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QUALIFICATION TEST RESULTS FOR BLUE-RED REFLECTING SOLAR CELL COVERS

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Recent market forces and design innovations have spurred the development of solar cell covers that significantly reduce the solar absorptance for a cell array. GaAs cells using Ge as the substrate host material, can have a significantly higher output if the solar absorbtance of the cell array is reduced. New optical coating design techniques have allowed the construction of covers that reflect the ultraviolet energy (below 350 nm) and the near infrared energy (above 900 nm) resulting in the beneficial reduction in absorbtance. Recent modeling[1] suggests three or more percent output increase due to the lowered temperature with such a device.

Within the last several months we have completed the testing of production samples of these new covers in a qualification series that included the usual environmental effects associated with the routine testing of solar cell covers and the combined effects of protons, electrons and solar UV as would be encountered in space.

For the combined effects testing the samples were exposed to 300 sun days equivalent UV, 5 x $10^{14}/cm^2$ of 0.5 MeV protons and $10^{15}/cm^2$ of 1.0 MeV electrons. Measurements of the reflectance, transmission, emittance and other appropriate parameters were made before and after the testing. As measured by the average transmission over the cell operating band, the change in transmission for the samples was less than or about equal to 1%.

The details of the testing and the results in terms of transmission, reflectance and emittance are discussed in the paper.

Key Words:
Space Power, Photovoltaic System, Space Qualification, Solar Reflector, Reduced Solar Absorptance, Temperature Reduction, Output Efficiency

INTRODUCTION

The results of this series of tests give quantitative data on the nominal performance of blue-red reflecting (BRR) solar cell covers designed for use on GaAs and silicon solar cells before and after exposure to the normal environmental tests for such devices, as well as the stability of that performance in simulated space environmental effects testing. The tests performed included the normal application specific performance parameters and environmental exposures that are important to the use of the devices in service.

The test program used samples prepared using standard production methods and procedures. The samples were manufactured in production lots from at least two different coating runs for each coating type and were divided into test groups in a randomized manner with each group being exposed to a specific series of tests and analyses. Many of the tests and characterizations were performed at OCLI. However, the space environmental exposure testing using UV and high energy protons plus electrons, was done at the *Boeing Corporation* . Low energy proton exposures and evaluations were done by the *Hughes Aircraft Co., Space and Communications Division*, and by the *Martin Marrietta, Astro Space Division*. Samples prepared for this test series were mostly[2] characterized at OCLI for the appropriate performance parameters before testing and after testing to assess the changes induced by the environmental exposures.

[1] See *Blue/Red Reflecting Solar Cell Covers for GaAs Cells*; Proceedings of the Twenty Third IEEE Photospecialist Conference; Louisville, KY; May 1994

[2] Some pre and post measurements of performance, as well as, the particle exposures were done by Martin Marrietta for the low energy series.

Product Descriptions and Codes

The products explicitly tested were blue-red reflecting solar cell covers for GaAs and silicon cells. For OCLI, the basic code used to designate a blue-red reflecting cover is BRR. If the cover is intended for use on a GaAs cell then a (g) is appended to this code to result in the BRR/g designation. If the cover substrate material is Corning 0213 glass - a cerium doped micro sheet material - then the designation becomes BRR/g-0213. Similarly, if the application requirements dictate the use of fused silica as the substrate material and the cell will be GaAs the designation would be BRR/g-FS. A BRR cover for use on a silicon solar cell would be designated as a BRR/s-0213 or BRR/s-FS. Another version of the basic conceptual design for these products deletes the UV reflection feature and substitutes an AR. This version would be designated as an AR-RR/g-0213, etc.

In this qualification series, samples of the BRR/g-0213 and the BRR/s-0213 covers were tested and evaluated.

Product Descriptions

The function of coatings on a reflecting solar cell cover is to reduce the solar absorption of the array with little or no change in the electrical output of the system. The reduction in solar absorption is accomplished by reflecting as much as possible of the incident solar energy that is at wavelengths outside of the response wavelength band for the cell. GaAs solar cells are responsive to energy at wavelengths from about 350 nm to about 900 nm. For silicon solar cells the response region is from about 350 nm to about 1100 nm. If the cover is designed to reflect both the UV energy below 350 nm and the near-infrared energy above 900 nm or 1100 nm, the lower solar absorbtance will allow the system to remain cool and the cell efficiency will be less degraded by temperature effects. Of course, the reduction in solar absorbtance will result in a lower temperature only if there is no significant change in the emittance of the array surface due to the cover and coating.

