https://doi.org/10.2352/issn.2168-3204.2023.20.1.25

A Simple Ultraviolet-Induced Visible Fluorescence Target or a low-cost alternative to a Spectralon®

Yosi Pozeilov; Senior Imaging Specialist and Photographer, LACMA Conservation Center; Los Angeles, CA. USA

Abstract

A prevailing question among conservators and imaging professionals producing cultural heritage documentation and research is how to obtain an ultraviolet-induced visible fluorescence (luminescence) image that allow us to assess the quality of the filtration used and the environment in which the image is being captured. The literature on this topic generally recommends use of delicate and expensive control targets. This article describes a simple low-cost method to create and use a target that can aid in capturing images that are consistent and thus raising the confidence level of the images created.

Introduction

This paper reports on the assembly and use of a simple, low-cost target to aid in the systematic production of ultraviolet-induced visible fluorescence (luminescence) images. The goal was to make a simple target - one that can be used as a calibration tool, monitors light leaks in the environment, and aids with the position of radiation fixtures. For the purpose of this paper the term ultraviolet-induced visible fluorescence [UV-F] will refer to the luminescence generated in the visible spectrum when the surface of an art object is irradiated with an ultraviolet source. The term "light leak" is used to denote the photographic evaluation of the environmental conditions under which an object is being imaged. An essential condition for this process is that there are no other light or radiation sources that would interfere with the generation of the UV-F image.

Many scholarly publications have been devoted to the methods used to obtain the best UV-F images possible. [1,2,3,4] They also have described the development of a purpose-built UV-F target by the company UV Innovations™. [5]

At the core of these techniques is the fundamental dependence on the use of at least one costly target. What they all have in common is that controlling and verifying the imaging environment is based on the use of Labsphere's Spectralon® standard ($400 and up) or similar commercial targets. In addition, the UV Innovations target ($875) is intended to generate more repeatable and comparable images by determining the intensity of fluorescence produced by different proprietary materials in the target itself. This target was not designed to evaluate the imaging environment, or the proper filtration used during the UV-F imaging session. Therefore, it is necessary to use a Spectralon® or similar targets in addition to the UV Innovations one.

The Spectralon® target most widely used, and the focus of this article is the 99% reflectance target, which appears flat and solid white to the naked eye. It is worth noting that Spectralon® standards are important to calibrate other imaging and analytical spectroscopic techniques. The Spectralon® standards are directly traceable to NIST, hence commanding a premium price.

Even though the UV Innovations™ website has information about its creation and testing, there are no published data describing the manufacture and composition of the UV Innovations™ target. The literature on the Spectralon® characterizes it as follows:

Spectralon® *is a fluoropolymer, which has the highest diffuse reflectance of any known material or coating over the ultraviolet, visible, and near-infrared regions of the spectrum. It exhibits highly Lambertian behavior and can be machined into a wide variety of shapes for the construction of optical components such as calibration targets, integrating spheres, and optical pump cavities for lasers.* [6]

A ***fluoropolymer*** *is a fluorocarbon-based polymer with multiple carbon–fluorine bonds. It is characterized by a high resistance to solvents, acids, and bases. The best-known fluoropolymer is polytetrafluoroethylene [PTFE]. The trademark Teflon was coined by the DuPont Company in 1946.* [7]

An issue with routine use of the Spectralon® is that this target has a very delicate surface, which is unexpected because Teflon is known to be an impermeable and inert material. But the fact is that the Spectralon® becomes dirty quickly if not handle with caution, accumulating oils and soil that fluoresce under UV radiation. Once dirty it loses its much-desired quality of remaining photographically neutral, i.e., appearing dark in an image taken under ideal environmental conditions. As can be seen in Figure 1b the two older, soiled Spectralon® standards fluoresce (in the circle) while the newer ones (in the rectangle) remain dark.

In an effort to refurbish the Spectralon® standards and remove the top soiled layer, an attempt was made to "clean" them. Initially they were treated with reagent grade acetone which prove ineffective. Next, they were sanded with several fine-grit micromesh sandpapers (used for cross-section preparation). Sanding was only partially successful as can be seen in the Figure 1d (red circle). Alternatively, a microtome might possibly be used to remove a thin layer from the surface of the Spectralon® to provide a "new" clean surface. [8] This method was not used due to inaccessibility to this tool.

