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Effects of the LDEF Environment on the Ag/FEP Thermal Blankets.

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This presentation was made by Francois Levadou at the NASA Langley Research Center LDEF materials workshop, November 19-22, 1991. It represents the results to date on the examination of silvered teflon thermal blankets primarily from the Ultra-heavy Cosmic Ray Experiment and also from the blanket from the Park Seed Company experiment. ESA/ESTEC and Boeing conducted a number of independent measurements on the blankets and in particular on the exposed fluorinated ethylene-propylene (FEP) layer of the blankets. Mass loss, thickness and thickness profile measurements have been used by ESA, Boeing, and NASA LeRC to determine recession and average erosion yield under atomic oxygen exposure. Tensile strength and percent elongation to failure data, surface characterization by ESCA, and SEM images are presented. The Jet Propulsion Laboratory analysis of vacuum radiation effects is also presented. The results obtained by the laboratories mentioned and additional results from The Aerospace Corporation on samples provided by Boeing are quite similar and give confidence in the validity of the data.

Ag/FEP THERMAL BLANKET INVESTIGATION

BOEING and ESA/ESTEC
- **Mass loss, thickness and thickness profile**
- **Mechanical properties: elongation and tensile strength**
- **ESCA**
- **Contamination**

NASA LeRC and ESA/ESTEC
- **Erosion yield and recession**
- **SEM**

JPL
- **Vacuum UV radiation effects**
- **SEM**

The Ag/FEP blankets were the thermal protection for the Ultra-Heavy Cosmic Ray Nuclei Experiment(AO178). This experiment was in sixteen locations around the spacecraft.

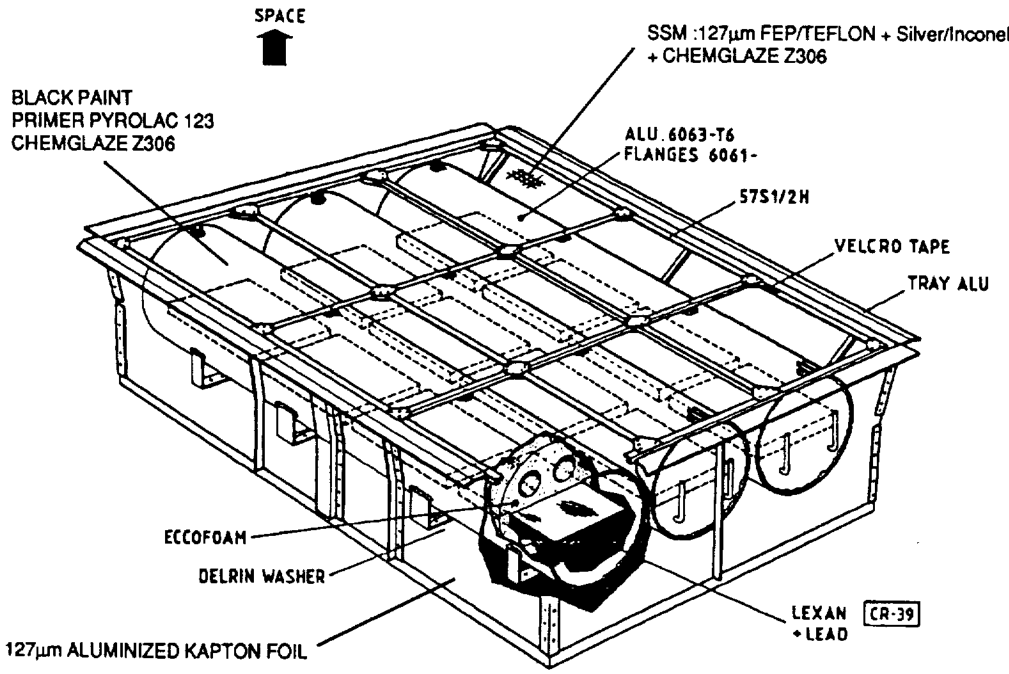
UHCRE [AO178]

ULTRA-HEAVY COSMIC RAY NUCLEI EXPERIMENT
A joint ESA/DIAS (Dublin Institute of Advanced Studies) experiment which flew on NASA's LDEF

The main objective is a detailled study of the charge spectra of ultra-heavy cosmic-ray nuclei from zinc (Z=30) to uranium (Z=92) and beyond using solid-state track detectors.

Among 72 trays mounted around the periphery of LDEF, 16 were devoted to UHCRE.

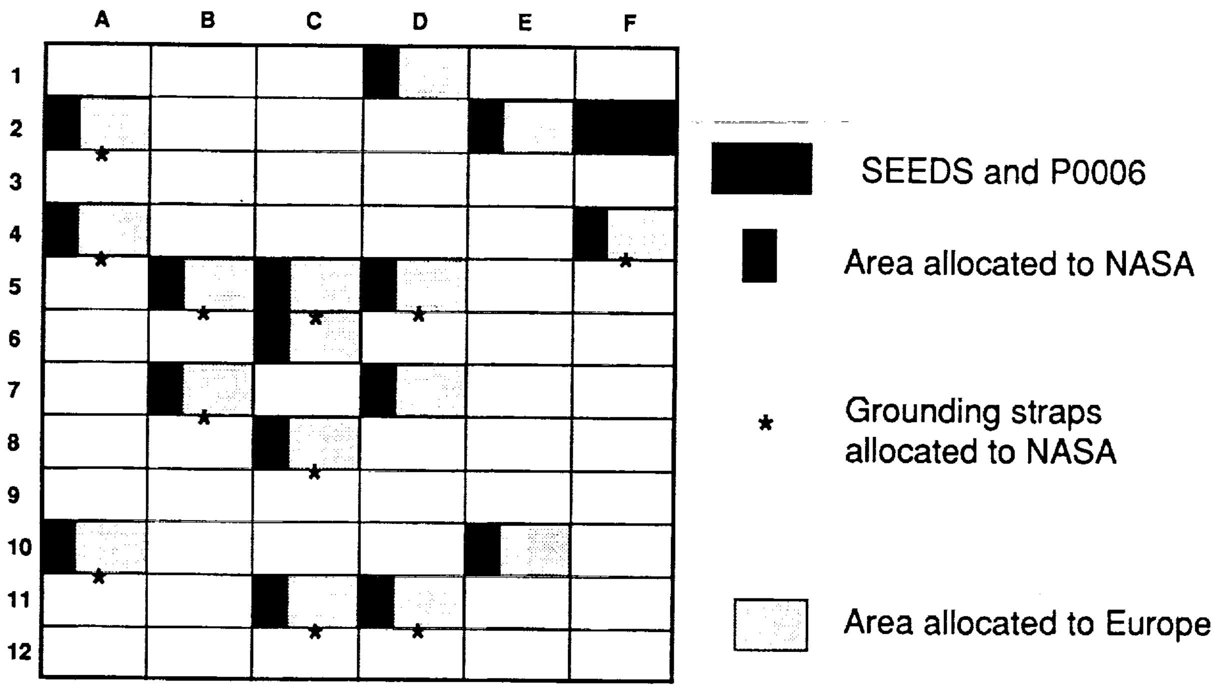
The thermal blankets were fastened to the frame of the tray using Astro-Velcro tape. Each of the blankets remained in place and each of the individual Velcro strips performed their function. The post-flight and pre-flight grip strengths of the Velcro were similar. The attachment location of each strip did provide a mechanical load on areas of each blanket because the fastened areas were not as free to expand and contract during thermal cycling as was the remainder of the blanket .



