame with delta E00 for UVA los
deltaE_UVA_los_SCI <- data.frame(
  glass = rep(c(1, 2, 3), each = 28),
  uva_los = rep(c(1, 2), each = 14, 3),
  dose = rep(c(43.18,
               70.43,
               286.72,
               470.91,
               580.71,
               763.37,
               1055.97,
               1055.97, # replicated because there was no
                        # dose measurement at this point
               1240.67,
               1314.16,
               1426.25,
               1496.04,
               1715.77,
               1826.59), 6),
  deltaE00 = c(
```

```
    results$glass1_UVA_los_1$delta_E00,
    results$glass1_UVA_los_2$delta_E00,
    results$glass2_UVA_los_1$delta_E00,
    results$glass2_UVA_los_2$delta_E00,
    results$glass3_UVA_los_1$delta_E00,
    results$glass3_UVA_los_2$delta_E00
  )
)


# Plot delta E00 as a function of dose
UVA_los_plot_dose_SCI <- ggplot(deltaE_UVA_los_SCI,
                     aes(x = dose, y = deltaE00,
                         color = factor(glass),
                         linetype = factor(uva_los),
                         fill = factor(glass))) +
  geom_point() +
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "UVA Dose (J/cm²)",
    y = "Delta E00 (SCI)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    caption = "95% confidence interval shown around regression lines"
  ) +
  theme_minimal()

UVA_los_plot_dose_SCI
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Xeno UV SCI

```
# Select only the Xeno_UV condition as dataset
Xeno_UV_SCI <- data_SCI |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Xeno_UV_1, Xeno_UV_2)

# Delete all NA values
Xeno_UV_SCI <- na.omit(Xeno_UV_SCI)

# Remove extra rows that are there for some reason
Xeno_UV_SCI <- Xeno_UV_SCI[1:45,]

# Split Xeno_UV dataset into three separate ones for all glasses
Xeno_UV_g1_SCI <- Xeno_UV_SCI |> filter(Glass == 1)
Xeno_UV_g2_SCI <- Xeno_UV_SCI |> filter(Glass == 2)
Xeno_UV_g3_SCI <- Xeno_UV_SCI |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Xeno_UV_l <- data |> filter(CIELAB == "l")
  Xeno_UV_a <- data |> filter(CIELAB == "a")
  Xeno_UV_b <- data |> filter(CIELAB == "b")
```

```
  # Reference values (first row)
  L1 <- Xeno_UV_l[[column_name]][1]
  a1 <- Xeno_UV_a[[column_name]][1]
  b1 <- Xeno_UV_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Xeno_UV_l[[column_name]][-1], Xeno_UV_a[[column_name]][-1],
  Xeno_UV_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Xeno_UV_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Xeno_UV_g1_SCI, glass2 = Xeno_UV_g2_SCI,
                glass3 = Xeno_UV_g3_SCI)
columns <- c("Xeno_UV_1", "Xeno_UV_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

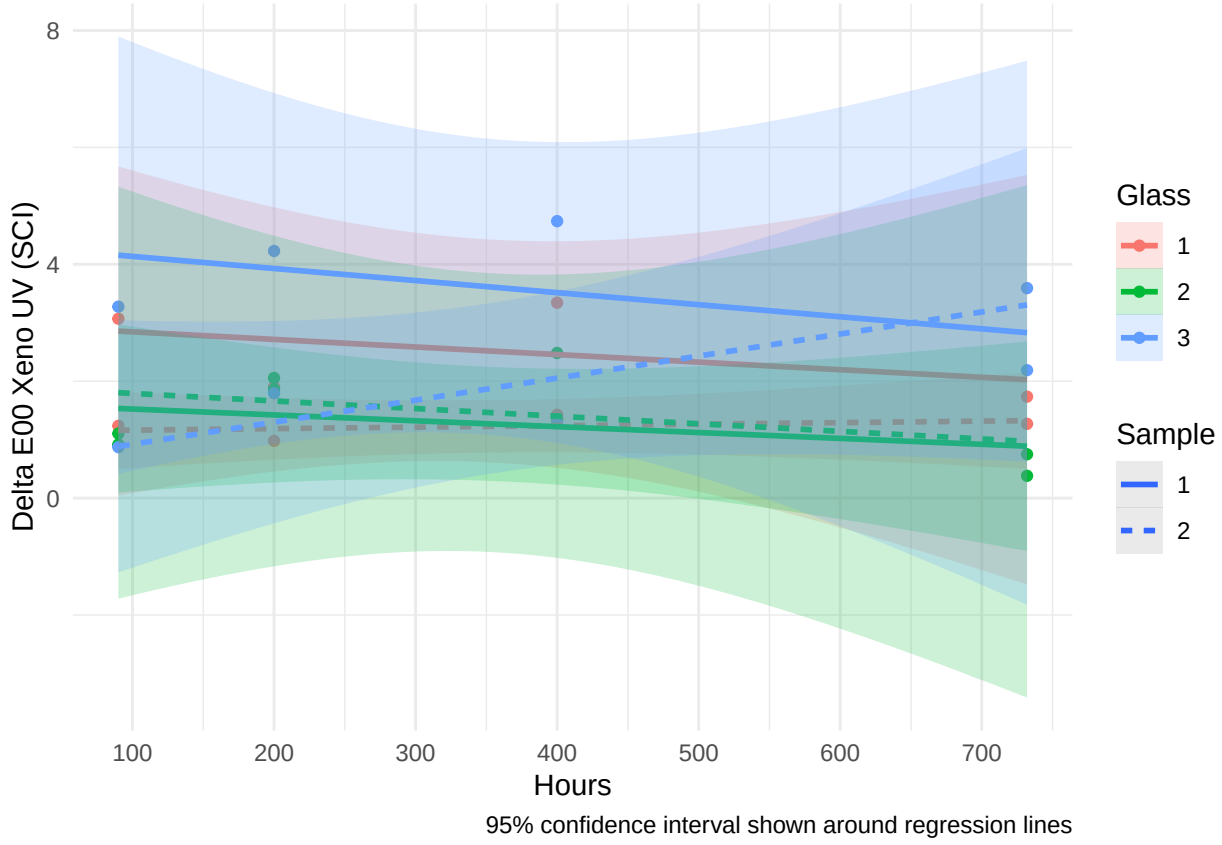
# Create data frame with delta E00 for Xeno UV
deltaE_Xeno_UV_SCI <- data.frame(
  glass = rep(c(1, 2, 3), each = 8),
  xeno_uv = rep(c(1, 2), each = 4, 3),
  hours = rep(c(90, 200, 400, 732),6),
  deltaE00 = c(
    results$glass1_Xeno_UV_1$delta_E00,
    results$glass1_Xeno_UV_2$delta_E00,
    results$glass2_Xeno_UV_1$delta_E00,
    results$glass2_Xeno_UV_2$delta_E00,
    results$glass3_Xeno_UV_1$delta_E00,
    results$glass3_Xeno_UV_2$delta_E00
  )
)

# Plot delta E00 as a function of dose
Xeno_UV_plot_SCI <- ggplot(deltaE_Xeno_UV_SCI,
                    aes(x = hours, y = deltaE00,
                        color = factor(glass),
                        linetype = factor(xeno_uv),
                        fill = factor(glass))) +
  geom_point() +
```

```
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "Hours",
    y = "Delta E00 Xeno UV (SCI)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    caption = "95% confidence interval shown around regression lines"
  ) + scale_x_continuous(breaks = c(100, 200, 300, 400, 500, 600, 700)) +
  theme_minimal()

Xeno_UV_plot_SCI
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Xeno no UV SCI

```
# Select only the Xeno_noUV condition as dataset
Xeno_noUV_SCI <- data_SCI |>
  select(Glass, Day, Measurement, `SCI / SCE`, CIELAB, Xeno_noUV_1,
         Xeno_noUV_2)
```

```r
# Delete all NA values
Xeno_noUV_SCI <- na.omit(Xeno_noUV_SCI)

# Remove extra rows that are there for some reason
Xeno_noUV_SCI <- Xeno_noUV_SCI[1:45,]

# Split Xeno_noUV dataset into three separate ones for all glasses
Xeno_noUV_g1_SCI <- Xeno_noUV_SCI |> filter(Glass == 1)
Xeno_noUV_g2_SCI <- Xeno_noUV_SCI |> filter(Glass == 2)
Xeno_noUV_g3_SCI <- Xeno_noUV_SCI |> filter(Glass == 3)

# Define helper function to compute delta_E00 for a single glass & condition
compute_delta_E00 <- function(data, column_name) {
  # Split l, a, b
  Xeno_noUV_l <- data |> filter(CIELAB == "l")
  Xeno_noUV_a <- data |> filter(CIELAB == "a")
  Xeno_noUV_b <- data |> filter(CIELAB == "b")

  # Reference values (first row)
  L1 <- Xeno_noUV_l[[column_name]][1]
  a1 <- Xeno_noUV_a[[column_name]][1]
  b1 <- Xeno_noUV_b[[column_name]][1]

  # Compute delta E00
  delta_E00 <- mapply(function(L2, a2, b2) {
    cie2000(L1, a1, b1, L2, a2, b2)
  }, Xeno_noUV_l[[column_name]][-1], Xeno_noUV_a[[column_name]][-1],
  Xeno_noUV_b[[column_name]][-1])

  # Return results as a data frame
  return(data.frame(row = 2:nrow(Xeno_noUV_l), delta_E00 = delta_E00))
}

# Store results in a list
results <- list()

# Define combinations of glasses and condition
glasses <- list(glass1 = Xeno_noUV_g1_SCI, glass2 = Xeno_noUV_g2_SCI,
                glass3 = Xeno_noUV_g3_SCI)
columns <- c("Xeno_noUV_1", "Xeno_noUV_2")

# Loop over all combinations
for (g in names(glasses)) {
  for (c in columns) {
    key <- paste0(g, "_", c)
    results[[key]] <- compute_delta_E00(glasses[[g]], c)
  }
}

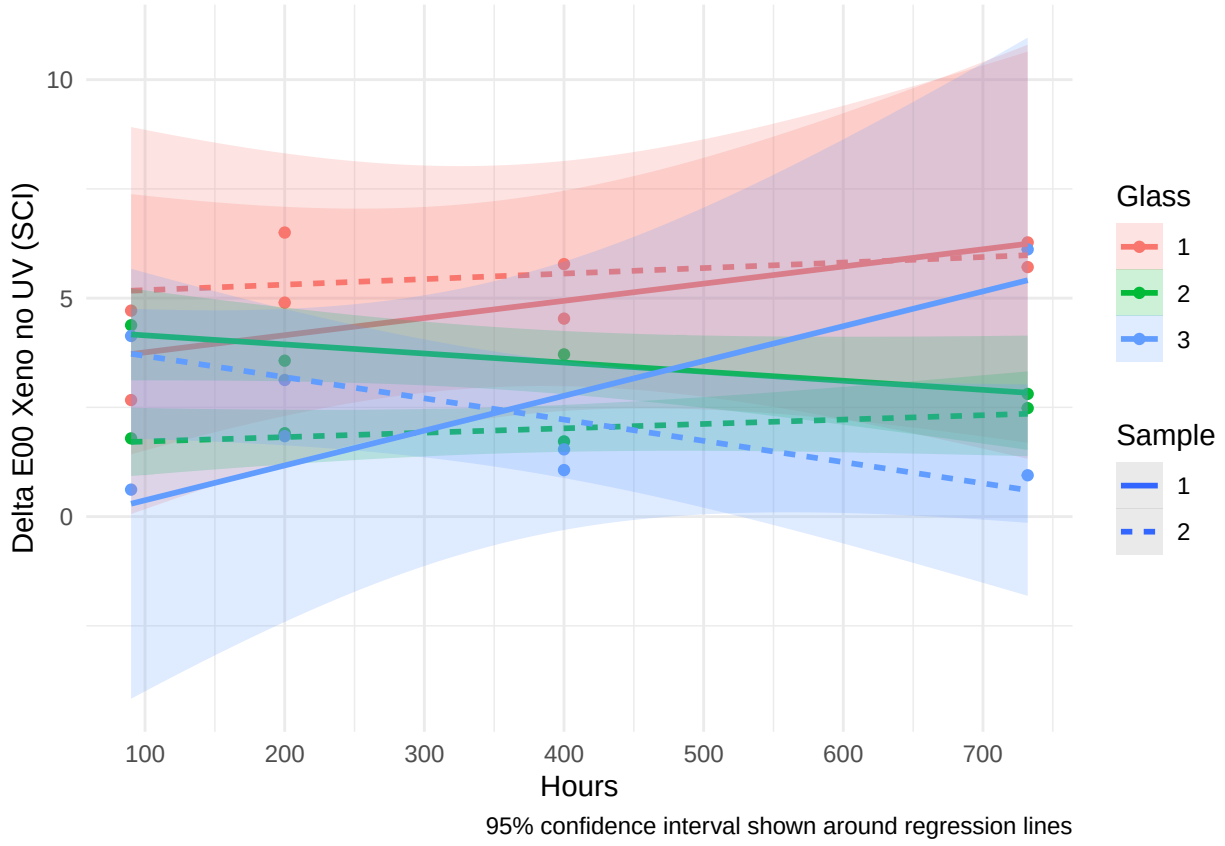
# Create data frame with delta E00 for Xeno noUV
deltaE_Xeno_noUV_SCI <- data.frame(
  glass = rep(c(1, 2, 3), each = 8),
  xeno_noUV = rep(c(1, 2), each = 4, 3),
```

```
  hours = rep(c(90, 200, 400, 732), 6),
  deltaE00 = c(
    results$glass1_Xeno_noUV_1$delta_E00,
    results$glass1_Xeno_noUV_2$delta_E00,
    results$glass2_Xeno_noUV_1$delta_E00,
    results$glass2_Xeno_noUV_2$delta_E00,
    results$glass3_Xeno_noUV_1$delta_E00,
    results$glass3_Xeno_noUV_2$delta_E00
  )
)

# Plot delta E00 as a function of hours
Xeno_noUV_plot_SCI <- ggplot(deltaE_Xeno_noUV_SCI,
                     aes(x = hours, y = deltaE00,
                         color = factor(glass),
                         linetype = factor(xeno_noUV),
                         fill = factor(glass))) +
  geom_point() +
  geom_smooth(method = "lm", se = TRUE, alpha = 0.2) +
  labs(
    x = "Hours",
    y = "Delta E00 Xeno no UV (SCI)",
    color = "Glass",
    fill = "Glass",
    linetype = "Sample",
    caption = "95% confidence interval shown around regression lines"
  ) + scale_x_continuous(breaks = c(100, 200, 300, 400, 500, 600, 700)) +
  theme_minimal()

Xeno_noUV_plot_SCI
```

```
## `geom_smooth()` using formula = 'y ~ x'
```




```
# Save plots as PDF

# Vector of plot names as strings
plot_names <- c("Dark_plot", "UVB_tl_plot_dose", "UVA_los_plot_dose",
                "Xeno_UV_plot", "Xeno_noUV_plot",
                "Dark_plot_SCI", "UVB_tl_plot_dose_SCI",
                "UVA_los_plot_dose_SCI", "Xeno_UV_plot_SCI",
                "Xeno_noUV_plot_SCI")

# Save each plot in a loop
for (plot_name in plot_names) {
  ggsave(paste0(plot_name, ".png"), plot = get(plot_name), width = 12,
         height = 6, units = "in")
}
```

```
split_by_glass <- function(base_name) {

  # Get the data frame from global environment
  df <- get(base_name, envir = .GlobalEnv)

  # Loop over glass 1, 2, 3
  for (g in 1:3) {
    new_name <- paste0(base_name, "_g", g)
    assign(new_name, df |> filter(glass == g), envir = .GlobalEnv)
  }
}
```

```
split_by_glass("deltaE_Dark")
split_by_glass("deltaE_UVB_tl")
split_by_glass("deltaE_UVA_los")
split_by_glass("deltaE_Xeno_UV")
split_by_glass("deltaE_Xeno_noUV")

split_by_glass("deltaE_Dark_SCI")
split_by_glass("deltaE_UVB_tl_SCI")
split_by_glass("deltaE_UVA_los_SCI")
split_by_glass("deltaE_Xeno_UV_SCI")
split_by_glass("deltaE_Xeno_noUV_SCI")
```

```
library(gridExtra)
```

```
##
## Attaching package: 'gridExtra'

## The following object is masked from 'package:dplyr':
##
##     combine
```

```
pdf("deltaE_Dark_g1.pdf", height=11, width=8.5)
grid.table(deltaE_Dark_g1)
dev.off()
```

```
## pdf
##   2
```

```
library(gridExtra)

# First define your base names:
base_names <- c(
  "deltaE_Dark", "deltaE_UVB_tl", "deltaE_UVA_los", "deltaE_Xeno_UV",
  "deltaE_Xeno_noUV","deltaE_Dark_SCI", "deltaE_UVB_tl_SCI",
  "deltaE_UVA_los_SCI", "deltaE_Xeno_UV_SCI", "deltaE_Xeno_noUV_SCI"
)

# Create folder for table PDFs if not exists
if (!dir.exists("plots/tables_grid")) {
  dir.create("plots/tables_grid", recursive = TRUE)
}

# Loop over all base names + g1/g2/g3 and save as PDF
for (base_name in base_names) {
  for (g in 1:3) {

    df_name <- paste0(base_name, "_g", g)
    filename_pdf <- paste0("plots/tables_grid/", df_name, ".pdf")

    # Open PDF device
    pdf(filename_pdf, height = 11, width = 8.5)
```

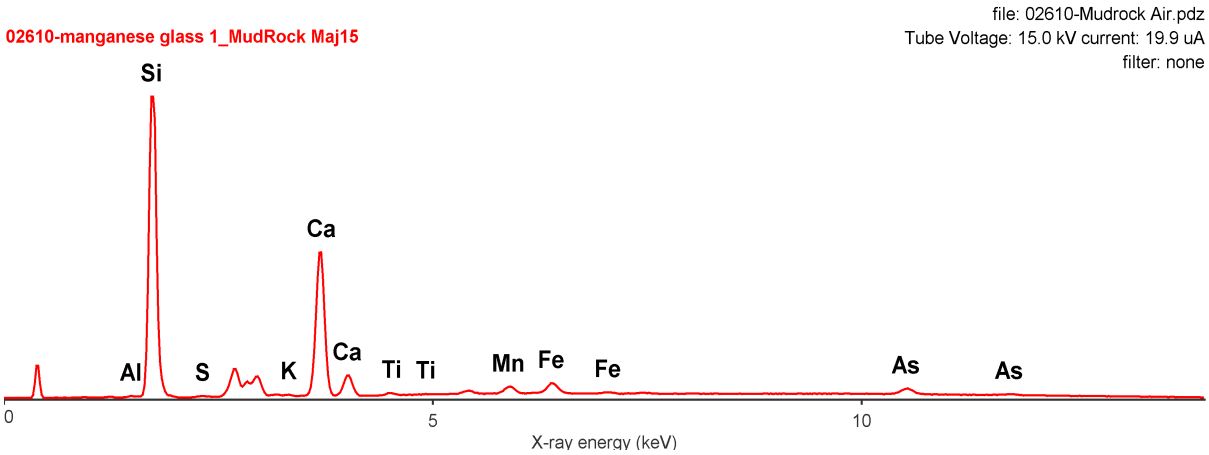
```
    # Draw table
    grid.table(get(df_name))

