

JPSS J2 Spectralon® Performance pre Launch

Vijay Murgai^{*a}, James J. Butler^b, and Xiaoxong Xiong^b

^aRTX

^bSciences and Exploration Directorate, NASA/GSFC, Greenbelt, MD 20771

ABSTRACT

Spectralon® is a high reflectance excellent diffuser used to reflect sunlight for use as a calibrator for on-orbit and ground instruments. Radiometric calibration of the reflective bands in the 0.4 to 2.5µm wavelength range is performed by measuring the sunlight reflected from Spectralon®. Reflected sunlight is directly proportional to the Bidirectional Reflectance Distribution Function (BRDF) of the Spectralon®. On-orbit exposure to sunlight results in solarization due to solar UV and the presence of residual contamination. Spectralon® quality is checked at start of build by measuring the change in reflectance on exposing a witness sample to 100 hours Solar UV as an indication of on orbit performance. For JPSS J2, the witness samples accompanied the sensor till 30 days before launch. Measuring the reflectance change on exposure to Solar UV of the witness samples accompanying the sensor through build and test is a better indication of on orbit performance as this includes any additional contamination during the build and test phase.

Keywords: spectral reflectance, SDSM, Spectralon®, solarization, JPSS, VIIRS, RSB, RSR

1 INTRODUCTION

Radiometric measurements frequently compare a known and unknown source by measuring the signal reflected from a standard. Examples of this include sensors such as VIIRS, Landsat, MODIS, MERIS, MISR, IKONOS, and Hyperion [1][2][3][4][5][6][7] which use the sun's reflection from a Lambertian surface (such as Spectralon®) to calibrate the sensor in the reflective bands (400 – 2500 nm). Other instances involve calibrating light sources relative to a known standard light source by reflection off a Lambertian surface. For Visible/Infrared Imaging Radiometer Suite (VIIRS), the radiometric calibration of the reflective bands depends on sunlight reflectance from a Spectralon® panel. Sun shines through the Solar Attenuator Screen onto the Solar Diffuser (Spectralon® panel). The radiance of the sun light reflected from the Solar Diffuser is given by Equation 1 (not including the transmission of the Solar Attenuator Screen). From Equation 1 we see that the illumination of the panel, L_{cal} , is proportional to the sunlight, E_{sun} , the Bidirectional Reflectance Function ($BRDF = BRF/\pi$) of the panel, and the cosine of the angle of incidence ($\cos\theta_{AOI}$). Thus, the error in the knowledge of the BRDF translates directly into error in the radiometric calibration of VIIRS for the reflective bands.

$$L_{cal} = E_{sun} \times \frac{BRF}{\pi} \cos\theta_{AOI} \quad 1$$

As the knowledge requirement of the radiometric calibration contribution from the diffuser reflectance is ~1% and as there is significant variation from piece to piece of Spectralon®, each panel is individually characterized (see [8] and references cited). Spectralon® reflectance at the blue end of the spectrum is known to degrade due to exposure to UV. This has been observed both in ground exposures ([9][10]) as well as on orbit ([11][12][13][14][15][16]). The degradation, which is a function of the trace organics and exposure, varies from panel to panel depending on the contamination. Additionally, each sensor has different amounts of Spectralon® exposure to the sun (e.g. MISR [17] exposure is once every two months, versus VIIRS which gets exposure every orbit). Therefore the Spectralon® onboard these spacecrafts will have different rates of degradation relative to time on orbit. MODIS and VIIRS use a SDSM (Solar Diffuser Stability Monitor) to track and correct for the reflectance changes [18]. Previously the level of organic contamination on the Spectralon® panel has been determined by measuring the reflectance degradation due to

*vijay.murgai@rtx.com; phone 310-647-0883; www.rtx.com; Raytheon, Bldg. E01, M/S D109, PO Box 902, El Segundo, CA 90245-0902

exposure to UV at the start of the build phase. Panels with degradation lower than a specified value were used while other panels rejected. Previous work has shown how to specify and select Spectralon® panels with the least degradation prior to UV exposure testing [19]. So as to have a better indication of Spectralon® panel change with solar UV exposure, the contamination just prior to launch, reflectance change due to UV exposure of witness samples that accompanied VIIRS through build test and integration for JPSS-2 is shown.