CONSTRUCTION OF UHCRE TRAY

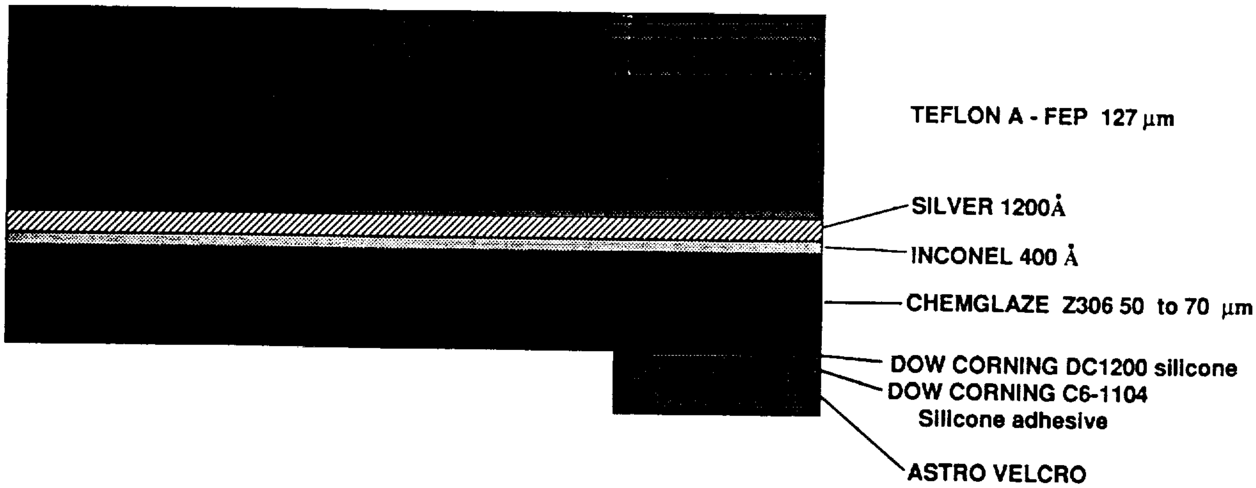
The light top frame supports the thermal tray FEP cover

The distribution of blanket locations on the spacecraft is shown in this figure. Two thirds of each blanket was retained by ESA and one third was provided to NASA. The blanket from location F2 was retained by NASA. Each blanket was electrically grounded to the main LDEF structure by copper straps attached to the Z-306 side of each blanket. Five copper straps were retained by ESA and twelve straps were sent to Boeing. Boeing received from NASA a strip approximately 4" wide by 16-18" long from the edge of the NASA portion of each blanket from AO178. Six strips about 2"x18" were provided from blanket F2.



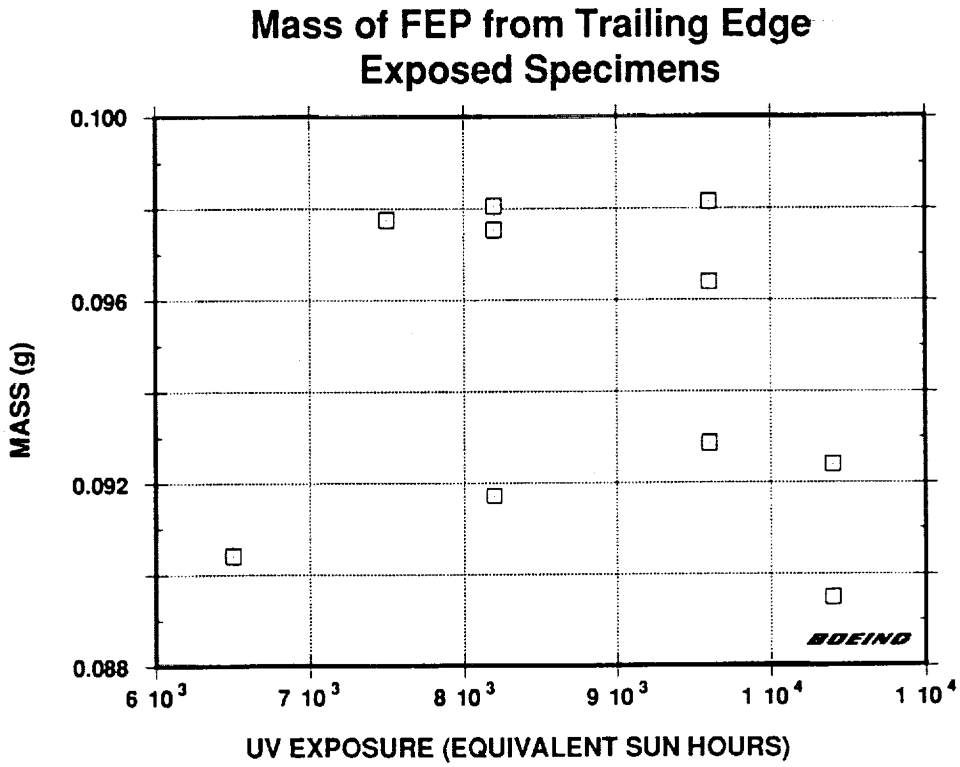
LDEF UHCRE [A0178] Thermal blanket allocations

The FEP layer was exposed to the external space environment. The chemglaze Z-306 and the silicone adhesive holding the Velcro were facing the interior of the trays and exposed only to vacuum and mild thermal cycling.