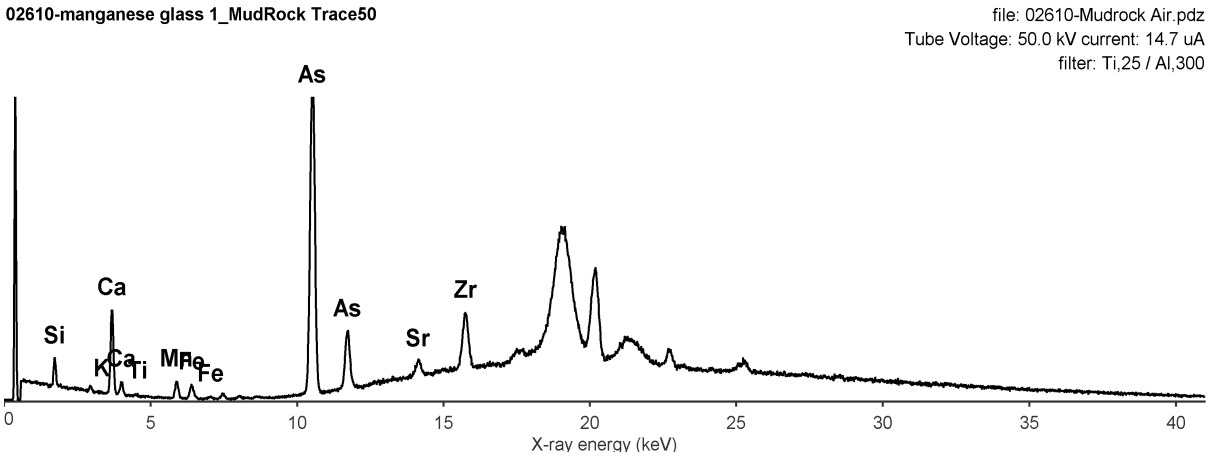
    # Close device
    dev.off()
      }
}
```

Appendix IV: pXRF Analysis Results

XRF sample results form

Object id	Case Study object 1
Analysis date	18-2-2025 17:24:20





Quantification with method: DualMudrock_Air version 730.0646.01 Na is not reliably quantified; Sn and Sb are not quantified.

Major elements (wt%)

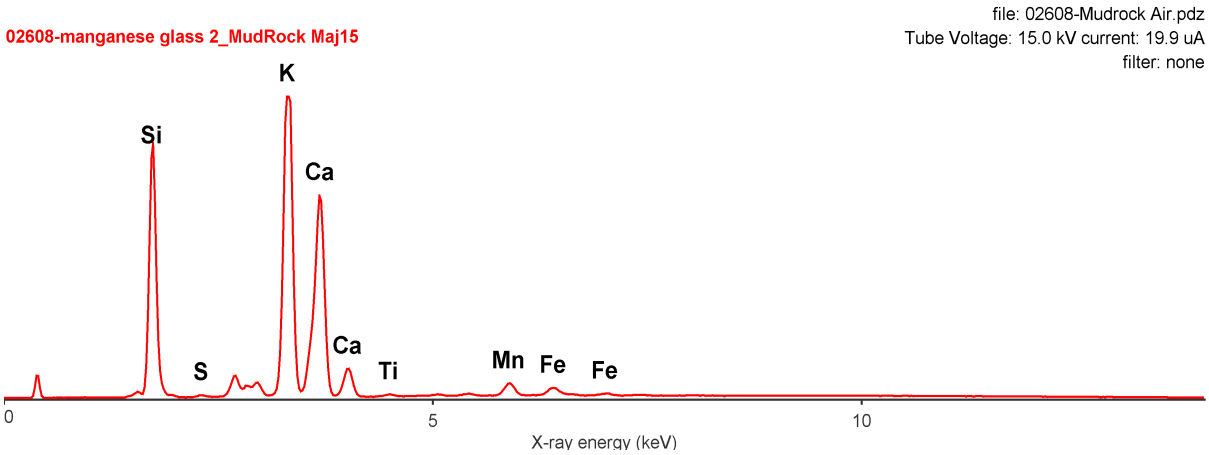
Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	BaO	UO2
2,76	1,71	< LOD	83,58	< LOD	0,13	0,05	3,34	0,01	< LOD

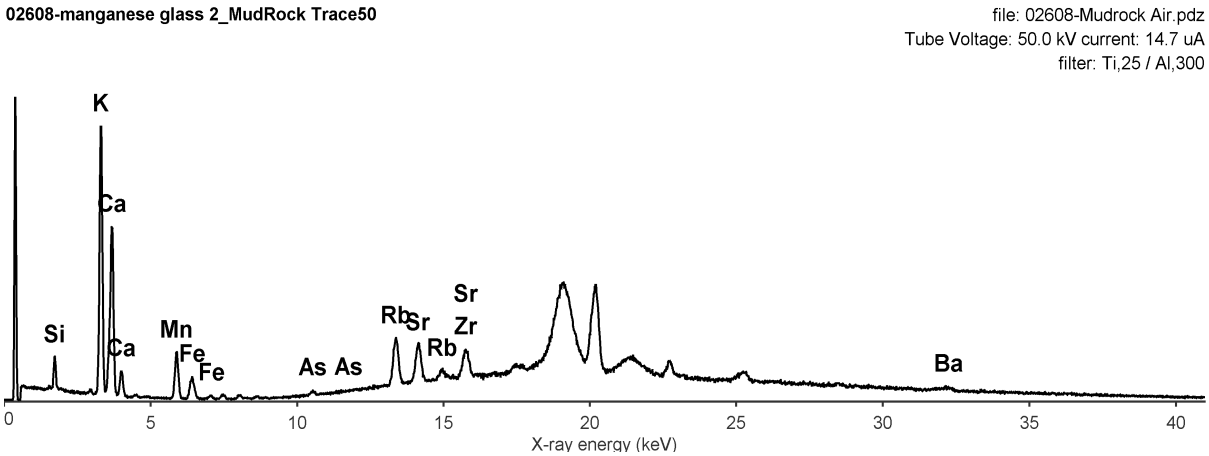
Trace elements (ppm)

Cl	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
829	197	36	< LOD	485	273	< LOD	20	< LOD	8	852	< LOD	32	103	< LOD

XRF sample results form

Object id	Case Study Object 2 -- bowl
Analysis date	18-2-2025 17:11:56





Quantification with method: DualMudrock_Air version 730.0646.01 Na is not reliably quantified; Sn and Sb are not quantified.

Major elements (wt%)

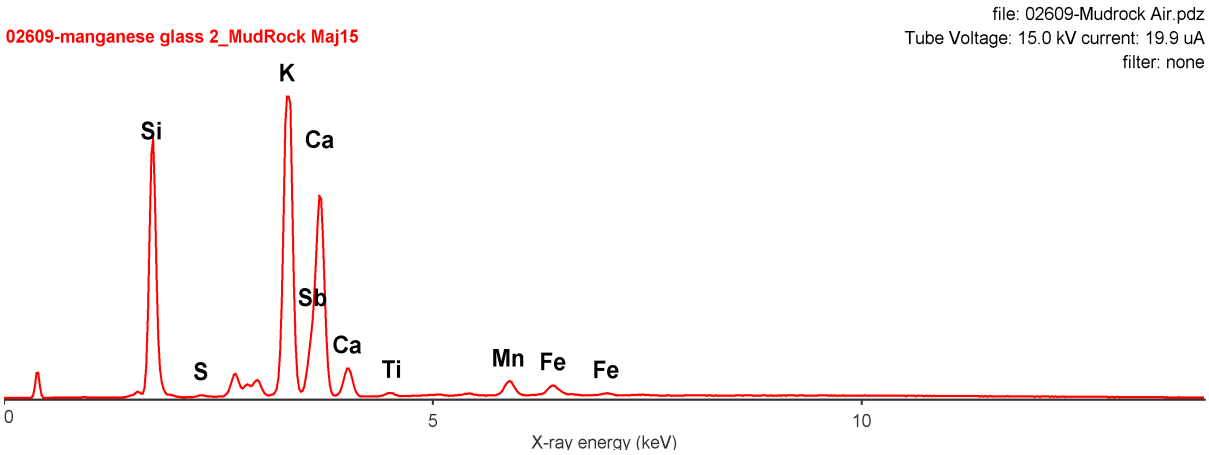
Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	BaO	UO2
1,39	0,32	1,13	83,86	0,12	0,29	14,52	5,94	0,03	< LOD

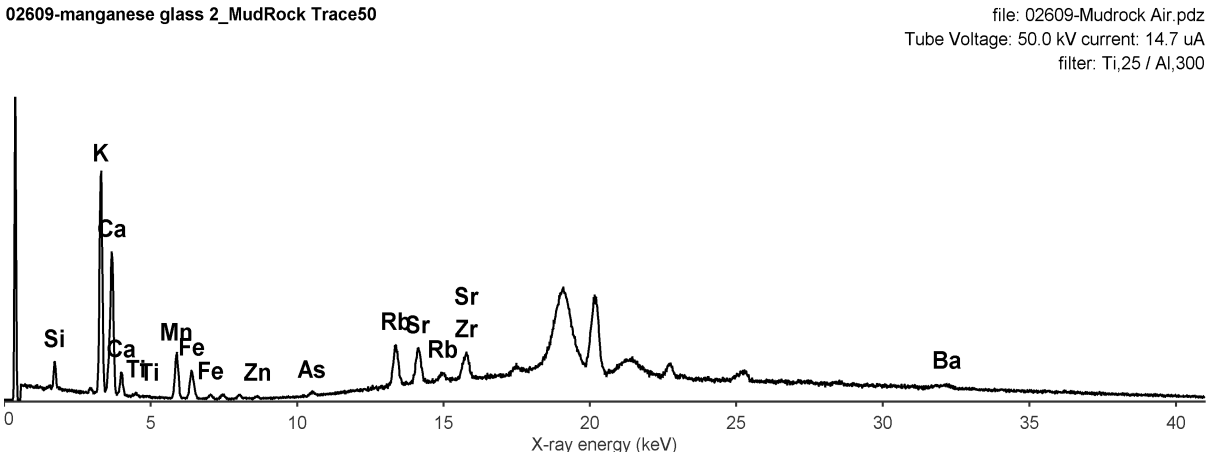
Trace elements (ppm)

Cl	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
< LOD	250	55	< LOD	1448	472	< LOD	25	27	13	11	145	121	68	< LOD

XRF sample results form

Object id	Case Study Object 2 -- Stem
Analysis date	18-2-2025 17:17:13





Quantification with method: DualMudrock_Air version 730.0646.01 Na is not reliably quantified; Sn and Sb are not quantified.

Major elements (wt%)

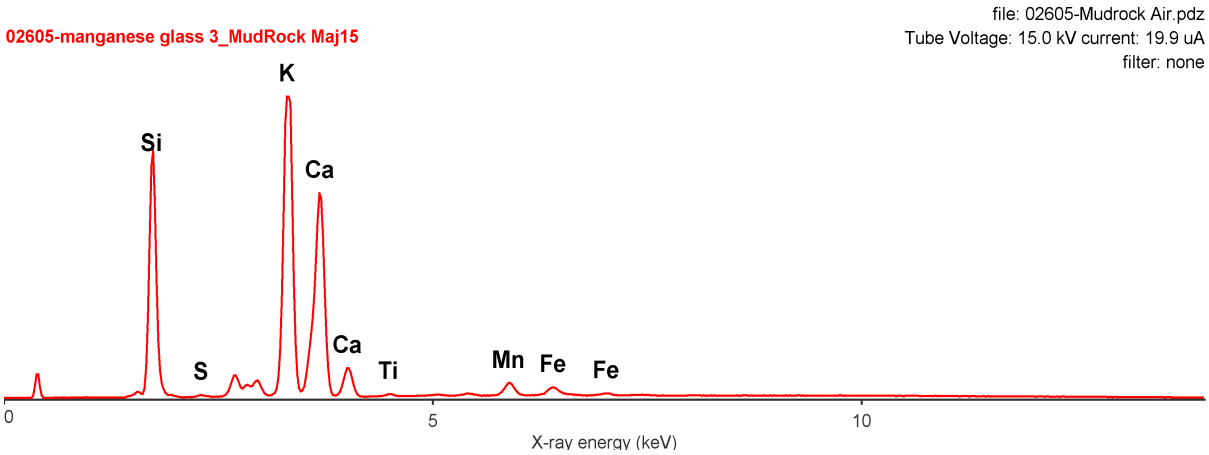
Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	BaO	UO2
1,33	0,34	0,87	73,75	0,08	0,25	12,16	5,09	0,03	0,00

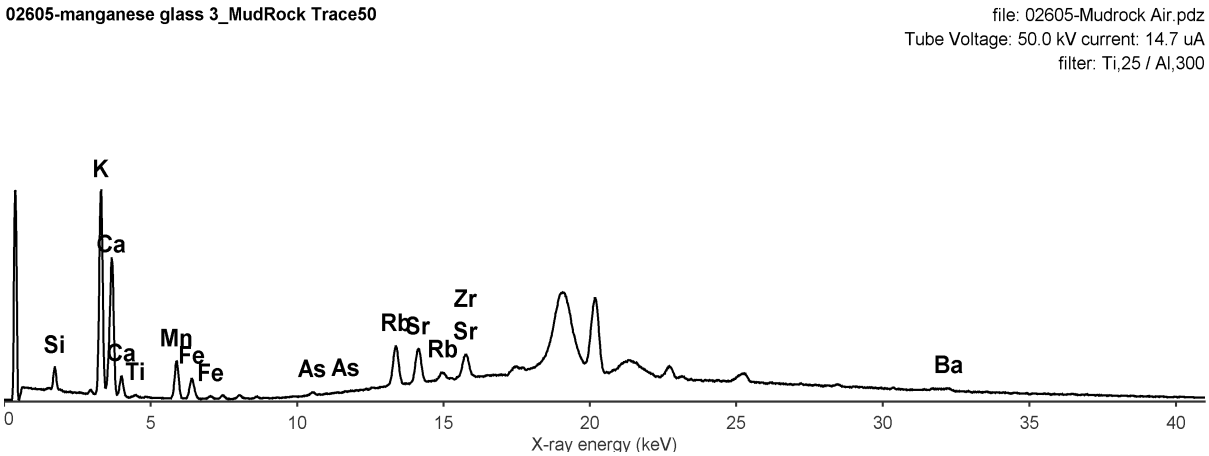
Trace elements (ppm)

Cl	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
< LOD	367	68	< LOD	1374	601	< LOD	28	30	15	13	133	112	67	< LOD

XRF sample results form

Object id	Case Study Object 3 – Bowl A
Analysis date	18-2-2025 16:58:21





Quantification with method: DualMudrock_Air version 730.0646.01 Na is not reliably quantified; Sn and Sb are not quantified.

Major elements (wt%)

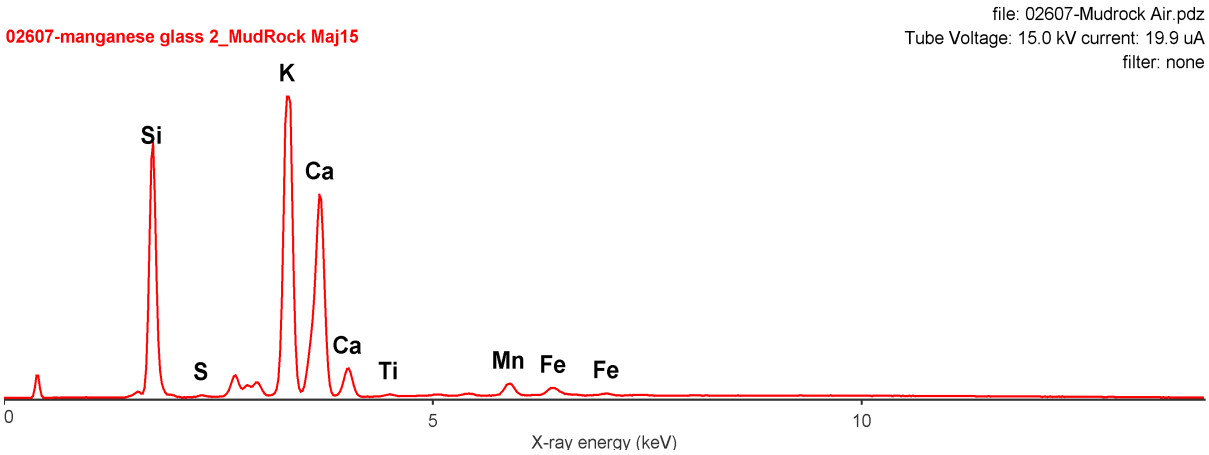
Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	BaO	UO2
1,16	0,35	0,85	74,47	0,10	0,28	12,98	5,46	0,02	< LOD

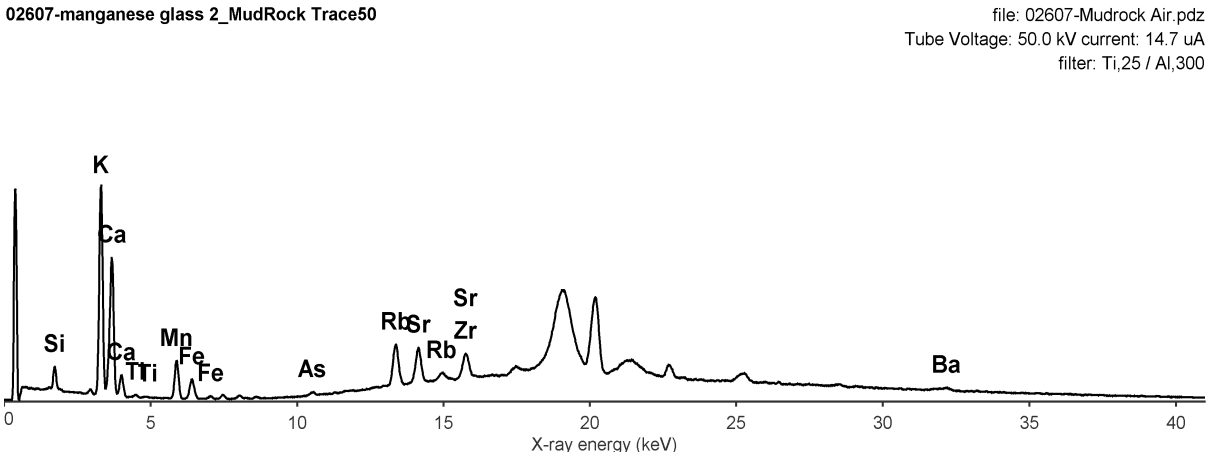
Trace elements (ppm)

Cl	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
< LOD	249	74	< LOD	1320	493	< LOD	25	33	13	12	140	121	65	5

0,98 XRF sample results form

Object id	Case Study Object 3 – Bowl B
Analysis date	18-2-2025 17:06:50





Quantification with method: DualMudrock_Air version 730.0646.01 Na is not reliably quantified; Sn and Sb are not quantified.

Major elements (wt%)

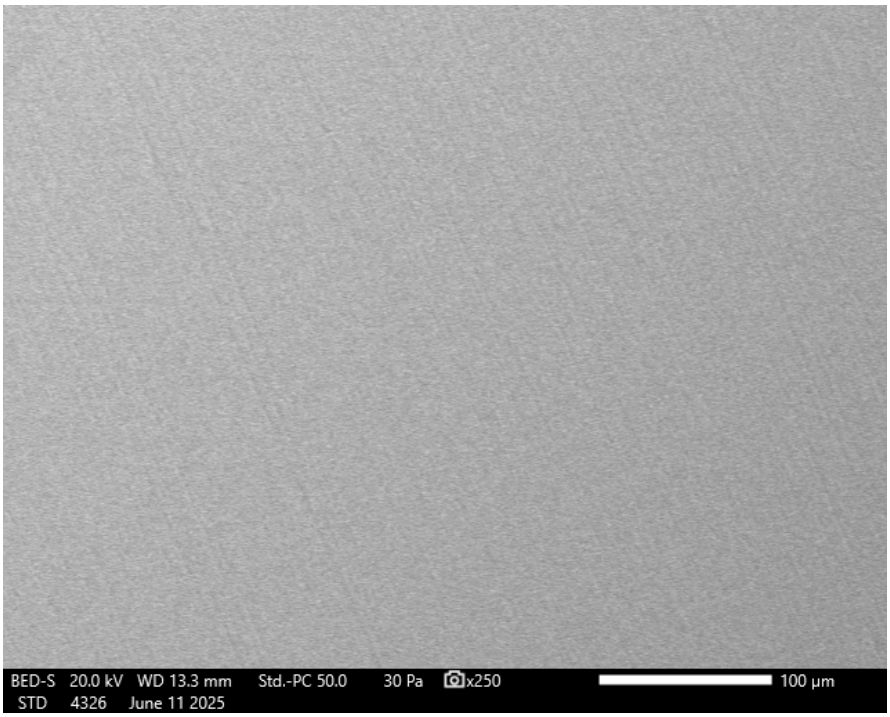
Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	BaO	UO2
0,98	0,26	1,08	82,66	0,09	0,27	14,21	5,89	0,02	< LOD

Trace elements (ppm)

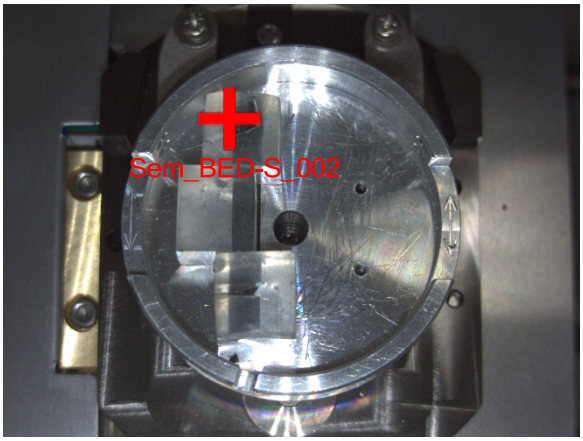
Cl	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Mo
< LOD	255	70	< LOD	1346	465	< LOD	26	27	14	12	140	116	65	5

Appendix V: Raw SEM-EDX Results 11-06-2025

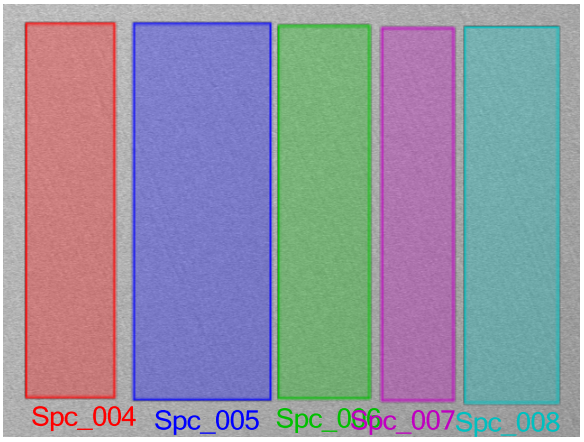
Sem_BED-S_002

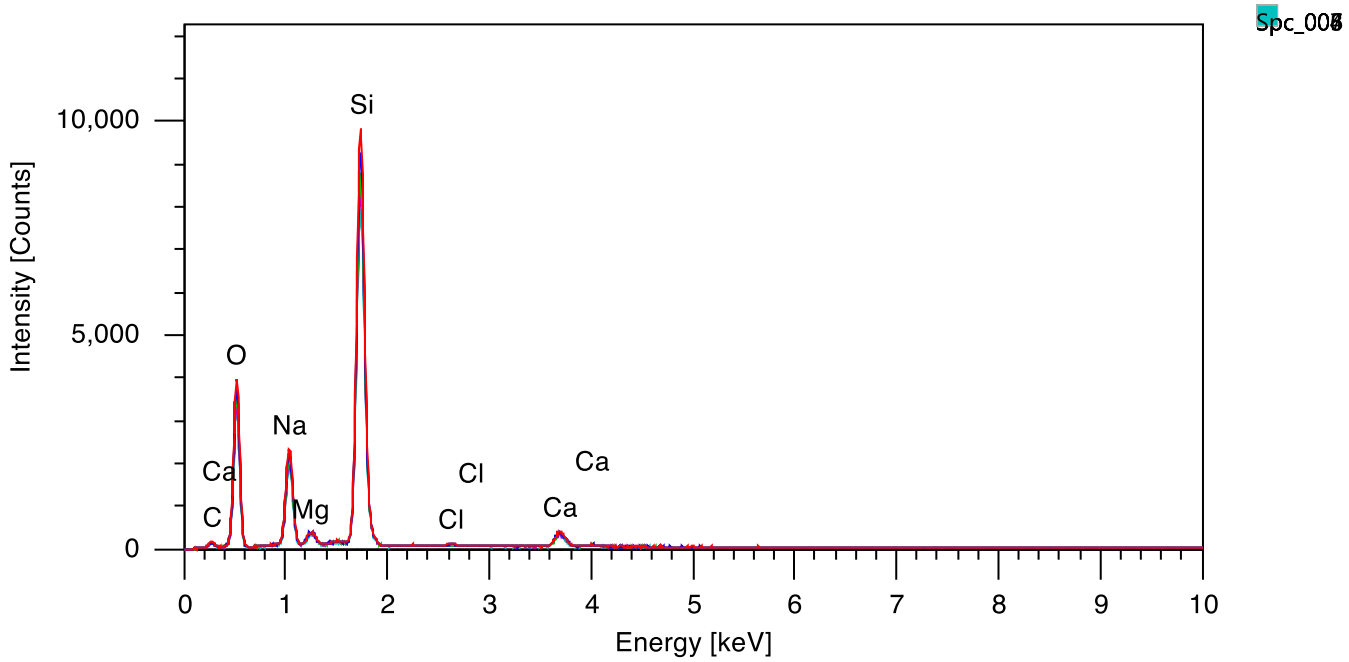


Smp_001



Sem_BED-S_002

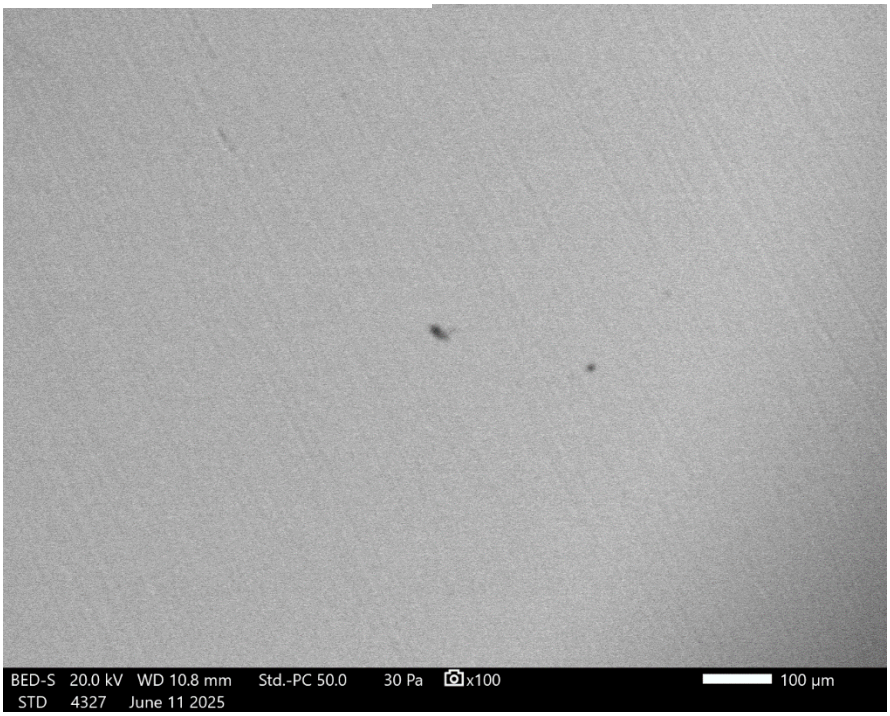




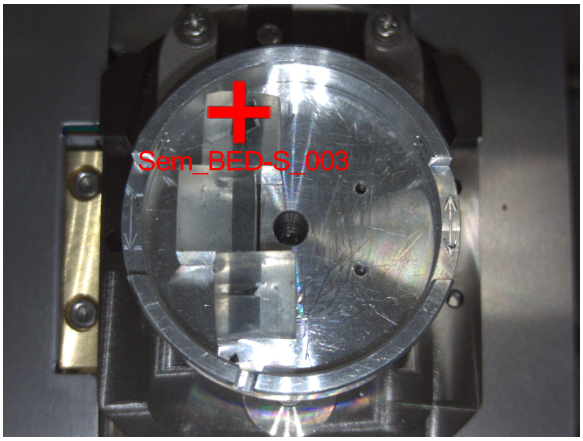
Name	C	O	Na2O	MgO	SiO2	Cl	CaO	Total
Spc_004	9.86		15.69	2.08	69.21	0.19	2.97	100.00
Spc_005	9.26		15.82	2.22	69.61	0.19	2.90	100.00
Spc_006	9.06		16.06	2.26	69.45		3.17	100.00
Spc_007	8.99		15.88	2.10	69.94		3.08	100.00
Spc_008	8.00		16.25	2.22	70.36		3.16	100.00
Average	9.04		15.94	2.18	69.72	0.19	3.06	
Standard Deviat	0.60		0.20	0.07	0.40	0.00	0.11	

Mass%

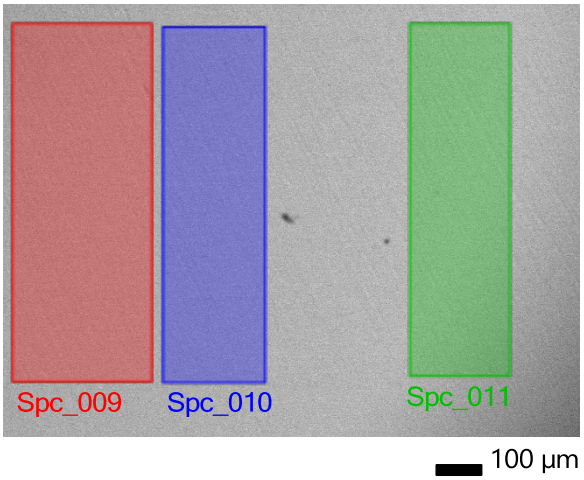
Sem_BED-S_003

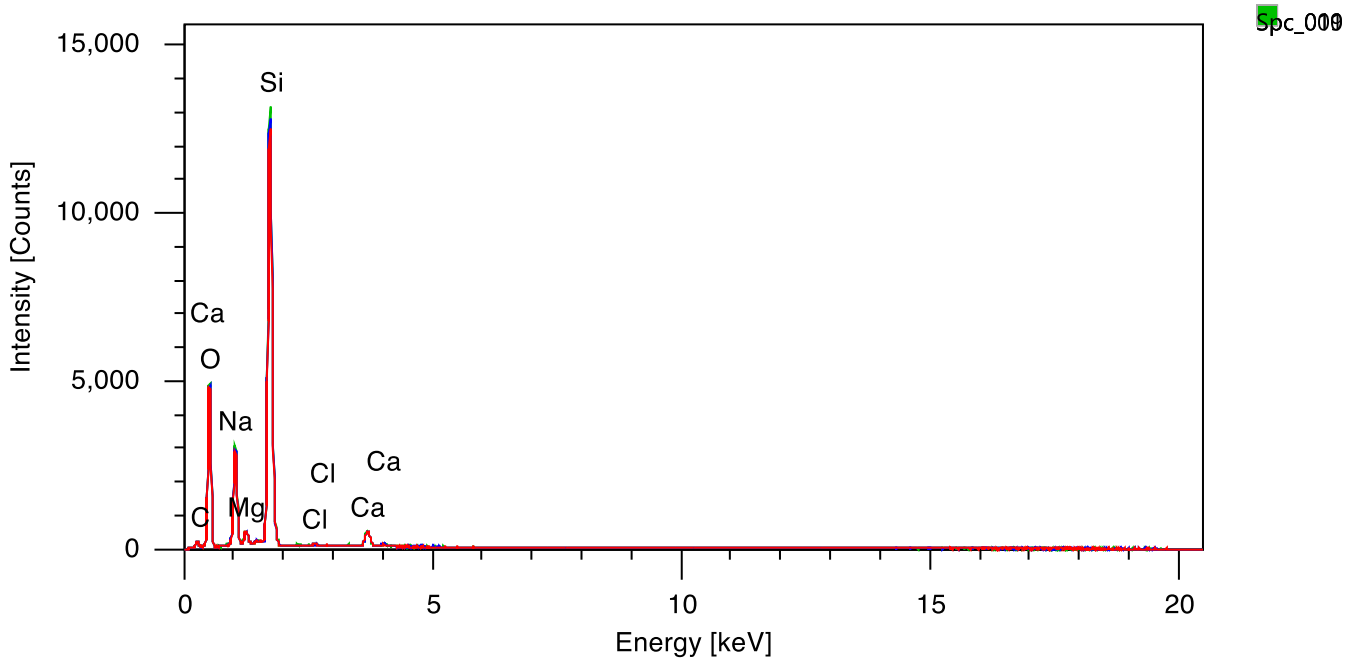

BED-S 20.0 kV WD 10.8 mm Std.-PC 50.0 30 Pa x100 100 µm
STD 4327 June 11 2025

Smp_001



Sem_BED-S_003

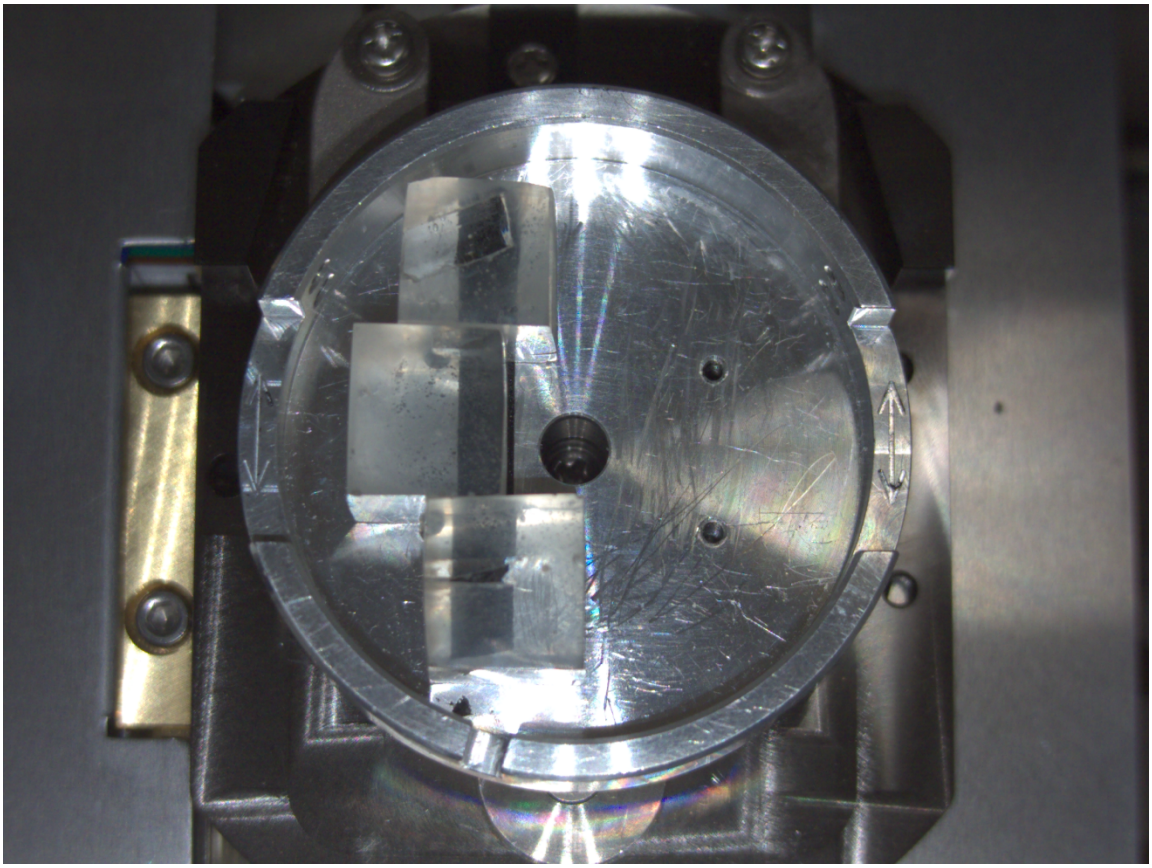




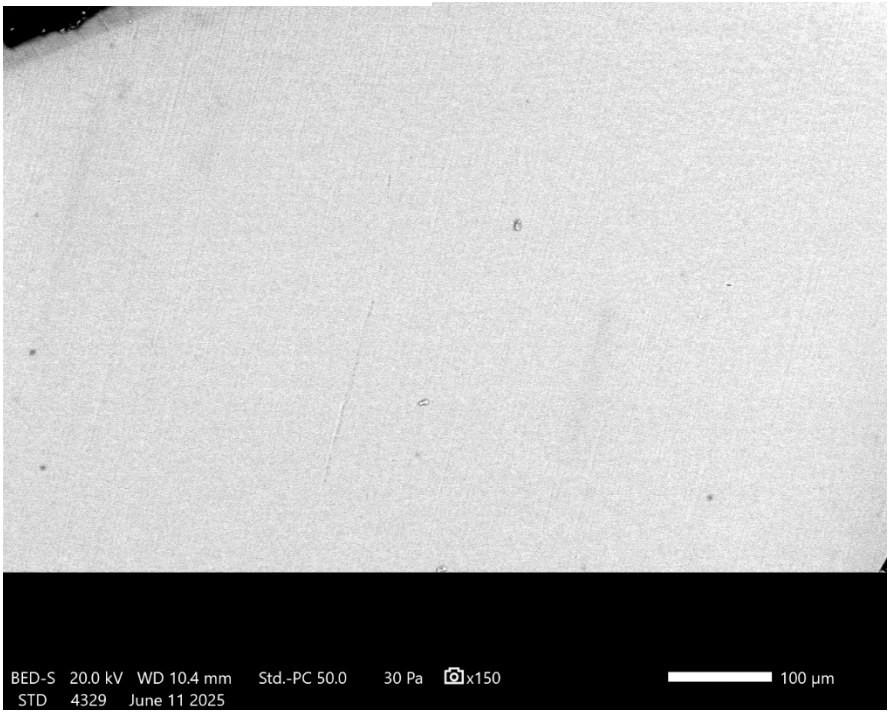
Name	C	O	Na2O	MgO	SiO2	Cl	CaO	Total
Spc_009	10.56		15.07	2.15	69.10		3.12	100.00
Spc_010	10.19		15.29	2.04	69.34	0.12	3.02	100.00
Spc_011	9.53		15.24	2.06	69.89	0.21	3.07	100.00
Average	10.09		15.20	2.08	69.44	0.17	3.07	
Standard D	0.43		0.09	0.05	0.33	0.04	0.04	

Mass%

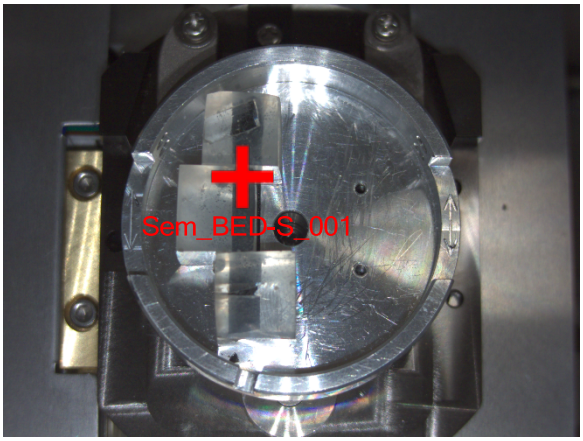
Smp_002



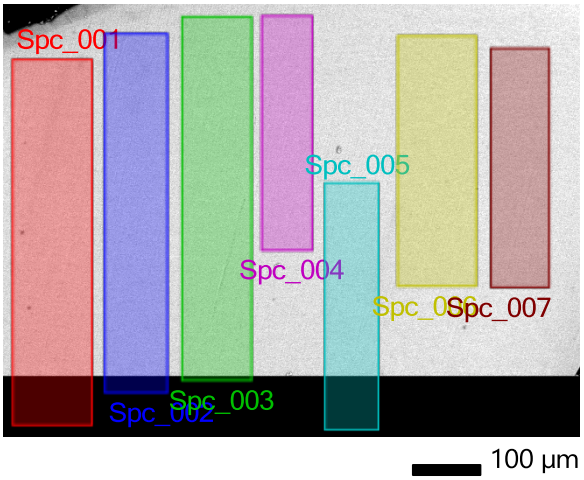
Sem_BED-S_001

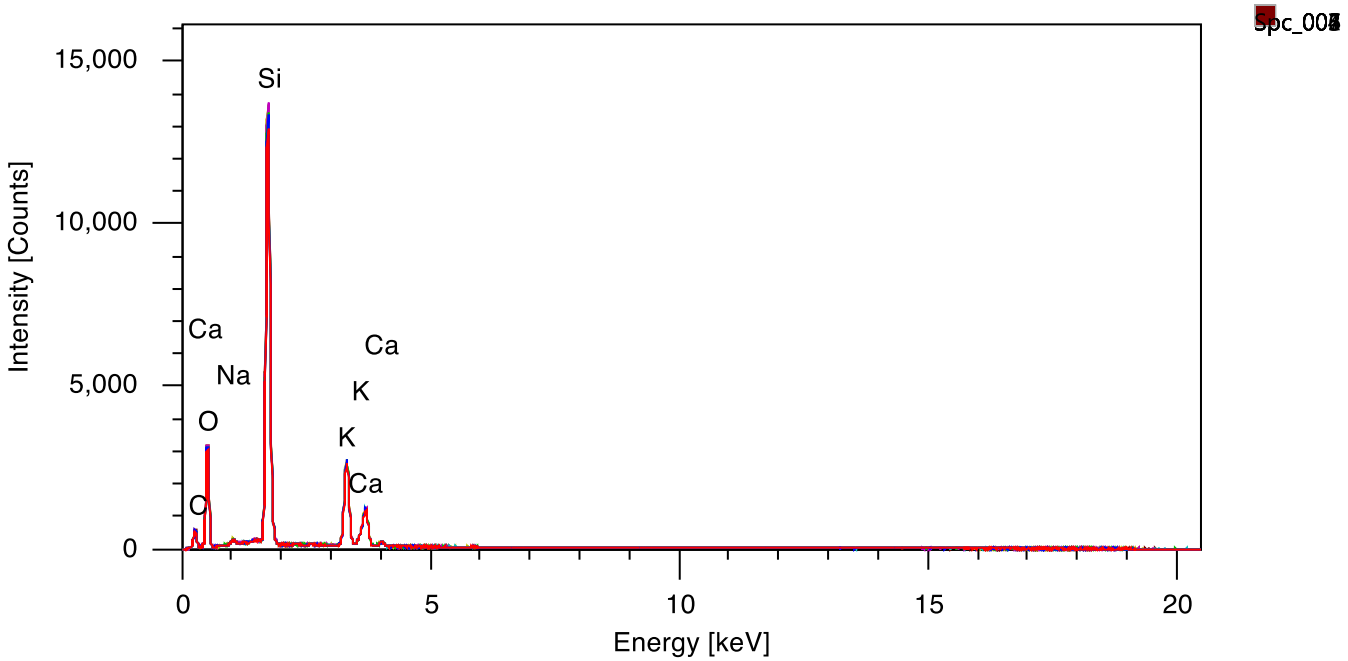

BED-S 20.0 kV WD 10.4 mm Std.-PC 50.0 30 Pa x150
STD 4329 June 11 2025
100 µm

Smp_002



Sem_BED-S_001

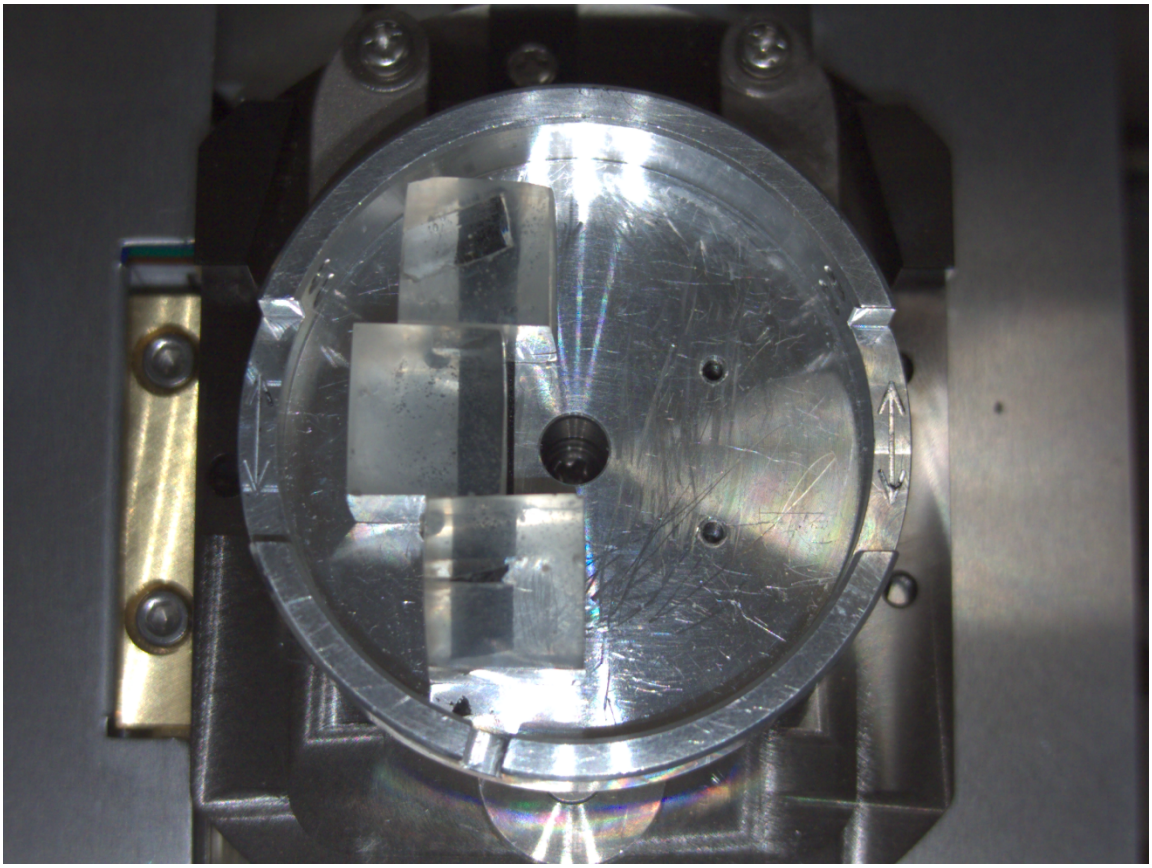




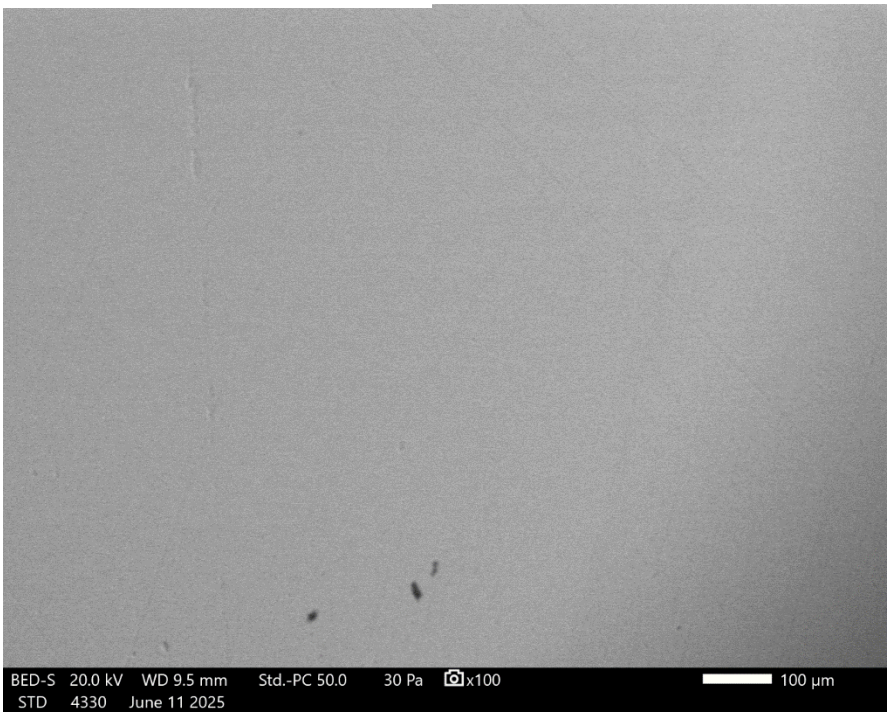
Name	C	O	Na2O	SiO2	K2O	CaO	Total
Spc_001	20.21		0.76	59.76	12.04	7.23	100.00
Spc_002	20.21		0.71	59.83	12.15	7.10	100.00
Spc_003	19.56		0.74	60.13	12.27	7.31	100.00
Spc_004	19.69		0.85	60.23	12.04	7.20	100.00
Spc_005	19.33		0.81	60.26	12.20	7.40	100.00
Spc_006	19.77		0.84	59.74	12.24	7.40	100.00
Spc_007	20.44		0.78	59.82	11.98	7.00	100.00
Average	19.89		0.78	59.97	12.13	7.23	
Standard Deviation	0.37		0.05	0.21	0.10	0.14	

Mass%

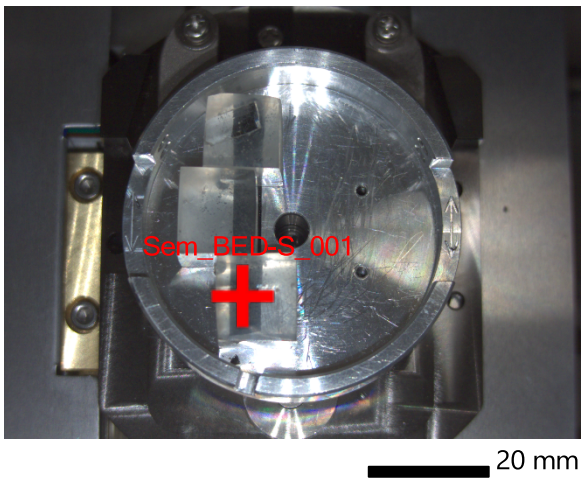
Smp_003



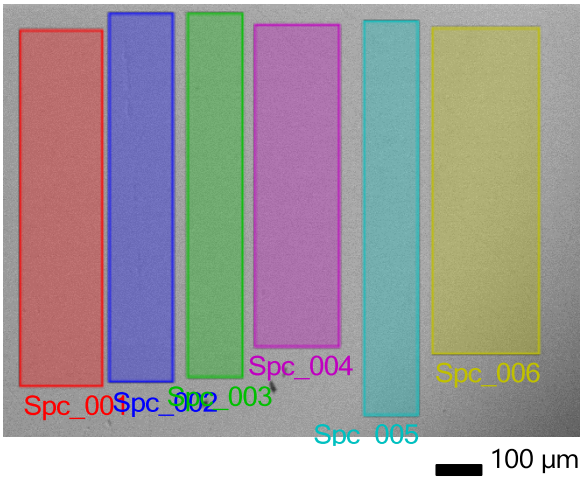
Sem_BED-S_001


BED-S 20.0 kV WD 9.5 mm Std.-PC 50.0 30 Pa x100 100 µm
STD 4330 June 11 2025

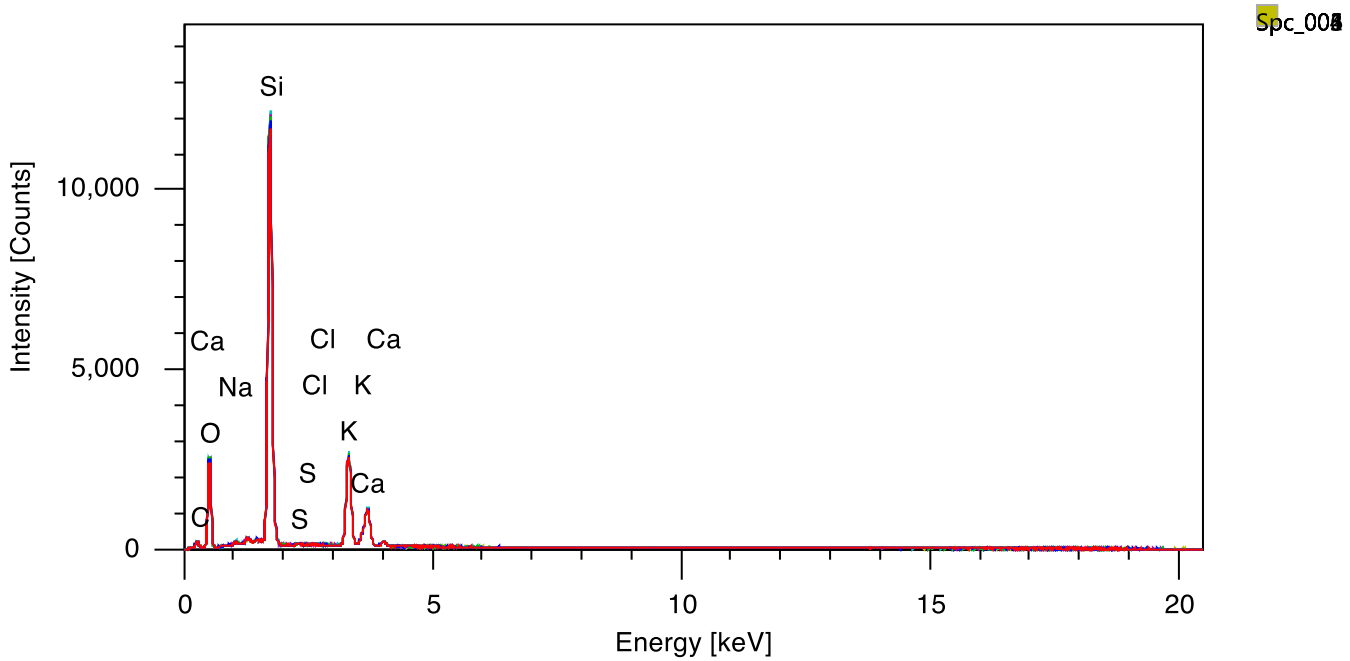
Smp_003



Sem_BED-S_001



Signal BED-S
Landing Voltage 20.0 kV
WD 9.5 mm
Magnification x100
Vacuum Mode LowVacuum



Name	C	O	Na2O	SiO2	SO3	Cl	K2O	CaO	Total
Spc_001	9.50		0.51	67.20			14.78	8.01	100.00
Spc_002	9.30		0.46	67.33			14.71	8.21	100.00
Spc_003	8.44		0.54	67.91		0.17	14.89	8.05	100.00
Spc_004	8.72		0.55	67.74			14.89	8.10	100.00
Spc_005	9.22		0.53	66.57	0.52		14.78	8.37	100.00
Spc_006	9.45		0.52	67.26			14.55	8.22	100.00
Average	9.10		0.52	67.33	0.52	0.17	14.77	8.16	
Standard Deviat	0.39		0.03	0.43			0.12	0.12	

Mass%

Appendix VI: Normalised SEM-EDX Results 11-06-2025

Table VI-1: The normalised SEM-EDX results of case study object 1.

Case study object 1 Normalised	Na2O	MgO	SiO2	Cl	CaO
Spc_004	17.4	2.3	76.8	0.2	3.3
Spc_005	17.4	2.5	76.7	0.2	3.2
Spc_006	17.7	2.5	76.4	0.0	3.5
Spc_007	17.5	2.3	76.9	0.0	3.4
Spc_008	17.7	2.4	76.5	0.0	3.4
Spc_009	16.9	2.4	77.3	0.0	3.5
Spc_010	17.0	2.3	77.2	0.1	3.4
Spc_011	16.9	2.3	77.3	0.2	3.4
Average	**17.3**	**2.4**	**76.9**	**0.1**	**3.4**
Standard deviation	**0.3**	**0.1**	**0.3**	**0.1**	**0.1**

Table VI-2: The normalised SEM-EDX results of case study object 2.

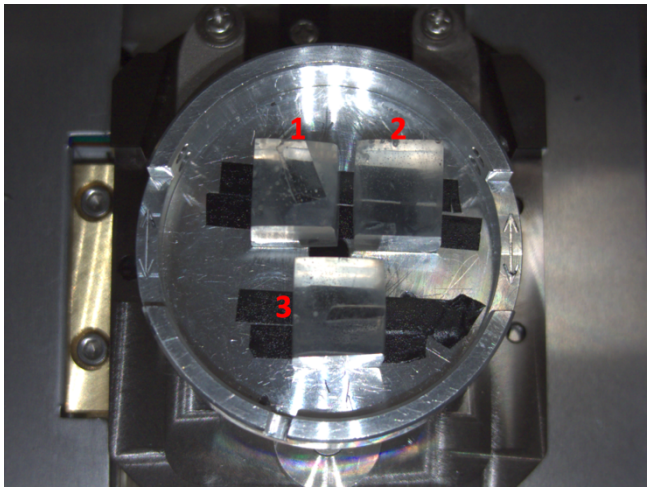
Case study object 2 Normalised	Na2O	SiO2	K2O	CaO
Spc_001	1.0	74.9	15.1	9.1
Spc_002	0.9	75.0	15.2	8.9
Spc_003	0.9	74.7	15.3	9.1
Spc_004	1.1	75.0	15.0	9.0
Spc_005	1.0	74.7	15.1	9.2
Spc_006	1.1	74.5	15.3	9.2
Spc_007	1.0	75.2	15.1	8.8
Average	**1.0**	**74.8**	**15.1**	**9.0**
Standard deviation	**0.1**	**0.2**	**0.1**	**0.1**

Table VI-3: The normalised SEM-EDX results of case study object 3.

Case study object 3 Normalise	Na2O	SiO2	SO3	Cl	K2O	CaO
Spc_001	0.6	74.3	0.0	0.0	16.3	8.9
Spc_002	0.5	74.2	0.0	0.0	16.2	9.1
Spc_003	0.6	74.2	0.0	0.2	16.3	8.8
Spc_004	0.6	74.2	0.0	0.0	16.3	8.9
Spc_005	0.6	73.3	0.6	0.0	16.3	9.2
Spc_006	0.6	74.3	0.0	0.0	16.1	9.1
Average	**0.6**	**74.1**	**0.1**	**0.0**	**16.2**	**9.0**
Standard deviation	**0.0**	**0.3**	**0.2**	**0.1**	**0.1**	**0.2**

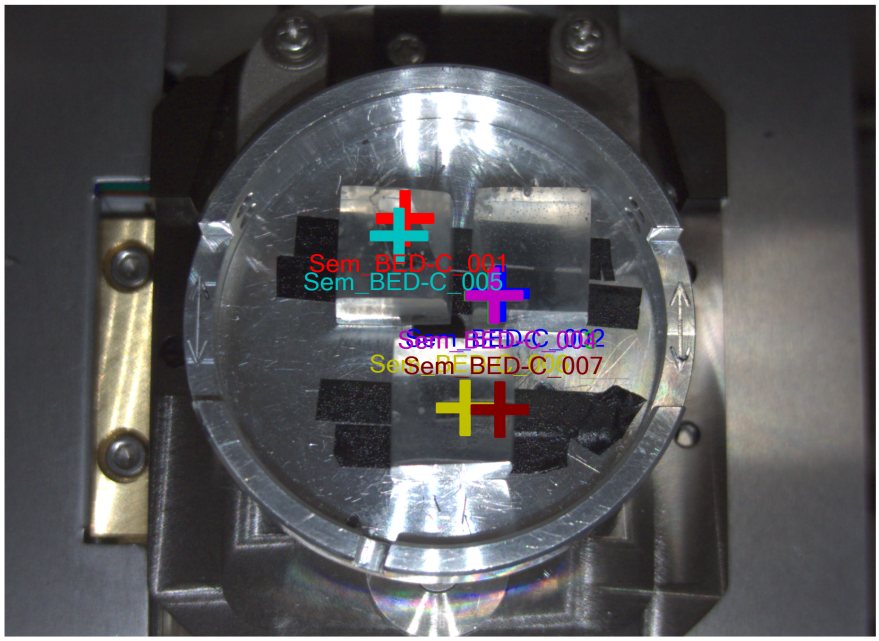
Appendix VII: Raw SEM-EDX Results 01-05-2025

SEM_EDX



Order of sample testing

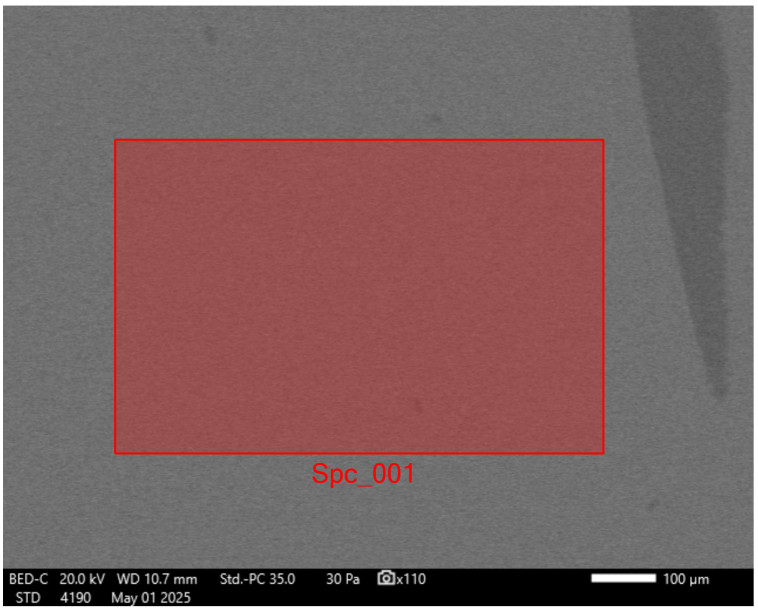
Glass UV thesis

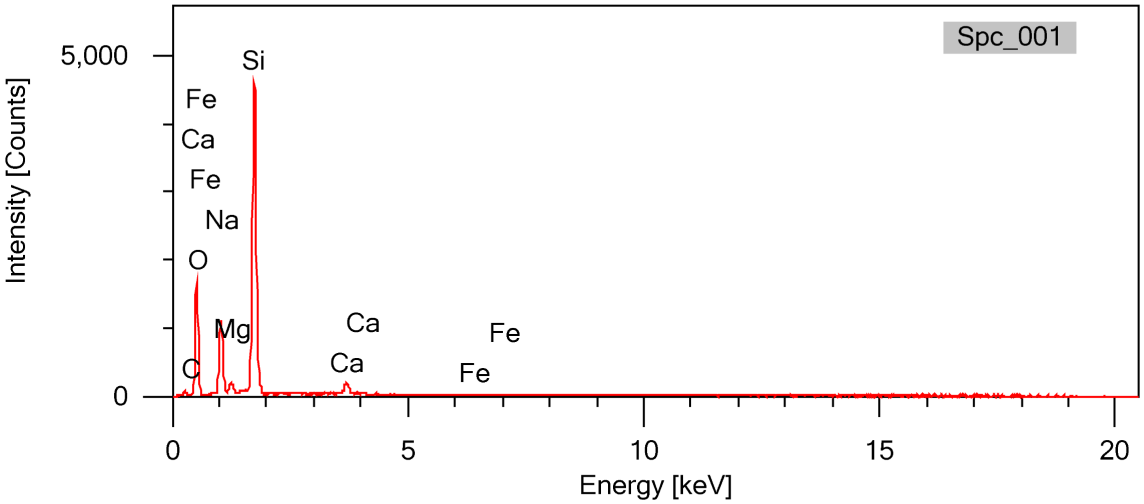


Sem_BED-C_001

Sample tested 1 – American pressed glass

Sem_BED-C_001



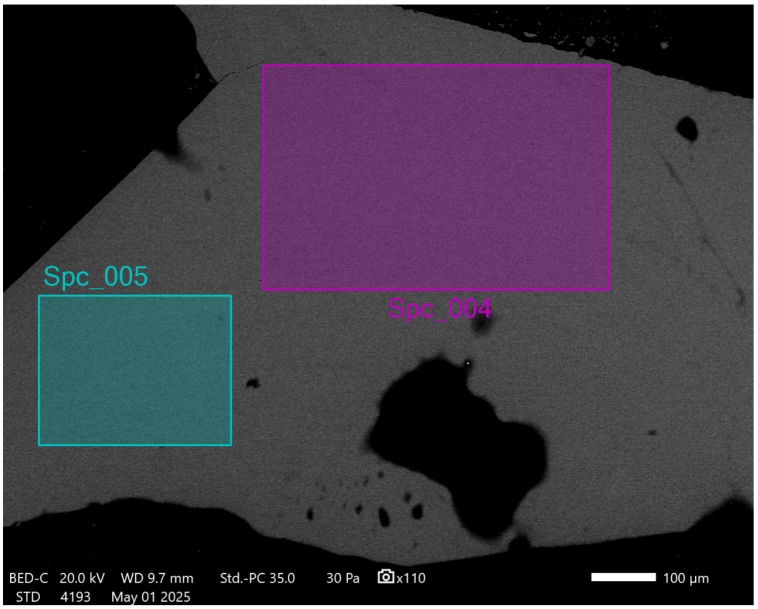


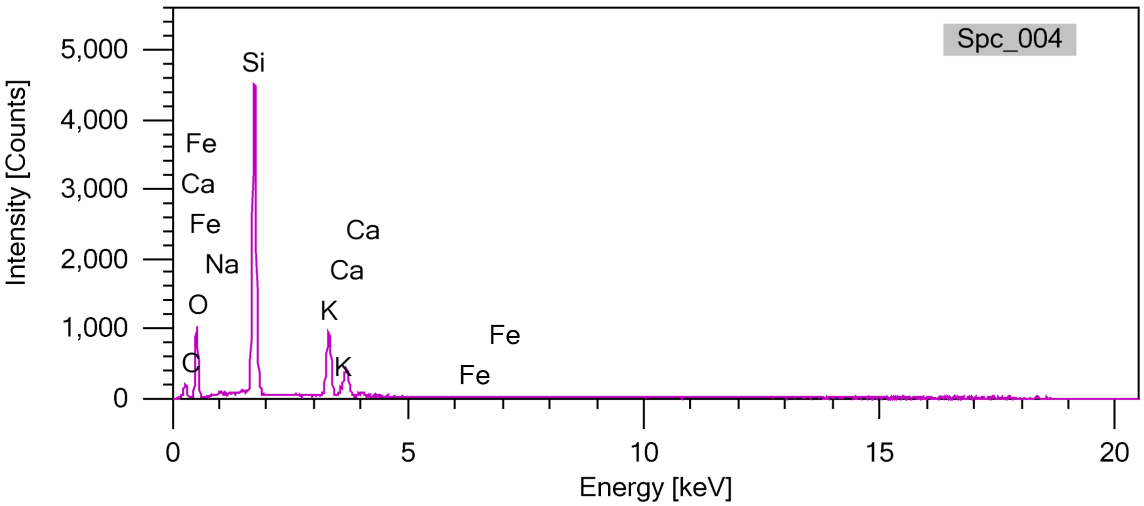
Chemical formula	Line	Mass%	Mol%	Cations
C	K	7.50±0.49	28.68±1.88	0.00
O	K			
Na2O	K	16.22±0.44	12.02±0.33	4.59
MgO	K	2.03±0.17	2.31±0.19	0.44
SiO2	K	71.00±0.95	54.31±0.72	10.38
CaO	K	3.26±0.19	2.67±0.16	0.51
Fe2O3	K	nd	nd	-
Total		100.00	100.00	
Spc_001				Fitting ratio 0.0257

Nb. The light green analysis num. 5 was cancelled

Glass 2.

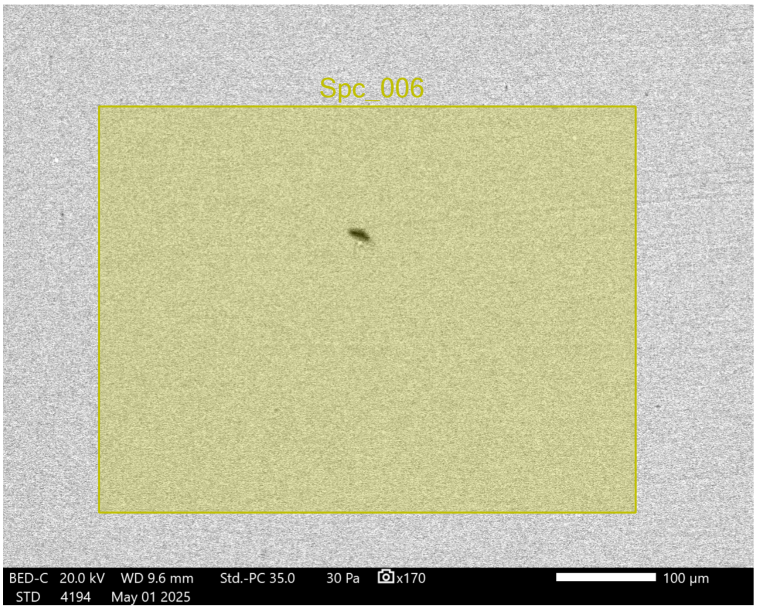
Sem_BED-C_004

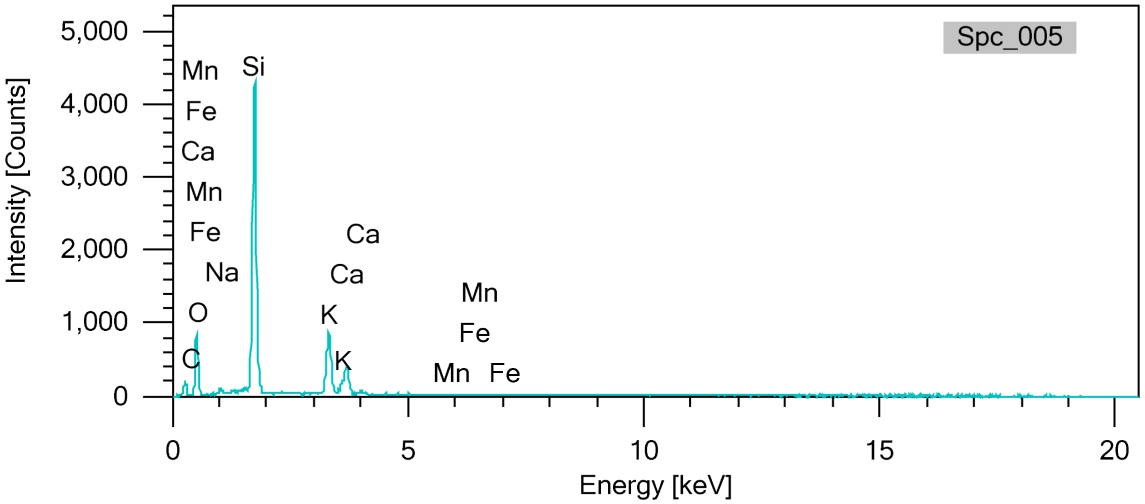




Chemical formula	Line	Mass%	Mol%	Cations
C	K	20.86±0.66	58.13±1.84	0.00
O	K			
Na2O	K	0.66±0.10	0.36±0.05	0.23
SiO2	K	59.04±0.79	32.89±0.44	10.55
K2O	K	12.21±0.31	4.34±0.11	2.78
CaO	K	7.18±0.28	4.28±0.17	1.37
Fe2O3	K	0.05±0.05	0.01±0.01	0.01
Total		100.00	100.00	
Spc_004				Fitting ratio 0.0313

Sem_BED-C_005



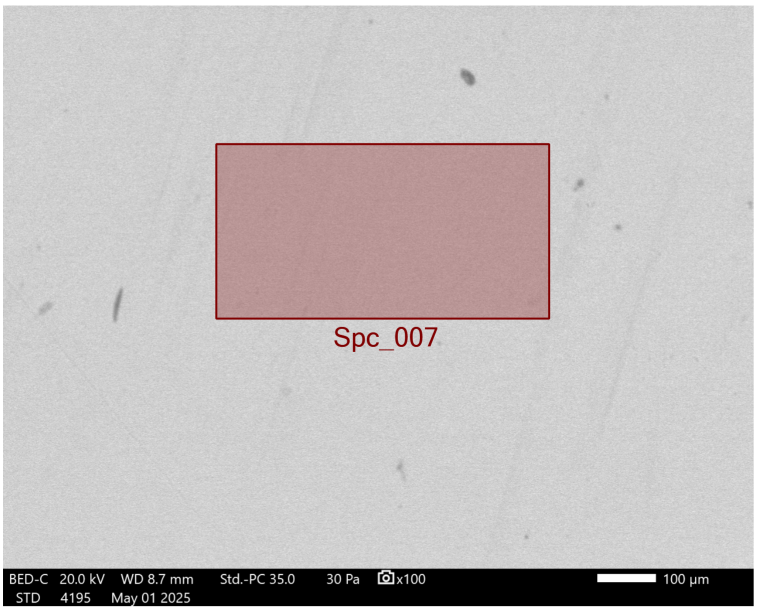


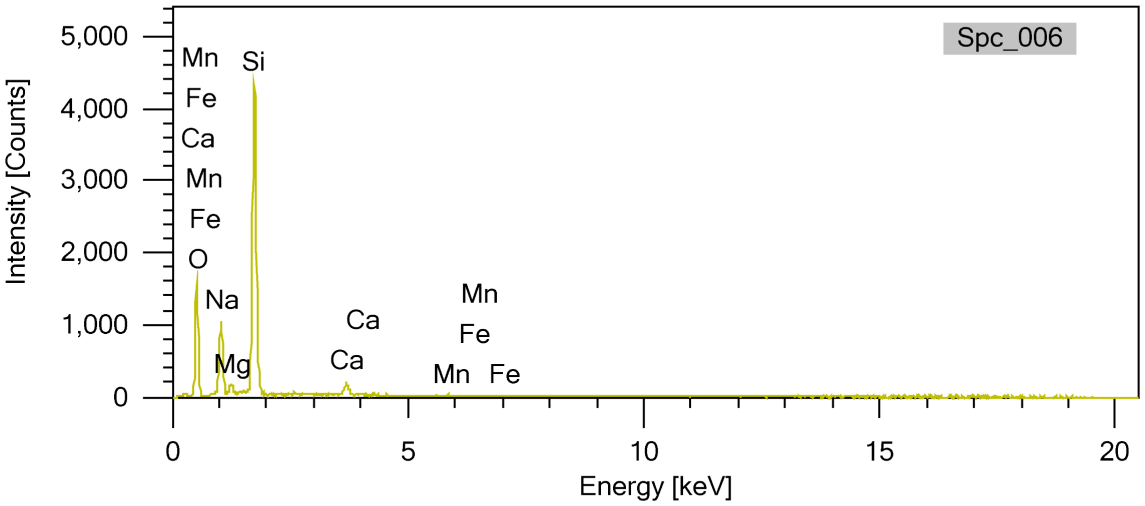
Chemical formula	Line	Mass%	Mol%	Cations
C	K	21.22±0.69	58.64±1.91	0.00
O	K			
Na2O	K	0.80±0.11	0.43±0.06	0.28
SiO2	K	58.81±0.82	32.49±0.45	10.55
K2O	K	11.81±0.32	4.16±0.11	2.70
CaO	K	7.09±0.29	4.19±0.17	1.36
MnO	K	0.15±0.07	0.07±0.03	0.02
Fe2O3	K	0.12±0.07	0.03±0.01	0.02
Total		100.00	100.00	
Spc_005				Fitting ratio 0.0333

Sample 3

(6,7,8,9)

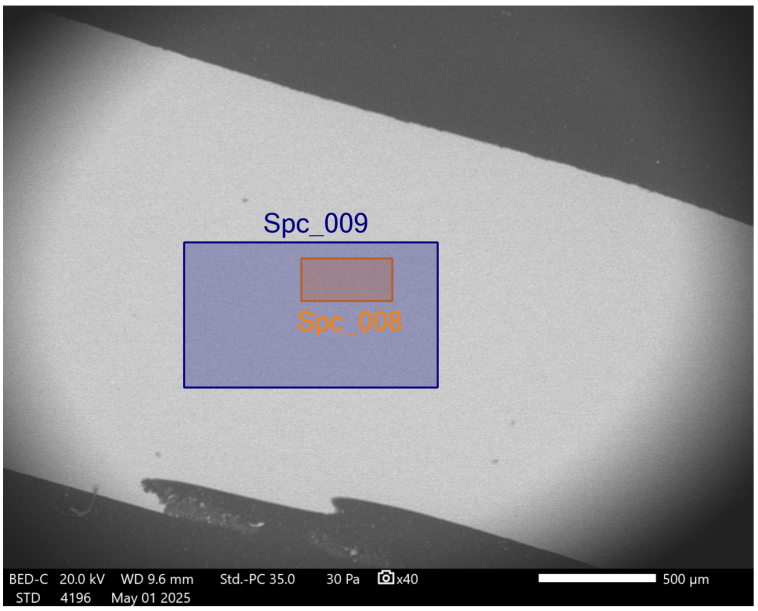
Sem_BED-C_006

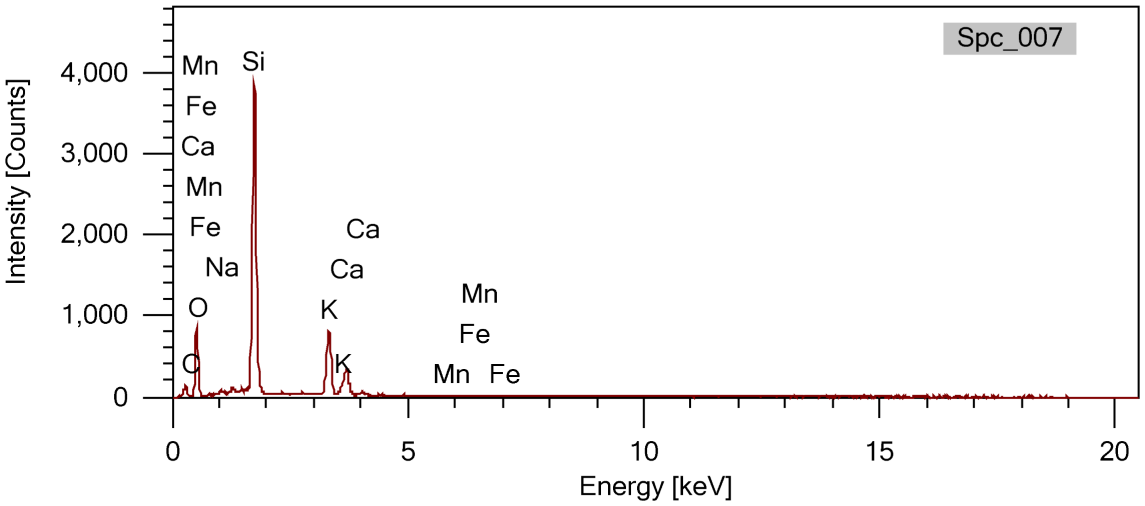




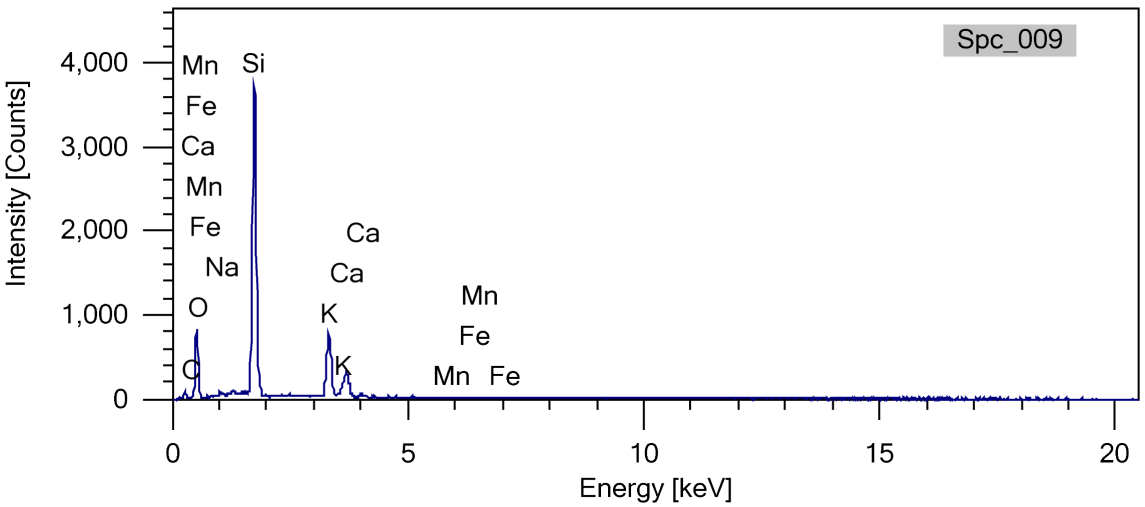
Chemical formula	Line	Mass%	Mol%	Cations
O	K			
Na2O	K	17.04±0.48	16.40±0.46	4.46
MgO	K	2.27±0.19	3.35±0.28	0.46
SiO2	K	76.90±1.06	76.32±1.05	10.39
CaO	K	3.43±0.21	3.65±0.23	0.50
MnO	K	0.31±0.10	0.26±0.08	0.04
Fe2O3	K	0.05±0.06	0.02±0.02	0.01
Total		100.00	100.00	
Spc_006				Fitting ratio 0.0333

Sem_BED-C_007





Chemical formula	Line	Mass%	Mol%	Cations
C	K	17.25±0.68	52.37±2.08	0.00
O	K			
Na2O	K	0.58±0.10	0.34±0.06	0.19
SiO2	K	61.91±0.91	37.58±0.55	10.58
K2O	K	12.94±0.36	5.01±0.14	2.82
CaO	K	7.04±0.31	4.58±0.20	1.29
MnO	K	0.20±0.08	0.10±0.04	0.03
Fe2O3	K	0.08±0.07	0.02±0.02	0.01
Total		100.00	100.00	
Spc_007				Fitting ratio 0.0398



Chemical formula	Line	Mass%	Mol%	Cations
C	K	10.53±0.59	38.30±2.15	0.00
O	K			
Na2O	K	0.63±0.12	0.45±0.08	0.19
SiO2	K	67.08±1.00	48.77±0.73	10.60
K2O	K	14.04±0.40	6.51±0.19	2.83
CaO	K	7.52±0.34	5.86±0.27	1.27
MnO	K	0.19±0.09	0.12±0.06	0.03
Fe2O3	K	nd	nd	-
Total		100.00	100.00	
Spc_009				Fitting ratio 0.0396

Appendix VIII: Normalised SEM-EDX Results 01-05-2025

Table VIII-1: The normalised SEM-EDX results of case study object 1.

Case study object 1 Normalised	Na2O	MgO	SiO2	Cl	CaO	MnO	FeO3
Spc_001	17.6	2.2	77.0	0.0	3.3	0.0	0.0
Spc_006	17.0	2.3	76.9	0.0	3.4	0.3	0.1
Average	**17.3**	**2.2**	**76.9**	**0.0**	**3.4**	**0.2**	**0.0**
Standard deviation	**0.4**	**0.0**	**0.1**	**0.0**	**0.1**	**0.2**	**0.0**

Table VIII-2: The normalised SEM-EDX results of case study object 2.

Case study object 2 Normalise	Na2O	SiO2	K2O	Cao	MnO	FeO3
Spc_004	0.8	74.6	15.4	9.1	0.0	0.1
Spc_005	1.0	74.7	15.0	9.0	0.2	0.2
Average	**0.9**	**74.6**	**15.2**	**9.0**	**0.1**	**0.1**
Standard deviation	**0.1**	**0.0**	**0.3**	**0.0**	**0.1**	**0.1**

Table VIII-3: The normalised SEM-EDX results of case study object 3.

Case study object 3 Normalised	Na2O	MgO	SiO2	K2O	Cao	MnO	FeO3
Spc_007	0.7	0.0	74.8	15.6	8.5	0.2	0.1
Spc_008	0.7	0.0	75.0	15.7	8.4	0.2	0.0
Average	**0.7**	**0.0**	**74.9**	**15.7**	**8.5**	**0.2**	**0.1**
Standard deviation	**0.0**	**0.0**	**0.1**	**0.0**	**0.1**	**0.0**	**0.1**

Appendix IX: Overview measurement days

Table 1-4

Day	Control samples	UVA exposure (Blak-Ray® UVL-56)	UVB and in lesser amount UVA exposure (Opsytec Dr. Gröbel UV chamber)	Sunlight through glass simulation (Xenotest)
1	x	x		x
2	x		x	
3	x	x		
4	x	x		
10	x	x		
14				
15	x	x	x	x
18	x	x	x	
19				
23	x	x	x	
27				
28			x	x
31	x	x	x	
37	x	x	x	
38				x
44	x	x	x	
45				
46	x	x	x	
49	x	x	x	
51	x	x	x	
57	x	x	x	
60	x	x	x	
64				x

Appendix XI: All Lab values and thicknesses of the case study objects

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
1	Ref. Index				1.48														
1	Thickness				mm	4.8	4.6	4.5	4.2	4.0	4.3	4.8	4.7	4.1	4.1	4.9	4.5	4.6	4.0
1	01/Apr	1	1	SCI	l	71.35	76.04	72.76	71.51	76.43	78.78	72.42	65.28	75.83	78.65	68.77	71.9	69.85	76.18
1	01/Apr	1	1	SCI	a	1.27	1.01	1.53	1.36	1.08	1.08	0.97	1.21	1.07	1.29	1.28	1.02	0.81	1.12
1	01/Apr	1	1	SCI	b	2.62	1.87	2.53	2.67	2.08	1.83	2.43	3.23	2.06	1.84	2.97	2.58	2.15	2.08
1	01/Apr	1	1	SCE	l	66.1	73.77	67.42	68.24	70.79	73.64	65.93	60.48	70.47	74.31	62.62	65.66	63.9	70.74
1	01/Apr	1	1	SCE	a	1.38	1.09	1.72	1.47	1.24	1.2	1.12	1.4	1.19	1.41	1.46	1.18	0.92	1.25
1	01/Apr	1	1	SCE	b	2.85	2.23	2.93	3.05	2.53	2.17	2.98	3.84	2.37	2.04	3.44	3.07	2.64	2.44
1	01/Apr	1	2	SCI	l	71.88	77.13	65.39	65.17	75.22	75.26	69.89	71.26	75.21	77.46	72.55	73.28	73.29	77.34
1	01/Apr	1	2	SCI	a	1.06	0.87	2.16	1.32	1.04	1.05	1.34	1.2	0.9	1.34	1.12	1.1	1.06	1.22
1	01/Apr	1	2	SCI	b	2.61	1.79	2.62	3.33	2.21	2.37	2.89	2.68	2.18	1.99	2.69	2.41	2.38	2.02
1	01/Apr	1	2	SCE	l	66.53	72.81	60.85	64.12	69.27	70.91	63.01	66.37	69.75	73.07	68.96	67.28	67.77	72.31
1	01/Apr	1	2	SCE	a	1.16	0.92	2.41	1.39	1.18	1.17	1.56	1.34	1.01	1.48	1.25	1.27	1.18	1.36
1	01/Apr	1	2	SCE	b	2.93	2.06	3.14	3.64	2.69	2.7	3.59	3.09	2.53	2.26	2.95	2.93	2.76	2.32
1	01/Apr	1	3	SCI	l	71.28	74.4	67.08	69.66	74.65	78.77	66.02	70.71	76.36	78.12	69.5	73.87	71.14	77.33
1	01/Apr	1	3	SCI	a	1.13	0.86	1.38	1.34	0.98	0.92	1.29	1.05	0.84	1.35	1.1	1.07	1.38	1.15
1	01/Apr	1	3	SCI	b	2.65	1.82	1.96	2.83	2.2	1.91	3.19	2.63	2.02	1.96	2.85	2.42	2.55	2.02
1	01/Apr	1	3	SCE	l	67.86	73.28	66.68	66.05	69.68	73.41	61.2	65.81	71.11	73.65	63.94	68.63	65.76	72.58
1	01/Apr	1	3	SCE	a	1.24	0.93	1.44	1.48	1.08	1.02	1.47	1.17	0.94	1.49	1.28	1.21	1.55	1.3
1	01/Apr	1	3	SCE	b	3.05	2.26	2.12	3.22	2.63	2.29	3.71	3.01	2.32	2.23	3.22	2.74	3.02	2.33
1	01/Apr	1	Δ	SCI	l	71.50	75.86	68.41	68.78	75.43	77.60	69.44	69.08	75.80	78.08	70.27	73.02	71.43	76.95
1	01/Apr	1	Δ	SCI	a	1.15	0.91	1.69	1.34	1.03	1.02	1.20	1.15	0.94	1.33	1.17	1.06	1.08	1.16
1	01/Apr	1	Δ	SCI	b	2.63	1.83	2.37	2.94	2.16	2.04	2.84	2.85	2.09	1.93	2.84	2.47	2.36	2.04
1	01/Apr	1	Δ	SCE	l	66.83	73.29	64.98	66.14	69.91	72.65	63.38	64.22	70.44	73.68	65.17	67.19	65.81	71.88
1	01/Apr	1	Δ	SCE	a	1.26	0.98	1.86	1.45	1.17	1.13	1.38	1.30	1.05	1.46	1.33	1.22	1.22	1.30
1	01/Apr	1	Δ	SCE	b	2.94	2.18	2.73	3.30	2.62	2.39	3.43	3.31	2.41	2.18	3.20	2.91	2.81	2.36
1	02/Apr	2	1	SCI	l	75.77	77.55												
1	02/Apr	2	1	SCI	a	1.08	1.31												
1	02/Apr	2	1	SCI	b	2.35	2.18												
1	02/Apr	2	1	SCE	l	71.29	73.76												
1	02/Apr	2	1	SCE	a	1.15	1.4												
1	02/Apr	2	1	SCE	b	2.54	2.47												
1	02/Apr	2	2	SCI	l	75.28	76.76												
1	02/Apr	2	2	SCI	a	1.34	1.28												
1	02/Apr	2	2	SCI	b	2.47	2.35												
1	02/Apr	2	2	SCE	l	71.11	73.78												
1	02/Apr	2	2	SCE	a	1.45	1.39												
1	02/Apr	2	2	SCE	b	2.66	2.71												
1	02/Apr	2	3	SCI	l	70.6	75.72												
1	02/Apr	2	3	SCI	a	1.24	1.41												
1	02/Apr	2	3	SCI	b	2.74	2.5												
1	02/Apr	2	3	SCE	l	70.04	72.12												
1	02/Apr	2	3	SCE	a	1.3	1.54												
1	02/Apr	2	3	SCE	b	3.01	2.88												
1	02/Apr	2	Δ	SCI	l	73.88	76.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	02/Apr	2	Δ	SCI	a	1.22	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	02/Apr	2	Δ	SCI	b	2.52	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	02/Apr	2	Δ	SCE	l	70.81	73.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	02/Apr	2	Δ	SCE	a	1.30	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	02/Apr	2	Δ	SCE	b	2.74	2.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	1	SCI	l	75.72	77.91					75.08	70.74						