A typical BRR cover reflectance for both types of cover - for GaAs and silicon cells - is shown in Fig. 1. In the response regions of the cells, the transmission is very high. In the out of band regions above 900 nm or 1100 nm and below 350 nm, the reflectance is as high and as broad as practical.[3] If the solar absorbtance is measured for a BRR cover adhered to a typical GaAs cell, the nominal solar absorbtance is on the order of 75% with this BRR/g-0213 design. (The absorption of the cell and the back contacts, as well as the glass, coating, and cement are included in the solar absorbtance value for the complete cell-cover system.)

By comparing the spectral plots in Figure 1, the difference between a GaAs BRR and a silicon BRR can be seen to be in the breadth of the transmission band. The position of the reflector for the NIR wavelengths is independent of the position of the reflector for the UV wavelengths. In addition, for the changes necessary to adapt from a reflector for use on GaAs to one for use on silicon, the transmission at wavelengths in the cell response bands can be kept very high. Therefore, the transition edge - from transmitting to reflecting - can be independently placed at a best position for each cover. The value of 1100 nm for silicon and 900 nm for GaAs on the long wavelength side of the transmission band and 350 nm for the short wavelength edge for both cell types was chosen based on extensive testing of cell/cover combinations for use on pointing arrays[4].

The typical construction for a BRR cover is to place the UV reflector on the front surface of the cover and the red reflector on the rear surface. Because the 0213 glass is highly absorbing at wavelengths less than 350 nm, the UV reflector must be on the front to be functional. The red reflector could also be on the front of the cover (under the UV reflector) but this might result in a significant reduction in the emittance for the cover. The coating(s) on the front surface will modify the emittance due to the optical properties of the materials in the far infrared. In particular the materials in the coating can add to

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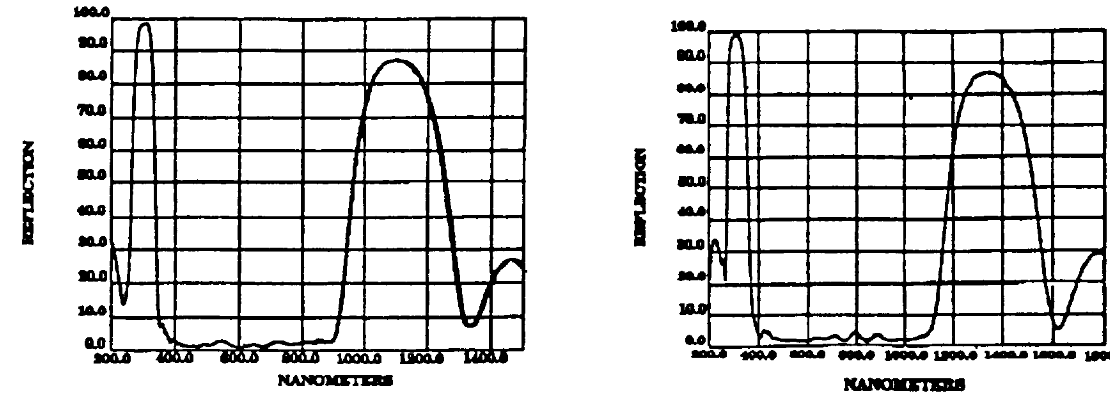
[3] There is a great flexibility in the width of the reflectance band for the cover in both the UV and the NIR. What is practical is determined by a host of factors including the reduction in solar absorbtance for broader reflectance measured against increased cost of manufacture, the possible effect on transmission over the cell response region associated with the more complex design, and possible greater warpage of the cover due to stress in the coatings as well as other technical factors.

[4] For the use of a BRR on a spinner satellite power system, the effects of angle of incidence on the coating must be taken into account. This results in the use of a NIR reflecting band positioned slightly farther out in wavelength than for the pointing array case.

Reststrahlen reflectance or Fresnel reflectance in the infrared resulting in a reduced emittance. This is particularly true for moderately thick coatings[5] such as the red reflector.

Figure 1. **Nominal Reflectance as a Function of Wavelength for a BRR/g-0213 Solar Cell Cover (a) and for a BRR/s-0213 Solar Cell Cover (b).**



Note: These scans have different wavelength scales.