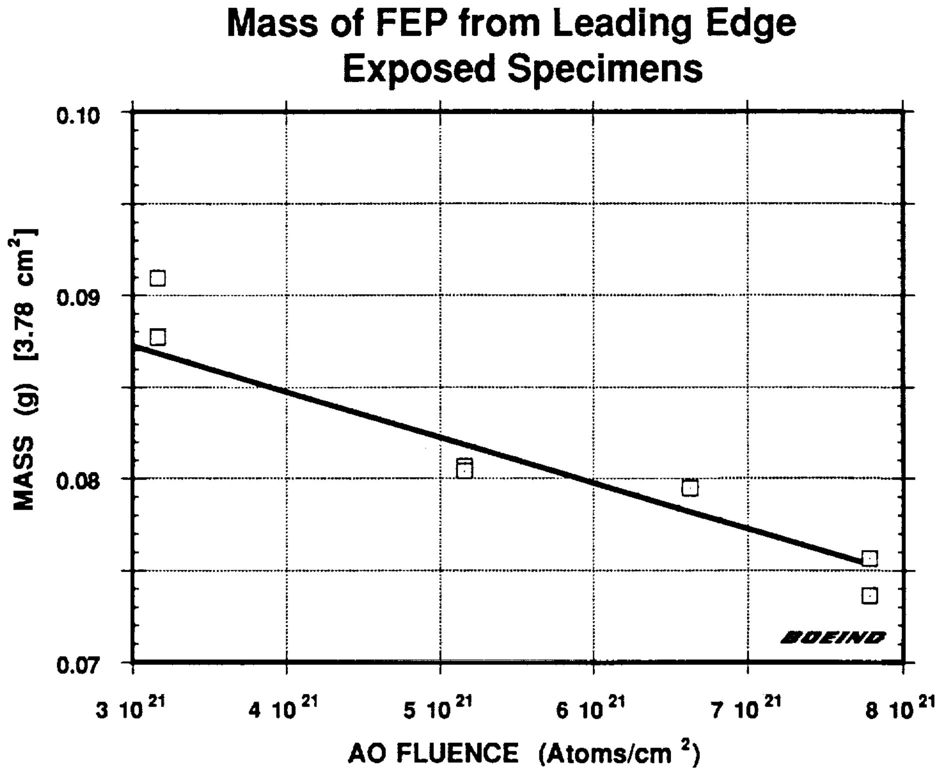


UHCRE & SEEDS THERMAL BLANKETS
Scheldahl G401500 with Chemglaze Z306

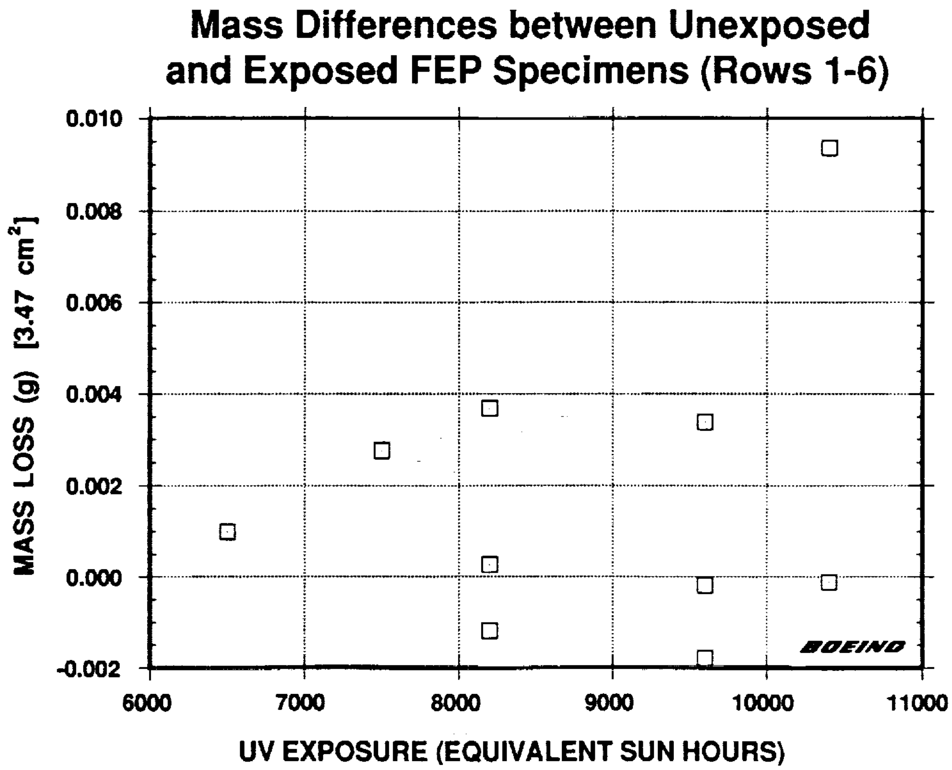
The wide variation in mass of specimens cut from the same die is partially due to natural thickness variation of the blankets as manufactured. The lack of any clear trend due to solar exposure indicates that the production of volatile UV degradation products, if this process occurs at all, is small.



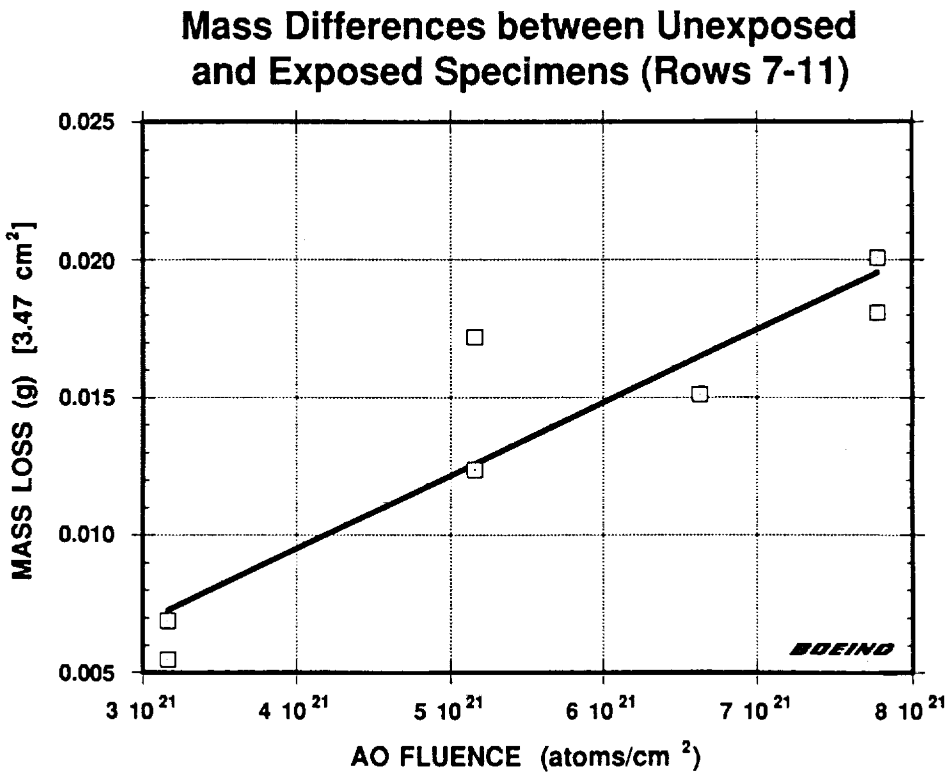
The masses of specimens taken from areas of blankets exposed to atomic oxygen, and cut with the same die, show a clear trend of increased recession with atomic oxygen exposure.



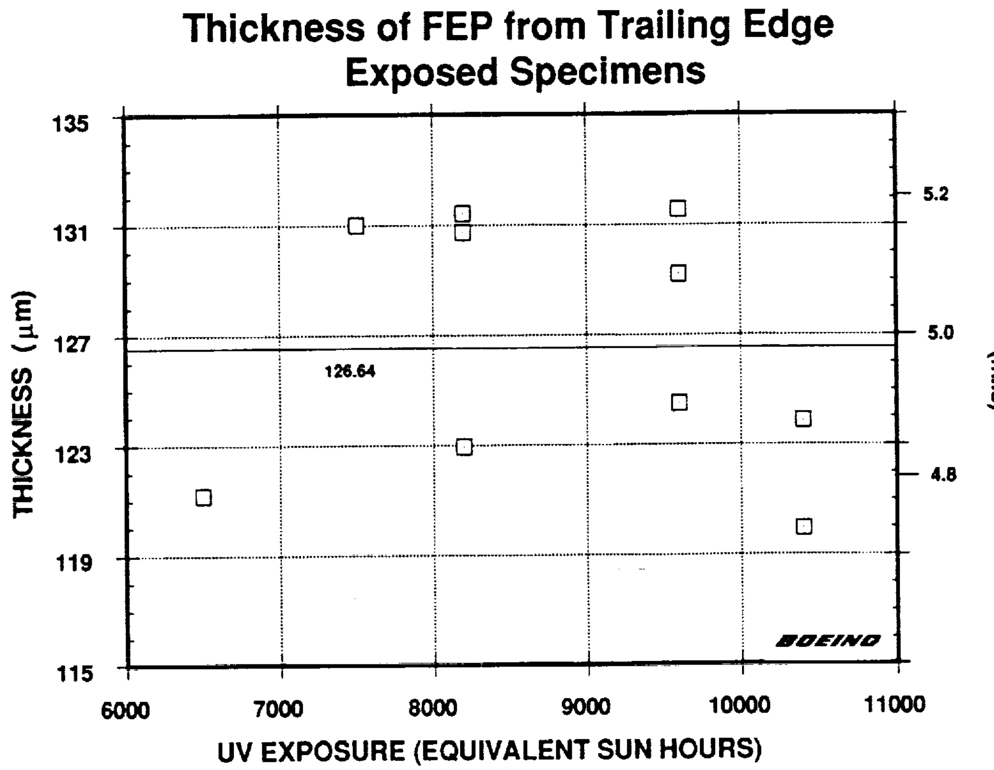
Mass differences between areas of each blanket exposed to only solar radiation and unexposed portions of the same blanket show essentially random distribution with respect to equivalent sun hours of solar exposure.



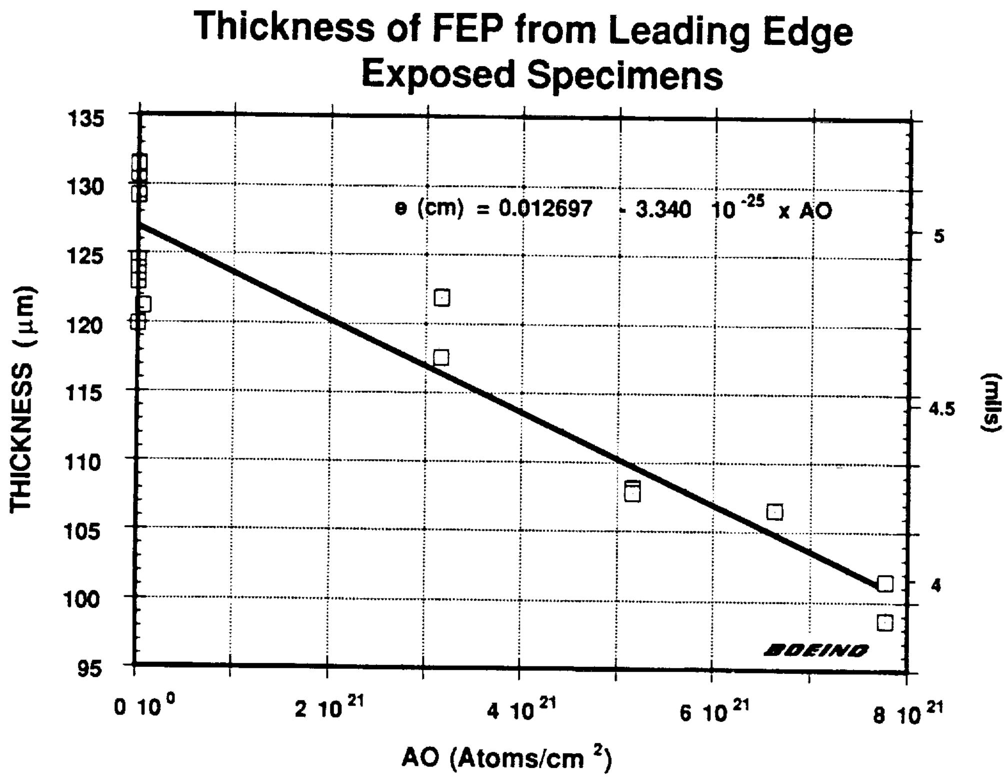
Mass differences between areas of each blanket exposed to atomic oxygen and solar ultraviolet radiation and unexposed portions of the same blanket show clearly increased mass loss with atomic oxygen fluence.