Given the sensitivity of the Spectralon® surface, the need to regenerate it frequently (if possible), and specially its high cost, finding an alternative would be very advantageous. It should be noted that even though the Spectralon® may look clean under visible light, damages due to dirt on the surface will make it inappropriate for use under UV radiation. For these reasons the search for another target material that is cost effective, accessible, easy to replace and worry-free, led to the development of the simple UV-F target described in this paper.

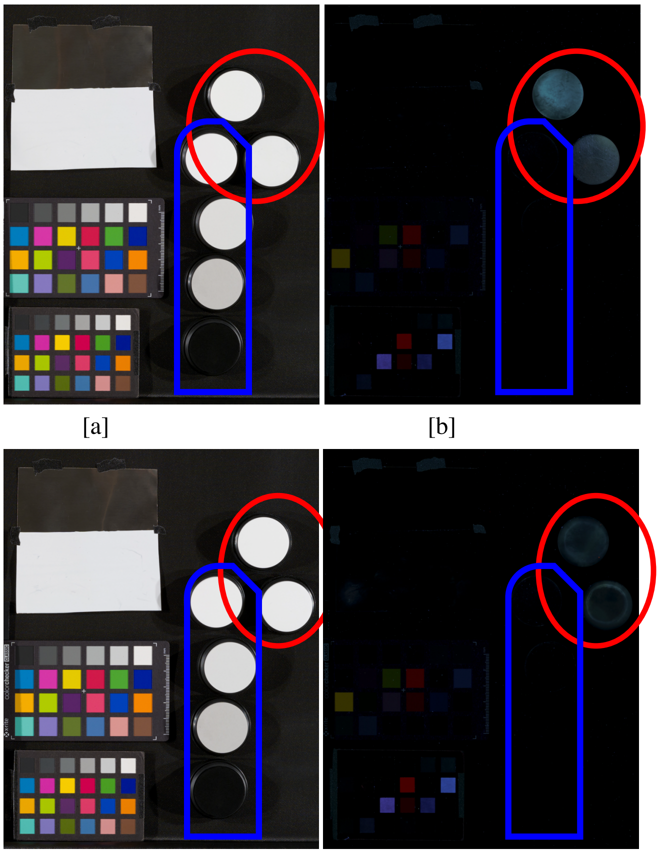


Figure 1. UV-F testing targets set-up: (a) and (c) are visible images; (b) and (d) are the UV-F images, (b) shows the two older/soiled Spectralon® standards {circled in red}, (d) shows the same Spectralon® standards {circled} after sanding.

Searching for a suitable, more affordable, substitute for the Spectralon® that is widely available to cultural heritage professionals was sought. The Passport ColorChecker® by Calibrite [formerly X-rite] ($100) was a possible candidate. This target is designed to profile a camera's response to color under visible light conditions. It does contain, however, a few patches that fluoresce under UV radiation (Figure 1b-d), thus providing a basic measurement of the UV exposure levels that is different from the UV-Innovation™ target. In contrast, the Spectralon® provides more information on the environmental lighting conditions.

A very simple and interesting way of testing for stray UV radiation and total light exposure was suggested by Peter Hansel in the book Photography for the Scientist. Hansel writes in chapter 8:

"A piece of polished metal, such as a penknife blade, should always be included…. As polished metal does not itself fluoresce, no image of it should be recorded. However, any visible reflections… will indicate the degree and character of visible light "leakage" within the system." [9]

Combining Hansel's comments with the fact that the Spectralon® is composed of Teflon, a search was undertaken to find comparable materials with which to construct a simple target for monitoring environmental light leaks. A target was developed to achieve this, and to serve as a calibration tool under UV radiation (Figure 2). Two materials were selected from the McMaster-Carr catalog - a polished stainless-steel mirror-like foil with adhesive backing, and high-density polytetrafluoroethylene (PTFE) white pipe thread sealant tape.

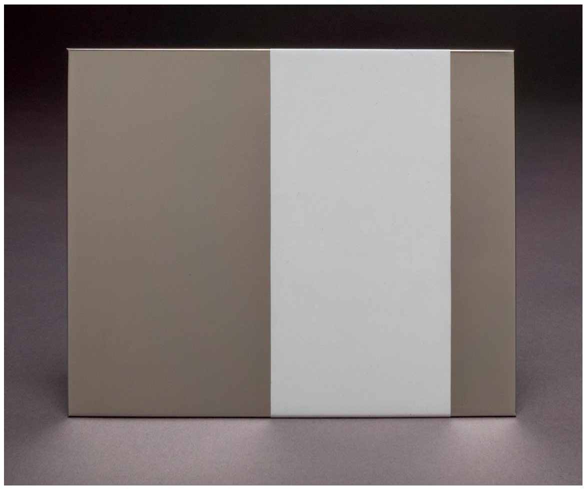


Figure 2. The simple ultraviolet-induced visible fluorescence target.