1	03/Apr	3	1	SCI	a	1.11	1.05					1.15	1.39						
1	03/Apr	3	1	SCI	b	2.39	2.13					2.67	2.87						
1	03/Apr	3	1	SCE	l	72.08	74.49					69.32	66.22						
1	03/Apr	3	1	SCE	a	1.21	1.12					1.3	1.55						
1	03/Apr	3	1	SCE	b	2.69	2.42					3.17	3.33						
1	03/Apr	3	2	SCI	l	73.3	76.35					74.08	72.15						
1	03/Apr	3	2	SCI	a	1.17	1.11					1.14	1.47						
1	03/Apr	3	2	SCI	b	2.44	2.29					2.8	2.98						
1	03/Apr	3	2	SCE	l	72.23	72.42					68.31	67.67						
1	03/Apr	3	2	SCE	a	1.25	1.19					1.28	1.64						
1	03/Apr	3	2	SCE	b	2.8	2.64					3.3	3.41						
1	03/Apr	3	3	SCI	l	72.04	71.9					73.65	72.71						
1	03/Apr	3	3	SCI	a	0.9	1.45					1.08	1.39						
1	03/Apr	3	3	SCI	b	2.52	2.62					2.65	2.86						
1	03/Apr	3	3	SCE	l	70.98	71.49					68.68	67.72						
1	03/Apr	3	3	SCE	a	0.97	1.51					1.22	1.55						
1	03/Apr	3	3	SCE	b	2.91	2.89					3.11	3.3						
1	03/Apr	3	Δ	SCI	l	73.69	75.39	0.00	0.00	0.00	0.00	74.27	71.87	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	Δ	SCI	a	1.06	1.20	0.00	0.00	0.00	0.00	1.12	1.42	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	Δ	SCI	b	2.45	2.35	0.00	0.00	0.00	0.00	2.71	2.90	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	Δ	SCE	l	71.76	72.80	0.00	0.00	0.00	0.00	68.77	67.20	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	Δ	SCE	a	1.14	1.27	0.00	0.00	0.00	0.00	1.27	1.58	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Apr	3	Δ	SCE	b	2.80	2.65	0.00	0.00	0.00	0.00	3.19	3.35	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	1	SCI	l	74.64	78.96					74.08	71.26						
1	04/Apr	4	1	SCI	a	1.31	0.93					1.02	1.03						
1	04/Apr	4	1	SCI	b	2.6	1.97					2.33	2.35						
1	04/Apr	4	1	SCE	l	71	74.68					68.23	64.98						
1	04/Apr	4	1	SCE	a	1.44	0.99					1.13	1.17						
1	04/Apr	4	1	SCE	b	2.94	2.19					2.65	2.79						
1	04/Apr	4	2	SCI	l	73.93	77.15					73.91	73.64						
1	04/Apr	4	2	SCI	a	1.26	1.07					1.46	1.14						
1	04/Apr	4	2	SCI	b	2.63	1.95					2.83	2.71						
1	04/Apr	4	2	SCE	l	71.95	73.14					68.74	67.91						
1	04/Apr	4	2	SCE	a	1.36	1.15					1.6	1.28						
1	04/Apr	4	2	SCE	b	3.05	2.21					3.17	3.2						
1	04/Apr	4	3	SCI	l	75.29	78.76					73.63	71.89						
1	04/Apr	4	3	SCI	a	0.96	1.13					1.57	1.11						
1	04/Apr	4	3	SCI	b	2.41	1.93					2.85	2.65						
1	04/Apr	4	3	SCE	l	71.62	74.3					68	66.43						
1	04/Apr	4	3	SCE	a	1.06	1.22					1.75	1.23						
1	04/Apr	4	3	SCE	b	2.75	2.15					3.26	3.06						
1	04/Apr	4	Δ	SCI	l	74.62	78.29	0.00	0.00	0.00	0.00	73.87	72.26	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	Δ	SCI	a	1.18	1.04	0.00	0.00	0.00	0.00	1.35	1.09	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	Δ	SCI	b	2.55	1.95	0.00	0.00	0.00	0.00	2.67	2.57	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	Δ	SCE	l	71.52	74.04	0.00	0.00	0.00	0.00	68.32	66.44	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	Δ	SCE	a	1.29	1.12	0.00	0.00	0.00	0.00	1.49	1.23	0.00	0.00	0.00	0.00	0.00	0.00
1	04/Apr	4	Δ	SCE	b	2.91	2.18	0.00	0.00	0.00	0.00	3.03	3.02	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	1	SCI	l	76.39	72.66					70.17	72.36						
1	10/Apr	10	1	SCI	a	1.05	1.28					1.26	1.26						
1	10/Apr	10	1	SCI	b	2.25	2.8					3.23	3.18						
1	10/Apr	10	1	SCE	l	73.92	71.17					66.14	66.27						
1	10/Apr	10	1	SCE	a	1.13	1.37					1.39	1.44						
1	10/Apr	10	1	SCE	b	2.65	3.32					3.58	3.72						
1	10/Apr	10	2	SCI	l	77.16	73.99					69.44	72.1						
1	10/Apr	10	2	SCI	a	1.18	1.22					1.34	1.51						
1	10/Apr	10	2	SCI	b	2.25	2.7					3.4	3.11						
1	10/Apr	10	2	SCE	l	73.17	70.78					65.45	66.52						
1	10/Apr	10	2	SCE	a	1.27	1.33					1.38	1.71						
1	10/Apr	10	2	SCE	b	2.6	3.16					3.79	3.6						
1	10/Apr	10	3	SCI	l	77.56	72.62					70.07	71.12						
1	10/Apr	10	3	SCI	a	1.08	1.15					1.38	1.39						
1	10/Apr	10	3	SCI	b	2.13	2.66					3.39	3.26						
1	10/Apr	10	3	SCE	l	74.05	71.61					66.02	65.69						
1	10/Apr	10	3	SCE	a	1.17	1.22					1.52	1.56						
1	10/Apr	10	3	SCE	b	2.47	3.1					3.75	3.7						

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vi al_1	Lissabon_No_Vi al_2	Lissabon_In_Vi al_1	Lissabon_In_Vi al_2
1	10/Apr	10	Δ	SCI	l	77.04	73.09	0.00	0.00	0.00	0.00	69.89	71.86	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	Δ	SCI	a	1.10	1.22	0.00	0.00	0.00	0.00	1.33	1.39	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	Δ	SCI	b	2.21	2.72	0.00	0.00	0.00	0.00	3.34	3.18	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	Δ	SCE	l	73.71	71.19	0.00	0.00	0.00	0.00	65.87	66.16	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	Δ	SCE	a	1.19	1.31	0.00	0.00	0.00	0.00	1.43	1.57	0.00	0.00	0.00	0.00	0.00	0.00
1	10/Apr	10	Δ	SCE	b	2.57	3.19	0.00	0.00	0.00	0.00	3.71	3.67	0.00	0.00	0.00	0.00	0.00	0.00
1	15/Apr	15	1	SCI	l	70.39	77.05	69.07	73.45	79.85	78.26	65.86	70.55	75.84	77.19				
1	15/Apr	15	1	SCI	a	1.12	1.27	1.67	1.55	1.17	1.39	1.72	1.52	1.12	1.04				
1	15/Apr	15	1	SCI	b	2.68	2.32	2.86	2.45	2.1	2.34	3.02	3.31	2.47	2.34				
1	15/Apr	15	1	SCE	l	69.87	73.21	68.72	72.6	75.38	73.09	61.29	65.22	73.41	72.42				
1	15/Apr	15	1	SCE	a	1.19	1.37	1.72	1.61	1.26	1.54	1.92	1.71	1.19	1.13				
1	15/Apr	15	1	SCE	b	2.92	2.58	3.07	2.81	2.35	2.77	3.51	3.77	2.95	2.7				
1	15/Apr	15	2	SCI	l	71.63	77	72.78	75.9	79.34	75.12	73.25	71.01	73.92	77.59				
1	15/Apr	15	2	SCI	a	1.45	1.34	1.67	1.44	1.18	1.08	1.48	1.54	1.41	1.09				
1	15/Apr	15	2	SCI	b	2.83	2.3	2.68	2.37	2	2.42	3.33	3.47	2.59	2.45				
1	15/Apr	15	2	SCE	l	71.3	73.18	71.72	70.7	74.63	73.91	68.33	65.45	72.52	72.52				
1	15/Apr	15	2	SCE	a	1.51	1.44	1.74	1.6	1.31	1.15	1.63	1.73	1.48	1.21				
1	15/Apr	15	2	SCE	b	3.06	2.62	3.13	2.82	2.35	2.88	3.69	3.97	2.94	2.84				
1	15/Apr	15	3	SCI	l	72.67	77	73.69	75.55	80.03	74.51	72.6	70.39	74.66	76.88				
1	15/Apr	15	3	SCI	a	1.22	1.33	1.71	1.41	1.12	1.05	1.38	1.48	1.466	1.43				
1	15/Apr	15	3	SCI	b	2.69	2.36	2.33	2.42	1.99	2.47	3.37	3.41	2.93	2.65				
1	15/Apr	15	3	SCE	l	71.25	73.86	72.88	71.25	75.53	73.89	67.4	66.13	70.09	72.54				
1	15/Apr	15	3	SCE	a	1.31	1.44	1.77	1.55	1.21	1.1	1.52	1.66	1.59	1.57				
1	15/Apr	15	3	SCE	b	3.16	2.65	2.8	2.75	2.27	2.84	3.73	3.9	3.33	3.04				
1	15/Apr	15	Δ	SCI	l	71.56	77.02	71.85	74.97	79.74	75.96	70.57	70.65	74.81	77.22	0.00	0.00	0.00	0.00
1	15/Apr	15	Δ	SCI	a	1.26	1.31	1.68	1.47	1.16	1.17	1.53	1.51	1.33	1.19	0.00	0.00	0.00	0.00
1	15/Apr	15	Δ	SCI	b	2.73	2.33	2.62	2.41	2.03	2.41	3.24	3.40	2.66	2.48	0.00	0.00	0.00	0.00
1	15/Apr	15	Δ	SCE	l	70.81	73.42	71.11	71.52	75.18	73.63	65.67	65.60	72.01	72.49	0.00	0.00	0.00	0.00
1	15/Apr	15	Δ	SCE	a	1.34	1.42	1.74	1.59	1.26	1.26	1.69	1.70	1.42	1.30	0.00	0.00	0.00	0.00
1	15/Apr	15	Δ	SCE	b	3.05	2.62	3.00	2.79	2.32	2.83	3.64	3.88	3.07	2.86	0.00	0.00	0.00	0.00
1	18/Apr	18	1	SCI	l	71.79	77.31					72.99	71.02	74.99	75.91				
1	18/Apr	18	1	SCI	a	1.03	1.11					1.35	1.45	1.77	1.68				
1	18/Apr	18	1	SCI	b	2.75	2.36					3.45	3.54	2.88	2.85				
1	18/Apr	18	1	SCE	l	71.05	73.05					69.07	67.02	70.44	71.62				
1	18/Apr	18	1	SCE	a	1.09	1.2					1.48	1.6	1.92	1.83				
1	18/Apr	18	1	SCE	b	3.11	2.64					3.88	3.98	3.17	3.17				
1	18/Apr	18	2	SCI	l	68.8	77.62					74.57	71.19	75.47	75.83				
1	18/Apr	18	2	SCI	a	1.51	1.2					1.28	1.63	1.72	1.78				
1	18/Apr	18	2	SCI	b	3.2	2.48					3.26	3.61	2.87	2.82				
1	18/Apr	18	2	SCE	l	68.13	74.06					69.67	67.51	70.6	71.33				
1	18/Apr	18	2	SCE	a	1.57	1.31					1.42	1.81	1.87	1.95				
1	18/Apr	18	2	SCE	b	3.42	2.81					3.59	4.11	3.15	3.23				
1	18/Apr	18	3	SCI	l	67.23	77.16					74.38	72.13	76.92	72.91				
1	18/Apr	18	3	SCI	a	1.33	1.1					1.35	1.58	1.59	1.96				
1	18/Apr	18	3	SCI	b	2.93	2.47					3.33	3.55	2.63	3.22				
1	18/Apr	18	3	SCE	l	66.62	73.63					69.5	68.35	72.05	72.47				
1	18/Apr	18	3	SCE	a	1.4	1.19					1.49	1.76	1.72	2.02				
1	18/Apr	18	3	SCE	b	3.18	2.78					3.69	4.06	2.86	3.52				
1	18/Apr	18	Δ	SCI	l	69.27	77.36	0.00	0.00	0.00	0.00	73.98	71.45	75.79	74.88	0.00	0.00	0.00	0.00
1	18/Apr	18	Δ	SCI	a	1.29	1.14	0.00	0.00	0.00	0.00	1.33	1.55	1.69	1.81	0.00	0.00	0.00	0.00
1	18/Apr	18	Δ	SCI	b	2.96	2.44	0.00	0.00	0.00	0.00	3.35	3.57	2.79	2.96	0.00	0.00	0.00	0.00
1	18/Apr	18	Δ	SCE	l	68.60	73.58	0.00	0.00	0.00	0.00	69.41	67.63	71.03	71.81	0.00	0.00	0.00	0.00
1	18/Apr	18	Δ	SCE	a	1.35	1.23	0.00	0.00	0.00	0.00	1.46	1.72	1.84	1.93	0.00	0.00	0.00	0.00
1	18/Apr	18	Δ	SCE	b	3.24	2.74	0.00	0.00	0.00	0.00	3.72	4.05	3.06	3.31	0.00	0.00	0.00	0.00
1	23/Apr	23	1	SCI	l	75.51	77.15					73.61	72.17	73.43	73.94				
1	23/Apr	23	1	SCI	a	1.35	1.43					1.49	1.42	1.94	2.48				
1	23/Apr	23	1	SCI	b	2.86	2.56					3.5	3.45	2.67	3.17				
1	23/Apr	23	1	SCE	l	69.9	74.16					69.67	66.71	72.12	69.12				
1	23/Apr	23	1	SCE	a	1.52	1.53					1.64	1.56	2.01	2.73				
1	23/Apr	23	1	SCE	b	3.31	2.9					3.97	3.86	3.12	3.67				
1	23/Apr	23	2	SCI	l	74.3	72.33					73.27	71.95	73.79	74.66				
1	23/Apr	23	2	SCI	a	1.17	1.38					1.09	1.62	2.25	2.16				
1	23/Apr	23	2	SCI	b	2.88	3.14					3.39	3.74	2.92	2.82				
1	23/Apr	23	2	SCE	l	72.09	71.54					69.17	67.3	70.54	70.36				
1	23/Apr	23	2	SCE	a	1.27	1.44					1.21	1.82	2.4	2.36				
1	23/Apr	23	2	SCE	b	3.37	3.44					3.83	4.25	3.39	3.3				
1	23/Apr	23	3	SCI	l	71.48	73.73					73.64	71.02	73.84	73.04				
1	23/Apr	23	3	SCI	a	0.91	1.38					1.16	1.54	1.88	1.95				
1	23/Apr	23	3	SCI	b	2.84	2.71					3.4	3.4	2.66	2.69				
1	23/Apr	23	3	SCE	l	70.8	72.6					69.71	65.98	72.62	70.06				
1	23/Apr	23	3	SCE	a	0.96	1.45					1.28	1.73	1.95	2.09				
1	23/Apr	23	3	SCE	b	3.16	3.13					3.85	3.86	3.06	3.24				
1	23/Apr	23	Δ	SCI	l	73.76	74.40	0.00	0.00	0.00	0.00	73.51	71.71	73.69	73.88	0.00	0.00	0.00	0.00
1	23/Apr	23	Δ	SCI	a	1.14	1.40	0.00	0.00	0.00	0.00	1.25	1.53	2.02	2.20	0.00	0.00	0.00	0.00
1	23/Apr	23	Δ	SCI	b	2.86	2.80	0.00	0.00	0.00	0.00	3.43	3.53	2.75	2.89	0.00	0.00	0.00	0.00
1	23/Apr	23	Δ	SCE	l	70.93	72.77	0.00	0.00	0.00	0.00	69.52	66.66	71.76	69.85	0.00	0.00	0.00	0.00
1	23/Apr	23	Δ	SCE	a	1.25	1.47	0.00	0.00	0.00	0.00	1.38	1.70	2.12	2.39	0.00	0.00	0.00	0.00
1	23/Apr	23	Δ	SCE	b	3.28	3.16	0.00	0.00	0.00	0.00	3.88	3.99	3.19	3.40	0.00	0.00	0.00	0.00
1	28/Apr	28	1	SCI	l			71.67	77.58	78.21	76.93			73.15	76.37				
1	28/Apr	28	1	SCI	a			1.5	1.25	1.32	1.47			2.24	2.24				
1	28/Apr	28	1	SCI	b			2.79	2.29	2.93	2.54			2.6	2.51				
1	28/Apr	28	1	SCE	l			71.2	72.33	75.07	71.92			71.83	71.55				
1	28/Apr	28	1	SCE	a			1.56	1.4	1.41	1.64			2.32	2.44				
1	28/Apr	28	1	SCE	b			3.09	2.75	2.93	3.03			3.03	2.89				
1	28/Apr	28	2	SCI	l			76.85	77.28	78.32	74.67			72.16	75.01				
1	28/Apr	28	2	SCI	a			1.28	1.32	1.2	1.16			2.26	2.28				
1	28/Apr	28	2	SCI	b			2.61	2.22	2.26	2.74			2.54	2.59				
1	28/Apr	28	2	SCE	l			72.77	72.45	74.33	69.71			71.55	70.45				
1	28/Apr	28	2	SCE	a			1.41	1.48	1.3	1.31			2.32	2.48				
1	28/Apr	28	2	SCE	b			3.08	2.61	2.58	3.17			2.87	3.02				
1	28/Apr	28	3	SCI	l			75.97	77.51	77.52	78			73.41	75.78				
1	28/Apr	28	3	SCI	a			1.47	1.39	1.25	1.31			2.43	2.26				
1	28/Apr	28	3	SCI	b			2.64	2.4	2.3	2.45			2.65	2.5				
1	28/Apr	28	3	SCE	l			72.94	72.4	74.27	72.75			71.4	70.95				
1	28/Apr	28	3	SCE	a			1.6	1.56	1.34	1.46			2.53	2.46				
1	28/Apr	28	3	SCE	b			3.08	2.86	2.71	2.88			3.09	2.86				
1	28/Apr	28	Δ	SCI	l	0.00	0.00	74.83	77.46	78.02	76.53	0.00	0.00	72.91	75.72	0.00	0.00	0.00	0.00
1	28/Apr	28	Δ	SCI	a	0.00	0.00	1.42	1.32	1.26	1.31	0.00	0.00	2.31	2.26	0.00	0.00	0.00	0.00
1	28/Apr	28	Δ	SCI	b	0.00	0.00	2.68	2.30	2.50	2.58	0.00	0.00	2.60	2.53	0.00	0.00	0.00	0.00
1	28/Apr	28	Δ	SCE	l	0.00	0.00	72.30	72.39	74.56	71.46	0.00	0.00	71.59	70.98	0.00	0.00	0.00	0.00
1	28/Apr	28	Δ	SCE	a	0.00	0.00	1.52	1.48	1.35	1.47	0.00	0.00	2.39	2.46	0.00	0.00	0.00	0.00
1	28/Apr	28	Δ	SCE	b	0.00	0.00	3.08	2.74	2.74	3.03	0.00	0.00	3.00	2.92	0.00	0.00	0.00	0.00
1	01/May	31	1	SCI	l	75.85	75.26					72.17	71.45	72.37	72.9				
1	01/May	31	1	SCI	a	1.17	1.22					1.59	1.59	2.49	2.43				
1	01/May	31	1	SCI	b	2.96	2.84					3.81	3.8	2.63	2.59				
1	01/May	31	1	SCE	l	70.87	73.05					66.58	66.24	69.93	71.14				
1	01/May	31	1	SCE	a	1.3	1.3					1.76	1.74	2.61	2.55				
1	01/May	31	1	SCE	b	3.3	3.16					4.27	4.27	3.12	3.02				
1	01/May	31	2	SCI	l	74.86	77.87					70.6	70.05	72.62	73.47				
1	01/May	31	2	SCI	a	1.15	1.11					1.43	1.57	2.64	2.47				
1	01/May	31	2	SCI	b	2.89	2.39					3.51	3.92	2.77	2.7				
1	01/May	31	2	SCE	l	70.7	73.56					69.19	65.81	70.05	70.35				
1	01/May	31	2	SCE	a	1.28	1.2					1.51	1.71	2.78	2.65				
1	01/May	31	2	SCE	b	3.3	2.71					3.95	4.4	3.24	3.09				
1	01/May	31	3	SCI	l	75.05	77.73					71.63	71.01	74.31	73.46				
1	01/May	31	3	SCI	a	1.15	1.2					1.39	1.51	2.73	2.43				

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
1	01/May	31	3	SCI	b	2.88	2.57					3.56	3.43	2.44	2.78				
1	01/May	31	3	SCE	l	71.02	73.52					69.5	65.65	69.8	70.68				
1	01/May	31	3	SCE	a	1.27	1.3					1.49	1.65	2.95	2.59				
1	01/May	31	3	SCE	b	3.29	2.9					4.04	3.83	2.87	3.21				
1	01/May	31	Δ	SCI	l	75.25	76.95	0.00	0.00	0.00	0.00	71.47	70.84	73.10	73.28	0.00	0.00	0.00	0.00
1	01/May	31	Δ	SCI	a	1.16	1.18	0.00	0.00	0.00	0.00	1.47	1.56	2.62	2.44	0.00	0.00	0.00	0.00
1	01/May	31	Δ	SCI	b	2.91	2.60	0.00	0.00	0.00	0.00	3.63	3.72	2.61	2.69	0.00	0.00	0.00	0.00
1	01/May	31	Δ	SCE	l	70.86	73.38	0.00	0.00	0.00	0.00	68.42	65.90	69.93	70.72	0.00	0.00	0.00	0.00
1	01/May	31	Δ	SCE	a	1.28	1.27	0.00	0.00	0.00	0.00	1.59	1.70	2.78	2.60	0.00	0.00	0.00	0.00
1	01/May	31	Δ	SCE	b	3.30	2.92	0.00	0.00	0.00	0.00	4.09	4.17	3.08	3.11	0.00	0.00	0.00	0.00
1	07/May	37	1	SCI	l	75.38	76.63					70.93	72.31	70.86	74.49				
1	07/May	37	1	SCI	a	0.98	1.12					1.53	1.65	3.29	2.95				
1	07/May	37	1	SCI	b	2.93	2.73					3.48	3.82	2.51	2.54				
1	07/May	37	1	SCE	l	72.19	72.51					69.38	67.29	67.05	70.32				
1	07/May	37	1	SCE	a	1.06	1.22					1.62	1.83	3.46	3.17				
1	07/May	37	1	SCE	b	3.22	3.1					4.06	4.25	3.05	2.86				
1	07/May	37	2	SCI	l	73.99	75.79					73.55	71.51	72.09	72.42				
1	07/May	37	2	SCI	a	1.22	1.32					1.38	1.75	3.34	2.96				
1	07/May	37	2	SCI	b	3.06	2.95					3.67	3.77	2.29	2.72				
1	07/May	37	2	SCE	l	72.15	71.93					68.85	65.92	69.15	70.3				
1	07/May	37	2	SCE	a	1.31	1.45					1.51	1.93	3.48	3.12				
1	07/May	37	2	SCE	b	3.53	3.33					4.1	4.24	2.78	3.09				
1	07/May	37	3	SCI	l	73.97	76.73					72.83	72.91	69.95	74.17				
1	07/May	37	3	SCI	a	1.07	1.28					1.48	1.79	3	2.99				
1	07/May	37	3	SCI	b	3.07	2.77					3.78	3.93	2.17	2.59				
1	07/May	37	3	SCE	l	69.78	72.77					67.57	68.17	69.52	70.23				
1	07/May	37	3	SCE	a	1.15	1.41					1.64	1.99	3.06	3.22				
1	07/May	37	3	SCE	b	3.37	3.13					4.22	4.4	2.47	2.95				
1	07/May	37	Δ	SCI	l	74.45	76.38	0.00	0.00	0.00	0.00	72.44	72.24	70.97	73.69	0.00	0.00	0.00	0.00
1	07/May	37	Δ	SCI	a	1.09	1.24	0.00	0.00	0.00	0.00	1.46	1.73	3.21	2.97	0.00	0.00	0.00	0.00
1	07/May	37	Δ	SCI	b	3.02	2.82	0.00	0.00	0.00	0.00	3.64	3.84	2.32	2.62	0.00	0.00	0.00	0.00
1	07/May	37	Δ	SCE	l	71.37	72.40	0.00	0.00	0.00	0.00	68.60	67.13	68.57	70.28	0.00	0.00	0.00	0.00
1	07/May	37	Δ	SCE	a	1.17	1.36	0.00	0.00	0.00	0.00	1.59	1.92	3.33	3.17	0.00	0.00	0.00	0.00
1	07/May	37	Δ	SCE	b	3.37	3.19	0.00	0.00	0.00	0.00	4.13	4.30	2.77	2.97	0.00	0.00	0.00	0.00
1	08/May	38	1	SCI	l			76.94	74.62	71	76.23								
1	08/May	38	1	SCI	a			1.34	1.55	1.77	1.7								
1	08/May	38	1	SCI	b			2.69	2.64	2.59	2.63								
1	08/May	38	1	SCE	l			72.27	69.63	70.83	71.25								
1	08/May	38	1	SCE	a			1.48	1.73	1.82	1.88								