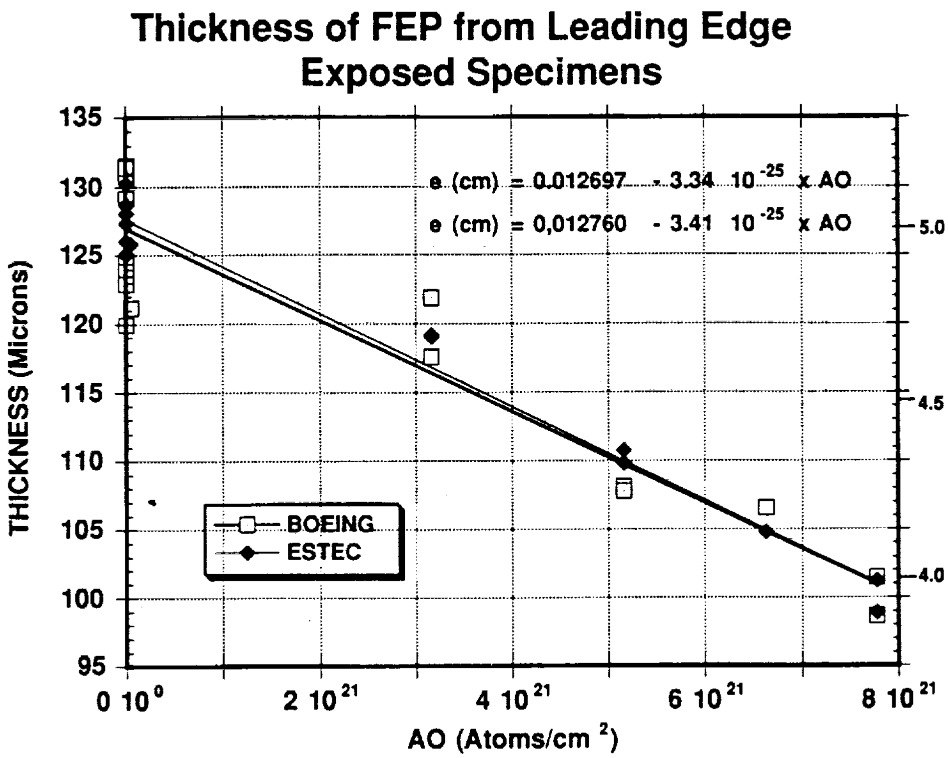
The thickness of the exposed specimens from the trailing edge was determined from the mass measurements and the assumption of 2.15 g/cm3 density for FEP.



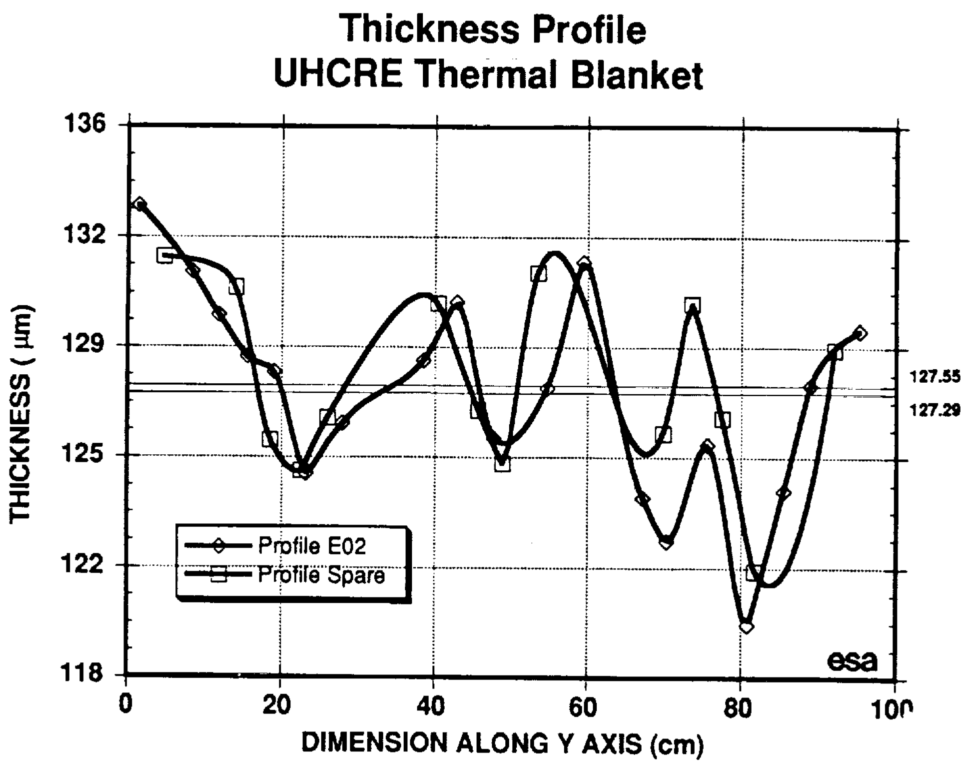
The thickness of leading edge exposed specimens measured at Boeing was determined from the mass measurements and the assumption of 2.15 g/cm3 FEP density. The data points at the left edge of the graph show the variation in the range of thicknesses for unexposed specimens from the trailing edge for comparison.



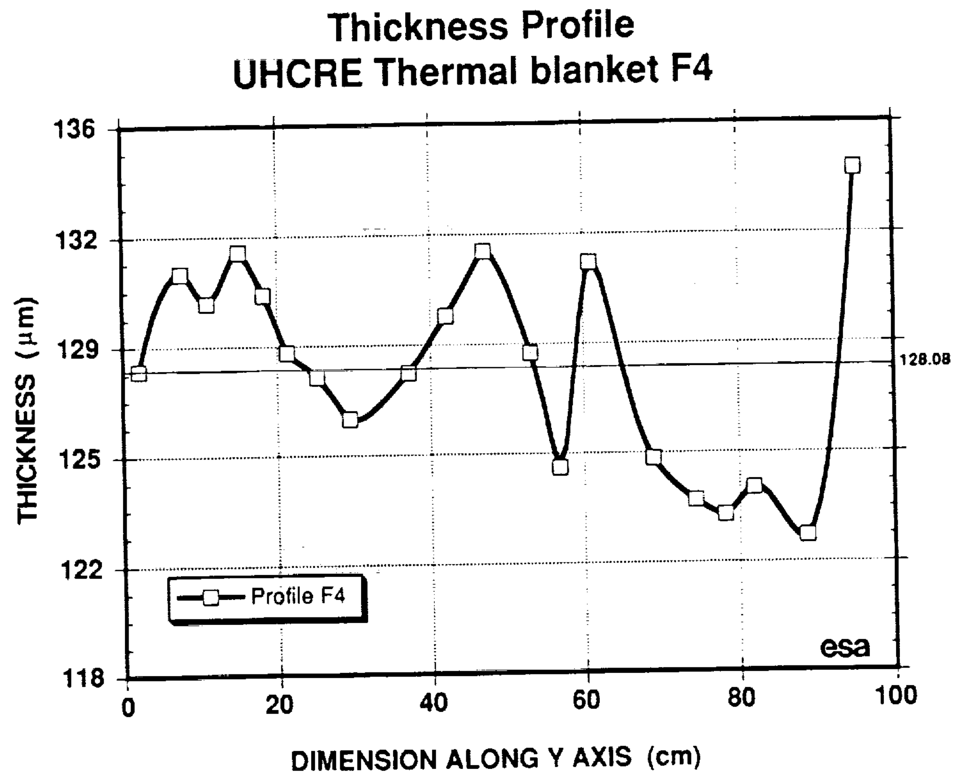
This chart shows the correlation between measurements at ESTEC and Boeing . The fits to the data give recession yields of 0.34 and 0.33 x ten to the minus twenty-four cm3 per atom, respectively.