Materials (Figure 3a)

1) Polished Multipurpose 304 Stainless Steel Mirror-Like Foil with adhesive backing 0.0020" Thick. 6" Wide (McMaster-Carr #8452K95) ($179.00)
2) High-Density Thread Sealant Tape PTFE, 0.0035" Thick, 2" Wide, 14 Yard Long, White (McMaster-Carr #6802K87) ($40.00)
3) Two-ply acid free mat board 4x5" ($10.00)
4) Non-fluorescing black paper tape ($10.00)

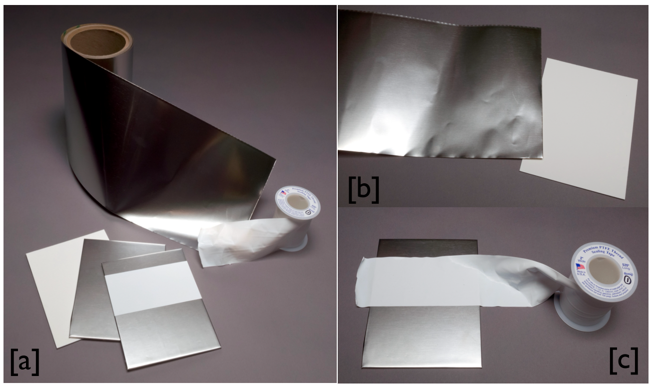


Figure 3. Assembling the UV-F target: (a) Polished stainless-steel mirror-like foil with adhesive backing, PTFE high-density pipe thread white tape 2" wide, 4x5 acid free mat board (shown in three stages). (b) Wrapping the stainless-steel foil around the mat board. (c) Wrapping the PTFE white tape around the foiled card. Finished UV-F target (See figure 2).

Assembling the simple UV-F Target

Making the target is straight forward (Figure 3):

1) Adhere the foil to a 4x5 inch acid-free mat board (Figure 3b).
2) Place a strip of the PTFE tape over the foil at one end, wrapping the PTFE tape around the board (Figure 3c).
3) Secure the PTFE at the back with non-fluorescing tape.

Note: Keep the working countertop clear and clean, providing the PTFE tape with a suitable protective contact surface while attaching to the foiled 4x5" board.

Avoid touching the surface of the PTFE tape during the assembly process, as well as while in use. As with the Spectralon®, the PTFE tape can get soiled with oils and grime which will appear as fluorescence. When this happens replacing the strip of PTFE tape with a new one is simple (Step 2 and figure 3c), and the cost is very low. This ensures that a fully functional target is always at hand and reliable (Figure 3d). If desired, different sized targets and configurations can be made to suit different imaging needs.

Measuring and Comparing the Simple UV-F Target vs the Spectralon® 99% reflectance standard

In order to validate the use of the PTFE tape as a low-cost replacement for the Spectralon® standard for this method of imaging, an unbiased scientific spectroscopic approach was implemented to measure and compare them. It is important to point out that this paper is not suggesting that the PTFE is a replacement when a scientific grade standard is needed for the calibration of analytical equipment and control of scientific data.

Spectroscopic measurements were performed to obtain reflectance data across the visible spectrum using commonly available instruments and a scientific grade one.

Instrumentation and Software

Measurements and processing of the spectra was done with:

- Cary 60 UV-Vis Spectrophotometer (250-850 nm) by Agilent with Barrelino remote diffuse reflectance accessory by Harrick Scientific
- Gregtagmacbeth i1Pro (1) Spectrophotometer (380-730 nm)
- X-Rite i1Pro (3) Spectrophotometer (380-730 nm)
- SpectraShop™ 6 by Robin Myers
- Microsoft Excel

Measurement results

Using the i1Pro (3) Spectrophotometer and processing the data using SpectraShop™ 6 (CIELAB 1976) spectral curves were obtained for four different 99% reflectance Spectralon® standards, three one-inch round and one 2x2 inch (left side of figure 4). From the graphs we can clearly see that the reflectance behavior is as expected, a linear response (for clean and soiled targets) at or close to 99% reflectance in the visible spectrum range of 380 to 730 nm. L*a*b* values are shown as reference as well.