2 EFFECT OF UV EXPOSURE ON REFLECTANCE

2.1 Reflectance and UV exposure Variation

Spectralon®, sintered PTFE, is the material of choice as a reference material due its high reflectance and near Lambertian scattering properties due to multiple ‘bounces’ of incident light. Though PTFE is known to be inert, organics are introduced from the manufacturing process or later due to storage, handling, and environmental exposure can introduce contaminants. During the development phase of MISR and MERIS, ground based UV exposure testing was performed and the results demonstrated sensitivity to UV exposure. The sensitivity and overall degradation due to UV exposure is dependent on the amount of organics that are introduced. Bake out of Spectralon® panels frequently resulted in reduction of magnitude of degradation for a given UV exposure. Labsphere incorporated this knowledge into their process for manufacturing Space Grade Spectralon® by minimizing contamination sources during the bake out of the as received resin, sintering process, and machining. In addition, Labsphere bakes out all parts and witness samples as a final step prior to shipping.

Raytheon process for use of the Spectralon® panel included measuring the BRF of each part in the as used configuration [8]. Each panel is manufactured individually with both the part and the witness samples cut out from the same panel. Testing over several panels (NPP, J1, J2, and J3) and Spectralon® samples (PASCAL reference for variation) demonstrated that there is variation from piece to piece in the magnitude of BRF, spatial variation, as well as variation with rotational orientation of the panel. From these results, we infer that the as manufactured properties of Spectralon® vary and therefore need to be characterized when knowledge of ~1% or better is desired.

In addition to characterizing the BRF of the Spectralon® panel, Raytheon tests the potential of degradation on orbit by measuring the change in hemispherical reflectance due to 100 hours of solar UV of a witness sample cut from the same Spectralon® panel as the part. The objective is to have the least possible degradation, which is determined by taking the ratio of the post UV exposure reflectance to the pre exposure reflectance. The reflectance degradation is at the blue end of the spectrum so that the sample will ‘yellow’ in analogy with yellowing / solarization of plastics: organic materials. This yellowing is due to UV breaking bonds of organic materials. Figure 1 shows the post UV exposure to pre UV exposure of witness samples from several panels from the set obtained for JPSS J1 and the set obtained for JPSS J2, J3, J4 as well as the specification limits of the minimum ratio in red. From Figure 1 we see large variations in degradation for the 4 panels acquired for JPSS J2, J3, J4 (S/N K, L, M, and P) with significantly less degradation observed for JPSS J1 whose panel was part of a previous set.

Variation in degradation is also observed for performance on orbit. For example, Figure 2 shows the time dependent change in reflectance as monitored by the SDSM for various bands ranging from 412 nm (black) to 930 nm (red) for MODIS Terra (dots), Suomi NPP (dashes), and JPSS J1 (solid). The spectral degradation is analogous to Figure 1 where maximum degradation is observed at the blue end of the spectrum and minimal to no changes past about 800 nm. From the figure, we see that Suomi NPP has lower degradation than Terra (MODIS). We also see that the degradation of JPSS-J1 is substantially lower than Suomi NPP though both panels are from the same lot. Exposure rate is the same for both cases. Thus, for both laboratory testing and on orbit performance we see significant variation in degradation.

For JPSS J2 VIIRS two Spectralon® witness samples of the Solar Diffuser Panel accompanied VIIRS through the build and test process in addition to a ‘fly away’ witness sample. These witness samples were brought back to Raytheon 30 days prior to launch and exposed to 100 hours UV to determine extent of contamination / degradation due to the build / test phase.