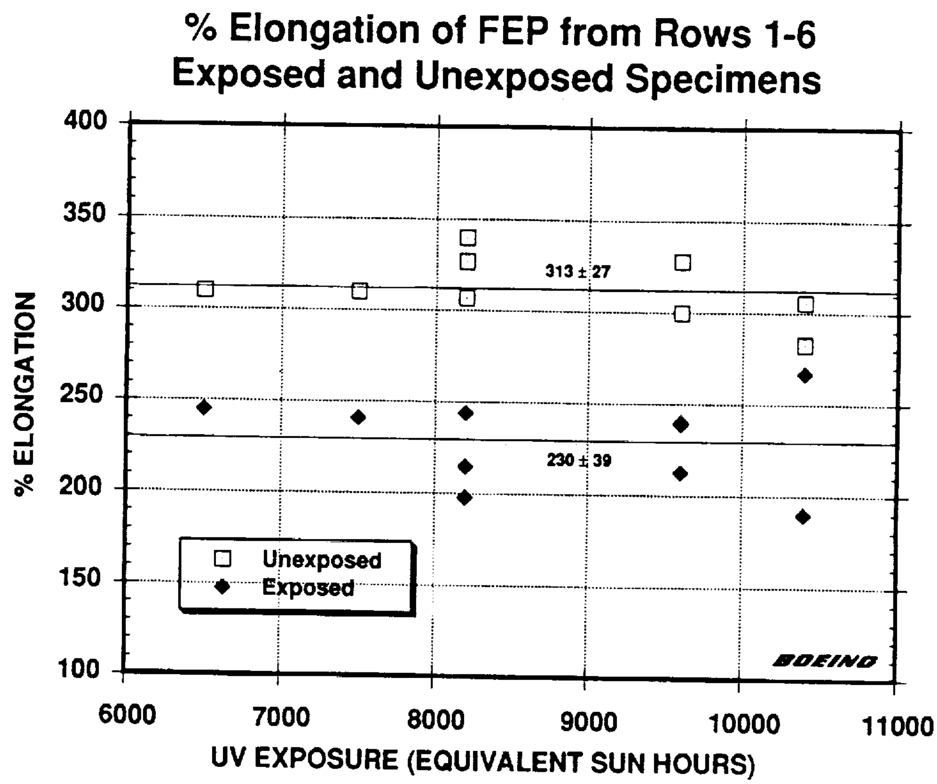
The variation in the blanket thickness along the length of a blanket is shown for blanket E02, which flew near the trailing edge, and a ground control blanket. The variation in manufactured thickness points out the need for care in obtaining recession data. Exposed and unexposed areas should be obtained from locations in as close proximity as possible to minimize the effects of the variation. A further point is that the thickness variation profiles for both the flown and ground stored blankets are quite similar.



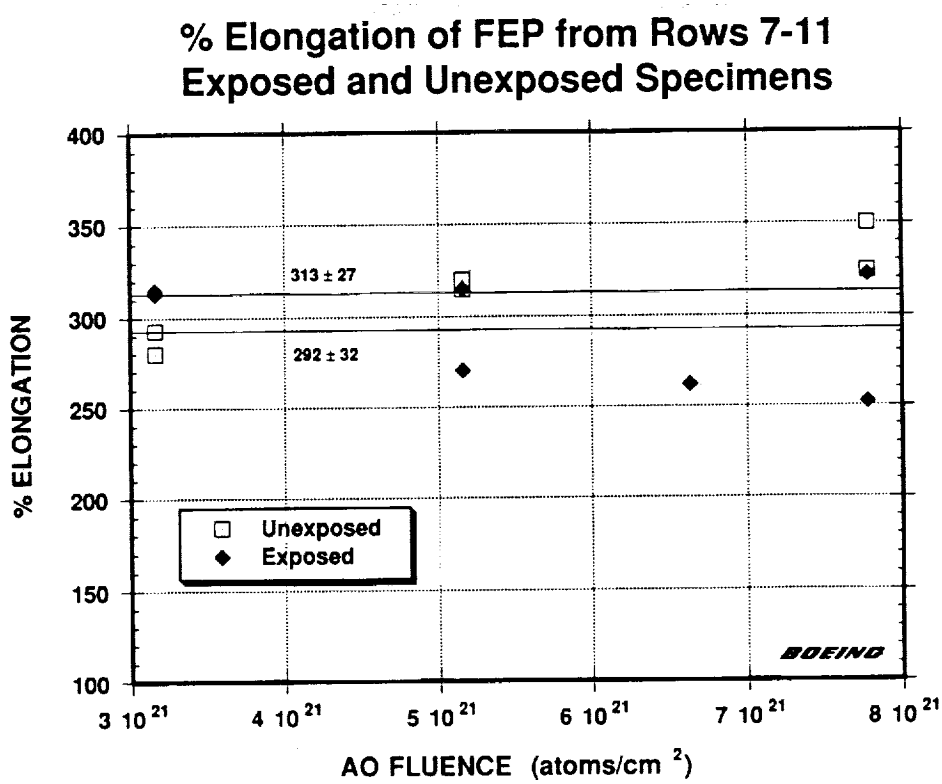
Additional data on thickness variation is shown for the blanket from tray F4. The trends are similar to the previous results.



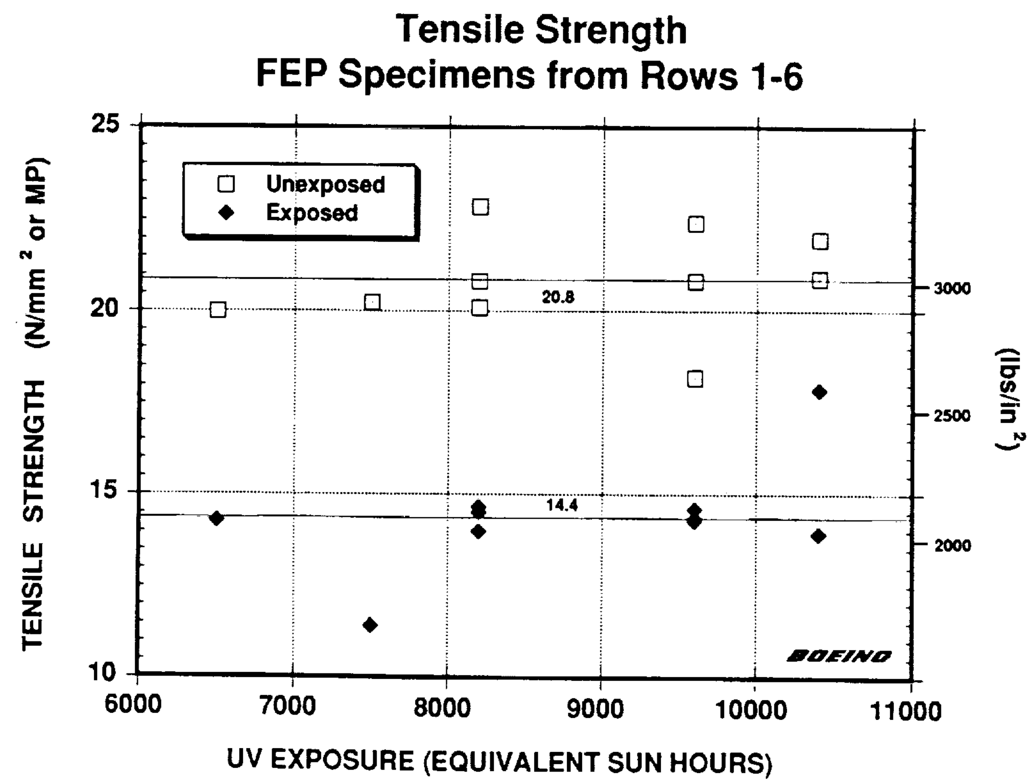
Tensile coupons were cut from both exposed and unexposed pieces of each blanket . Ultimate tensile strength and percent elongation at failure were measured. The results show that the exposed material has become imbrittled relative to the unexposed material. The unexposed material generally shows a percent elongation of about 300%; this is a typical value expected for FEP. It is also significant that the percent elongation of the exposed materials does not show a trend with hours of solar exposure. This implies the damage had essentially reached an equilibrium state prior to the 6400 equivalent sun hour exposure.