The covers evaluated in this test series were all constructed on 0.006 inches (6 mils) thick Corning 0213 cerium doped microsheet. The 0213 glass was taken from stock material used at OCLI for routine manufacturing of solar cell covers and qualified for space use as a cover material, uncoated and in conjunction with a UVR coating on the front, in a qualification test discussed in the 1989 OCLI Qualification Report APD 89011.

Part Preparation and Sample Selection

The parts tested for this qualification were prepared using manufacturing procedures for the particular design, and were deposited in equipment regularly used for manufacturing of covers as well as other products. The samples were, as much as practical, selected at random from two separate lots and/or two separate coating runs for each coated surface on the covers. Control samples in the tests included uncoated 0213 glass and the UVR covers. These control samples showed changes consistent with, and in statistical agreement with, the data contained in the OCLI qualification test report for the UVR's and Corning 0213 microsheet glass (report APD 89011).

TESTS PERFORMED AND QUALIFICATION TEST GROUPS

The parameters measured and the environmental tests performed are shown in Table 1. This list of evaluations dictated the sequence of tests for each group and the data to be gathered.

Because of limited space in the test facilities at Boeing, the number of samples that could be exposed to combined space effects was further limited. To insure statistical validity in the results, a minimum of 5 samples of each design type were tested in two independent sets.

Facilities and Equipment Used for the Testing and Exposures.

For the measurements of the optical performance properties of the covers before and after the exposures, a Shimadzu 160 spectrophotometer was the primary instrument used. For measurements of the infrared reflectance, a Perkin Elmer 983 was used (this was primarily for the emittance determination). The regular environmental exposures for humidity and other durability tests were performed in the OCLI testing laboratory to the military specifications pertinent to the individual tests.

[5] The red reflector is of the order of 5 to 6 times as thick as the UVR.

Table 1 **Qualification Test Matrix for the BRR/g-0213 (GaAs BRR) and the BRR/s-0213 (Silicon BRR) Qualification Series.**

	Test Group								
REQUIREMENT	A	B	C	D	E	F	G	H	I
QTY	5+5	5+5	5+5	5+5	5+5	5+5	5+5	4+4	
SIZES	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	2 cm x 4 cm	Tested by others
Surface Quality; Workmanship; 80-50 requirement	X	X	X	X	X	X	X	X	X
Coating Orientation	X	X	X	X	X	X	X	X	X
Normal Emittance (1-R 5 to 50 microns)								X	X
Cuton/Cutoff Wavelength	X	X	X	X	X		X	X	X
Ultraviolet Rejection- ≥ 85% @ 300 nm +/- 20 nm	X	X	X	X	X		X	X	X
Transmittance	X	X	X	X	X		X	X	X
Humidity A-72 hours @120°F; ≥ 95% R.H.	X								
Humidity B-10 days per MIL-STD-810B		X							
Thermal Shock-LN2 1 hr. & 350°F 1 hr.			X						
Temperature Cycle-1000 cycles; -180°C to +195°C				X					
Salt Fog-48 hours					X				
Ultraviolet Exposure-300 sun days								X	
Radiation Resistance-20 to 30 KeV protons									X
Radiation Resistance-500 KeV protons								X	
Radiation Resistance-1 MeV electrons								X	
Abrasion Resistance-20 rub	X		X		X				
Adhesion-Slow tape	X					X			
15' Boil/Slow tape							X		
Transmittance & Cuton	X	X	X	X	X		X	X	X

The radiation and UV exposures were done at the *Boeing Company Physical Sciences Laboratories* using their X-200 Solar Simulator (at Organization 9-5574, Boeing, Renton, WA) and the Dynamitron Accelerator at the *Physical Sciences Research Center* (Seattle, WA.). The 1200 total hours UV exposure started on November 1, 1993 and finished on December 23, 1993. The UV exposure was done at about 6x the solar intensity (Air Mass Zero (AM0) Solar Spectrum) for a resultant 300 sun days equivalent exposure. This was followed by the exposure at the Dynamitron to 0.5 MeV protons to > 5 x $10^{14}/cm^2$ and then to 1 MeV electrons to $>10^{15}/cm^2$.

Radiation exposure at low energies (20 KeV to 30 KeV) for protons was done by the *Astro Space Division of the Martin Marietta Co.* and the *Space and Communications Division of the Hughes Aircraft Co.*

During exposure the radiation test samples were kept at or near room temperature by actively cooling the mounting plates with flowing water.