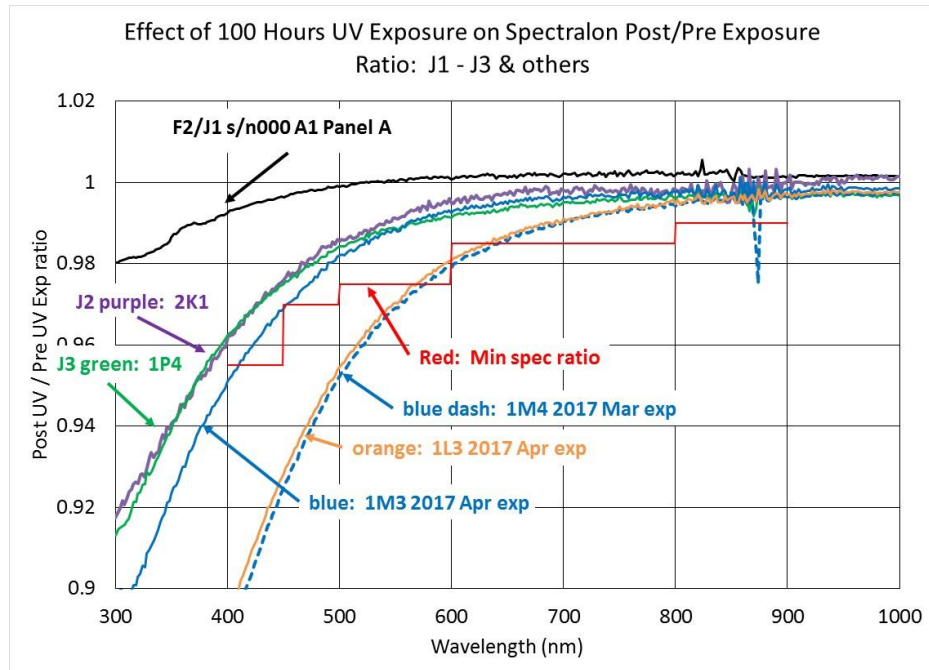


Figure 1 Spectral reflectance degradation for witness samples from various Spectralon® panels.

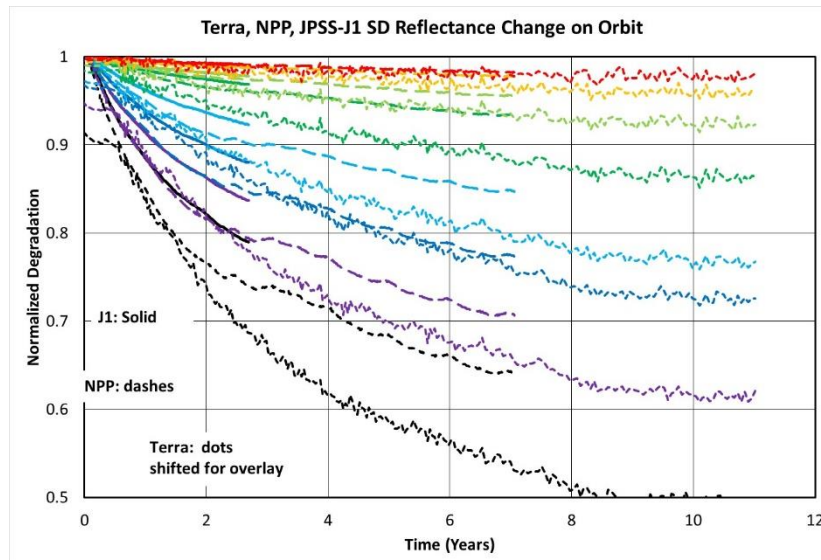


Figure 2: Comparison of JPSS J1 (solid), Suomi NPP (dashes) and Modis Terra (dots) Reflectance degradation as a function of time on orbit measured by SDSM bands from 412 nm (black) to 930 nm (red). Terra time shifted to overlay Suomi NPP and JPSS J1 from time door left open

2.2 Hemispherical Reflectance Methods

Hemispherical reflectance measurements at Labsphere are made relative to pressed PTFE powder. The spectral response of the pressed PTFE is known and traceable to NIST. Thus, the baseline, scan is done with the pressed PTFE in the sample position. The standard is then replaced with the sample to be measured. The resulting scan is then multiplied with PTFE reflectance [20].

For hemispherical reflectance measurements at Raytheon, measurements are made relative to a Spectralon® standard. The standard is calibrated at Labsphere using the measurements described above. The Spectralon® standards used at Raytheon are not part of the panels purchased for flight. References [23][24][25][26][26] provide additional information on the properties and use of Spectralon®.