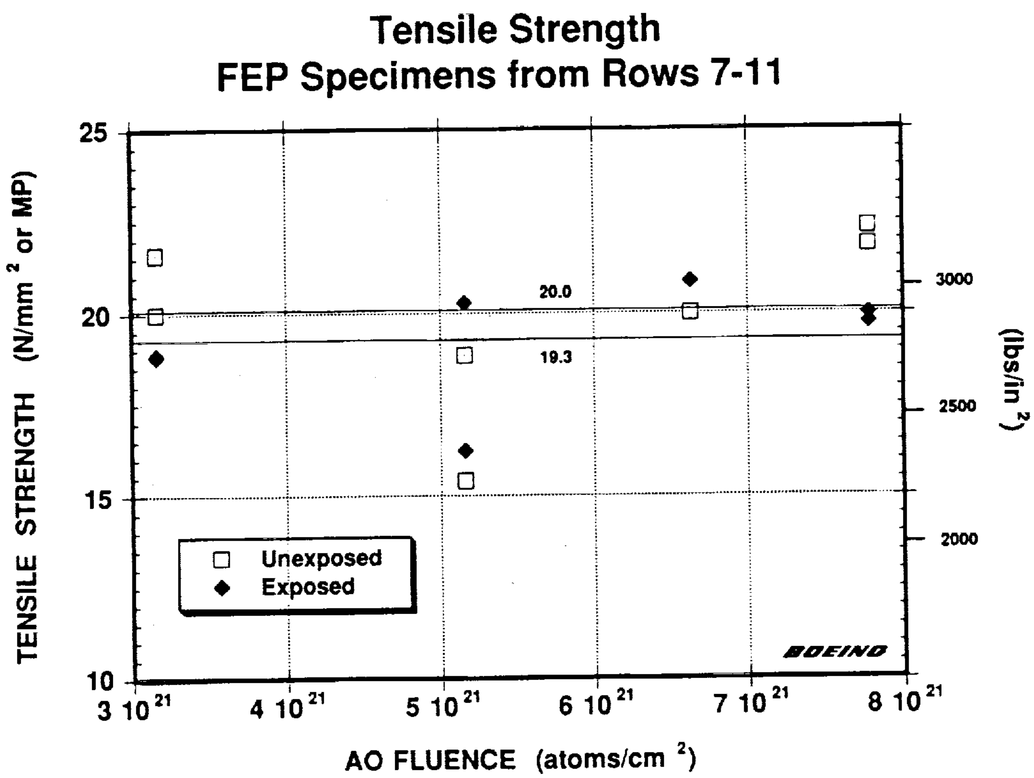
The percent elongation measurements for specimens from leading edge specimens show only slight differences between exposed and unexposed specimens. The averages between the two sets of measurements are not significantly different to a high degree of confidence. However, ESCA measurements do show differences between the surfaces of exposed and unexposed specimens. The imbrittled portion of the FEP material is being removed by surface oxidation, continually exposing fresh FEP. Thus, while the material is recessing, the oxygen is removing the observable effects of the ultraviolet-induced damage.



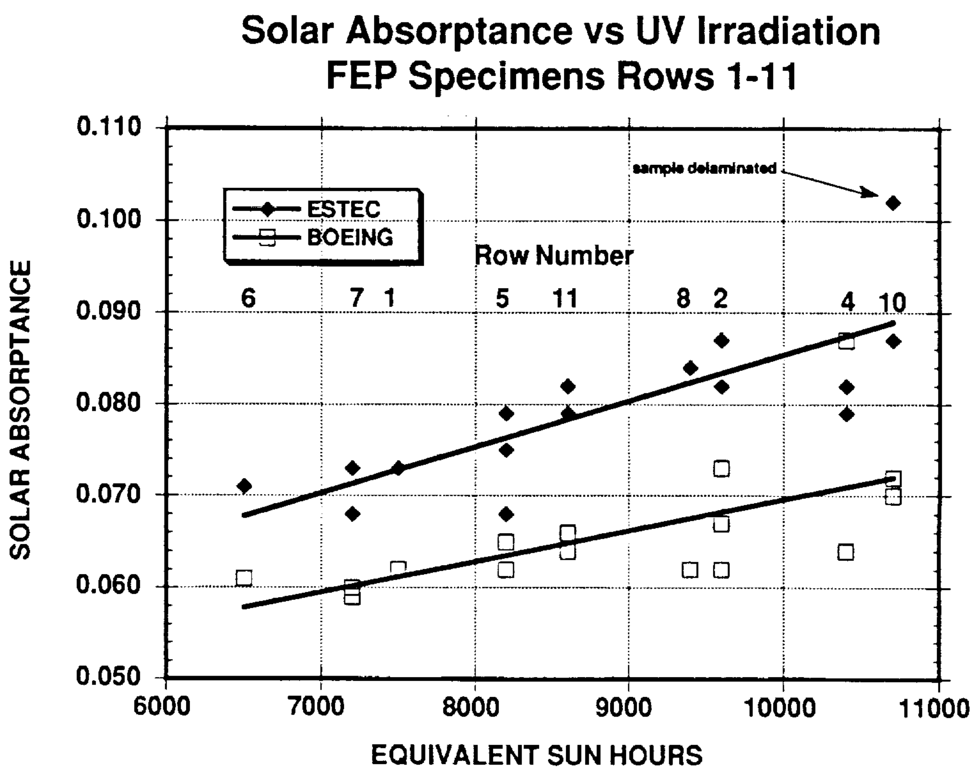
Ultimate tensile strengths for exposed and unxeposed areas of blankets from the leading edge show essentially no difference within the uncertainty of the measurements.



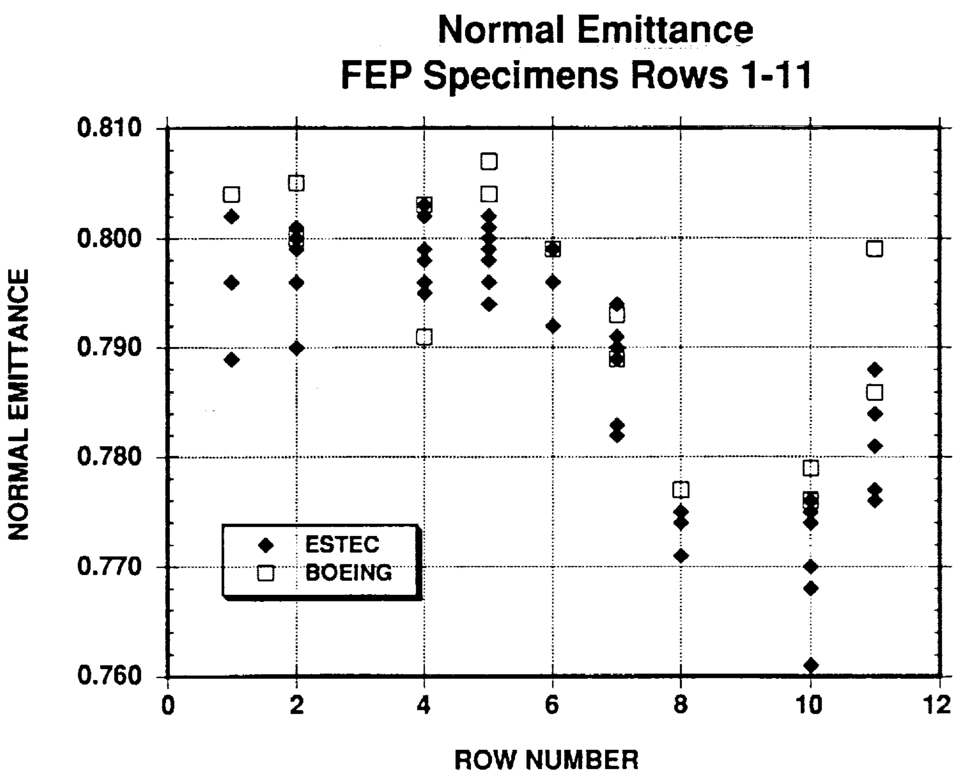
Ultimate tensile strength measurements on trailing edge specimens show the same pattern as the % elongation measurements. The exposed areas of the blankets have decreased mechanical strength relative to protected areas.