Measurement Error Analysis

Repetitive measurements of known wavelength and photometric standards have established the following measurement errors for transmission:

	Accuracy	Repeatability
Wavelength:	± 0.5 nm	± 0.1 nm
Photometric:	0.05%	0.02%

QUALIFICATION TEST RESULTS FOR THE BRR/GaAs COVERS

All parts were measured for transmittance, UV reflectance, and NIR reflectance before test and met the OCLI Product Specification No. 6067001-08.

Before and after measurements of transmittance were done for all test groups except group F. Group F only involved observations of the surface quality and coating orientation for the samples. Measurements of reflectance are included in the data after testing for completeness, but no data was taken for this group before.

Only the samples in test group H were measured before and after the test for emittance as well as for the transmittance values. The values for the emittance of the covers were calculated as one minus the reflectance in the range 5 µm to 50 µm.

Summaries of the before measurements of transmittance for the BRR/g-0213 test samples are shown in Table 2. The values of the arithmetic average transmission for various wavelength ranges are shown in the table. Data is presented for each of the test groups (however, the thermal cycle tests - Group D - have not been completed as of this writing).

The after exposure transmittance measurements for each of the test groups is shown in Table 3. In this data set the values for the transmittance of the group F samples are also included, as measured after test, for reference. The changes in transmittance, absorbtance, reflectance and emittance for the test sample sets in each group are given in Table 4.

The surface quality of all test parts in the test groups was ≤ 80-50 per MIL-O-13830A.

The normal spectral emittance for the BRR/g covers was found to be unaffected, well within the accuracy of determination of the emittance, by the combined effects testing. Nominal values for the normal spectral emittance as determined by these measurements, were in the range of 86% to 87% The average transmittances in the 400 nm to 900 nm wavelength band were also unaffected by the normal environmental exposures.

The 50% cut-on wavelengths (transmission) of all BRR/GaAs coatings were 359.5 nm ± 1.7 nm at the UV position and 972 nm ± 7 nm at the near infrared position. All measured BRR/g-0213 parts had less than 1% average transmission between 200 nm and 320 nm before and after testing.

The BRR/g-0213 parts in test group H were subjected to combined UV exposure for 300 AM0 UV sun days equivalent (at 6x sun intensity), followed by proton irradiation (0.50 MeV) to $5 \times 10^{14}/cm^2$, in a vacuum of 1×10^{-6} torr and then electron irradiation (1.0 MeV) to $1.0 \times 10^{15}/cm^2$. The average transmission from 400 nm to 900 nm was lowered an average of 1.12%. This change is a little higher than was expected. However, it is near the change limit specified for other cover products such as the UVR only. The specification limit for change in solar transmittance is usually set at less than 1%. The change in the cut-on edge at the UV was about 5.6 nm on average and at the NIR edge was 0.69 nm on average.

Summary of Qualification for the BRR/GaAs

For all qualification test groups discussed above, transmission changes due to the testing were less than 1%, except for the samples irradiated in test group H. The change in transmission for the samples in test group H was about 1.12% on average.

QUALIFICATION TEST RESULTS FOR THE BRR/SILICON COVERS

The matrix of qualification test groups for the BRR/silicon (BRR/s-0213) covers is identical to the matrix for the BRR/g-0213 covers shown in Table 1. All parts were measured for transmittance, UV reflectance, and NIR reflectance before test and met the OCLI Product Specification No. 6067001-09. As with the other test sets, the before and after measurements of transmittance were done for all test groups except group F. Group F only included observations of the surface quality and coating orientation for the samples. Measurements of reflectance are included in the data after testing for completeness, but no data was taken for this group before.

Table 2 Transmittance & Emittance for the BRR/g-0213 Samples Before Testing.