2.3 JPSS Panel and Witness Samples

For JPSS-1, a panel from the same batch of four panels as Suomi NPP was used (manufactured 2004). As the remaining two panels were not sufficiently flat, an additional set of four panels (batch 2) was ordered from Labsphere with modifications in the shipping container so that the panels were stored / held horizontal rather than vertical. Of the four additional panels purchased for JPSS-2, JPSS-3, and JPSS-4, three of the panels showed excessive degradation due to UV exposure as discussed in Reference [19]. This led to development of new specification and analysis methods that allowed Labsphere to have a good indication of contamination based on pre and post bake reflectance data prior to any UV exposure. The methods developed were used for the purchase of Spectralon® panels for JPSS-3 and JPSS-4 (batch 3) [19] while panel K from batch 2 was used for JPSS-2.

For JPSS-2 in addition to the ‘fly away’ 1" OD Spectralon® witness sample mounted next to the Solar Diffuser Panel, a 1" OD Spectralon® witness sample (1K7) was added to the witness sample holder. Also a 2" OD Spectralon® witness sample (2K4) was kept adjacent to VIIRS and opened to the environment. The 1" OD Spectralon® witness sample (1K7) accompanied the sensor into spacecraft for TVAC and EMI but not for vibe where it remained in the Northrop Grumman clean rooms. Though the 2" OD Spectralon® witness sample accompanied VIIRS in clean rooms, it did not accompany the sensor into TVAC, EMI or vibe. Thus the 1" OD Spectralon® witness sample (1K7) saw more of the sensor environment than 2" OD Spectralon® witness sample (2K4).

Both the Spectralon® witness samples (1K7 and 2K4) were brought back to Raytheon approximately 30 days prior to JPSS-2 launch. Hemispherical reflectance measurements were made on these two samples as well as a 2" OD Spectralon® control sample (2K2) manufactured adjacent to the same Solar Diffuser Panel. Figure 3 shows the hemispherical reflectance of the two witness samples (1K7 and 2K4) and the control sample (2K2) before and after exposure to 100 hours UV. The witness samples accompanying VIIRS (JPSS-2) were exposed while the control sample was left in a purged environment.

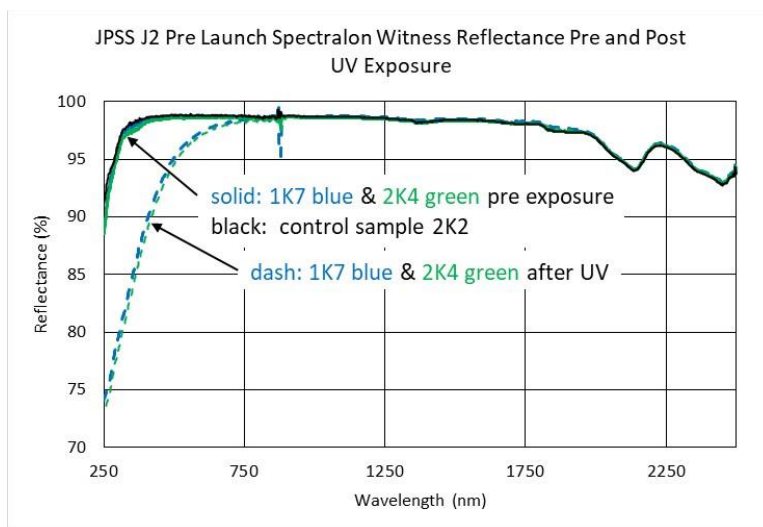


Figure 3 JPSS-2 1K7 (blue), 2K4 (green), and 2K2 (control black) hemispherical reflectance before and after exposure to 100 hours of UV

Rather than relying on absolute values, the ratio of reflectance post UV exposure to pre UV exposure was calculated. This is analogous to the ratio calculated for on orbit changes. In addition to the control sample (2K2) and the samples that accompanied JPSS-2 (1K7, 2K4), Figure 4 also shows the ratio of the sample tested at the start of the build phase