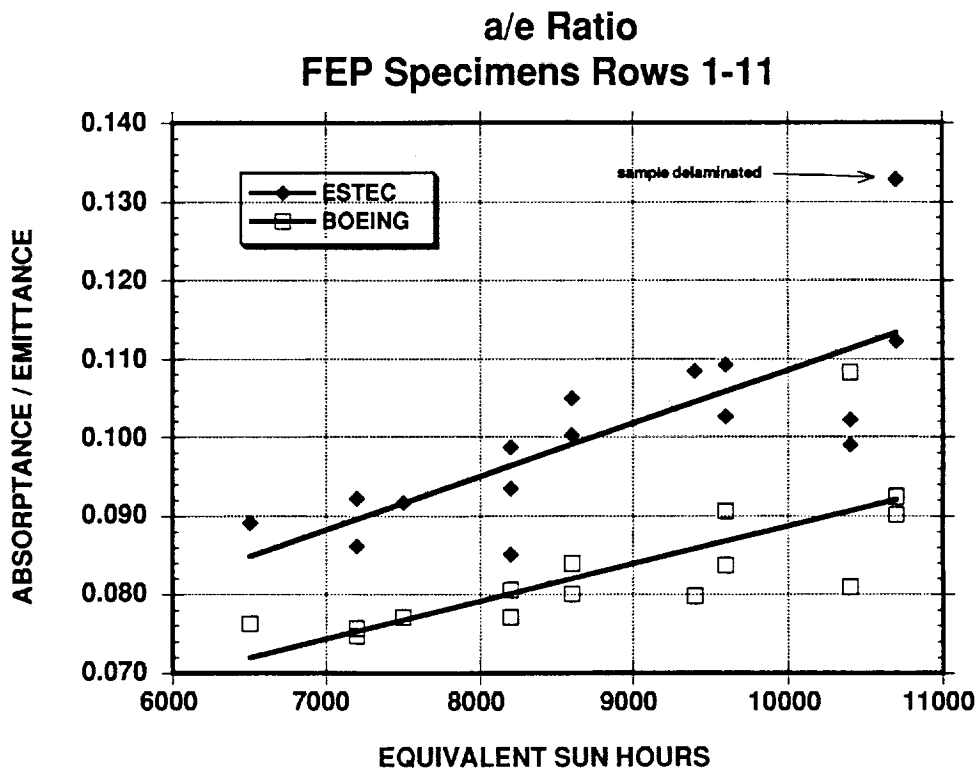
Measurements of solar absorptance vs equivalent sun hours of ultraviolet exposure made at both ESTEC and Boeing indicate a very slight increase in absorptance with increased solar exposure. It should be pointed out, however, that the absolute error associated with such measurements is at least +-0.02 absorptance units. The differences between the absolute values obtained by the two laboratories are within this error and are most likely due to differences in calibration of the instruments used.



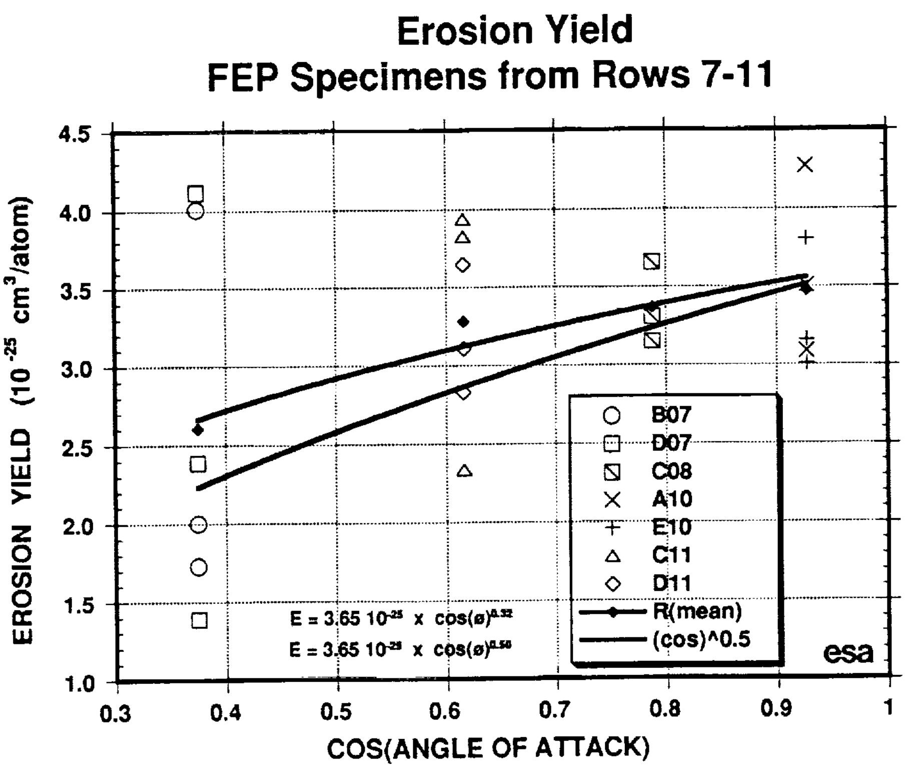
The normal emittance measurements made at ESTEDC and Boeing show a small but reproducible decrease in the emittance of specimens exposed to atomic oxygen. This reflects the slightly decreased thickness of leading edge specimens. The spread in the data is due mainly to initial thickness differences rather than uncertainty in the measurements. The short term reproducibility of the equipment used (Geir-Dunkle DB100) is +-0.003.



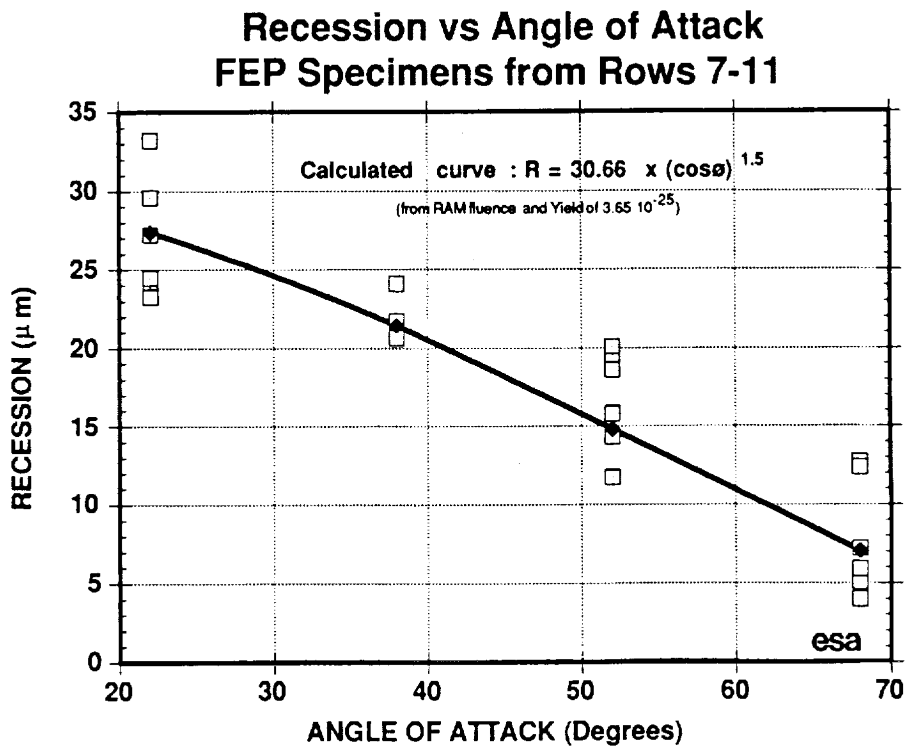
The absorptance to emittance ratio for the silver-backed FEP blankets increases with increased solar exposure. Measurements were made on areas of the blankets free from any noticeable impacts and represent the least damaged areas of the blanket. The fraction of areas punctured and delaminated by impact must be considered when determining the overall efficiency of this type of blanket as thermal protection.