1	08/May	38	1	SCE	b			3.16	3.14	2.78	3.16								
1	08/May	38	2	SCI	l			75.3	74.63	70.62	76.26								
1	08/May	38	2	SCI	a			1.46	1.61	1.52	1.68								
1	08/May	38	2	SCI	b			2.69	2.74	2.59	2.58								
1	08/May	38	2	SCE	l			73.56	69.73	70.43	71.113								
1	08/May	38	2	SCE	a			1.55	1.79	1.57	1.87								
1	08/May	38	2	SCE	b			3.21	3.28	2.78	3.14								
1	08/May	38	3	SCI	l			75.91	74.95	71.65	76.03								
1	08/May	38	3	SCI	a			1.42	1.68	1.5	1.59								
1	08/May	38	3	SCI	b			2.57	2.75	2.57	2.63								
1	08/May	38	3	SCE	l			72.97	71.83	71.4	70.91								
1	08/May	38	3	SCE	a			1.54	1.82	1.55	1.76								
1	08/May	38	3	SCE	b			3.09	3.22	2.86	3.14								
1	08/May	38	Δ	SCI	l	0.00	0.00	76.05	74.73	71.09	76.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	08/May	38	Δ	SCI	a	0.00	0.00	1.41	1.61	1.60	1.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	08/May	38	Δ	SCI	b	0.00	0.00	2.65	2.71	2.58	2.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	08/May	38	Δ	SCE	l	0.00	0.00	72.93	70.40	70.89	71.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	08/May	38	Δ	SCE	a	0.00	0.00	1.52	1.78	1.65	1.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	08/May	38	Δ	SCE	b	0.00	0.00	3.15	3.21	2.81	3.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	14/May	44	1	SCI	l	69.79	72.28					72.32	67.02	70.94	72.52				
1	14/May	44	1	SCI	a	1	1.26					1.43	0.08	3.08	3				
1	14/May	44	1	SCI	b	3.06	3.03					3.9	2.94	1.79	1.86				
1	14/May	44	1	SCE	l	71.02	73.15					69.08	61.65	71.14	68.74				
1	14/May	44	1	SCE	a	0.82	1.1					1.31	-0.23	2.79	2.92				
1	14/May	44	1	SCE	b	4.26	4.16					4.81	3.95	3.07	2.9				
1	14/May	44	2	SCI	l	70.49	77.51					70.18	71.91	70.49	71.3				
1	14/May	44	2	SCI	a	0.96	1					1.5	1.28	3.05	3.1				
1	14/May	44	2	SCI	b	3.04	2.71					3.94	3.61	1.68	2.06				
1	14/May	44	2	SCE	l	71.73	74.41					66.07	68.43	70.45	69.7				
1	14/May	44	2	SCE	a	0.79	0.94					1.4	1.19	2.75	2.93				
1	14/May	44	2	SCE	b	4.18	3.54					5.04	4.54	2.94	3.19				
1	14/May	44	3	SCI	l	72.19	72.79					72.3	69.54	71.05	70.79				
1	14/May	44	3	SCI	a	0.94	0.87					1.58	1.44	3.11	3.35				
1	14/May	44	3	SCI	b	3.06	2.89					3.95	3.94	1.77	2.12				
1	14/May	44	3	SCE	l	72.65	73.11					68.96	65.85	80.48	68.39				
1	14/May	44	3	SCE	a	0.82	0.75					1.47	1.32	2.84	3.24				
1	14/May	44	3	SCE	b	4.29	3.96					4.88	4.94	3.01	3.24				
1	14/May	44	Δ	SCI	l	70.82	74.19	0.00	0.00	0.00	0.00	71.60	69.49	70.83	71.54	0.00	0.00	0.00	0.00
1	14/May	44	Δ	SCI	a	0.97	1.04	0.00	0.00	0.00	0.00	1.50	0.93	3.08	3.15	0.00	0.00	0.00	0.00
1	14/May	44	Δ	SCI	b	3.05	2.88	0.00	0.00	0.00	0.00	3.93	3.50	1.75	2.01	0.00	0.00	0.00	0.00
1	14/May	44	Δ	SCE	l	71.80	73.56	0.00	0.00	0.00	0.00	68.04	65.31	74.02	68.94	0.00	0.00	0.00	0.00
1	14/May	44	Δ	SCE	a	0.81	0.93	0.00	0.00	0.00	0.00	1.39	0.76	2.79	3.03	0.00	0.00	0.00	0.00
1	14/May	44	Δ	SCE	b	4.24	3.89	0.00	0.00	0.00	0.00	4.91	4.48	3.01	3.11	0.00	0.00	0.00	0.00
1	16/May	46	1	SCI	l	74.93	76.57					72.46	71.4	67.65	72.6				
1	16/May	46	1	SCI	a	1.38	0.93					1.54	1.4	3.21	3.46				
1	16/May	46	1	SCI	b	3.23	2.94					3.89	3.69	1.81	1.88				
1	16/May	46	1	SCE	l	69.98	72.48					68.13	65.91	67.2	67.3				
1	16/May	46	1	SCE	a	1.54	1.02					1.69	1.54	3.27	3.78				
1	16/May	46	1	SCE	b	3.58	3.33					4.28	4.07	2.04	2.31				
1	16/May	46	2	SCI	l	75.03	77.12					71.4	71.22	69.73	72.6				
1	16/May	46	2	SCI	a	1.16	1.14					1.72	1.53	3.25	3.46				
1	16/May	46	2	SCI	b	3.17	3.08					4.07	4.04	1.81	1.88				
1	16/May	46	2	SCE	l	69.6	72.96					67.71	65.51	69.25	67.34				
1	16/May	46	2	SCE	a	1.32	1.25					1.88	1.7	3.32	3.77				
1	16/May	46	2	SCE	b	3.63	3.52					4.52	4.56	2.09	2.24				
1	16/May	46	3	SCI	l	74.91	75.29					71.52	71.43	68.54	73.43				
1	16/May	46	3	SCI	a	1.37	1.33					1.48	1.74	3.34	3.44				
1	16/May	46	3	SCI	b	3.41	3.18					3.99	4.15	1.96	1.81				
1	16/May	46	3	SCE	l	70.99	71.65					68.02	65.8	68.16	68.22				
1	16/May	46	3	SCE	a	1.5	1.46					1.63	1.93	3.37	3.73				
1	16/May	46	3	SCE	b	3.85	3.65					4.47	4.68	2.23	2.17				
1	16/May	46	Δ	SCI	l	74.96	76.33	0.00	0.00	0.00	0.00	71.79	71.35	68.64	72.88	0.00	0.00	0.00	0.00
1	16/May	46	Δ	SCI	a	1.30	1.13	0.00	0.00	0.00	0.00	1.58	1.56	3.27	3.45	0.00	0.00	0.00	0.00
1	16/May	46	Δ	SCI	b	3.27	3.07	0.00	0.00	0.00	0.00	3.98	3.96	1.86	1.86	0.00	0.00	0.00	0.00
1	16/May	46	Δ	SCE	l	70.19	72.36	0.00	0.00	0.00	0.00	67.95	65.74	68.20	67.62	0.00	0.00	0.00	0.00
1	16/May	46	Δ	SCE	a	1.45	1.24	0.00	0.00	0.00	0.00	1.73	1.72	3.32	3.76	0.00	0.00	0.00	0.00
1	16/May	46	Δ	SCE	b	3.69	3.50	0.00	0.00	0.00	0.00	4.42	4.44	2.12	2.24	0.00	0.00	0.00	0.00
1	19/May	49	1	SCI	l	70.31	75.42					70.23	67.77	67.89	71.44				
1	19/May	49	1	SCI	a	1.23	1.15					1.44	1.72	3.7	3.61				
1	19/May	49	1	SCI	b	2.63	1.98					3.29	3.53	1.31	1.25				
1	19/May	49	1	SCE	l	67.82	71.21					66.27	61.13	66.46	67.12				
1	19/May	49	1	SCE	a	1.33	1.23					1.59	1.95	3.78	3.91				
1	19/May	49	1	SCE	b	3.26	2.27					3.68	4.1	1.79	1.62				
1	19/May	49	2	SCI	l	67.1	76.13					69.7	71.29	71.93	70.85				
1	19/May	49	2	SCI	a	1.14	0.97					1.59	1.67	3.4	3.63				
1	19/May	49	2	SCI	b	2.57	1.99					3.35	3.17	0.87	1.39				
1	19/May	49	2	SCE	l	66.43	72.78					65.78	65.64	68.89	67.78				

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
1	19/May	49	2	SCE	a	1.2	1.05					1.75	1.84	3.53	3.87				
1	19/May	49	2	SCE	b	2.84	2.33					3.8	3.55	1.22	1.76				
1	19/May	49	3	SCI	l	69.74	73.41					70.74	71.49	71.04	70.77				
1	19/May	49	3	SCI	a	1	0.87					1.58	1.63	3.39	3.6				
1	19/May	49	3	SCI	b	2.37	1.91					3.13	3.01	1.02	1.21				
1	19/May	49	3	SCE	l	69.08	72.65					67	65.8	67.88	66.68				
1	19/May	49	3	SCE	a	1.06	0.94					1.74	1.8	3.51	3.89				
1	19/May	49	3	SCE	b	2.71	2.29					3.52	3.35	1.44	1.55				
1	19/May	49	Δ	SCI	l	69.05	74.99	0.00	0.00	0.00	0.00	70.22	70.18	70.29	71.02	0.00	0.00	0.00	0.00
1	19/May	49	Δ	SCI	a	1.12	1.00	0.00	0.00	0.00	0.00	1.54	1.67	3.50	3.61	0.00	0.00	0.00	0.00
1	19/May	49	Δ	SCI	b	2.52	1.96	0.00	0.00	0.00	0.00	3.26	3.24	1.07	1.28	0.00	0.00	0.00	0.00
1	19/May	49	Δ	SCE	l	67.78	72.21	0.00	0.00	0.00	0.00	66.35	64.19	67.74	67.19	0.00	0.00	0.00	0.00
1	19/May	49	Δ	SCE	a	1.20	1.07	0.00	0.00	0.00	0.00	1.69	1.86	3.61	3.89	0.00	0.00	0.00	0.00
1	19/May	49	Δ	SCE	b	2.94	2.30	0.00	0.00	0.00	0.00	3.67	3.67	1.48	1.64	0.00	0.00	0.00	0.00
1	21/May	51	1	SCI	l	74.93	74.92					70.69	69.87	70.29	72.64				
1	21/May	51	1	SCI	a	1.17	1.06					1.44	1.63	3.46	3.73				
1	21/May	51	1	SCI	b	2.5	2.19					3.16	3.3	0.75	0.93				
1	21/May	51	1	SCE	l	70.31	72.53					66.69	65.86	68.32	68.2				
1	21/May	51	1	SCE	a	1.27	1.15					1.57	1.8	3.52	4.02				
1	21/May	51	1	SCE	b	2.84	2.54					3.57	3.75	1.18	1.22				
1	21/May	51	2	SCI	l	74.97	77.93					72.3	70.55	71.09	72.41				
1	21/May	51	2	SCI	a	1.19	1.16					1.45	1.42	3.76	3.71				
1	21/May	51	2	SCI	b	2.37	2.1					3.17	3.19	0.99	0.95				
1	21/May	51	2	SCE	l	70.56	74.17					66.81	66.63	66.1	68.33				
1	21/May	51	2	SCE	a	1.3	1.24					1.6	1.57	4.03	3.97				
1	21/May	51	2	SCE	b	2.67	2.36					3.49	3.62	1.33	1.27				
1	21/May	51	3	SCI	l	73.16	77.3					73.56	70.6	71.29	72.16				
1	21/May	51	3	SCI	a	1.21	0.78					1.47	1.46	3.61	3.84				
1	21/May	51	3	SCI	b	2.4	1.87					3.12	3.21	0.85	1.06				
1	21/May	51	3	SCE	l	71.54	73.52					68.96	66.61	67.94	67.79				
1	21/May	51	3	SCE	a	1.3	0.83					1.6	1.6	3.77	4.13				
1	21/May	51	3	SCE	b	2.86	2.15					3.41	3.65	1.25	1.39				
1	21/May	51	Δ	SCI	l	74.35	76.72	0.00	0.00	0.00	0.00	72.18	70.34	70.89	72.40	0.00	0.00	0.00	0.00
1	21/May	51	Δ	SCI	a	1.19	1.00	0.00	0.00	0.00	0.00	1.45	1.50	3.61	3.76	0.00	0.00	0.00	0.00
1	21/May	51	Δ	SCI	b	2.42	2.05	0.00	0.00	0.00	0.00	3.15	3.23	0.86	0.98	0.00	0.00	0.00	0.00
1	21/May	51	Δ	SCE	l	70.80	73.41	0.00	0.00	0.00	0.00	67.49	66.37	67.45	68.11	0.00	0.00	0.00	0.00
1	21/May	51	Δ	SCE	a	1.29	1.07	0.00	0.00	0.00	0.00	1.59	1.66	3.77	4.04	0.00	0.00	0.00	0.00
1	21/May	51	Δ	SCE	b	2.79	2.35	0.00	0.00	0.00	0.00	3.49	3.67	1.25	1.29	0.00	0.00	0.00	0.00
1	27/May	57	1	SCI	l	73	75.37					72.05	71.3	68.65	73.38				
1	27/May	57	1	SCI	a	1.3	1.01					1.26	1.6	3.31	3.77				
1	27/May	57	1	SCI	b	2.56	2.3					3.44	3.28	0.7	0.74				
1	27/May	57	1	SCE	l	72.34	73.54					66.59	65.35	68.21	72.94				
1	27/May	57	1	SCE	a	1.37	1.09					1.35	1.81	3.35	3.8				
1	27/May	57	1	SCE	b	2.95	2.69					3.64	3.75	0.9	0.69				
1	27/May	57	2	SCI	l	73.48	75.36					73.54	65.26	71.18	72.94				
1	27/May	57	2	SCI	a	1.29	0.97					1.66	1.68	3.6	3.8				
1	27/May	57	2	SCI	b	2.6	2.22					3.37	2.78	0.7	0.69				
1	27/May	57	2	SCE	l	71.3	74.41					68.45	62.15	69.44	67.86				
1	27/May	57	2	SCE	a	1.38	1.04					1.79	1.83	3.68	4.11				
1	27/May	57	2	SCE	b	3.07	2.58					3.55	3.3	1.17	0.88				
1	27/May	57	3	SCI	l	73.77	72.78					74.41	71.38	71.28	72.62				
1	27/May	57	3	SCI	a	1.36	0.76					1.56	1.59	3.65	3.66				
1	27/May	57	3	SCI	b	2.63	2.2					3.23	3.25	0.78	0.71				
1	27/May	57	3	SCE	l	72.34	72.27					69.22	65.27	69.51	67.3				
1	27/May	57	3	SCE	a	1.44	0.81					1.69	1.78	3.74	3.95				
1	27/May	57	3	SCE	b	3.11	2.42					3.47	3.72	1.23	0.88				
1	27/May	57	Δ	SCI	l	73.42	74.50	0.00	0.00	0.00	0.00	73.33	69.31	70.37	72.98	0.00	0.00	0.00	0.00
1	27/May	57	Δ	SCI	a	1.32	0.91	0.00	0.00	0.00	0.00	1.49	1.62	3.52	3.74	0.00	0.00	0.00	0.00
1	27/May	57	Δ	SCI	b	2.60	2.24	0.00	0.00	0.00	0.00	3.35	3.10	0.73	0.71	0.00	0.00	0.00	0.00
1	27/May	57	Δ	SCE	l	71.99	73.41	0.00	0.00	0.00	0.00	68.09	64.26	69.05	69.37	0.00	0.00	0.00	0.00
1	27/May	57	Δ	SCE	a	1.40	0.98	0.00	0.00	0.00	0.00	1.61	1.81	3.59	3.95	0.00	0.00	0.00	0.00
1	27/May	57	Δ	SCE	b	3.04	2.56	0.00	0.00	0.00	0.00	3.55	3.59	1.10	0.82	0.00	0.00	0.00	0.00
1	30/May	60	1	SCI	l	73.48	76.8					71.04	70.4	70.33	69.04				
1	30/May	60	1	SCI	a	0.94	1.2					1.57	1.57	3.78	3.71				
1	30/May	60	1	SCI	b	2.52	2.42					3.55	3.57	0.86	0.91				
1	30/May	60	1	SCE	l	71.6	73.2					67.16	65.58	67.5	68.43				
1	30/May	60	1	SCE	a	1.01	1.29					1.69	1.71	3.87	3.76				
1	30/May	60	1	SCE	b	3.01	2.7					3.92	3.88	1.29	1.18				
1	30/May	60	2	SCI	l	75.02	77.27					66.93	73.17	69.46	69.17				
1	30/May	60	2	SCI	a	0.96	1.2					1.31	1.74	3.53	3.6				
1	30/May	60	2	SCI	b	2.53	2.41					3.53	3.37	0.74	0.86				
1	30/May	60	2	SCE	l	72.13	73.81					65.93	67.94	69.19	68.57				
1	30/May	60	2	SCE	a	1.04	1.29					1.36	1.92	3.55	3.66				
1	30/May	60	2	SCE	b	2.9	2.71					3.88	3.73	0.91	1.12				
1	30/May	60	3	SCI	l	74.75	76.68					70.95	72.12	72.87	71.47				
1	30/May	60	3	SCI	a	1.19	1.38					1.57	1.67	3.89	3.72				
1	30/May	60	3	SCI	b	2.78	2.44					3.56	3.43	0.59	0.79				
1	30/May	60	3	SCE	l	71.55	73					67.69	67.33	67.43	69.02				
1	30/May	60	3	SCE	a	1.29	1.46					1.69	1.84	4.19	3.9				
1	30/May	60	3	SCE	b	3.21	2.71					4.01	3.8	0.77	1.05				
1	30/May	60	Δ	SCI	l	74.42	76.92	0.00	0.00	0.00	0.00	69.64	71.90	70.89	69.89	0.00	0.00	0.00	0.00
1	30/May	60	Δ	SCI	a	1.03	1.26	0.00	0.00	0.00	0.00	1.48	1.66	3.73	3.68	0.00	0.00	0.00	0.00
1	30/May	60	Δ	SCI	b	2.61	2.42	0.00	0.00	0.00	0.00	3.55	3.46	0.73	0.85	0.00	0.00	0.00	0.00
1	30/May	60	Δ	SCE	l	71.76	73.34	0.00	0.00	0.00	0.00	66.93	66.95	68.04	68.67	0.00	0.00	0.00	0.00
1	30/May	60	Δ	SCE	a	1.11	1.35	0.00	0.00	0.00	0.00	1.58	1.82	3.87	3.77	0.00	0.00	0.00	0.00
1	30/May	60	Δ	SCE	b	3.04	2.71	0.00	0.00	0.00	0.00	3.94	3.80	0.99	1.12	0.00	0.00	0.00	0.00
1	03/Jun	64	1	SCI	l			75.65	76.97	70.34	75.3								
1	03/Jun	64	1	SCI	a			1.68	1.6	2.09	1.69								
1	03/Jun	64	1	SCI	b			2.23	2.04	1.96	2.04								
1	03/Jun	64	1	SCE	l			72.84	72.13	70.17	72.76								
1	03/Jun	64	1	SCE	a			1.8	1.77	2.13	1.79								
1	03/Jun	64	1	SCE	b			2.65	2.38	2.15	2.57								
1	03/Jun	64	2	SCI	l			75.05	77.18	74.62	77.25								
1	03/Jun	64	2	SCI	a			1.78	1.6	1.9	1.76								
1	03/Jun	64	2	SCI	b			2.21	2.04	1.59	1.81								
1	03/Jun	64	2	SCE	l			71.16	72.33	73.83	72.25								
1	03/Jun	64	2	SCE	a			1.93	1.77	1.96	1.93								
1	03/Jun	64	2	SCE	b			2.59	2.37	2.04	2.19								
1	03/Jun	64	3	SCI	l			77.25	77.1	76.86	77.25								
1	03/Jun	64	3	SCI	a			1.48	1.33	1.82	1.82								
1	03/Jun	64	3	SCI	b			2.07	1.87	1.7	1.83								
1	03/Jun	64	3	SCE	l			72.83	72.1	74.57	72.29								
1	03/Jun	64	3	SCE	a			1.63	1.47	1.92	1.99								
1	03/Jun	64	3	SCE	b			2.43	2.2	2.21	2.21								
1	03/Jun	64	Δ	SCI	l	0.00	0.00	75.98	77.08	73.94	76.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Jun	64	Δ	SCI	a	0.00	0.00	1.65	1.51	1.94	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Jun	64	Δ	SCI	b	0.00	0.00	2.17	1.98	1.75	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Jun	64	Δ	SCE	l	0.00	0.00	72.28	72.19	72.86	72.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Jun	64	Δ	SCE	a	0.00	0.00	1.79	1.67	2.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	03/Jun	64	Δ	SCE	b	0.00	0.00	2.56	2.32	2.13	2.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
2	Ref. Index	1.49			1.48														
2	Thickness				mm	2.1	1.5	2.2	1.6	1.5	1.6	1.6	1.7	2.1	2.1	1.6	1.7	2.2	1.6
2	01/Apr	1	1	SCI	l	70.77	65.56	74.11	84.58	83.6	78.16	84.2	82.24			74.03	85.69		
2	01/Apr	1	1	SCI	a	0.91	0.29	3.76	0.19	-0.17	0.8	0.35	-0.11			1.38	0.25		
2	01/Apr	1	1	SCI	b	1.92	2.64	2.24	0.23	0.49	1.52	0.12	0.52			1.37	0.01		
2	01/Apr	1	1	SCE	l	69.66	64.74	75.59	83.83	80.02	75.28	84.48	80.27			74.26	82.74		
2	01/Apr	1	1	SCE	a	0.97	0.33	3.71	0.25	-0.17	0.85	0.4	-0.06			1.42	0.35		
2	01/Apr	1	1	SCE	b	2.31	2.88	2.52	0.58	0.57	1.8	0.34	0.72			1.55	0.21		
2	01/Apr	1	2	SCI	l	75.38	76.79	76.6	81.2	82.38	80.69	83.47	84.26			82.59	85.49		
2	01/Apr	1	2	SCI	a	0.84	-0.41	2.06	0.57	-0.2	0.26	0.35	0.31			0.66	0.24		
2	01/Apr	1	2	SCI	b	1.3	0.54	1.38	0.77	0.86	0.55	0.28	0.51			0.41	0.08		
2	01/Apr	1	2	SCE	l	72.92	76.53	76.83	80.92	79.48	80.8	83.6	82.78			82.69	81.66		
2	01/Apr	1	2	SCE	a	0.84	-0.37	2.09	0.62	-0.2	0.31	0.39	0.37			0.71	0.38		
2	01/Apr	1	2	SCE	b	1.57	0.75	1.78	1.12	0.9	0.78	0.52	0.74			0.62	0.16		
2	01/Apr	1	3	SCI	l	71.7	83.52	71.86	78.56	83.18	78.99	87.05	84.29			80.73	83.62		
2	01/Apr	1	3	SCI	a	0.96	-0.22	3.41	0.79	0.18	-0.82	-0.03	0.3			0.82	0.61		
2	01/Apr	1	3	SCI	b	1.64	0.36	2.28	0.98	0.6	0.98	-0.07	0.46			0.73	0.29		
2	01/Apr	1	3	SCE	l	69.08	81.4	73.13	78.8	79.5	76.52	83.37	81.24			80.75	83.49		
2	01/Apr	1	3	SCE	a	0.98	-0.16	3.38	0.84	0.19	-0.8	0.06	0.37			0.86	0.65		
2	01/Apr	1	3	SCE	b	1.95	0.47	2.55	1.23	0.71	1.28	0.09	0.55			0.96	0.54		
2	01/Apr	1	Δ	SCI	l	72.62	75.29	74.19	81.45	83.05	79.28	84.91	83.60	0.00	0.00	79.12	84.93	0.00	0.00
2	01/Apr	1	Δ	SCI	a	0.90	-0.11	3.08	0.52	-0.06	0.08	0.22	0.17	0.00	0.00	0.95	0.37	0.00	0.00
2	01/Apr	1	Δ	SCI	b	1.62	1.18	1.97	0.66	0.65	1.02	0.11	0.50	0.00	0.00	0.84	0.13	0.00	0.00
2	01/Apr	1	Δ	SCE	l	70.55	74.22	75.18	81.18	79.67	77.53	83.82	81.43	0.00	0.00	79.23	82.63	0.00	0.00
2	01/Apr	1	Δ	SCE	a	0.93	-0.07	3.06	0.57	-0.06	0.12	0.28	0.23	0.00	0.00	1.00	0.46	0.00	0.00
2	01/Apr	1	Δ	SCE	b	1.94	1.37	2.28	0.98	0.73	1.29	0.32	0.67	0.00	0.00	1.04	0.30	0.00	0.00
2	02/Apr	2	1	SCI	l	75.92	82.58							70.61	74.93			65.26	85.83
2	02/Apr	2	1	SCI	a	0.1	0.92							2.11	0.92			0.67	-0.08
2	02/Apr	2	1	SCI	b	1.27	0.84							2.73	2.07			2.8	0.11
2	02/Apr	2	1	SCE	l	73.9	82.95							70.96	72.443			64.82	82.33
2	02/Apr	2	1	SCE	a	0.08	0.96							2.14	1			0.7	0.07
2	02/Apr	2	1	SCE	b	1.52	1.03							2.88	2.23			2.98	0.19
2	02/Apr	2	2	SCI	l	77.47	83.27							69.22	76.33			71.24	84.54