(Summary - Set 1 Run Numbers 466-1686/1688)*

Test Group		50% Trans Cuton Lower	Upper	Peak 200-230	at	Avg 400-900	Avg 600-800	Emitt
A	Average	359.86	960.96	0.61	200.60	96.42	97.62	
	Std Dev	1.25	5.91	0.05	0.55	0.21	0.05	
B	Average	360.02	949.34	0.57	201.00	96.36	97.70	
	Std Dev	1.66	5.43	0.01	0.00	0.04	0.04	
C	Average	357.96	975.82	0.60	200.60	96.53	97.69	
	Std Dev	0.64	15.02	0.06	0.55	0.10	0.12	
D	Average	358.60	975.66	0.52	200.20	96.41	97.68	
	Std Dev	0.31	12.59	0.02	0.45	0.47	0.10	
E	Average	359.24	989.92	0.54	200.00	96.52	97.83	
	Std Dev	1.67	4.67	0.05	0.00	0.03	0.05	
F	Average		No Data	Taken				
	Std Dev							
G	Average	358.38	958.58	0.54	200.00	96.65	97.68	
	Std Dev	0.96	7.17	0.05	0.00	0.11	0.03	
H	Average	359.25	961.33	0.58	200.00	95.47	96.68	86.57
	Std Dev	0.52	3.26	0.02	0.00	0.28	0.24	0.27

Table 3 Transmittance & Emittance for the BRR/g-0213 Samples After Testing.

(Summary - Set 1 Run Numbers 466-1686/1688)*

Test Group		50% Trans. Cuton Lower	Upper	Peak 200-230	at	Avg 400-900	Avg 600-800	Emitt
A	Average	360.16	960.28	0.13	320.00	96.28	97.57	
	Std Dev	1.32	5.87	0.03	0.00	0.03	0.03	
B	Average	361.60	948.88	0.09	320.00	96.31	97.69	
	Std Dev	2.47	5.90	0.02	0.00	0.06	0.03	
C	Average	358.02	976.14	0.14	320.00	96.46	97.67	
	Std Dev	0.46	15.65	0.02	0.00	0.10	0.11	
D	Average	TBD	TBD	TBD	TBD	TBD	TBD	
	Std Dev							
E	Average	359.44	990.32	0.12	320.00	96.28	97.59	
	Std Dev	1.58	4.38	0.00	0.00	0.23	0.25	
F	Average	359.50	971.08	0.47	320.00	96.37	97.62	
	Std Dev	0.31	1.20	0.01	0.00	0.23	0.19	
G	Average	358.48	958.40	0.15	320.00	96.49	97.57	
	Std Dev	0.97	7.76	0.00	0.00	0.10	0.03	
H	Average	364.48	962.00	0.25	320.00	94.27	96.39	86.25
	Std Dev	0.45	.030	0.00	0.00	0.12	0.03	0.19

* Set 1 of two sets. Second set not displayed to save space. Data and conclusions are the same for Set 1 and Set 2. For an expaination of the TBD's in group D see the text.

Table 4 **Changes in Transmittance and Emittance for the BRR/g-0213 Samples**

Set 1[*] Run Numbers 466-1686/1688

Test Group		50% Trans Cuton Lower	Upper	Peak 200-320	Avg 400-900	Avg 600-800	Emitt
A	Average	-0.30	0.68	0.49	0.14	0.05	
B	Average	-1.58	0.46	0.48	0.06	0.01	
C	Average	-0.06	-0.32	0.46	0.06	0.02	
D	Average	TBD	TBD	TBD	TBD	TBD	
E	Average	-0.20	-0.40	0.42	0.24	0.24	
G	Average	-0.10	0.18	0.39	0.16	0.10	
H	Average	-5.23	-0.67	0.33	1.21	0.29	0.32

A negative number signifies an increase in value

Space Environmental Tests

The BRR/s-0213 test group H was also the sample set sent to Boeing for particle irradiation. This test group was measured before and after test for emittance as well as for the transmittance values. The values for the emittance for the covers are calculated as one minus the reflectance in the range 5 μm to 50 μm.

Summaries of the before measurements of transmittance for the BRR/s-0213 test samples are shown in Table 5. The arithmetic average transmission for various wavelength ranges are shown in the table. (as mentioned before, the thermal cycle tests - Group D - have not been completed as of this writing).

The values for the reflectance of the covers in the UV and the position of the maximum value are also given. Data is presented for each of the test groups (the test group I has not been completed as of this writing.) Values for the emittance of the covers calculated as one minus the reflectance in the range 5 μm to 50 μm, are also shown for each cover in the H test group, as measured before testing.

The after exposure transmittance measurements for each of the BRR/s-0213 test groups are shown in Table 6. Again the values are the average or minimum transmittances in the selected wavelength ranges. In this data set, the values for the transmittance of the group F samples are also included, as measured after test, for reference. The change in transmittance, absorbtance, reflectance and emittance for the test sample sets in each group are given in Table 7.