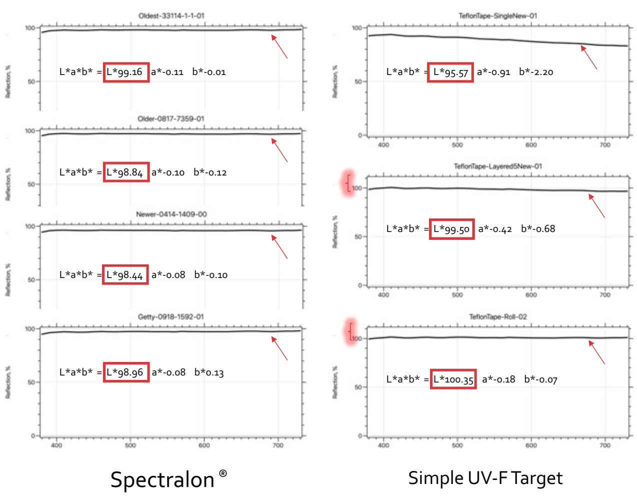


***Figure 4.** Reflectance measurements*

When comparing against measurements made for the PTFE tape on the simple UV-F target,

we can see that the curves obtained vary depending on the amount of PTFE layers used. When a single layer of PTFE is used, we can see reflectance interference coming from the shiny foil underneath, causing the curve to slope down at higher visible nanometer values (Figure 4, top right graph). In contrast when we measured the 5-layer PTFE tape, the shiny foil effect is eliminated, and we obtain a straight-line across the spectrum very much like the Spectralon's® one (Figure 4, middle right graph).

Please note the slight shift up on the Y axis of these two last graphs marked with the red bracket.

The last graph was made out of curiosity to see what result would be obtained when measuring the PTFE tape directly in its spool (Figure 4, bottom right graph).

To corroborate the i1Pro (3) measurements, the scientific grade Cary60 with the Barrelino attachment was used to measure reflectance spectra response from 250 to 850 nm, data processing was done with Agilent's software and Microsoft Excel®.

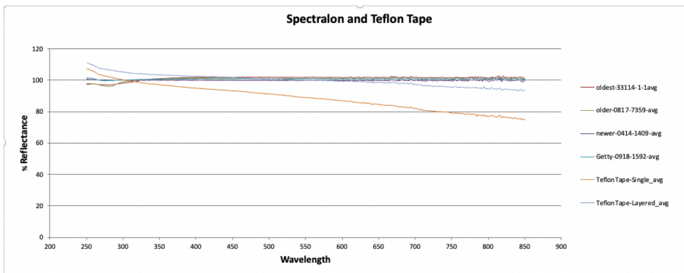


***Figure 5.** Reflectance measurements*

The measurement results from the Carry60 plus Barrelino yield spectral curves that are very much in line with the previous findings (Figure 5), corroborating the i1Pro (3) measurements. The 5-layered PTFE tape behaves very similarly to the other four Spectralon® targets. Although the Carry 60 provides measurements in a wider range of spectra, the values graphed are cropped to resemble and match the ones produced by the i1Pro (3).

Using the simple UV-F target

As with any other target the UV-F target must be positioned within the scene to be imaged, close to the artwork and under the same lighting/radiation conditions as the subject being photographed. When it is placed near the center of the scene, the target helps to determine if the radiation sources are positioned appropriately at the right distance and angle. Under proper lighting conditions the polished stainless-steel foil remains completely dark, without reflecting any blue/violet light. The foil will also reveal any other light source that is leaking into the scene by reflecting the invasive light.