2	02/Apr	2	2	SCI	a	0.11	-0.66							1.08	0.45			0.47	0.24
2	02/Apr	2	2	SCI	b	0.82	0.15							3.07	1.16			1.73	0.45
2	02/Apr	2	2	SCE	l	76.02	82.72							69	75.75			70.73	81.63
2	02/Apr	2	2	SCE	a	0.1	-0.62							1.13	0.51			0.51	0.3
2	02/Apr	2	2	SCE	b	1.09	0.42							3.26	1.39			1.96	0.6
2	02/Apr	2	3	SCI	l	76.04	86.35							66.55	79.21			71.47	80.17
2	02/Apr	2	3	SCI	a	0.23	-0.31							0.54	0.19			0.32	-0.24
2	02/Apr	2	3	SCI	b	1.64	0.26							3.21	0.69			1.49	1.06
2	02/Apr	2	3	SCE	l	73.6	84.42							66.06	78.67			69.64	78.1
2	02/Apr	2	3	SCE	a	0.19	-0.28							0.59	0.24			0.35	-0.23
2	02/Apr	2	3	SCE	b	1.89	0.46							3.39	0.89			1.81	1.24
2	02/Apr	2	Δ	SCI	l	76.48	84.07	0.00	0.00	0.00	0.00	0.00	0.00	68.79	76.82	0.00	0.00	69.32	83.51
2	02/Apr	2	Δ	SCI	a	0.15	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.52	0.00	0.00	0.49	-0.03
2	02/Apr	2	Δ	SCI	b	1.24	0.42	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.31	0.00	0.00	2.01	0.54
2	02/Apr	2	Δ	SCE	l	74.51	83.36	0.00	0.00	0.00	0.00	0.00	0.00	68.67	75.62	0.00	0.00	68.40	80.69
2	02/Apr	2	Δ	SCE	a	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.29	0.58	0.00	0.00	0.52	0.05
2	02/Apr	2	Δ	SCE	b	1.50	0.64	0.00	0.00	0.00	0.00	0.00	0.00	3.18	1.50	0.00	0.00	2.25	0.68
2	03/Apr	3	1	SCI	l	76.87	86					85.84	85.83						
2	03/Apr	3	1	SCI	a	0.5	0.03					0.1	-0.1						
2	03/Apr	3	1	SCI	b	1.17	0.24					0.29	0.39						
2	03/Apr	3	1	SCE	l	75.17	82.89					82.01	81.93						
2	03/Apr	3	1	SCE	a	0.51	0.06					0.2	-0.02						
2	03/Apr	3	1	SCE	b	1.46	0.26					0.52	0.65						
2	03/Apr	3	2	SCI	l	76.39	85.29					85.49	84.14						
2	03/Apr	3	2	SCI	a	0.3	0.33					-0.02	-0.13						
2	03/Apr	3	2	SCI	b	1.26	0.52					0.28	0.49						
2	03/Apr	3	2	SCE	l	74.97	82.29					81.63	80.73						
2	03/Apr	3	2	SCE	a	0.31	0.38					0.07	-0.06						
2	03/Apr	3	2	SCE	b	1.56	0.58					0.47	0.76						
2	03/Apr	3	3	SCI	l	75.27	84.8					85.04	84.53						
2	03/Apr	3	3	SCI	a	0.15	0.09					0.03	-0.22						
2	03/Apr	3	3	SCI	b	1.5	0.44					0.3	0.47						
2	03/Apr	3	3	SCE	l	73.53	81.59					81.06	81.66						
2	03/Apr	3	3	SCE	a	0.16	0.12					0.15	-0.16						
2	03/Apr	3	3	SCE	b	1.8	0.51					0.51	0.8						
2	03/Apr	3	Δ	SCI	l	76.18	85.36	0.00	0.00	0.00	0.00	85.46	84.83	0.00	0.00	0.00	0.00	0.00	0.00
2	03/Apr	3	Δ	SCI	a	0.32	0.15	0.00	0.00	0.00	0.00	0.04	-0.15	0.00	0.00	0.00	0.00	0.00	0.00
2	03/Apr	3	Δ	SCI	b	1.31	0.40	0.00	0.00	0.00	0.00	0.29	0.45	0.00	0.00	0.00	0.00	0.00	0.00
2	03/Apr	3	Δ	SCE	l	74.56	82.26	0.00	0.00	0.00	0.00	81.57	81.44	0.00	0.00	0.00	0.00	0.00	0.00
2	03/Apr	3	Δ	SCE	a	0.33	0.19	0.00	0.00	0.00	0.00	0.14	-0.08	0.00	0.00	0.00	0.00	0.00	0.00
2	03/Apr	3	Δ	SCE	b	1.61	0.45	0.00	0.00	0.00	0.00	0.50	0.74	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	1	SCI	l	75.04	81.15					84.9	83.88						
2	04/Apr	4	1	SCI	a	0.51	0.68					0.32	-0.1						
2	04/Apr	4	1	SCI	b	1.91	0.98					0.55	0.52						
2	04/Apr	4	1	SCE	l	72.63	77.79					81.06	82.18						
2	04/Apr	4	1	SCE	a	0.49	0.79					0.44	-0.04						
2	04/Apr	4	1	SCE	b	2.2	1.04					0.77	0.88						
2	04/Apr	4	2	SCI	l	75.38	83.07					83.37	83.69						
2	04/Apr	4	2	SCI	a	0.52	0.59					0.48	0.06						
2	04/Apr	4	2	SCI	b	1.55	0.76					0.62	0.64						
2	04/Apr	4	2	SCE	l	73.17	81.38					80.15	81.37						
2	04/Apr	4	2	SCE	a	0.53	0.69					0.6	0.12						
2	04/Apr	4	2	SCE	b	1.81	0.97					0.88	1.04						
2	04/Apr	4	3	SCI	l	76.86	86.05					84.85	82.87						
2	04/Apr	4	3	SCI	a	0.22	-0.32					0.11	-0.17						
2	04/Apr	4	3	SCI	b	1.58	0.16					0.38	0.79						
2	04/Apr	4	3	SCE	l	74.58	85.37					81.5	80.48						
2	04/Apr	4	3	SCE	a	0.18	-0.27					0.22	-0.11						
2	04/Apr	4	3	SCE	b	1.82	0.43					0.64	1.18						
2	04/Apr	4	Δ	SCI	l	75.76	83.42	0.00	0.00	0.00	0.00	84.37	83.48	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	Δ	SCI	a	0.42	0.32	0.00	0.00	0.00	0.00	0.30	-0.07	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	Δ	SCI	b	1.68	0.63	0.00	0.00	0.00	0.00	0.52	0.65	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	Δ	SCE	l	73.46	81.51	0.00	0.00	0.00	0.00	80.90	81.34	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	Δ	SCE	a	0.40	0.40	0.00	0.00	0.00	0.00	0.42	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
2	04/Apr	4	Δ	SCE	b	1.94	0.81	0.00	0.00	0.00	0.00	0.76	1.03	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	1	SCI	l	73.78	80.21					85.73	83.43						
2	10/Apr	10	1	SCI	a	0.13	1.01					-0.08	0.16						
2	10/Apr	10	1	SCI	b	2.04	1.08					0.42	0.91						
2	10/Apr	10	1	SCE	l	71.2	79.44					82.49	80.94						
2	10/Apr	10	1	SCE	a	0.05	1.07					0	0.24						
2	10/Apr	10	1	SCE	b	2.29	1.39					0.72	1.33						
2	10/Apr	10	2	SCI	l	79.29	82.81					84.17	84.15						
2	10/Apr	10	2	SCI	a	0.48	0.65					0.29	0.14						
2	10/Apr	10	2	SCI	b	1.08	0.9					0.68	0.61						
2	10/Apr	10	2	SCE	l	77.89	79.93					80.19	80.42						
2	10/Apr	10	2	SCE	a	0.49	0.75					0.42	0.23						
2	10/Apr	10	2	SCE	b	1.35	1.08					0.96	0.86						
2	10/Apr	10	3	SCI	l	78.9	82.34					82.03	84.5						
2	10/Apr	10	3	SCI	a	0.37	0.11					0.11	-0.15						
2	10/Apr	10	3	SCI	b	1.13	0.74					0.82	0.65						
2	10/Apr	10	3	SCE	l	77.18	81					81	81.92						
2	10/Apr	10	3	SCE	a	0.35	0.17					0.16	-0.08						
2	10/Apr	10	3	SCE	b	1.37	0.96					1.13	1.03						

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
2	10/Apr	10	Δ	SCI	l	77.32	81.79	0.00	0.00	0.00	0.00	83.98	84.03	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	Δ	SCI	a	0.33	0.59	0.00	0.00	0.00	0.00	0.11	0.05	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	Δ	SCI	b	1.42	0.91	0.00	0.00	0.00	0.00	0.64	0.72	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	Δ	SCE	l	75.42	80.12	0.00	0.00	0.00	0.00	81.23	81.09	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	Δ	SCE	a	0.30	0.66	0.00	0.00	0.00	0.00	0.19	0.13	0.00	0.00	0.00	0.00	0.00	0.00
2	10/Apr	10	Δ	SCE	b	1.67	1.14	0.00	0.00	0.00	0.00	0.94	1.07	0.00	0.00	0.00	0.00	0.00	0.00
2	15/Apr	15	1	SCI	l	75.82	85.15	67.68	80.59	83.55	79.91	84.77	84.26	62.75	78.17				
2	15/Apr	15	1	SCI	a	0.73	-0.13	1.3	-0.61	0.21	-1.13	0.63	0.01	0.86	1.2				
2	15/Apr	15	1	SCI	b	1.72	0.51	2.33	0.46	0.63	0.17	0.59	0.77	4.17	1.32				
2	15/Apr	15	1	SCE	l	73.46	83.62	64.33	79.93	79.82	79.36	84.14	80.77	62.12	76.52				
2	15/Apr	15	1	SCE	a	0.72	-0.1	1.32	-0.59	0.23	-1.11	0.7	0.11	0.9	1.29				
2	15/Apr	15	1	SCE	b	2.03	0.65	2.9	0.74	0.84	0.41	0.88	1.02	4.36	1.57				
2	15/Apr	15	2	SCI	l	77.21	75.31	70.48	84.76	84.53	79.77	84.86	85.25	65.58	77.13				
2	15/Apr	15	2	SCI	a	0.56	3.13	0.9	-0.31	0.14	0.52	0.21	0	1.23	2.17				
2	15/Apr	15	2	SCI	b	1.3	2.27	1.7	0.32	0.53	0.66	0.79	0.73	4.02	2.12				
2	15/Apr	15	2	SCE	l	76.37	76.43	67.33	81.53	81.1	79.91	81.32	81.41	65.2	75.27				
2	15/Apr	15	2	SCE	a	0.58	3.1	0.86	-0.29	0.15	0.55	0.32	0.09	1.28	2.31				
2	15/Apr	15	2	SCE	b	1.61	2.36	2.13	0.63	0.74	0.9	1.08	1	4.21	2.33				
2	15/Apr	15	3	SCI	l	81.36	78.61	71.24	83.6	85.54	80.59	85.15	84.28	62.86	77.61				
2	15/Apr	15	3	SCI	a	0.69	1.47	0.62	-0.4	0.39	0.08	0.03	0.01	1.29	1.65				
2	15/Apr	15	3	SCI	b	1.1	1.31	1.53	0.25	0.35	0.33	0.61	0.84	4.26	1.6				
2	15/Apr	15	3	SCE	l	79.5	78.99	69.58	82.39	82.14	80.09	81.63	80.53	62.41	75.83				
2	15/Apr	15	3	SCE	a	0.7	1.5	0.61	-0.38	0.42	0.12	0.13	0.1	1.33	1.76				
2	15/Apr	15	3	SCE	b	1.31	1.54	1.84	0.54	0.52	0.7	0.86	1.11	4.43	1.86				
2	15/Apr	15	Δ	SCI	l	78.13	79.69	69.80	82.98	84.54	80.09	84.93	84.60	63.73	77.64	0.00	0.00	0.00	0.00
2	15/Apr	15	Δ	SCI	a	0.66	1.49	0.94	-0.44	0.25	-0.18	0.29	0.01	1.13	1.67	0.00	0.00	0.00	0.00
2	15/Apr	15	Δ	SCI	b	1.37	1.36	1.85	0.34	0.50	0.39	0.66	0.78	4.15	1.68	0.00	0.00	0.00	0.00
2	15/Apr	15	Δ	SCE	l	76.44	79.68	67.08	81.28	81.02	79.79	82.36	80.90	63.24	75.87	0.00	0.00	0.00	0.00
2	15/Apr	15	Δ	SCE	a	0.67	1.50	0.93	-0.42	0.27	-0.15	0.38	0.10	1.17	1.79	0.00	0.00	0.00	0.00
2	15/Apr	15	Δ	SCE	b	1.65	1.52	2.29	0.64	0.70	0.67	0.94	1.04	4.33	1.92	0.00	0.00	0.00	0.00
2	18/Apr	18	1	SCI	l	73.08	73.53					84.92	82.98	62.54	76.05				
2	18/Apr	18	1	SCI	a	0.05	1.74					0.32	-0.1	1.96	0.66				
2	18/Apr	18	1	SCI	b	2.06	1.7					0.78	1.01	4.15	1.58				
2	18/Apr	18	1	SCE	l	71.04	73.96					81.19	79.27	62.22	74.4				
2	18/Apr	18	1	SCE	a	0.03	1.77					0.45	-0.03	2.01	0.72				
2	18/Apr	18	1	SCE	b	2.32	1.84					1.11	1.22	4.34	1.78				
2	18/Apr	18	2	SCI	l	77.79	80.92					86.31	83.88	61.05	78.33				
2	18/Apr	18	2	SCI	a	0.63	0.57					-0.05	-0.05	1.53	0.74				
2	18/Apr	18	2	SCI	b	1.9	1.01					0.63	0.9	4.26	1.24				
2	18/Apr	18	2	SCE	l	75.55	79.61					83.6	80.36	60.46	76.52				
2	18/Apr	18	2	SCE	a	0.61	0.66					0.03	0.03	1.47	0.81				
2	18/Apr	18	2	SCE	b	2.16	1.3					0.87	1.11	4.44	1.4				
2	18/Apr	18	3	SCI	l	77.93	84.63					87.56	83.19	62.28	77.71				
2	18/Apr	18	3	SCI	a	0.62	0.33					0.14	0.1	1.49	0.35				
2	18/Apr	18	3	SCI	b	1.82	0.75					0.47	0.85	4.15	1.21				
2	18/Apr	18	3	SCE	l	75.79	82.31					84.39	79.52	61.68	76.41				
2	18/Apr	18	3	SCE	a	0.6	0.42					0.23	0.18	1.54	0.4				
2	18/Apr	18	3	SCE	b	2.09	1.04					0.72	1.06	4.33	1.39				
2	18/Apr	18	Δ	SCI	l	76.27	79.69	0.00	0.00	0.00	0.00	86.26	83.35	61.96	77.36	0.00	0.00	0.00	0.00
2	18/Apr	18	Δ	SCI	a	0.43	0.88	0.00	0.00	0.00	0.00	0.14	-0.02	1.66	0.58	0.00	0.00	0.00	0.00
2	18/Apr	18	Δ	SCI	b	1.93	1.15	0.00	0.00	0.00	0.00	0.63	0.92	4.19	1.34	0.00	0.00	0.00	0.00
2	18/Apr	18	Δ	SCE	l	74.13	78.63	0.00	0.00	0.00	0.00	83.06	79.72	61.45	75.78	0.00	0.00	0.00	0.00
2	18/Apr	18	Δ	SCE	a	0.41	0.95	0.00	0.00	0.00	0.00	0.24	0.06	1.67	0.64	0.00	0.00	0.00	0.00
2	18/Apr	18	Δ	SCE	b	2.19	1.39	0.00	0.00	0.00	0.00	0.90	1.13	4.37	1.52	0.00	0.00	0.00	0.00
2	23/Apr	23	1	SCI	l	77.24	86.26					82.83	84.62	62.5	74.92				
2	23/Apr	23	1	SCI	a	0.63	0.22					-0.4	-0.13	2.25	0.99				
2	23/Apr	23	1	SCI	b	2.28	0.72					1.05	0.96	4.23	1.44				
2	23/Apr	23	1	SCE	l	74.81	83.33					81.51	81.27	62.27	73.34				
2	23/Apr	23	1	SCE	a	0.61	0.31					0.03	-0.05	2.3	1.07				
2	23/Apr	23	1	SCE	b	2.54	0.83					1.31	1.31	4.42	1.68				
2	23/Apr	23	2	SCI	l	77.89	85.58					84.75	84.5	65.34	75				
2	23/Apr	23	2	SCI	a	0.7	-0.17					-0.53	-0.13	2.1	0.86				
2	23/Apr	23	2	SCI	b	1.85	0.54					0.53	1.03	3.9	1.66				
2	23/Apr	23	2	SCE	l	75.98	84.42					84.11	80.85	65.16	73.02				
2	23/Apr	23	2	SCE	a	0.7	-0.12					-0.47	-0.05	2.15	0.95				
2	23/Apr	23	2	SCE	b	2.12	0.75					0.87	1.33	4.11	1.9				
2	23/Apr	23	3	SCI	l	79.06	82.31					85.07	83.24	66.22	74.13				
2	23/Apr	23	3	SCI	a	0.51	-0.61					-0.44	-0.04	2	0.8				
2	23/Apr	23	3	SCI	b	1.79	0.66					0.65	1.13	3.78	1.75				
2	23/Apr	23	3	SCE	l	76.98	82.13					84.25	79.5	66.06	72.93				
2	23/Apr	23	3	SCE	a	0.49	-0.57					-0.38	0.05	2.05	0.86				
2	23/Apr	23	3	SCE	b	2.05	0.87					0.95	1.4	3.97	2				
2	23/Apr	23	Δ	SCI	l	78.06	84.72	0.00	0.00	0.00	0.00	84.22	84.12	64.69	74.68	0.00	0.00	0.00	0.00
2	23/Apr	23	Δ	SCI	a	0.61	-0.19	0.00	0.00	0.00	0.00	-0.46	-0.10	2.12	0.88	0.00	0.00	0.00	0.00
2	23/Apr	23	Δ	SCI	b	1.97	0.64	0.00	0.00	0.00	0.00	0.74	1.04	3.97	1.62	0.00	0.00	0.00	0.00
2	23/Apr	23	Δ	SCE	l	75.92	83.29	0.00	0.00	0.00	0.00	83.29	80.54	64.50	73.10	0.00	0.00	0.00	0.00
2	23/Apr	23	Δ	SCE	a	0.60	-0.13	0.00	0.00	0.00	0.00	-0.27	-0.02	2.17	0.96	0.00	0.00	0.00	0.00
2	23/Apr	23	Δ	SCE	b	2.24	0.82	0.00	0.00	0.00	0.00	1.04	1.35	4.17	1.86	0.00	0.00	0.00	0.00
2	28/Apr	28	1	SCI	l			76.03	84.3	85.37	83.5			62.18	77.46				
2	28/Apr	28	1	SCI	a			0.5	-0.22	0.35	0.61			1.31	1.17				
2	28/Apr	28	1	SCI	b			1.2	0.62	0.59	0.66			3.86	1.2				
2	28/Apr	28	1	SCE	l			74.7	84.28	82.29	83.72			61.52	76.25				
2	28/Apr	28	1	SCE	a			0.53	-0.17	0.39	0.65			1.35	1.25				
2	28/Apr	28	1	SCE	b			1.65	0.88	0.8	0.93			4.03	1.44				
2	28/Apr	28	2	SCI	l			75.75	84	86.36	81.84			63.32	75.71				
2	28/Apr	28	2	SCI	a			0.71	-0.19	0.12	0.45			1.67	1.23				
2	28/Apr	28	2	SCI	b			1.42	0.61	0.35	0.91			3.82	1.39				
2	28/Apr	28	2	SCE	l			73	84.04	82.73	82.07			62.97	75.05				
2	28/Apr	28	2	SCE	a			0.71	-0.15	0.15	0.5			1.72	1.29				
2	28/Apr	28	2	SCE	b			1.9	0.85	0.54	1.13			3.97	1.65				
2	28/Apr	28	3	SCI	l			76.27	82.74	85.44	80.43			66.2	77.26				
2	28/Apr	28	3	SCI	a			0.68	-0.41	0.49	1.14			1.35	1.1				
2	28/Apr	28	3	SCI	b			1.4	0.54	0.64	1.15			3.43	1.09				
2	28/Apr	28	3	SCE	l			73.68	82.62	82.08	80.8			65.85	76.22				
2	28/Apr	28	3	SCE	a			0.69	-0.36	0.56	1.17			1.4	1.18				
2	28/Apr	28	3	SCE	b			1.87	0.78	0.84	1.36			3.61	1.32				
2	28/Apr	28	Δ	SCI	l	0.00	0.00	76.02	83.68	85.72	81.92	0.00	0.00	63.90	76.81	0.00	0.00	0.00	0.00
2	28/Apr	28	Δ	SCI	a	0.00	0.00	0.63	-0.27	0.32	0.73	0.00	0.00	1.44	1.17	0.00	0.00	0.00	0.00
2	28/Apr	28	Δ	SCI	b	0.00	0.00	1.34	0.59	0.53	0.91	0.00	0.00	3.70	1.23	0.00	0.00	0.00	0.00
2	28/Apr	28	Δ	SCE	l	0.00	0.00	73.79	83.65	82.37	82.20	0.00	0.00	63.45	75.84	0.00	0.00	0.00	0.00
2	28/Apr	28	Δ	SCE	a	0.00	0.00	0.64	-0.23	0.37	0.77	0.00	0.00	1.49	1.24	0.00	0.00	0.00	0.00
2	28/Apr	28	Δ	SCE	b	0.00	0.00	1.81	0.84	0.73	1.14	0.00	0.00	3.87	1.47	0.00	0.00	0.00	0.00
2	01/May	31	1	SCI	l	77.75	86.03					84.65	84.73	63.39	78.16				
2	01/May	31	1	SCI	a	0.72	0.47					-0.46	-0.09	1.38	0.14				
2	01/May	31	1	SCI	b	2.17	0.75					0.64	1.23	3.88	0.64				
2	01/May	31	1	SCE	l	75.47	84.35					84.65	82.38	62.94	75.48				
2	01/May	31	1	SCE	a	0.7	0.56					-0.42	-0.06	1.42	0.19				
2	01/May	31	1	SCE	b	2.46	1.05					0.86	1.54	4.06	0.82				
2	01/May	31	2	SCI	l	78.3	83.04					85.6	84.7	60.39	77.95				
2	01/May	31	2	SCI	a	0.47	-0.77					-0.35	0	1.54	0.36				
2	01/May	31	2	SCI	b	1.69	0.75					0.67	1.03	4.15	0.96				
2	01/May	31	2	SCE	l	76.56	81.85					84.53	81.64	59.75	75.38				
2	01/May	31	2	SCE	a	0.48	-0.73					-0.29	0.05	1.58	0.42				
2	01/May	31	2	SCE	b	2.01	0.99					0.97	1.28	4.32	1.16				
2	01/May	31	3	SCI	l	79.45	85.79					84.06	84.35	62.85	77.4				
2	01/May	31	3	SCI	a	0.2	-0.62					-0.65	-0.15	1.66	0.44				

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
2	01/May	31	3	SCI	b	1.29	0.53					0.5	1.12	3.9	0.95				
2	01/May	31	3	SCE	l	77.25	85.1					84.06	80.72	62.43	75.03				
2	01/May	31	3	SCE	a	0.17	-0.58					-0.61	-0.11	1.72	0.49				
2	01/May	31	3	SCE	b	1.62	0.76					0.69	1.33	4.07	1.08				
2	01/May	31	Δ	SCI	l	78.50	84.95	0.00	0.00	0.00	0.00	84.77	84.59	62.21	77.84	0.00	0.00	0.00	0.00
2	01/May	31	Δ	SCI	a	0.46	-0.31	0.00	0.00	0.00	0.00	-0.49	-0.08	1.53	0.31	0.00	0.00	0.00	0.00
2	01/May	31	Δ	SCI	b	1.72	0.68	0.00	0.00	0.00	0.00	0.60	1.13	3.98	0.85	0.00	0.00	0.00	0.00
2	01/May	31	Δ	SCE	l	76.43	83.77	0.00	0.00	0.00	0.00	84.41	81.58	61.71	75.30	0.00	0.00	0.00	0.00
2	01/May	31	Δ	SCE	a	0.45	-0.25	0.00	0.00	0.00	0.00	-0.44	-0.04	1.57	0.37	0.00	0.00	0.00	0.00
2	01/May	31	Δ	SCE	b	2.03	0.93	0.00	0.00	0.00	0.00	0.84	1.38	4.15	1.02	0.00	0.00	0.00	0.00
2	07/May	37	1	SCI	l	78.62	82.88					85.98	84.57	60.89	76.1				
2	07/May	37	1	SCI	a	1.08	0.12					-0.25	0.18	1.77	1.24				
2	07/May	37	1	SCI	b	1.95	1					1.03	1.21	3.88	1.49				
2	07/May	37	1	SCE	l	76.54	82.71					82.27	81.91	60.41	74.61				
2	07/May	37	1	SCE	a	1.09	0.19					-0.19	0.24	1.81	1.32				
2	07/May	37	1	SCE	b	2.34	1.13					1.22	1.53	4.06	1.72				
2	07/May	37	2	SCI	l	78.74	84.8					84.44	84.87	65.05	75.59				
2	07/May	37	2	SCI	a	0.43	-0.29					0.07	-0.42	1.64	1.1				
2	07/May	37	2	SCI	b	1.5	0.83					1.27	0.76	3.13	1.49				
2	07/May	37	2	SCE	l	76.57	84.19					80.82	84.44	64.71	73.92				
2	07/May	37	2	SCE	a	0.41	-0.24					0.15	-0.38	1.68	1.19				
2	07/May	37	2	SCE	b	1.82	1.15					1.47	1.13	3.3	1.73				