The surface quality of all BRR/s-0213 test parts in the test groups is ≤ 80-50 per MIL-O-13830A.

All parts were measured for transmittance before test and met the OCLI Product Specification No. 6067001-09.

The normal spectral emittance for the BRR/s-0213 covers was found to be unaffected, well within the accuracy of determination of the emittance value, by the combined effects testing. Nominal values for the normal spectral emittance as determined by these measurements was in the range of 86% to 87% The average transmittances in the 450 nm to 1100 nm wavelength band were also unaffected by the normal environmental exposures.

The 50% cut-on wavelengths (transmission) of all BRR/Silicon coatings were 359.5 (± 15) nm at the UV position and 1160 (± 10) nm at the near infrared position. BRR/s-0213 test covers were placed into a test chamber at a controlled temperature for 72 hours at a temperature of 49°C ± 2.5°C and > 95%

[*] Set 1 of two sets. Second set not displayed to save space. Data and conclusions are the same for Set 1 and Set 2.

relative humidity per MIL-C-675A (test group A). After humidity all parts were tested for 20 rub eraser abrasion resistance per MIL-C-675A and slow tape adhesion per MIL-M-13508B. No physical degradation was observed on any part and the change in transmission for the wavelengths 450 nm to 1100 nm was less than 0.57% on average. The change in the 50% transmittance cut-on edge was less than about 0.4 nm to 1.2 nm on average at the UV position.

The BRR/s-0213 parts in test group H were subjected to combined UV exposure to 300 AM0 UV sun days equivalent at 6x sun intensity, followed by 0.5 MeV proton irradiation to $5 \times 10^{14}/cm^2$ in a vacuum of 10^{-6} torr and then 1.0 MeV electron irradiation to $10^{15}/cm^2$. The average transmission from 450 nm to 1100 nm was lowered an average of 0.36%. The change in the cut-on edge at the UV was about 3.4 nm on average and at the NIR edge was about 5 nm on average.

It is interesting to note that the design of the BRR/silicon coating is the same as the design for the BRR/GaAs design, with the exception of the increase in the red reflector coating thickness to shift the reflectance band out beyond 1.1 μm. This represents a thickening of all of the layers in the design by about 15%. If the changes shown are compared between the two designs, however, it is not clear why the GaAs version should have changed so much while the silicon version changed so little.

Summary of Qualification for the BRR/Silicon

For all qualification test groups in the silicon BRR evaluations, the change in transmission was less than 1%. This is within the specification for the BRR covers and the BRR/s-0213 covers can therefore be qualified for space applications.

QUALIFICATIONS BY SIMILARITY

Based on the results of this testing and flight experience with other cover/coating combinations, it is possible to qualify other specific products by similarity. These include the blue-red reflecting solar cell covers using fused silica as the substrate and an AR-red reflector cover.

Other Versions of The Red Reflecting Solar Cell Cover

Among the alternate product forms for red reflecting solar cell covers are products that substitute other substrate materials such as fused silica, and product forms that substitute an antireflective coating on the front surface for the UVR.

As noted in the introduction, the version of the design that substitutes fused silica for the substrate is designated by appending an FS to the product code in place of the 0213. The difference between the BRR/g-FS and the BRR/g-0213 and between the BRR/s-FS and the BRRs-0213 solar cell covers is the substrate material and the addition to a small amount of UV absorbing material in the front coating (the UV reflector). The 0213 glass, qualified in the testing described in OCLI report no. APD 89011, changes very little when exposed to the particle irradiation, the other tests described in that report, and in this series of tests. However, fused silica is even more stable in these same tests. Therefore, the use of fused silica as the substrate would result in an even more stable cover product.

The coating design and material used for the front surface coating on the BRR/x-FS product is also a space qualified product that has flown for many years. This coating on fused silica is the blue reflector used in the AR/BR design that was the staple of the solar cell cover market for the years prior to the introduction of the CeO_2 stabilized glasses such as Corning 0213.

The reflectance and transmittance for these product forms are nearly identical to the glass based products. The solar absorbtance for the fused silica based BRR products is a little less than that for the glass based product.