(2K1). From the figure we see that the control sample (2K2, black) did not show any change in reflectance indicating acceptable reflectance measurements. All the samples exposed to UV show reduction in reflectance below 850 nm with the post / pre exposure ratio decreasing with decreasing wavelength consistent with results shown above. We also see that the samples accompanying JPSS-2 2K4 (purple) and 1K7 (green) overlay each other indicating that they have the same amount of the degradation though 2K4 did not accompany JPSS-2 for TVAC or EMI. Thus TVAC and EMI did not have a significant addition to contamination on the Spectralon® samples. However the reduction in reflectance is larger than for the Spectralon® sample exposed to UV at the beginning of the sensor build (2K1). At 411 nm the post UV to pre UV exposure is 0.962 while for the pre launch samples (2K4 and 1K7) the ratio is 0.91. Clearly there is an increase in organic contamination during the build and test process.

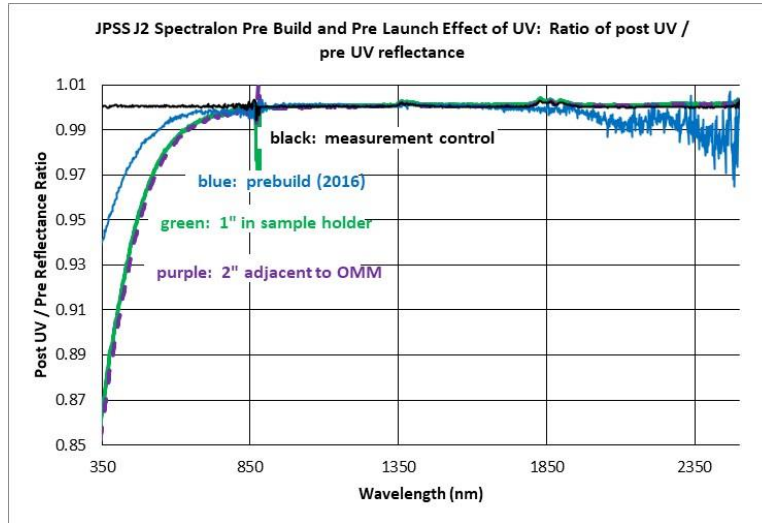


Figure 4 Reflection ratio of post UV exposure to pre UV exposure for JPSS-2 2K2 (control black), 2K1 pre build test (blue), 1K7 (green), 2K4 (purple)

3 COMPARISON WITH ON ORBIT PERFORMANCE

3.1 On Orbit UV Exposure Rate

The objective of determining the effect of UV exposure on the hemispherical reflectance on Spectralon® samples is to have an indication of expected on performance degradation rates. As seen in Figure 2, the reflectance degrades rapidly initially and then asymptotically approaches limiting degradation. We expect that the larger the degradation at 100 hours of UV exposure, the larger the initial rate of degradation as well as lower end of life Solar Diffuser Panel reflectance.

So as to compare with on orbit performance, we need to calculate the rate of UV exposure on orbit. For JPSS exposure is a combination of direct illumination through the Solar Attenuator Screen as well as earth shine through the nadir door. Direct illumination rate is calculated using the equation below. The Solar Attenuator Screen transmission, τ_{sas} , has been presented previously [27]. The sun to Solar Diffuser normal angle is centered at 53.75 degrees. Thus there is ~100 hours of direct UV illumination in 2 years.

$$UVminutes/day = \tau_{sas} \times \cos(\text{sun to SD deg}) \times \frac{8.3 \text{ min}}{\text{orbit}} \times 24 \text{ hours} \times \frac{60 \text{ min/hour}}{101.5 \text{ min/orbit}} \quad 2$$

Direct line of sight occurs between the solar diffuser and earth through the nadir door as a function of the rotating telescope assembly angle. The solid angle is a function of the rotating telescope assembly angle. At the center of the

solid diffuser with Solar Diffuser to nadir angle of 16.8 degrees, an albedo of 0.2, and solid angle calculated from ray tracing, the equation below gives a UV exposure of 74.9 hours over 2 years.

$$\frac{UV \text{ hours}}{\text{day}} = \frac{\text{albedo}}{\pi} \times \cos(SD \text{ to nadir deg}) \times \Omega_{\text{solid angle}} \times \text{fraction in sunlight} \times 24 \quad 3$$

Combining the direct illumination through the Solar Attenuator Screen and earth shine through the nadir door, the total exposure rate is 174.9 hours of UV every two years.