2	07/May	37	3	SCI	l	77.99	80.31					85.14	85.13	68.52	75.34				
2	07/May	37	3	SCI	a	0.8	0.01					-0.19	0.14	2.18	1.4				
2	07/May	37	3	SCI	b	2.38	1.33					1.26	1.36	3.08	1.55				
2	07/May	37	3	SCE	l	75.89	78.11					81.18	81.58	68.52	74.86				
2	07/May	37	3	SCE	a	0.82	0.06					-0.12	0.22	2.22	1.46				
2	07/May	37	3	SCE	b	2.63	1.59					1.48	1.63	3.26	1.8				
2	07/May	37	Δ	SCI	l	78.45	82.66	0.00	0.00	0.00	0.00	85.19	84.86	64.82	75.68	0.00	0.00	0.00	0.00
2	07/May	37	Δ	SCI	a	0.77	-0.05	0.00	0.00	0.00	0.00	-0.12	-0.03	1.86	1.25	0.00	0.00	0.00	0.00
2	07/May	37	Δ	SCI	b	1.94	1.05	0.00	0.00	0.00	0.00	1.19	1.11	3.36	1.51	0.00	0.00	0.00	0.00
2	07/May	37	Δ	SCE	l	76.33	81.67	0.00	0.00	0.00	0.00	81.42	82.64	64.55	74.46	0.00	0.00	0.00	0.00
2	07/May	37	Δ	SCE	a	0.77	0.00	0.00	0.00	0.00	0.00	-0.05	0.03	1.90	1.32	0.00	0.00	0.00	0.00
2	07/May	37	Δ	SCE	b	2.26	1.29	0.00	0.00	0.00	0.00	1.39	1.43	3.54	1.75	0.00	0.00	0.00	0.00
2	08/May	38	1	SCI	l			75.63	83.27	80.8	80.1								
2	08/May	38	1	SCI	a			0.92	0.28	0.64	0.56								
2	08/May	38	1	SCI	b			1.59	0.66	1.42	1.19								
2	08/May	38	1	SCE	l			75.16	82.1	78.02	80.32								
2	08/May	38	1	SCE	a			0.96	0.34	0.69	0.6								
2	08/May	38	1	SCE	b			1.87	1.01	1.71	1.39								
2	08/May	38	2	SCI	l			78.68	83.87	81.19	73.88								
2	08/May	38	2	SCI	a			0.78	0.39	0.42	0.25								
2	08/May	38	2	SCI	b			1.28	0.73	1.31	1.7								
2	08/May	38	2	SCE	l			76.52	82.75	78.47	73.77								
2	08/May	38	2	SCE	a			0.8	0.44	0.46	0.29								
2	08/May	38	2	SCE	b			1.67	1.09	1.49	1.88								
2	08/May	38	3	SCI	l			77.39	84.87	82.92	73.56								
2	08/May	38	3	SCI	a			0.85	0.61	0.41	-0.14								
2	08/May	38	3	SCI	b			1.37	0.57	0.87	1.56								
2	08/May	38	3	SCE	l			75.9	84.04	80.18	73.37								
2	08/May	38	3	SCE	a			0.87	0.65	0.45	-0.1								
2	08/May	38	3	SCE	b			1.72	0.92	1.08	1.73								
2	08/May	38	Δ	SCI	l	0.00	0.00	77.23	84.00	81.64	75.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	08/May	38	Δ	SCI	a	0.00	0.00	0.85	0.43	0.49	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	08/May	38	Δ	SCI	b	0.00	0.00	1.41	0.65	1.20	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	08/May	38	Δ	SCE	l	0.00	0.00	75.86	82.96	78.89	75.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	08/May	38	Δ	SCE	a	0.00	0.00	0.88	0.48	0.53	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	08/May	38	Δ	SCE	b	0.00	0.00	1.75	1.01	1.43	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	14/May	44	1	SCI	l	77.16	86.98					85.93	80.86	64.42	76.2				
2	14/May	44	1	SCI	a	0.61	-0.05					-0.29	0.16	0.68	-0.04				
2	14/May	44	1	SCI	b	2.11	0.98					1.05	1.48	3.2	0.81				
2	14/May	44	1	SCE	l	76.32	85.06					82.83	81.93	66.29	75.55				
2	14/May	44	1	SCE	a	0.45	-0.08					-0.26	0.1	0.43	-0.15				
2	14/May	44	1	SCE	b	2.97	1.45					1.62	2.41	4.41	1.75				
2	14/May	44	2	SCI	l	79.38	85.08					84.68	85.12	66.23	77.05				
2	14/May	44	2	SCI	a	0.58	-0.13					-0.34	-0.12	0.94	-0.75				
2	14/May	44	2	SCI	b	1.75	1.05					1.14	1.41	3.08	0.66				
2	14/May	44	2	SCE	l	79.08	84					84.65	81.88	68.1	75.57				
2	14/May	44	2	SCE	a	0.47	-0.12					-0.35	-0.07	0.7	-0.88				
2	14/May	44	2	SCE	b	2.53	1.66					1.87	2.03	4.24	1.47				
2	14/May	44	3	SCI	l	77.59	83.42					79.91	84.56	67.7	76.31				
2	14/May	44	3	SCI	a	0.74	-0.65					-0.52	-0.16	1.9	0.2				
2	14/May	44	3	SCI	b	1.84	0.83					1.43	1.16	3.16	1.06				
2	14/May	44	3	SCE	l	76.69	81.92					80.93	84.13	69.76	76.41				
2	14/May	44	3	SCE	a	0.6	-0.67					-0.58	-0.17	1.64	0.11				
2	14/May	44	3	SCE	b	2.74	1.46					2.32	2.07	4.27	1.94				
2	14/May	44	Δ	SCI	l	78.04	85.16	0.00	0.00	0.00	0.00	83.51	83.51	66.12	76.52	0.00	0.00	0.00	0.00
2	14/May	44	Δ	SCI	a	0.64	-0.28	0.00	0.00	0.00	0.00	-0.38	-0.04	1.17	-0.20	0.00	0.00	0.00	0.00
2	14/May	44	Δ	SCI	b	1.90	0.95	0.00	0.00	0.00	0.00	1.21	1.35	3.15	0.84	0.00	0.00	0.00	0.00
2	14/May	44	Δ	SCE	l	77.36	83.66	0.00	0.00	0.00	0.00	82.80	82.65	68.05	75.84	0.00	0.00	0.00	0.00
2	14/May	44	Δ	SCE	a	0.51	-0.29	0.00	0.00	0.00	0.00	-0.40	-0.05	0.92	-0.31	0.00	0.00	0.00	0.00
2	14/May	44	Δ	SCE	b	2.75	1.52	0.00	0.00	0.00	0.00	1.94	2.17	4.31	1.72	0.00	0.00	0.00	0.00
2	16/May	46	1	SCI	l	74.9	84.8					85.96	85.22	70.46	76.79				
2	16/May	46	1	SCI	a	1.1	0.6					0.22	-0.21	0.26	1.4				
2	16/May	46	1	SCI	b	2.66	0.99					1.2	1.44	2.38	1.15				
2	16/May	46	1	SCE	l	72.92	84.92					84.61	81.86	70	76.81				
2	16/May	46	1	SCE	a	1.12	0.65					0.29	-0.13	0.31	1.45				
2	16/May	46	1	SCE	b	3.03	1.27					1.5	1.8	2.53	1.38				
2	16/May	46	2	SCI	l	76.55	85.72					85.95	83.21	68.51	76.52				
2	16/May	46	2	SCI	a	0.92	0.32					-0.25	-0.22	0.45	1.24				
2	16/May	46	2	SCI	b	2.37	1.05					1	1.92	2.55	1.1				
2	16/May	46	2	SCE	l	74.3	83.2					82.34	80.73	68.03	76.19				
2	16/May	46	2	SCE	a	0.94	0.41					-0.16	-0.15	0.48	1.3				
2	16/May	46	2	SCE	b	2.76	1.27					1.32	2.37	2.72	1.33				
2	16/May	46	3	SCI	l	77.08	85					84.28	83.28	69.26	78.44				
2	16/May	46	3	SCI	a	1.14	0.41					-0.04	-0.35	0.36	1.6				
2	16/May	46	3	SCI	b	2.52	1.03					1.4	1.74	2.37	1.05				
2	16/May	46	3	SCE	l	74.71	84.15					81.12	82.05	68.79	77.4				
2	16/May	46	3	SCE	a	1.16	0.48					0.06	-0.29	0.39	1.68				
2	16/May	46	3	SCE	b	2.89	1.29					1.78	2.12	2.55	1.24				
2	16/May	46	Δ	SCI	l	76.18	85.17	0.00	0.00	0.00	0.00	85.40	83.90	69.41	77.25	0.00	0.00	0.00	0.00
2	16/May	46	Δ	SCI	a	1.05	0.44	0.00	0.00	0.00	0.00	-0.02	-0.26	0.36	1.41	0.00	0.00	0.00	0.00
2	16/May	46	Δ	SCI	b	2.52	1.02	0.00	0.00	0.00	0.00	1.20	1.70	2.43	1.10	0.00	0.00	0.00	0.00
2	16/May	46	Δ	SCE	l	73.98	84.09	0.00	0.00	0.00	0.00	82.69	81.55	68.94	76.80	0.00	0.00	0.00	0.00
2	16/May	46	Δ	SCE	a	1.07	0.51	0.00	0.00	0.00	0.00	0.06	-0.19	0.39	1.48	0.00	0.00	0.00	0.00
2	16/May	46	Δ	SCE	b	2.89	1.28	0.00	0.00	0.00	0.00	1.53	2.10	2.60	1.32	0.00	0.00	0.00	0.00
2	19/May	49	1	SCI	l	76	83.62					82.65	82.94	59.94	76.2				
2	19/May	49	1	SCI	a	0.41	-0.21					0.15	-0.15	1.05	0.14				
2	19/May	49	1	SCI	b	1.09	0.09					0.61	0.79	2.65	0.11				
2	19/May	49	1	SCE	l	73.75	81.83					78.66	80.85	59.3	73.33				
2	19/May	49	1	SCE	a	0.39	-0.16					0.26	-0.1	1.1	0.19				
2	19/May	49	1	SCE	b	1.39	0.23					0.8	1.17	2.83	0.26				
2	19/May	49	2	SCI	l	79.96	77.72					85.31	83.68	62.54	76.03				
2	19/May	49	2	SCI	a	0.21	0.65					0.24	-0.2	0.44	0.4				
2	19/May	49	2	SCI	b	0.77	1.19					0.29	0.62	2.19	0.59				
2	19/May	49	2	SCE	l	77.9	74.03					81.76	80.24	61.86	73.1				

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
2	19/May	49	2	SCE	a	0.19	0.78					0.35	-0.15	0.46	0.46				
2	19/May	49	2	SCE	b	0.98	1.36					0.46	0.86	2.35	0.76				
2	19/May	49	3	SCI	l	75.69	80.52					83.96	82.21	61.78	75.7				
2	19/May	49	3	SCI	a	1.14	-0.01					0.18	-0.32	0.59	0.44				
2	19/May	49	3	SCI	b	1.45	0.44					0.51	0.71	2.22	0.67				
2	19/May	49	3	SCE	l	73.14	80.34					80.09	80.7	61.16	72.75				
2	19/May	49	3	SCE	a	1.16	0.03					0.3	-0.26	0.61	0.52				
2	19/May	49	3	SCE	b	1.8	0.71					0.73	1.08	2.37	0.85				
2	19/May	49	Δ	SCI	l	77.22	80.62	0.00	0.00	0.00	0.00	83.97	82.94	61.42	75.98	0.00	0.00	0.00	0.00
2	19/May	49	Δ	SCI	a	0.59	0.14	0.00	0.00	0.00	0.00	0.19	-0.22	0.69	0.33	0.00	0.00	0.00	0.00
2	19/May	49	Δ	SCI	b	1.10	0.57	0.00	0.00	0.00	0.00	0.47	0.71	2.35	0.46	0.00	0.00	0.00	0.00
2	19/May	49	Δ	SCE	l	74.93	78.73	0.00	0.00	0.00	0.00	80.17	80.60	60.77	73.06	0.00	0.00	0.00	0.00
2	19/May	49	Δ	SCE	a	0.58	0.22	0.00	0.00	0.00	0.00	0.30	-0.17	0.72	0.39	0.00	0.00	0.00	0.00
2	19/May	49	Δ	SCE	b	1.39	0.77	0.00	0.00	0.00	0.00	0.66	1.04	2.52	0.62	0.00	0.00	0.00	0.00
2	21/May	51	1	SCI	l	77.45	82.72					84.3	84.8	62.59	77.41				
2	21/May	51	1	SCI	a	0.29	0.55					0.24	-0.44	0.9	1.21				
2	21/May	51	1	SCI	b	1.5	0.57					0.46	0.4	2.42	0.2				
2	21/May	51	1	SCE	l	74.88	81.25					82.3	81.43	62.05	76.07				
2	21/May	51	1	SCE	a	0.25	0.62					0.31	-0.4	0.93	1.29				
2	21/May	51	1	SCE	b	1.8	0.78					0.68	0.7	2.6	0.41				
2	21/May	51	2	SCI	l	75.51	82.6					85.26	84.15	65.88	78.13				
2	21/May	51	2	SCI	a	0.6	-0.5					0.24	-0.22	0.6	1.12				
2	21/May	51	2	SCI	b	1.73	0.06					0.34	0.38	1.82	0.1				
2	21/May	51	2	SCE	l	72.78	82.6					82.62	83.59	65.46	76.45				
2	21/May	51	2	SCE	a	0.57	-0.47					0.33	-0.18	0.63	1.2				
2	21/May	51	2	SCE	b	2.12	0.27					0.55	0.75	2	0.31				
2	21/May	51	3	SCI	l	77.59	82.25					82.52	84.76	64.74	76.34				
2	21/May	51	3	SCI	a	0.82	0.1					0.58	-0.31	0.2	1.32				
2	21/May	51	3	SCI	b	1.66	0.49					0.59	0.44	1.77	0.44				
2	21/May	51	3	SCE	l	75.05	82.1					81.79	81.93	64.15	74.19				
2	21/May	51	3	SCE	a	0.82	0.14					0.63	-0.27	0.22	1.43				
2	21/May	51	3	SCE	b	1.92	0.77					0.85	0.75	1.94	0.61				
2	21/May	51	Δ	SCI	l	76.85	82.52	0.00	0.00	0.00	0.00	84.03	84.57	64.40	77.29	0.00	0.00	0.00	0.00
2	21/May	51	Δ	SCI	a	0.57	0.05	0.00	0.00	0.00	0.00	0.35	-0.32	0.57	1.22	0.00	0.00	0.00	0.00
2	21/May	51	Δ	SCI	b	1.63	0.37	0.00	0.00	0.00	0.00	0.46	0.41	2.00	0.25	0.00	0.00	0.00	0.00
2	21/May	51	Δ	SCE	l	74.24	81.98	0.00	0.00	0.00	0.00	82.24	82.32	63.89	75.57	0.00	0.00	0.00	0.00
2	21/May	51	Δ	SCE	a	0.55	0.10	0.00	0.00	0.00	0.00	0.42	-0.28	0.59	1.31	0.00	0.00	0.00	0.00
2	21/May	51	Δ	SCE	b	1.95	0.61	0.00	0.00	0.00	0.00	0.69	0.73	2.18	0.44	0.00	0.00	0.00	0.00
2	27/May	57	1	SCI	l	71.03	77.17					75.73	84.55	61.61	75.15				
2	27/May	57	1	SCI	a	-0.93	0.23					0.65	-0.29	0.77	1.05				
2	27/May	57	1	SCI	b	1.69	1.14					1.77	0.73	2.8	0.62				
2	27/May	57	1	SCE	l	70.24	76.21					72.31	81.27	60.96	74.32				
2	27/May	57	1	SCE	a	-0.91	0.28					0.76	-0.25	0.8	1.11				
2	27/May	57	1	SCE	b	1.9	1.34					2	0.92	3.04	0.81				
2	27/May	57	2	SCI	l	74.94	76.11					85	85.99	61.36	75.34				
2	27/May	57	2	SCI	a	0.67	0.94					0.44	-0.29	0.82	1.07				
2	27/May	57	2	SCI	b	1.95	1.38					0.67	0.55	2.8	0.53				
2	27/May	57	2	SCE	l	72.59	76.01					82.15	82.36	60.78	75.04				
2	27/May	57	2	SCE	a	0.78	0.98					0.51	-0.25	0.84	1.11				
2	27/May	57	2	SCE	b	2.28	1.63					0.8	0.75	2.96	0.75				
2	27/May	57	3	SCI	l	74	79.75					85.3	86.1	61.76	74.13				
2	27/May	57	3	SCI	a	1.09	0.96					0.25	-0.31	0.58	1.29				
2	27/May	57	3	SCI	b	2.17	1.06					0.57	0.49	2.53	0.9				
2	27/May	57	3	SCE	l	73.84	78.18					82.22	82.47	61.21	73.03				
2	27/May	57	3	SCE	a	1.14	1.06					0.32	-0.26	0.6	1.37				
2	27/May	57	3	SCE	b	2.38	1.25					0.71	0.72	2.69	1.11				
2	27/May	57	Δ	SCI	l	73.32	77.68	0.00	0.00	0.00	0.00	82.01	85.55	61.58	74.87	0.00	0.00	0.00	0.00
2	27/May	57	Δ	SCI	a	0.28	0.71	0.00	0.00	0.00	0.00	0.45	-0.30	0.72	1.14	0.00	0.00	0.00	0.00
2	27/May	57	Δ	SCI	b	1.94	1.19	0.00	0.00	0.00	0.00	1.00	0.59	2.71	0.68	0.00	0.00	0.00	0.00
2	27/May	57	Δ	SCE	l	72.22	76.80	0.00	0.00	0.00	0.00	78.89	82.03	60.98	74.13	0.00	0.00	0.00	0.00
2	27/May	57	Δ	SCE	a	0.34	0.77	0.00	0.00	0.00	0.00	0.53	-0.25	0.75	1.20	0.00	0.00	0.00	0.00
2	27/May	57	Δ	SCE	b	2.19	1.41	0.00	0.00	0.00	0.00	1.17	0.80	2.90	0.89	0.00	0.00	0.00	0.00
2	30/May	60	1	SCI	l	76.89	70.22					77.04	81.57	58.33	73.75				
2	30/May	60	1	SCI	a	0.58	0.63					0.32	-0.25	1.38	1.46				
2	30/May	60	1	SCI	b	1.76	2.21					1.45	1.13	3.39	1.4				
2	30/May	60	1	SCE	l	74.97	68.6					75.2	81.15	57.66	72.4				
2	30/May	60	1	SCE	a	0.57	0.7					0.39	-0.21	1.42	1.53				
2	30/May	60	1	SCE	b	1.91	2.4					1.6	1.42	3.53	1.59				
2	30/May	60	2	SCI	l	77.53	74.04					85.78	80.66	59.67	72.5				
2	30/May	60	2	SCI	a	0.91	-0.61					-0.16	-0.37	1.46	1.36				
2	30/May	60	2	SCI	b	1.87	1.26					0.46	1.15	3.41	1.53				
2	30/May	60	2	SCE	l	75.58	73.81					84.43	80.22	59.09	69.7				
2	30/May	60	2	SCE	a	0.9	-0.59					-0.12	-0.34	1.49	1.48				
2	30/May	60	2	SCE	b	2.06	1.41					0.59	1.43	3.56	1.64				
2	30/May	60	3	SCI	l	76.87	78.52					83.9	82.27	61.13	72.47				
2	30/May	60	3	SCI	a	0.75	0.11					-0.58	-0.39	1.8	1.45				
2	30/May	60	3	SCI	b	1.78	1.15					0.66	0.99	3.37	1.51				
2	30/May	60	3	SCE	l	75.49	78.06					82.16	80.94	60.71	70.12				
2	30/May	60	3	SCE	a	0.75	0.15					-0.54	-0.35	1.82	1.54				
2	30/May	60	3	SCE	b	1.97	1.35					0.81	1.28	3.5	1.68				
2	30/May	60	Δ	SCI	l	77.10	74.26	0.00	0.00	0.00	0.00	82.24	81.50	59.71	72.91	0.00	0.00	0.00	0.00
2	30/May	60	Δ	SCI	a	0.75	0.04	0.00	0.00	0.00	0.00	-0.14	-0.34	1.55	1.42	0.00	0.00	0.00	0.00
2	30/May	60	Δ	SCI	b	1.80	1.54	0.00	0.00	0.00	0.00	0.86	1.09	3.39	1.48	0.00	0.00	0.00	0.00
2	30/May	60	Δ	SCE	l	75.35	73.49	0.00	0.00	0.00	0.00	80.60	80.77	59.15	70.74	0.00	0.00	0.00	0.00
2	30/May	60	Δ	SCE	a	0.74	0.09	0.00	0.00	0.00	0.00	-0.09	-0.30	1.58	1.52	0.00	0.00	0.00	0.00
2	30/May	60	Δ	SCE	b	1.98	1.72	0.00	0.00	0.00	0.00	1.00	1.38	3.53	1.64	0.00	0.00	0.00	0.00
2	03/Jun	64	1	SCI	l			71.26	85.46	83.51	79.7								
2	03/Jun	64	1	SCI	a			1.36	0.24	0.61	0.66								
2	03/Jun	64	1	SCI	b			1.6	-0.07	0.41	0.74								
2	03/Jun	64	1	SCE	l			68.5	82.59	79.82	76.21								
2	03/Jun	64	1	SCE	a			1.4	0.29	0.64	0.79								
2	03/Jun	64	1	SCE	b			2	0.2	0.45	1.01								
2	03/Jun	64	2	SCI	l			75.72	83.78	78.77	78.87								
2	03/Jun	64	2	SCI	a			0.95	0.81	0.36	-0.46								
2	03/Jun	64	2	SCI	b			1.02	0.32	1.38	1.08								
2	03/Jun	64	2	SCE	l			73.72	84.1	78.38	75.2								
2	03/Jun	64	2	SCE	a			0.98	0.83	0.39	-0.43								
2	03/Jun	64	2	SCE	b			1.28	0.54	1.53	1.3								
2	03/Jun	64	3	SCI	l			76.22	85.86	85.68	77.72								
2	03/Jun	64	3	SCI	a			0.69	0.27	0.26	0.2								
2	03/Jun	64	3	SCI	b			0.96	-0.22	0.04	0.98								
2	03/Jun	64	3	SCE	l			74.37	84.95	82.7	75.75								
2	03/Jun	64	3	SCE	a			0.69	0.32	0.28	0.27								
2	03/Jun	64	3	SCE	b			1.2	0.12	0.03	1.3								
2	03/Jun	64	Δ	SCI	l			74.40	85.03	82.65	78.76								
2	03/Jun	64	Δ	SCI	a			1.00	0.44	0.41	0.13								
2	03/Jun	64	Δ	SCI	b			1.19	0.01	0.61	0.93								
2	03/Jun	64	Δ	SCE	l			72.20	83.88	80.30	75.72								
2	03/Jun	64	Δ	SCE	a			1.02	0.48	0.44	0.21								
2	03/Jun	64	Δ	SCE	b			1.49	0.29	0.67	1.20								

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
3	Ref. Index	1.51			1.48														
3	Thickness				mm	1.8	1.7	2.3	1.7	1.8	1.6	1.9	1.6	1.8	1.7	2.5	1.7	1.8	1.7
3	01/Apr	1	1	SCI	l	76.2	85.41	81.88	81.96	80.24	83.56	78.82	85.36			77.03	85.33		
3	01/Apr	1	1	SCI	a	0.96	0.75	0.23	0.7	0.01	0.03	0.97	0.01			0.99	0.96		
3	01/Apr	1	1	SCI	b	2.3	0.81	0.71	1.26	1.21	0.78	2.03	0.78			2.18	0.88		
3	01/Apr	1	1	SCE	l	71.72	83.87	80.47	80.06	77.06	83.57	76.91	82.09			74.86	85.71		
3	01/Apr	1	1	SCE	a	1	0.75	0.3	0.73	0.12	0.08	1.13	0.05			1.15	1.01		
3	01/Apr	1	1	SCE	b	2.23	1.05	0.91	1.45	1.47	1.02	2.26	0.85			2.43	1.1		
3	01/Apr	1	2	SCI	l	82.42	81.22	83.94	79.02	81.5	83.89	81.84	85.75			76.11	87		
3	01/Apr	1	2	SCI	a	0.64	0.7	-0.16	0.33	0.54	0.03	0.44	0.07			0.99	0.26		
3	01/Apr	1	2	SCI	b	1.31	1.33	0.65	1.65	1.34	0.73	1.33	0.75			2.24	0.58		
3	01/Apr	1	2	SCE	l	78.24	78.27	83.15	78.67	77.73	83.39	79.25	82.78			73.68	83.57		
3	01/Apr	1	2	SCE	a	0.63	0.67	-0.12	0.37	0.71	0.08	0.59	0.05			1.15	0.12		
3	01/Apr	1	2	SCE	b	1.22	1.46	0.89	1.96	1.51	1.06	1.54	0.82			2.53	0.67		
3	01/Apr	1	3	SCI	l	84.43	83.5	82.85	78.59	74.37	82.08	80.65	85.57			72.23	86.21		
3	01/Apr	1	3	SCI	a	0.47	0.31	0.01	0.54	0.26	0.07	0.63	0.29			1.21	0.66		
3	01/Apr	1	3	SCI	b	0.8	0.95	0.84	1.99	2.04	0.87	1.65	0.67			2.62	0.54		
3	01/Apr	1	3	SCE	l	81.95	80.52	81.29	77.78	72.1	80.44	78.92	82.48			71.95	85.78		
3	01/Apr	1	3	SCE	a	0.49	0.25	0.08	0.57	0.36	0.11	0.74	0.27			1.27	0.67		
3	01/Apr	1	3	SCE	b	0.85	1.21	1.12	2.28	2.46	1.07	1.92	0.74			2.85	0.85		