Table 5 **Transmittance and Emittance for the BRR/s-0213 Samples Before Testing.**

Set 1 Run Numbers 466-1685/1688*

Test Group		50% Trans Cuton Lower	Upper	Peak 200-230	at	Avg 450-1100	Emitt
A	Average	363.36	(ND)	0.71	200.60	96.49	
	Std Dev	0.38		0.05	0.55	0.07	
B	Average	364.68	(ND)	0.73	200.40	96.57	
	Std Dev	1.11		0.05	0.55	0.08	
C	Average	363.02	(ND)	0.66	200.80	96.55	
	Std Dev	2.88		0.02	0.45	0.06	
D	Average	362.54	(ND)	0.70	201.00	96.64	
	Std Dev	1.85		0.04	0.00	0.14	
E	Average	366.72	(ND)	0.72	200.60	96.72	
	Std Dev	2.43		0.05	0.55	0.08	
F	Average		No Data	Taken	(ND)		
	Std Dev						
G	Average	365.84	(ND)	0.68	200.60	96.68	
	Std Dev	2.76		0.05	0.55	0.12	
H	Average	364.40	(ND)	0.59	200.00	95.84	86.28
	Std Dev	1.44		0.01	0.00	0.15	0.06

Table 6 **Transmittance and Emittance for the BRR/s-0213 Samples After Testing.**

Set 1 Run Numbers 466-1685/1688*

Test Group		50% Trans Cuton Lower	Upper	Peak 200-230	at	Avg 450-1100	Emitt
A	Average	363.78	1209.02	0.15	320.00	96.12	
	Std Dev	0.40	4.79	0.03	0.00	0.19	
B	Average	365.28	1212.28	0.10	320.00	96.35	
	Std Dev	1.03	10.79	0.02	0.00	0.43	
C	Average	363.10	1214.48	0.12	320.00	96.43	
	Std Dev	3.03	13.45	0.03	0.00	0.11	
D	Average	TBD	TBD	TBD	TBD	TBD	
	Std Dev						
E	Average	366.74	1202.72	0.12	320.00	96.67	
	Std Dev	2.46	1.32	0.04	0.00	0.09	
F	Average	364.40	1227.92	0.36	320.00	96.67	
	Std Dev	2.60	7.62	0.06	0.00	0.24	
G	Average	366.34	1228.08	0.10	320.00	96.59	
	Std Dev	3.08	10.32	0.03	0.00	0.15	
H	Average	368.45	1182.05	0.30	320.00	95.99	86.29
	Std Dev	2.47	1.16	0.01	0.00	0.11	0.50

* Set 1 of two sets. Second set not displayed to save space. Data and conclusions are the same for Set 1 and Set 2. For an expaination of the TBD's in group D see the text.

Table 7 Changes In Transmittance and Emittance for the BRR/s-0213 Samples

Set 1[*] Run Numbers 466-1685/1690

Test Group		50% Trans Cuton Lower	Upper	Peak 200-320	Avg 450-1100	Avg 400-450	Emitt
A	Average	-0.42	(ND)	0.56	0.36	0.12	
B	Average	-0.60	(ND)	0.63	0.22	-0.30	
C	Average	-0.08	(ND)	0.55	0.11	-0.15	
D	Average	TBD	(ND)	TBD	TBD	TBD	
E	Average	-0.02	(ND)	0.60	0.05	0.27	
G	Average	-0.50	(ND)	0.58	0.09	-0.40	
H	Average	-4.05	(ND)	0.29	-0.15	5.45	-0.01

A negative number signifies an increase in value. ND indicates no data due to no before measurements of the cut on edge. For an expaination of the TBD's in group D see the text.

The second alternate product form with an AR on the front has the designation AR-RR/g-0213 when the coatings are on the Corning 0213 microsheet glass. This product differs from the BRR/g-0213 product because the front coating is the conventional single layer magnesium fluoride antireflection coating that has flown in space for many years. In the same manner, the difference between the AR-RR/s-0213 product and the BRR/s-0213 cover is the same single layer antireflection coating design.

It may be possible, because of the flight history for parts of these designs and the results of the testing discussed here, to consider these alternate product forms qualified by similarity. Due to the high cost associated with such testing and the time required for a test program, it is hoped that the similarity of the products to the BRR/g-0213 and BRR/s-0213 will be sufficient for qualification. However, if there is sufficient justification for the specific testing of any of these alternate product forms, OCLI will entertain the suggestion that a test series be conducted for the AR-RR.

CONCLUSION

Based on the testing discussed here, the blue-red reflecting solar cell covers can be considered qualified for space use.

[*] Set 1 of two sets. Second set not displayed to save space. Data and conclusions are the same for Set 1 and Set 2.