For MODIS (Terra and Aqua), again the UV exposure consists of direct illumination as well as earth shine. Direct exposure over 2.5 years is 6.816 hours. For Earth shine the exposure is 74.403 hours over 2.5 years. For Terra, the direct exposure rate increased after the door to the calibrators was left in the ‘open’ position.

3.2 Comparison with on orbit Measurements

Using the exposure rates shown in the previous section (174.9 hours UV / 2 years for Suomi NPP and JPSS, 82.2 hours / 2.5 years for MODIS), we can calculate the degradation due to UV exposure on orbit and compare with lab UV exposure of witness samples. Figure 5 shows on orbit data for MODIS (Terra and Aqua) in black, Suomi NPP purple, and JPSS-1 green. JPSS-1 and JPSS-2 UV exposure degradation pre build and JPSS-2 pre launch are shown as solid symbols. Figure 2 compares Terra, Suomi NPP, and JPSS-1 as a function of time on orbit. However as shown above the rate of UV exposure is different for VIIRS (Suomi NPP and JPSS-1). Figure 5 shows degradation as a function of UV exposure. From Figure 5 we see that degradation per UV exposure hour is highest Suomi NPP, then J1 and least for Aqua and Terra. For on orbit versus ground degradation rate, we see that JPSS-1 pre build has a substantially lower degradation rate than J1 on orbit. This implies that some additional organic contamination occurred during the build and test process. This was measured on JPSS-2 by doing UV exposure pre build and pre launch with the 100 hour UV exposure ratio going from 0.96 to 0.91. The JPSS-2 degradation pre launch at 100 hours UV is less than JPSS-1 on orbit. This appears to suggest that JPSS-2 will have lower degradation at 100 hours effective UV exposure than JPSS-1.

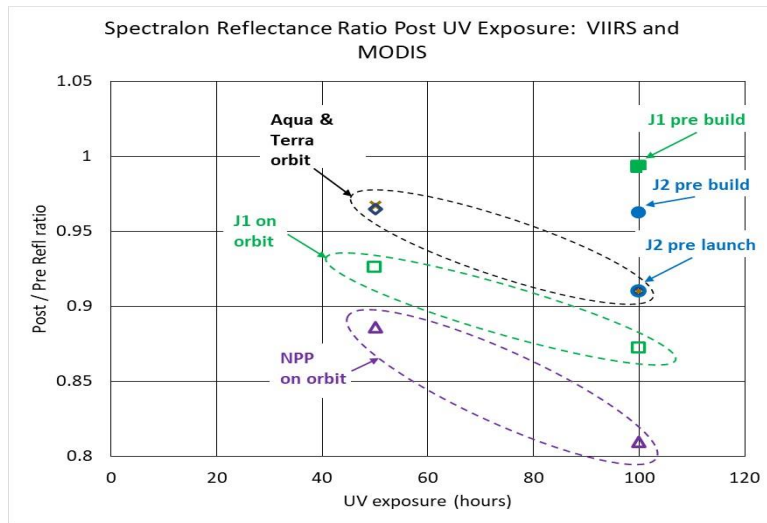


Figure 5 Comparison of on orbit degradation with UV exposure (open symbols) and ground testing (solid symbols): Aqua and Terra (black), J1 green, J2 blue, NPP purple. Ground testing only available for J1 and J2.

4 CONCLUSIONS

Spectralon® is used as a diffuse reflector as part of on orbit calibration systems for reflective solar bands. Spectralon® is known to solarize due to exposure to solar UV. Our previous procedure with JPSS-1 performed UV exposure only on a

witness sample pre build. For JPSS-2 UV exposure was done pre build as well as pre launch. This showed additional contamination resulting in the post UV to pre UV ratio at 411 nm going from 0.962 to 0.91. This is the level of degradation expected for JPSS-2 when it reaches the equivalent of 100 hours UV.

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