3	01/Apr	1	Δ	SCI	l	81.02	83.38	82.89	79.86	78.70	83.18	80.44	85.56	0.00	0.00	75.12	86.18	0.00	0.00
3	01/Apr	1	Δ	SCI	a	0.69	0.59	0.03	0.52	0.27	0.04	0.68	0.12	0.00	0.00	1.06	0.63	0.00	0.00
3	01/Apr	1	Δ	SCI	b	1.47	1.03	0.73	1.63	1.53	0.79	1.67	0.73	0.00	0.00	2.35	0.67	0.00	0.00
3	01/Apr	1	Δ	SCE	l	77.30	80.89	81.64	78.84	75.63	82.47	78.36	82.45	0.00	0.00	73.50	85.02	0.00	0.00
3	01/Apr	1	Δ	SCE	a	0.71	0.56	0.09	0.56	0.40	0.09	0.82	0.12	0.00	0.00	1.19	0.60	0.00	0.00
3	01/Apr	1	Δ	SCE	b	1.43	1.24	0.97	1.90	1.81	1.05	1.91	0.80	0.00	0.00	2.60	0.87	0.00	0.00
3	02/Apr	2	1	SCI	l	85.18	87.17							85.93	82.43			80.32	80.31
3	02/Apr	2	1	SCI	a	-0.18	0.44							0.49	0.69			0.63	0.52
3	02/Apr	2	1	SCI	b	0.65	0.62							0.86	1.47			1.97	1.28
3	02/Apr	2	1	SCE	l	84.29	83.64							84.08	79.72			77.03	76.03
3	02/Apr	2	1	SCE	a	-0.17	0.38							0.49	0.71			0.71	0.35
3	02/Apr	2	1	SCE	b	0.88	0.78							1.1	1.82			2.1	1.47
3	02/Apr	2	2	SCI	l	81.34	86.84							84.58	80.96			82.04	84.41
3	02/Apr	2	2	SCI	a	-0.36	0.18							0.76	0.48			0.73	0.76
3	02/Apr	2	2	SCI	b	0.72	0.73							0.99	1.23			1.53	0.98
3	02/Apr	2	2	SCE	l	81.27	84.45							84.7	79.53			81.36	83.28
3	02/Apr	2	2	SCE	a	-0.32	0.15							0.8	0.51			0.78	0.74
3	02/Apr	2	2	SCE	b	0.92	0.95							1.25	1.7			1.69	1.22
3	02/Apr	2	3	SCI	l	83.52	86.72							84.17	82.17			84.4	85.06
3	02/Apr	2	3	SCI	a	-0.35	0.47							0.63	0.41			0.18	0.34
3	02/Apr	2	3	SCI	b	0.67	0.75							0.97	1.53			0.89	0.77
3	02/Apr	2	3	SCE	l	83.46	85.77							84.18	78.02			82.58	82.39
3	02/Apr	2	3	SCE	a	-0.31	0.49							0.66	0.37			0.26	0.24
3	02/Apr	2	3	SCE	b	0.88	1.01							1.26	1.63			1.14	0.97
3	02/Apr	2	Δ	SCI	l	83.35	86.91	0.00	0.00	0.00	0.00	0.00	0.00	84.89	81.85	0.00	0.00	82.25	83.26
3	02/Apr	2	Δ	SCI	a	-0.30	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.53	0.00	0.00	0.51	0.54
3	02/Apr	2	Δ	SCI	b	0.68	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.94	1.41	0.00	0.00	1.46	1.01
3	02/Apr	2	Δ	SCE	l	83.01	84.62	0.00	0.00	0.00	0.00	0.00	0.00	84.32	79.09	0.00	0.00	80.32	80.57
3	02/Apr	2	Δ	SCE	a	-0.27	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.53	0.00	0.00	0.58	0.44
3	02/Apr	2	Δ	SCE	b	0.89	0.91	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.72	0.00	0.00	1.64	1.22
3	03/Apr	3	1	SCI	l	86.88	86.66					84.34	84.97						
3	03/Apr	3	1	SCI	a	0.51	0.32					0.3	0.12						
3	03/Apr	3	1	SCI	b	0.6	0.67					1.11	1.15						
3	03/Apr	3	1	SCE	l	83.81	83.12					80.33	83.54						
3	03/Apr	3	1	SCE	a	0.49	0.29					0.47	0.19						
3	03/Apr	3	1	SCE	b	0.7	0.85					1.37	1.31						
3	03/Apr	3	2	SCI	l	87.03	85.34					85.12	86.58						
3	03/Apr	3	2	SCI	a	0.49	0.68					0.56	0.09						
3	03/Apr	3	2	SCI	b	0.65	0.91					1.19	0.92						
3	03/Apr	3	2	SCE	l	84.32	84.68					82.35	82.75						
3	03/Apr	3	2	SCE	a	0.47	0.72					0.75	0.14						
3	03/Apr	3	2	SCE	b	0.72	1.2					1.42	1.09						
3	03/Apr	3	3	SCI	l	85.83	85.53					85.18	86.24						
3	03/Apr	3	3	SCI	a	-0.16	0.72					0.35	0.27						
3	03/Apr	3	3	SCI	b	0.68	0.97					1.04	1.08						
3	03/Apr	3	3	SCE	l	82.28	84.18					81.31	82.58						
3	03/Apr	3	3	SCE	a	-0.25	0.74					0.56	0.38						
3	03/Apr	3	3	SCE	b	0.62	1.26					1.26	1.15						
3	03/Apr	3	Δ	SCI	l	86.58	85.84	0.00	0.00	0.00	0.00	84.88	85.93	0.00	0.00	0.00	0.00	0.00	0.00
3	03/Apr	3	Δ	SCI	a	0.28	0.57	0.00	0.00	0.00	0.00	0.40	0.16	0.00	0.00	0.00	0.00	0.00	0.00
3	03/Apr	3	Δ	SCI	b	0.64	0.85	0.00	0.00	0.00	0.00	1.11	1.05	0.00	0.00	0.00	0.00	0.00	0.00
3	03/Apr	3	Δ	SCE	l	83.47	83.99	0.00	0.00	0.00	0.00	81.33	82.96	0.00	0.00	0.00	0.00	0.00	0.00
3	03/Apr	3	Δ	SCE	a	0.24	0.58	0.00	0.00	0.00	0.00	0.59	0.24	0.00	0.00	0.00	0.00	0.00	0.00
3	03/Apr	3	Δ	SCE	b	0.68	1.10	0.00	0.00	0.00	0.00	1.35	1.18	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	1	SCI	l	84.32	86.93					84.72	85.81						
3	04/Apr	4	1	SCI	a	0.88	0.18					0.57	0.38						
3	04/Apr	4	1	SCI	b	0.99	0.58					1.3	1.2						
3	04/Apr	4	1	SCE	l	84.24	83.76					82.02	82.89						
3	04/Apr	4	1	SCE	a	0.92	0.13					0.75	0.42						
3	04/Apr	4	1	SCE	b	1.27	0.72					1.48	1.25						
3	04/Apr	4	2	SCI	l	82.53	86.24					85.46	86.6						
3	04/Apr	4	2	SCI	a	0.31	0.79					0.27	0.41						
3	04/Apr	4	2	SCI	b	1.03	1.05					1.16	1.13						
3	04/Apr	4	2	SCE	l	80.49	85.46					82.08	83.18						
3	04/Apr	4	2	SCE	a	0.29	0.83					0.46	0.46						
3	04/Apr	4	2	SCE	b	1.24	1.36					1.28	1.21						
3	04/Apr	4	3	SCI	l	84.91	84.58					85.17	87.29						
3	04/Apr	4	3	SCI	a	0.08	1.14					0.46	0.37						
3	04/Apr	4	3	SCI	b	0.86	1.13					1.05	0.98						
3	04/Apr	4	3	SCE	l	81.49	84.44					82.2	84						
3	04/Apr	4	3	SCE	a	0.01	1.19					0.64	0.41						
3	04/Apr	4	3	SCE	b	0.82	1.44					1.2	1.05						
3	04/Apr	4	Δ	SCI	l	83.92	85.92	0.00	0.00	0.00	0.00	85.12	86.57	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	Δ	SCI	a	0.42	0.70	0.00	0.00	0.00	0.00	0.43	0.39	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	Δ	SCI	b	0.96	0.92	0.00	0.00	0.00	0.00	1.17	1.10	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	Δ	SCE	l	82.07	84.55	0.00	0.00	0.00	0.00	82.10	83.36	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	Δ	SCE	a	0.41	0.72	0.00	0.00	0.00	0.00	0.62	0.43	0.00	0.00	0.00	0.00	0.00	0.00
3	04/Apr	4	Δ	SCE	b	1.11	1.17	0.00	0.00	0.00	0.00	1.32	1.17	0.00	0.00	0.00	0.00	0.00	0.00
3	10/Apr	10	1	SCI	l	86.35	85.07					84.61	86.38						
3	10/Apr	10	1	SCI	a	0.09	0.85					0.46	0.63						
3	10/Apr	10	1	SCI	b	0.72	1.06					1.39	1.39						
3	10/Apr	10	1	SCE	l	82.88	85.3					81.43	82.7						
3	10/Apr	10	1	SCE	a	-0.02	0.88					0.59	0.66						
3	10/Apr	10	1	SCE	b	0.63	1.31					1.64	1.54						
3	10/Apr	10	2	SCI	l	87.54	86.04					84.2	86.01						
3	10/Apr	10	2	SCI	a	0.13	0.82					0.65	0.79						
3	10/Apr	10	2	SCI	b	0.71	0.94					1.36	1.36						
3	10/Apr	10	2	SCE	l	84.68	85.31					83.05	82.3						
3	10/Apr	10	2	SCE	a	0.04	0.85					0.73	0.81						
3	10/Apr	10	2	SCE	b	0.68	1.22					1.63	1.44						
3	10/Apr	10	3	SCI	l	86.47	86.3					85.66	85.85						
3	10/Apr	10	3	SCI	a	0.09	0.7					0.4	0.63						
3	10/Apr	10	3	SCI	b	0.72	0.84					1.3	1.43						
3	10/Apr	10	3	SCE	l	84.2	84.67					82.08	82.07						
3	10/Apr	10	3	SCE	a	0.05	0.72					0.53	0.64						
3	10/Apr	10	3	SCE	b	0.8	1.1					1.58	1.55						
3	10/Apr	10	Δ	SCI	l	86.79	85.80	0.00	0.00	0.00	0.00	84.82	86.08	0.00	0.00	0.00	0.00	0.00	0.00
3	10/Apr	10	Δ	SCI	a	0.10	0.79	0.00	0.00	0.00	0.00	0.50	0.68	0.00	0.00	0.00	0.00	0.00	0.00
3	10/Apr	10	Δ	SCI	b	0.72	0.95	0.00	0.00	0.00	0.00	1.35	1.39	0.00	0.00	0.00	0.00	0.00	0.00
3	10/Apr	10	Δ	SCE	l	83.92	85.09	0.00	0.00	0.00	0.00	82.19	82.36	0.00	0.00	0.00	0.00	0.00	0.00
3	10/Apr	10	Δ	SCE	a	0.02	0.82	0.00	0.00	0.00	0.00	0.62	0.70	0.00	0.00	0.00	0.00	0.00	0.00

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
3	10/Apr	10	Δ	SCE	b	0.70	1.21	0.00	0.00	0.00	0.00	1.62	1.51	0.00	0.00	0.00	0.00	0.00	0.00
3	15/Apr	15	1	SCI	l	85.73	86.48	81.47	87.04	83.85	82.01	83.38	85.45	84.77	81.55				
3	15/Apr	15	1	SCI	a	0.62	0.61	0.59	0.41	0.18	0.38	0.82	0.58	1.07	1				
3	15/Apr	15	1	SCI	b	0.96	1.08	1.08	0.71	1.53	1.63	1.67	1.34	1.57	1.84				
3	15/Apr	15	1	SCE	l	84.25	84.99	80.24	83.98	80.25	81.91	79.7	82.28	83.53	77.53				
3	15/Apr	15	1	SCE	a	0.62	0.64	0.65	0.38	0.26	0.42	1.03	0.67	1.1	0.98				
3	15/Apr	15	1	SCE	b	1.16	1.3	1.4	0.88	1.6	1.85	1.9	1.41	1.86	1.97				
3	15/Apr	15	2	SCI	l	86.41	86.59	84.3	86.57	83.45	83.32	85.02	85.38	85.36	85.24				
3	15/Apr	15	2	SCI	a	0.37	0.52	0.2	0.62	0.36	0.47	0.74	0.56	1.06	0.63				
3	15/Apr	15	2	SCI	b	0.87	1.14	0.83	0.83	1.66	1.59	1.5	1.39	1.51	1.25				
3	15/Apr	15	2	SCE	l	83.75	84.51	80.47	84.4	80.34	82.06	81.53	82.66	85.38	82.34				
3	15/Apr	15	2	SCE	a	0.32	0.52	0.32	0.63	0.47	0.53	0.95	0.63	1.09	0.59				
3	15/Apr	15	2	SCE	b	1	1.38	1	1.08	1.76	1.75	1.66	1.51	1.79	1.39				
3	15/Apr	15	3	SCI	l	87	86.21	85.04	84.17	82.96	85.6	84.89	85.29	85.74	84.15				
3	15/Apr	15	3	SCI	a	0.52	0.6	0.02	1.08	1.36	0.36	0.91	0.49	0.54	0.88				
3	15/Apr	15	3	SCI	b	0.86	0.95	0.82	1.39	1.83	1.14	1.57	1.31	1.18	1.55				
3	15/Apr	15	3	SCE	l	84.61	85.58	81.42	82.07	83.18	84.52	83.86	82.99	82.58	81.82				
3	15/Apr	15	3	SCE	a	0.49	0.64	0.12	1.11	1.4	0.4	1.02	0.51	0.53	0.87				
3	15/Apr	15	3	SCE	b	1.01	1.21	1.04	1.65	2.11	1.33	1.78	1.46	1.43	1.77				
3	15/Apr	15	Δ	SCI	l	86.38	86.43	83.60	85.93	83.42	83.64	84.43	85.37	85.29	83.65	0.00	0.00	0.00	0.00
3	15/Apr	15	Δ	SCI	a	0.50	0.58	0.27	0.70	0.63	0.40	0.82	0.54	0.89	0.84	0.00	0.00	0.00	0.00
3	15/Apr	15	Δ	SCI	b	0.90	1.06	0.91	0.98	1.67	1.45	1.58	1.35	1.42	1.55	0.00	0.00	0.00	0.00
3	15/Apr	15	Δ	SCE	l	84.20	85.03	80.71	83.48	81.26	82.83	81.70	82.64	83.83	80.56	0.00	0.00	0.00	0.00
3	15/Apr	15	Δ	SCE	a	0.48	0.60	0.36	0.71	0.71	0.45	1.00	0.60	0.91	0.81	0.00	0.00	0.00	0.00
3	15/Apr	15	Δ	SCE	b	1.06	1.30	1.15	1.20	1.82	1.64	1.78	1.46	1.69	1.71	0.00	0.00	0.00	0.00
3	18/Apr	18	1	SCI	l	86.54	82.22					83.62	85.52	84.92	83.77				
3	18/Apr	18	1	SCI	a	0.19	1.47					0.66	0.42	1.38	1.26				
3	18/Apr	18	1	SCI	b	0.78	1.83					1.73	1.56	1.7	1.79				
3	18/Apr	18	1	SCE	l	83.65	82.58					79.94	82.55	83.17	81.12				
3	18/Apr	18	1	SCE	a	0.13	1.5					0.88	0.42	1.42	1.29				
3	18/Apr	18	1	SCE	b	0.88	2.03					1.85	1.75	1.98	1.94				
3	18/Apr	18	2	SCI	l	86.27	87.62					83.56	86.47	83.24	81.59				
3	18/Apr	18	2	SCI	a	0.36	0.13					0.82	0.5	1.72	1.35				
3	18/Apr	18	2	SCI	b	0.97	0.88					1.7	1.53	1.93	1.96				
3	18/Apr	18	2	SCE	l	82.61	84.19					79.87	83.31	83.48	77.59				
3	18/Apr	18	2	SCE	a	0.27	0.06					1.05	0.57	1.77	1.35				
3	18/Apr	18	2	SCE	b	1.07	1.04					1.87	1.65	2.18	2.1				
3	18/Apr	18	3	SCI	l	86.74	87.18					84.35	86.05	83.97	80.87				
3	18/Apr	18	3	SCI	a	0.43	0.65					0.7	0.49	1.14	1.61				
3	18/Apr	18	3	SCI	b	0.92	1.11					1.66	1.44	1.61	2.27				
3	18/Apr	18	3	SCE	l	83.31	84.95					81.26	83.34	80.73	76.73				
3	18/Apr	18	3	SCE	a	0.36	0.65					0.89	0.56	1.07	1.63				
3	18/Apr	18	3	SCE	b	0.93	1.33					1.84	1.62	1.88	2.44				
3	18/Apr	18	Δ	SCI	l	86.52	85.67	0.00	0.00	0.00	0.00	83.84	86.01	84.04	82.08	0.00	0.00	0.00	0.00
3	18/Apr	18	Δ	SCI	a	0.33	0.75	0.00	0.00	0.00	0.00	0.73	0.47	1.41	1.41	0.00	0.00	0.00	0.00
3	18/Apr	18	Δ	SCI	b	0.89	1.27	0.00	0.00	0.00	0.00	1.70	1.51	1.75	2.01	0.00	0.00	0.00	0.00
3	18/Apr	18	Δ	SCE	l	83.19	83.91	0.00	0.00	0.00	0.00	80.36	83.07	82.46	78.48	0.00	0.00	0.00	0.00
3	18/Apr	18	Δ	SCE	a	0.25	0.74	0.00	0.00	0.00	0.00	0.94	0.52	1.42	1.42	0.00	0.00	0.00	0.00
3	18/Apr	18	Δ	SCE	b	0.96	1.47	0.00	0.00	0.00	0.00	1.85	1.67	2.01	2.16	0.00	0.00	0.00	0.00
3	23/Apr	23	1	SCI	l	84.48	86.68					84.02	85.48	84.93	83.84				
3	23/Apr	23	1	SCI	a	0.63	0.69					0.7	0.73	1.54	1.27				
3	23/Apr	23	1	SCI	b	1.3	1.38					1.86	1.53	1.63	1.58				
3	23/Apr	23	1	SCE	l	80.94	84.68					80.66	82.68	82.63	80.93				
3	23/Apr	23	1	SCE	a	0.58	0.66					0.86	0.82	1.58	1.28				
3	23/Apr	23	1	SCE	b	1.35	1.51					2.03	1.71	1.9	1.76				
3	23/Apr	23	2	SCI	l	86.17	86.17					85.18	85.51	84.89	84.31				
3	23/Apr	23	2	SCI	a	0.39	0.27					0.5	0.75	1.53	1.33				
3	23/Apr	23	2	SCI	b	1.07	1.21					1.6	1.68	1.58	1.55				
3	23/Apr	23	2	SCE	l	82.72	83.84					81.85	82.86	83.04	81.49				
3	23/Apr	23	2	SCE	a	0.29	0.23					0.74	0.83	1.56	1.34				
3	23/Apr	23	2	SCE	b	1.12	1.38					1.75	1.86	1.86	1.74				
3	23/Apr	23	3	SCI	l	86.82	86.49					85.3	85.71	85.35	83.23				
3	23/Apr	23	3	SCI	a	0.21	0.54					0.57	0.78	1.48	1.35				
3	23/Apr	23	3	SCI	b	0.99	1.27					1.65	1.76	1.53	1.66				
3	23/Apr	23	3	SCE	l	83.93	84.52					82.03	82.68	82.69	80.71				
3	23/Apr	23	3	SCE	a	0.17	0.54					0.71	0.84	1.53	1.38				
3	23/Apr	23	3	SCE	b	1.05	1.45					1.82	1.94	1.81	1.92				
3	23/Apr	23	Δ	SCI	l	85.82	86.45	0.00	0.00	0.00	0.00	84.83	85.57	85.06	83.79	0.00	0.00	0.00	0.00
3	23/Apr	23	Δ	SCI	a	0.41	0.50	0.00	0.00	0.00	0.00	0.59	0.75	1.52	1.32	0.00	0.00	0.00	0.00
3	23/Apr	23	Δ	SCI	b	1.12	1.29	0.00	0.00	0.00	0.00	1.70	1.66	1.58	1.60	0.00	0.00	0.00	0.00
3	23/Apr	23	Δ	SCE	l	82.53	84.35	0.00	0.00	0.00	0.00	81.51	82.74	82.79	81.04	0.00	0.00	0.00	0.00
3	23/Apr	23	Δ	SCE	a	0.35	0.48	0.00	0.00	0.00	0.00	0.77	0.83	1.56	1.33	0.00	0.00	0.00	0.00
3	23/Apr	23	Δ	SCE	b	1.17	1.45	0.00	0.00	0.00	0.00	1.87	1.84	1.86	1.81	0.00	0.00	0.00	0.00
3	28/Apr	28	1	SCI	l			80.08	84.08	85.15	81.64			78.28	79.38				
3	28/Apr	28	1	SCI	a			0.51	0.41	0.66	1.6			2.38	1.67				
3	28/Apr	28	1	SCI	b			1.62	1.6	1.38	2.03			2.01	1.66				
3	28/Apr	28	1	SCE	l			77.62	79.86	81.67	81.99			78.55	75.55				
3	28/Apr	28	1	SCE	a			0.58	0.42	0.81	1.65			2.43	1.71				
3	28/Apr	28	1	SCE	b			1.88	1.86	1.49	2.22			2.21	1.78				
3	28/Apr	28	2	SCI	l			79.91	85.42	83.49	85.66			80.76	79.49				
3	28/Apr	28	2	SCI	a			0.2	0.3	0.56	1.06			1.95	2.05				
3	28/Apr	28	2	SCI	b			1.62	1.21	1.28	1.56			1.72	2.06				
3	28/Apr	28	2	SCE	l			77.61	84.28	83.54	84.46			80.82	75.3				
3	28/Apr	28	2	SCE	a			0.25	0.34	0.62	1.12			2	2.11				
3	28/Apr	28	2	SCE	b			1.85	1.63	1.57	1.8			2	2.21				
3	28/Apr	28	3	SCI	l			81.53	83.83	86.03	85.77			81.81	81.18				
3	28/Apr	28	3	SCI	a			0.18	0.09	0.36	0.39			1.98	1.55				
3	28/Apr	28	3	SCI	b			1.43	1.46	1.28	1.34			1.73	1.61				
3	28/Apr	28	3	SCE	l			80.41	83.87	83.74	83.02			82.02	77.12				
3	28/Apr	28	3	SCE	a			0.25	0.14	0.44	0.39			2.02	1.54				
3	28/Apr	28	3	SCE	b			1.69	1.71	1.54	1.43			1.98	1.79				
3	28/Apr	28	Δ	SCI	l	0.00	0.00	80.51	84.44	84.89	84.36	0.00	0.00	80.28	80.02	0.00	0.00	0.00	0.00
3	28/Apr	28	Δ	SCI	a	0.00	0.00	0.30	0.27	0.53	1.02	0.00	0.00	2.10	1.76	0.00	0.00	0.00	0.00
3	28/Apr	28	Δ	SCI	b	0.00	0.00	1.56	1.42	1.31	1.64	0.00	0.00	1.82	1.78	0.00	0.00	0.00	0.00
3	28/Apr	28	Δ	SCE	l	0.00	0.00	78.55	82.67	82.98	83.16	0.00	0.00	80.46	75.99	0.00	0.00	0.00	0.00
3	28/Apr	28	Δ	SCE	a	0.00	0.00	0.36	0.30	0.62	1.05	0.00	0.00	2.15	1.79	0.00	0.00	0.00	0.00
3	28/Apr	28	Δ	SCE	b	0.00	0.00	1.81	1.73	1.53	1.82	0.00	0.00	2.06	1.93	0.00	0.00	0.00	0.00
3	01/May	31	1	SCI	l	86.73	85.83					83.13	83.4	80.4	82.52				
3	01/May	31	1	SCI	a	0.23	0.55					1.02	0.31	2.38	1.78				
3	01/May	31	1	SCI	b	0.99	1.22					2.02	1.59	1.71	1.33				
3	01/May	31	1	SCE	l	83.45	85.3					79.55	83.29	80.5	78.96				
3	01/May	31	1	SCE	a	0.16	0.58					1.24	0.36	2.43	1.82				
3	01/May	31	1	SCE	b	1.04	1.5					2.21	1.84	2.01	1.52				
3	01/May	31	2	SCI	l	85.56	86.19					83.71	84.32	79.99	82.99				
3	01/May	31	2	SCI	a	-0.06	0.63					0.91	0.14	2.53	1.76				
3	01/May	31	2	SCI	b	1.18	1.29					1.99	1.99	1.82	1.27				
3	01/May	31	2	SCE	l	84.74	85.26					80.53	81.62	80.34	79.76				
3	01/May	31	2	SCE	a	-0.04	0.65					1.07	0.13	2.56	1.8				
3	01/May	31	2	SCE	b	1.42	1.56					2.18	2.09	2.03	1.5				
3	01/May	31	3	SCI	l	85.74	86.03					84.05	83.53	82.57	82.49				
3	01/May	31	3	SCI	a	-0.26	0.61					0.84	0.3	2.07	1.52				
3	01/May	31	3	SCI	b	1.04	1.28					1.96	2.05	1.35	1.35				
3	01/May	31	3	SCE	l	85.58	85.28					80.52	81.2	81.99	80.78				
3	01/May	31	3	SCE	a	-0.21	0.64					0.99	0.34	2.11	1.58				
3	01/May	31	3	SCE	b	1.3	1.56					2.13	2.28	1.68	1.71				
3	01/May	31	Δ	SCI	l	86.01	86.02	0.00	0.00	0.00	0.00	83.63	83.75	80.99	82.67	0.00	0.00	0.00	0.00
3	01/May	31	Δ	SCI	a	-0.03	0.60	0.00	0.00	0.00	0.00	0.92	0.25	2.33	1.69	0.00	0.00	0.00	0.00
3	01/May	31	Δ	SCI	b	1.07	1.26	0.00	0.00	0.00	0.00	1.99	1.88	1.63	1.32	0.00	0.00	0.00	0.00
3	01/May	31	Δ	SCE	l	84.59	85.28	0.00	0.00	0.00	0.00	80.20	82.04	80.94	79.83	0.00	0.00	0.00	0.00
3	01/May	31	Δ	SCE	a	-0.03	0.62	0.00	0.00	0.00	0.00	1.10	0.28	2.37	1.73	0.00	0.00	0.00	0.00