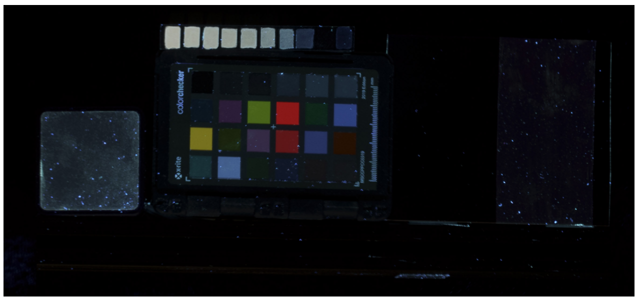
The next step, after determining that the environment is appropriate to successfully acquire UV-F images, is to evaluate the quality of the UV radiation sources and the efficacy of the camera filtration. This is accomplished by confirming that the strip of PTFE is completely dark in the captured images (do not rely on the *insitu* visual appearance). If the PTFE tape shows any color (e.g., violet or magenta), this indicates that the radiation sources are not properly filtered and/or that the camera filtration pack is not the appropriate one to use. Results achieved with this procedure should be comparable to those obtained when using the Spectralon® target.

Figure 6 shows examples of the UV-F target in use. Figure 6a is a visible image containing a new Spectralon® on the right and the UV-F target in the center. Figure 6b is the same image under UV radiation. Note how the UV-F target and Spectralon® responded similarly, remaining completely dark. Figures 6c and 6d represent a different setup showing the effect that the UV radiation has on an older, used Spectralon®. Note here how the UV-F target remains dark, but the Spectralon® fluoresces. Lastly Figures 6e and 6f show the behavior of the UV-F targets under controlled conditions described above; in contrast to Figure 6g indicating a light leak (this image has been enhanced to show this fine distinction for this publication).

[a]

[b]

[c]



[d]

[e]

[f]

[g]

Figure 6. *Using the simple UV-F target. (a) Visible image of targets. Left: older ColorChecker® Mini; center: UV-F target; right 4 Spectralon® 99, 75, 50 and 2 % diffuse reflectance. (b) UV fluorescence comparing the UV-F target to the Spectralon®. (c) Visible image of targets. Left: Spectralon 99% reflectance; bottom center: new ColorChecker® Passport; upper center: Egyptian blue target; right: UV-F target. (d) UV fluorescence comparing the soiled Spectralon to the UV-F target. (e) Visible image. Left: partial ColorChecker® Mini; right: UV-F target. (f) UV fluorescence with the UV-F target, without light leak. (g) with light leak.*

Conclusion

Imaging targets are an essential tool in the acquisition of thorough cultural heritage documentation. They enable the photographer to evaluate an array of conditions that impact the quality of the images generated. Commercial UV-F target selection is limited, they are costly and improper handling can render them useless. This paper introduces a cost-effective and simple solution to achieving the similar results for UV-F imaging as obtained with the commercial Spectralon®. Constructed from the same material as the Spectralon® (PTFE), the simple UV-F target uses PTFE tape in combination with a highly reflective metal sheet. This simple combination will provide confirmation of a light leak free environment and indicate that the proper camera filtration and radiation emission is achieved to obtain accurate results. The simple UV-F target is accessible to everyone, easy to assemble, affordable, and ensures that a reliable system will always be available when capturing UV-F images.

References

[1] Ultraviolet and Fluorescence Photography, Kodak Data Book Publication No. M-27 (1972)

[2] Dyer, J., Verri, G., Cupitt, J., Multispectral Imaging in Reflectance and Photo-induced Luminescence Modes: A User Manual, *CHARISMA* guidelines by the British Museum and Seventh Framework Programme (2013)

[3] Picollo, M., Stols-Witlox, M., Fuster-Lopez, L. (Eds.) UV-Vis Luminescence, Imaging Techniques, Conservation 360°, Editorial Universitat Politècnica de València (2019)

[4] AIC-IWG wiki

[5] Messier, P *et al,* UV-Innovation™ Target; https://www.uvinnovations.com

[6] *Wikipedia:* https://en.m.wikipedia.org/wiki/Spectralon

[7] *Wikipedia:* https://en.m.wikipedia.org/wiki/Fluoropolymer

[8] Personal conversation with Giovanni Verri

[9] Hansel, P., *Ultraviolet and Fluorescence Recording*, chapter 8 in Photography for the Scientist, Engel, C.E. (Ed.), Academic Press (1999) page 378.

Author Biography

Yosi Pozeilov joined the Los Angeles County Museum of Art (LACMA), Conservation Center as the Senior Conservation Photographer in 2003. In addition to being responsible for all the technical and scientific imaging for the Conservation Center, Yosi has been implementing computational imaging techniques like Reflectance Transformation Imaging (RTI), photogrammetry and spectral imaging. He also established protocols to streamline condition reporting with the use of mobile technology and imaging-based systems on handheld devices.