3	01/May	31	Δ	SCE	b	1.25	1.54	0.00	0.00	0.00	0.00	2.17	2.07	1.91	1.58	0.00	0.00	0.00	0.00

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
3	07/May	37	1	SCI	l	87.08	86.62					84.19	85.54	81.82	81.63				
3	07/May	37	1	SCI	a	0.18	0.62					0.79	0.79	2.12	1.96				
3	07/May	37	1	SCI	b	1.17	1.5					2.07	1.99	1.41	1.2				
3	07/May	37	1	SCE	l	83.91	84.05					80.56	82.15	79.85	78.51				
3	07/May	37	1	SCE	a	0.1	0.6					1	0.83	2.15	1.96				
3	07/May	37	1	SCE	b	1.31	1.68					2.24	2.1	1.7	1.31				
3	07/May	37	2	SCI	l	86.95	86.93					84.28	86.24	82.19	80.15				
3	07/May	37	2	SCI	a	-0.06	0.53					1.04	0.65	2.09	1.85				
3	07/May	37	2	SCI	b	1.26	1.49					2.26	1.84	1.21	1.27				
3	07/May	37	2	SCE	l	84.57	84.16					81.61	82.94	79.27	77.95				
3	07/May	37	2	SCE	a	-0.1	0.51					1.21	0.7	2.13	1.89				
3	07/May	37	2	SCE	b	1.47	1.66					2.48	1.96	1.46	1.5				
3	07/May	37	3	SCI	l	86.81	85.96					83.89	86.32	82.09	81.11				
3	07/May	37	3	SCI	a	0.22	0.74					0.54	0.52	2.25	1.68				
3	07/May	37	3	SCI	b	1.33	1.53					1.92	2	1.53	1.33				
3	07/May	37	3	SCE	l	84.74	85.21					82.69	82.89	80.9	78.28				
3	07/May	37	3	SCE	a	0.21	0.77					0.62	0.54	2.28	1.7				
3	07/May	37	3	SCE	b	1.55	1.79					2.28	2.07	1.83	1.46				
3	07/May	37	Δ	SCI	l	86.95	86.50	0.00	0.00	0.00	0.00	84.12	86.03	82.03	80.96	0.00	0.00	0.00	0.00
3	07/May	37	Δ	SCI	a	0.11	0.63	0.00	0.00	0.00	0.00	0.79	0.65	2.15	1.83	0.00	0.00	0.00	0.00
3	07/May	37	Δ	SCI	b	1.25	1.51	0.00	0.00	0.00	0.00	2.08	1.94	1.38	1.27	0.00	0.00	0.00	0.00
3	07/May	37	Δ	SCE	l	84.41	84.47	0.00	0.00	0.00	0.00	81.62	82.66	80.01	78.25	0.00	0.00	0.00	0.00
3	07/May	37	Δ	SCE	a	0.07	0.63	0.00	0.00	0.00	0.00	0.94	0.69	2.19	1.85	0.00	0.00	0.00	0.00
3	07/May	37	Δ	SCE	b	1.44	1.71	0.00	0.00	0.00	0.00	2.33	2.04	1.66	1.42	0.00	0.00	0.00	0.00
3	08/May	38	1	SCI	l			78.91	80.63	85.24	78.83								
3	08/May	38	1	SCI	a			0.36	-1	0.62	0.76								
3	08/May	38	1	SCI	b			1.86	1.52	1.56	2.16								
3	08/May	38	1	SCE	l			78.3	80.28	81.47	78.71								
3	08/May	38	1	SCE	a			0.41	-0.97	0.73	0.81								
3	08/May	38	1	SCE	b			2.09	1.71	1.63	2.39								
3	08/May	38	2	SCI	l			81.73	83.76	85.34	84.3								
3	08/May	38	2	SCI	a			-0.14	0.15	0.63	0.52								
3	08/May	38	2	SCI	b			1.42	1.53	1.84	1.58								
3	08/May	38	2	SCE	l			81.68	83.77	81.49	82.05								
3	08/May	38	2	SCE	a			-0.09	0.2	0.75	0.58								
3	08/May	38	2	SCE	b			1.63	1.74	1.93	1.71								
3	08/May	38	3	SCI	l			84.5	80.74	86.4	85.29								
3	08/May	38	3	SCI	a			-0.14	0.63	0.6	0.61								
3	08/May	38	3	SCI	b			1.12	1.84	1.62	1.6								
3	08/May	38	3	SCE	l			84.1	80.36	82.8	82.57								
3	08/May	38	3	SCE	a			-0.1	0.68	0.69	0.64								
3	08/May	38	3	SCE	b			1.38	2.15	1.72	1.7								
3	08/May	38	Δ	SCI	l	0.00	0.00	81.71	81.71	85.66	82.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	08/May	38	Δ	SCI	a	0.00	0.00	0.03	-0.07	0.62	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	08/May	38	Δ	SCI	b	0.00	0.00	1.47	1.63	1.67	1.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	08/May	38	Δ	SCE	l	0.00	0.00	81.36	81.47	81.92	81.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	08/May	38	Δ	SCE	a	0.00	0.00	0.07	-0.03	0.72	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	08/May	38	Δ	SCE	b	0.00	0.00	1.70	1.87	1.76	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	14/May	44	1	SCI	l	84.98	86.15					84.79	84.4	81.73	79.53				
3	14/May	44	1	SCI	a	-0.33	0.56					0.81	0.49	2.1	2.04				
3	14/May	44	1	SCI	b	1.35	1.68					2.22	1.95	0.64	1.13				
3	14/May	44	1	SCE	l	85.79	85.45					82.53	81.37	80.83	76.39				
3	14/May	44	1	SCE	a	-0.37	0.47					0.92	0.48	1.93	1.86				
3	14/May	44	1	SCE	b	2.06	2.29					2.73	2.45	1.41	1.66				
3	14/May	44	2	SCI	l	84.27	86.55					83.99	84.9	79.36	77.69				
3	14/May	44	2	SCI	a	0.05	0.14					0.67	0.37	2.41	1.69				
3	14/May	44	2	SCI	b	1.48	1.3					2.17	1.84	1.17	1.43				
3	14/May	44	2	SCE	l	80.89	83.5					81.17	82.68	80.84	75.77				
3	14/May	44	2	SCE	a	-0.17	0.01					0.75	0.35	2.22	1.5				
3	14/May	44	2	SCE	b	1.81	1.7					2.6	2.41	2.03	2.09				
3	14/May	44	3	SCI	l	85.02	86.41					80.76	84.54	80.63	81.36				
3	14/May	44	3	SCI	a	0.06	0.56					0.62	0.4	2.2	2.01				
3	14/May	44	3	SCI	b	1.46	1.75					2.48	1.79	1.09	0.9				
3	14/May	44	3	SCE	l	82.68	85.15					77.3	82.14	80.95	78.67				
3	14/May	44	3	SCE	a	-0.11	0.49					0.74	0.35	2.04	1.8				
3	14/May	44	3	SCE	b	1.89	2.31					3.09	2.31	1.94	1.4				
3	14/May	44	Δ	SCI	l	84.76	86.37	0.00	0.00	0.00	0.00	83.18	84.61	80.57	79.53	0.00	0.00	0.00	0.00
3	14/May	44	Δ	SCI	a	-0.07	0.42	0.00	0.00	0.00	0.00	0.70	0.42	2.24	1.91	0.00	0.00	0.00	0.00
3	14/May	44	Δ	SCI	b	1.43	1.58	0.00	0.00	0.00	0.00	2.29	1.86	0.97	1.15	0.00	0.00	0.00	0.00
3	14/May	44	Δ	SCE	l	83.12	84.70	0.00	0.00	0.00	0.00	80.33	82.06	80.87	76.94	0.00	0.00	0.00	0.00
3	14/May	44	Δ	SCE	a	-0.22	0.32	0.00	0.00	0.00	0.00	0.80	0.39	2.06	1.72	0.00	0.00	0.00	0.00
3	14/May	44	Δ	SCE	b	1.92	2.10	0.00	0.00	0.00	0.00	2.81	2.39	1.79	1.72	0.00	0.00	0.00	0.00
3	16/May	46	1	SCI	l	84.93	86.16					84.18	85	82.39	79.63				
3	16/May	46	1	SCI	a	-0.29	0.72					0.81	0.6	2.2	2.02				
3	16/May	46	1	SCI	b	1.15	1.78					2.26	1.96	0.94	0.77				
3	16/May	46	1	SCE	l	84.85	85.49					81.17	82.25	78.73	78.85				
3	16/May	46	1	SCE	a	-0.24	0.75					0.99	0.68	2.18	2.08				
3	16/May	46	1	SCE	b	1.41	2.08					2.45	2.19	1.18	1.15				
3	16/May	46	2	SCI	l	86	85.91					83.65	84.76	82.18	80.25				
3	16/May	46	2	SCI	a	-0.16	0.77					0.66	0.63	2.13	2.12				
3	16/May	46	2	SCI	b	1.21	1.9					2.28	2.01	0.98	0.97				
3	16/May	46	2	SCE	l	85.6	85.73					79.8	82.94	78.74	78.39				
3	16/May	46	2	SCE	a	-0.1	0.81					0.85	0.7	2.15	2.19				
3	16/May	46	2	SCE	b	1.48	2.19					2.49	2.31	1.22	1.34				
3	16/May	46	3	SCI	l	84.21	86.69					85.64	85.53	82.33	81.66				
3	16/May	46	3	SCI	a	-0.21	0.57					0.67	0.52	2.06	2.23				
3	16/May	46	3	SCI	b	1.34	1.81					2.09	1.94	0.95	1.04				
3	16/May	46	3	SCE	l	84.19	85.34					82.03	82.35	78.73	79.02				
3	16/May	46	3	SCE	a	-0.16	0.58					0.84	0.59	2.08	2.29				
3	16/May	46	3	SCE	b	1.55	2.08					2.32	2.12	1.17	1.33				
3	16/May	46	Δ	SCI	l	85.05	86.25	0.00	0.00	0.00	0.00	84.49	85.10	82.30	80.51	0.00	0.00	0.00	0.00
3	16/May	46	Δ	SCI	a	-0.22	0.69	0.00	0.00	0.00	0.00	0.71	0.58	2.13	2.12	0.00	0.00	0.00	0.00
3	16/May	46	Δ	SCI	b	1.23	1.83	0.00	0.00	0.00	0.00	2.21	1.97	0.96	0.93	0.00	0.00	0.00	0.00
3	16/May	46	Δ	SCE	l	84.88	85.52	0.00	0.00	0.00	0.00	81.00	82.51	78.73	78.75	0.00	0.00	0.00	0.00
3	16/May	46	Δ	SCE	a	-0.17	0.71	0.00	0.00	0.00	0.00	0.89	0.66	2.14	2.19	0.00	0.00	0.00	0.00
3	16/May	46	Δ	SCE	b	1.48	2.12	0.00	0.00	0.00	0.00	2.42	2.21	1.19	1.27	0.00	0.00	0.00	0.00
3	19/May	49	1	SCI	l	86.41	85.24					82.77	84.29	80.21	75.58				
3	19/May	49	1	SCI	a	0.35	0.75					0.97	0.79	2.22	2.14				
3	19/May	49	1	SCI	b	0.68	0.75					1.47	1.24	0.01	0.79				
3	19/May	49	1	SCE	l	82.8	84.54					79.42	81.16	76.71	71.76				
3	19/May	49	1	SCE	a	0.31	0.78					1.18	0.81	2.22	2.23				
3	19/May	49	1	SCE	b	0.58	1					1.65	1.28	0.17	0.9				
3	19/May	49	2	SCI	l	86.6	84.44					83.21	85.31	81.47	76.7				
3	19/May	49	2	SCI	a	0.16	0.9					0.97	0.68	2.05	2.63				
3	19/May	49	2	SCI	b	0.51	0.94					1.38	1.01	-0.27	0.82				
3	19/May	49	2	SCE	l	83.54	84.44					80.61	82.11	77.5	72.36				
3	19/May	49	2	SCE	a	0.11	0.94					1.14	0.75	2.01	2.73				
3	19/May	49	2	SCE	b	0.47	1.23					1.64	1.06	-0.13	0.95				
3	19/May	49	3	SCI	l	86.34	86.62					82.94	85.58	82.52	76.55				
3	19/May	49	3	SCI	a	-0.08	0.5					0.7	0.67	1.97	2.54				
3	19/May	49	3	SCI	b	0.4	0.64					1.27	1.17	-0.28	0.87				
3	19/May	49	3	SCE	l	84.41	84.09					80.35	82.43	78.46	72.1				
3	19/May	49	3	SCE	a	-0.09	0.48					0.85	0.71	1.87	2.62				
3	19/May	49	3	SCE	b	0.48	0.75					1.51	1.24	-0.11	0.96				
3	19/May	49	Δ	SCI	l	86.45	85.43	0.00	0.00	0.00	0.00	82.97	85.06	81.40	76.28	0.00	0.00	0.00	0.00
3	19/May	49	Δ	SCI	a	0.14	0.72	0.00	0.00	0.00	0.00	0.88	0.71	2.08	2.44	0.00	0.00	0.00	0.00
3	19/May	49	Δ	SCI	b	0.53	0.78	0.00	0.00	0.00	0.00	1.37	1.14	-0.18	0.83	0.00	0.00	0.00	0.00
3	19/May	49	Δ	SCE	l	83.58	84.36	0.00	0.00	0.00	0.00	80.13	81.90	77.56	72.07	0.00	0.00	0.00	0.00
3	19/May	49	Δ	SCE	a	0.11	0.73	0.00	0.00	0.00	0.00	1.06	0.76	2.03	2.53	0.00	0.00	0.00	0.00
3	19/May	49	Δ	SCE	b	0.51	0.99	0.00	0.00	0.00	0.00	1.60	1.19	-0.02	0.94	0.00	0.00	0.00	0.00
3	21/May	51	1	SCI	l	83.94	86.25					82.29	85.21	73.56	76.48				

Glass	Date	Day	Measurement	SCI / SCE	CIELAB	Dark_1	Dark_2	Xeno_noUV_1	Xeno_noUV_2	Xeno_UV_1	Xeno_UV_2	UVA_los_1	UVA_los_2	UVB_tl_1	UVB_tl_2	Lissabon_No_Vial_1	Lissabon_No_Vial_2	Lissabon_In_Vial_1	Lissabon_In_Vial_2
3	21/May	51	1	SCI	a	0.64	0.26					1.01	0.91	3.15	2.78				
3	21/May	51	1	SCI	b	0.85	0.76					1.49	1.1	1.05	0.97				
3	21/May	51	1	SCE	l	80.38	82.7					79.34	81.95	73.73	72.08				
3	21/May	51	1	SCE	a	0.59	0.22					1.18	0.99	3.19	2.9				
3	21/May	51	1	SCE	b	0.9	0.9					1.67	1.17	1.23	1.09				
3	21/May	51	2	SCI	l	86.17	86.02					82.67	85.51	78.32	77.58				
3	21/May	51	2	SCI	a	0.27	0.33					0.91	0.67	2.95	2.77				
3	21/May	51	2	SCI	b	0.61	0.69					1.41	1.11	0.34	0.68				
3	21/May	51	2	SCE	l	83.36	82.44					79.04	81.97	78.57	73.21				
3	21/May	51	2	SCE	a	0.22	0.29					1.13	0.75	2.99	2.89				
3	21/May	51	2	SCE	b	0.67	0.83					1.53	1.19	0.54	0.84				
3	21/May	51	3	SCI	l	85.75	86.77					83	85.73	76.85	77.26				
3	21/May	51	3	SCI	a	0.26	0.46					0.87	0.62	3.35	2.72				
3	21/May	51	3	SCI	b	0.68	0.65					1.31	0.97	0.69	0.76				
3	21/May	51	3	SCE	l	82.72	84.05					79.64	82.24	77.24	72.85				
3	21/May	51	3	SCE	a	0.21	0.43					1.07	0.7	3.38	2.83				
3	21/May	51	3	SCE	b	0.74	0.83					1.44	1.04	0.87	0.92				
3	21/May	51	Δ	SCI	l	85.29	86.35	0.00	0.00	0.00	0.00	82.65	85.48	76.24	77.11	0.00	0.00	0.00	0.00
3	21/May	51	Δ	SCI	a	0.39	0.35	0.00	0.00	0.00	0.00	0.93	0.73	3.15	2.76	0.00	0.00	0.00	0.00
3	21/May	51	Δ	SCI	b	0.71	0.70	0.00	0.00	0.00	0.00	1.40	1.06	0.69	0.80	0.00	0.00	0.00	0.00
3	21/May	51	Δ	SCE	l	82.15	83.06	0.00	0.00	0.00	0.00	79.34	82.05	76.51	72.71	0.00	0.00	0.00	0.00
3	21/May	51	Δ	SCE	a	0.34	0.31	0.00	0.00	0.00	0.00	1.13	0.81	3.19	2.87	0.00	0.00	0.00	0.00
3	21/May	51	Δ	SCE	b	0.77	0.85	0.00	0.00	0.00	0.00	1.55	1.13	0.88	0.95	0.00	0.00	0.00	0.00
3	27/May	57	1	SCI	l	83.14	84.74					84.06	84.96	77.92	80.17				
3	27/May	57	1	SCI	a	0.5	0.75					1.04	0.83	2.22	2.49				
3	27/May	57	1	SCI	b	1	1.03					1.35	1.28	0.33	0.19				
3	27/May	57	1	SCE	l	80.59	83.1					82.52	81.2	75.31	76.99				
3	27/May	57	1	SCE	a	0.48	0.76					1.16	0.92	2.31	2.58				
3	27/May	57	1	SCE	b	1.21	1.3					1.6	1.41	0.55	0.39				
3	27/May	57	2	SCI	l	84.75	85.6					82.44	84.96	77.44	82.11				
3	27/May	57	2	SCI	a	0.38	0.7					1.09	0.84	1.97	2.32				
3	27/May	57	2	SCI	b	0.79	0.87					1.55	1.31	0.04	-0.13				
3	27/May	57	2	SCE	l	81.44	84.74					79.97	81.03	77.34	78.08				
3	27/May	57	2	SCE	a	0.32	0.73					1.22	0.93	2.01	2.36				
3	27/May	57	2	SCE	b	0.93	1.15					1.74	1.45	0.24	-0.08				
3	27/May	57	3	SCI	l	86.83	86.48					83.76	85.64	78.15	81.14				
3	27/May	57	3	SCI	a	0.09	0.57					0.89	0.76	1.95	2.61				
3	27/May	57	3	SCI	b	0.5	0.81					1.26	1.18	-0.1	0.09				
3	27/May	57	3	SCE	l	84.28	85.38					80.63	81.77	78	77.71				
3	27/May	57	3	SCE	a	0.04	0.59					1.01	0.83	1.99	2.69				
3	27/May	57	3	SCE	b	0.67	1.08					1.44	1.27	0.13	0.24				
3	27/May	57	Δ	SCI	l	84.91	85.61	0.00	0.00	0.00	0.00	83.42	85.19	77.84	81.14	0.00	0.00	0.00	0.00
3	27/May	57	Δ	SCI	a	0.32	0.67	0.00	0.00	0.00	0.00	1.01	0.81	2.05	2.47	0.00	0.00	0.00	0.00
3	27/May	57	Δ	SCI	b	0.76	0.90	0.00	0.00	0.00	0.00	1.39	1.26	0.09	0.05	0.00	0.00	0.00	0.00
3	27/May	57	Δ	SCE	l	82.10	84.41	0.00	0.00	0.00	0.00	81.04	81.33	76.88	77.59	0.00	0.00	0.00	0.00
3	27/May	57	Δ	SCE	a	0.28	0.69	0.00	0.00	0.00	0.00	1.13	0.89	2.10	2.54	0.00	0.00	0.00	0.00
3	27/May	57	Δ	SCE	b	0.94	1.18	0.00	0.00	0.00	0.00	1.59	1.38	0.31	0.18	0.00	0.00	0.00	0.00
3	30/May	60	1	SCI	l	83.34	87.39					82.35	84.31	80.93	78.04				
3	30/May	60	1	SCI	a	0.15	0.45					0.77	0.83	2.66	2.21				
3	30/May	60	1	SCI	b	1.04	0.84					1.77	1.51	-0.05	0.33				
3	30/May	60	1	SCE	l	83.48	84.68					79.4	80.56	81.09	73.71				
3	30/May	60	1	SCE	a	0.18	0.44					0.95	0.86	2.7	2.28				
3	30/May	60	1	SCE	b	1.21	0.98					1.91	1.49	0.15	0.33				
3	30/May	60	2	SCI	l	84.23	87.23					82.6	84.53	81.5	77.19				
3	30/May	60	2	SCI	a	0.04	0.4					0.47	0.87	2.84	2.81				
3	30/May	60	2	SCI	b	0.86	0.72					1.46	1.64	-0.05	0.73				
3	30/May	60	2	SCE	l	83.58	84.74					81.53	81.15	81.17	73.25				
3	30/May	60	2	SCE	a	0.06	0.37					0.54	0.92	2.89	2.95				
3	30/May	60	2	SCE	b	1.05	0.86					1.79	1.61	0.16	0.79				
3	30/May	60	3	SCI	l	83.03	87.69					84.72	85.34	79.98	75.93				
3	30/May	60	3	SCI	a	0.42	0.34					0.47	0.76	3.17	2.93				
3	30/May	60	3	SCI	b	1.24	0.75					1.23	1.46	0.23	0.96				
3	30/May	60	3	SCE	l	81.5	84.46					81.48	81.74	80.37	72.94				
3	30/May	60	3	SCE	a	0.41	0.31					0.62	0.79	3.19	3.07				
3	30/May	60	3	SCE	b	1.42	0.87					1.46	1.47	0.41	1.06				
3	30/May	60	Δ	SCI	l	83.53	87.44	0.00	0.00	0.00	0.00	83.22	84.73	80.80	77.05	0.00	0.00	0.00	0.00
3	30/May	60	Δ	SCI	a	0.20	0.40	0.00	0.00	0.00	0.00	0.57	0.82	2.89	2.65	0.00	0.00	0.00	0.00
3	30/May	60	Δ	SCI	b	1.05	0.77	0.00	0.00	0.00	0.00	1.49	1.54	0.04	0.67	0.00	0.00	0.00	0.00
3	30/May	60	Δ	SCE	l	82.85	84.63	0.00	0.00	0.00	0.00	80.80	81.15	80.88	73.30	0.00	0.00	0.00	0.00
3	30/May	60	Δ	SCE	a	0.22	0.37	0.00	0.00	0.00	0.00	0.70	0.86	2.93	2.77	0.00	0.00	0.00	0.00
3	30/May	60	Δ	SCE	b	1.23	0.90	0.00	0.00	0.00	0.00	1.72	1.52	0.24	0.73	0.00	0.00	0.00	0.00
3	03/Jun	64	1	SCI	l			70.34	82.6	82.19	79.16								
3	03/Jun	64	1	SCI	a			0.34	0.13	0.73	1.05								
3	03/Jun	64	1	SCI	b			2.21	1.18	1.13	1.65								
3	03/Jun	64	1	SCE	l			70.1	82.55	78.82	78.17								
3	03/Jun	64	1	SCE	a			0.38	0.17	0.86	1.1								
3	03/Jun	64	1	SCE	b			2.35	1.38	1.19	1.76								
3	03/Jun	64	2	SCI	l			72.77	77.93	82.51	78.7								
3	03/Jun	64	2	SCI	a			0.5	0.03	0.19	0.4								
3	03/Jun	64	2	SCI	b			2.19	1.4	0.88	1.06								
3	03/Jun	64	2	SCE	l			72.65	77.91	82.05	78.67								
3	03/Jun	64	2	SCE	a			0.54	0.06	0.24	0.43								
3	03/Jun	64	2	SCE	b			2.34	1.53	1.09	1.21								
3	03/Jun	64	3	SCI	l			79.92	80.04	80.66	77.05								
3	03/Jun	64	3	SCI	a			0.13	-0.31	0.09	0.94								
3	03/Jun	64	3	SCI	b			1.24	1.07	1.07	1.86								
3	03/Jun	64	3	SCE	l			80	80.03	80.69	76.99								
3	03/Jun	64	3	SCE	a			0.17	-0.27	0.13	0.98								
3	03/Jun	64	3	SCE	b			1.38	1.2	1.21	2								
3	03/Jun	64	Δ	SCI	l			74.34	80.19	81.79	78.30								
3	03/Jun	64	Δ	SCI	a			0.32	-0.05	0.34	0.80								
3	03/Jun	64	Δ	SCI	b			1.88	1.22	1.03	1.52								
3	03/Jun	64	Δ	SCE	l			74.25	80.16	80.52	77.94								
3	03/Jun	64	Δ	SCE	a			0.36	-0.01	0.41	0.84								
3	03/Jun	64	Δ	SCE	b			2.02	1.37	1.16	1.66								

Appendix XI: Conversion of microwatts per lumen to joule per square centimetre per hour

1. Conversion of the microwatt per square meter to watt per square meter:

$$\frac{1mW}{m^2} = \frac{0.001W}{m^2}$$

2. Conversion to joules per second, per square meter:

$$0.001\frac{W}{m^2} = 0.001\frac{J/s}{m^2}$$

3. Conversion to joule per hour:

$$0.001\frac{J/s}{m^2} * 3600\frac{s}{h} = 3.6\frac{J/h}{m^2}$$

4. Conversion to joule per hour per square centimetre:

$$1m^2 = 10.000cm^2 \rightarrow \frac{3.6}{10.000} = 0.00036\frac{J/h}{cm^2}$$