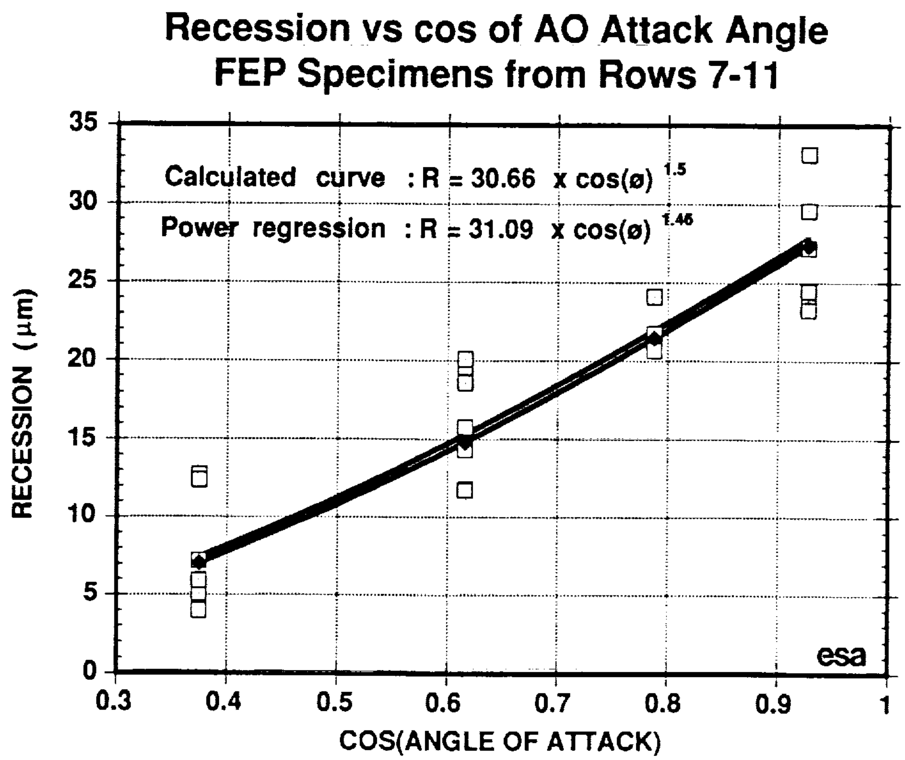
The erosion yield for individual measurements on specimens shows a wide range of values within each row. The determination atomic oxygen fluence, which is dependent on atmospheric density values used in model atmospheres, has its own uncertainty. However, for LDEF, the atomic oxygen fluences are based on one model. The wide range of values of erosion yield for each row is mainly due to the lack of precise knowledge of the initial thickness of each specimen. The best power fit through the mean values gives a power 0.32 of the cos of angle from ram and a value of 0.365x10(-24) cm3 per oxygen atom for the erosion yield at ram. The power curve 0.5 of the cos of angle from ram, previously reported by Bruce Banks of NASA LeRC, is plotted for comparison.



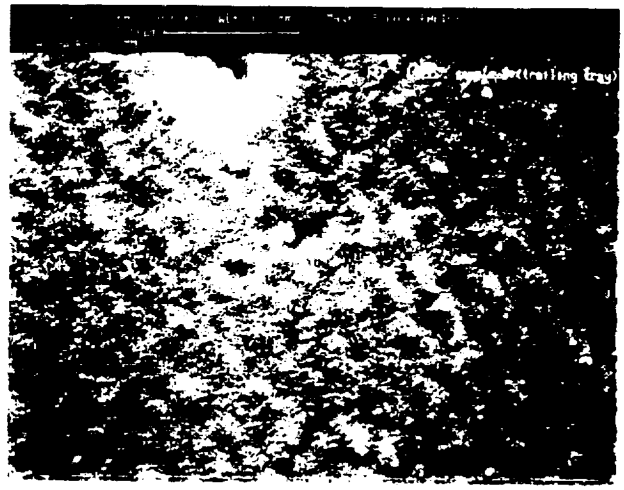
The recession for specimens from rows 7, 8, 10, and 11 on which the erosion yields are based plotted against the angle from ram. The calculated curve is based on an erosion yield of 0.365 x 10(-24) cm3 per oxygen atom and the power 1.5 of cos of angle from ram.



The recession of the FEP layer as a function of cos of angle from ram is plotted. The curves plotted predict about 31 microns recession in the ram direction. One of the cos factors is essentially from the nearly cosine dependence of the atomic oxygen fluence.



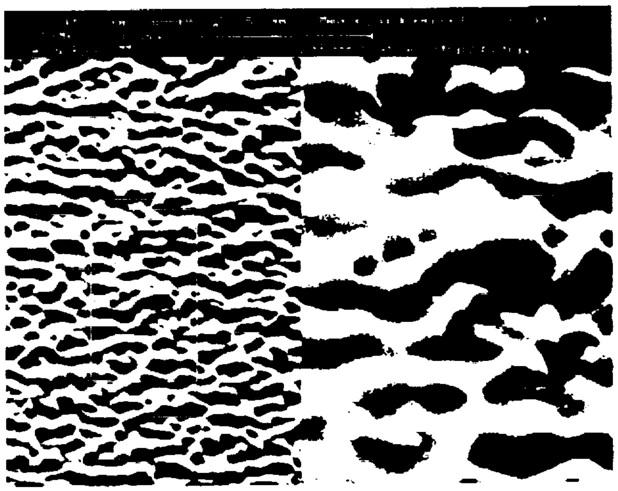
This SEM image of FEP from an exposed region of blanket E02 is representative of large areas of all the blankets exposed only to UV. The surface is smooth and apparently not affected.



SEM of FEP
Trailing Edge E02

(Original photograph unavailable)

In contrast, some effects can be observed visually on a sample of blanket F04. The following SEM images, showing the same area under increasing magnification, clearly show a textured area due to unexplained phenomena. Furthermore this effect seems to be directional.



SEM of FEP
Trailing Edge F04

(Original photograph unavailable)

The mass loss and mechanical properties data obtained at Boeing is presented in this table.

BOEING DATA

Blanket Nr	Mass Unexp (g)	Mass Exp (g)	Thick Unexp (μm)	Thick Exp (μm)	Elong Unexp (%)	Elong Exp (%)	Load Unexp (N)	Load Exp (N)	Tensile Unexp (N/mm2)	Tensile Exp (N/mm2)
D1	0.10052(2)	0.09775(3)	134.74	131.02	310(2)	241(2)	12.32	6.76	20.23	11.41
A2	0.09636(2)	0.09815(3)	129.16	131.56	300(1)	240(2)	10.63	8.54	18.21	14.36
E2	0.09627(3)	0.09288(3)	129.04	124.50	328(2)	213(2)	13.08	8.05	22.42	14.30
F2		0.09640(6)		129.21		239(4)		8.54		14.62
A4	0.09230(3)	0.09241(6)	123.72	123.87	283(2)	267(6)	11.70	10.01	20.92	17.87
F4	0.09886(3)	0.08949(4)	132.51	119.95	306(3)	190(5)	13.17	7.56	21.98	13.94
B5	0.09541(2)	0.09173(2)	127.89	122.95	340(2)	215(2)	13.21	7.78	22.85	14.00
C5	0.09636(2)	0.09754(3)	129.16	130.74	307(2)	198(2)	11.74	8.67	20.11	14.67
D5	0.09834(3)	0.09806(3)	131.81	131.44	327(2)	244(2)	12.41	8.63	20.82	14.52
C6	0.09142(3)	0.09042(3)	122.54	121.2	310(2)	245(2)	11.08	7.83	19.99	14.29
B7	0.09645(3)	0.09096(3)	129.28	121.92	293(2)	313(2)	12.63	10.41	21.61	18.88
D7		0.08773(3)		117.59	280(2)	315(2)	9.25	10.01		18.83
C8		0.07951(3)		106.57		262(4)		10.05		20.86
A10	0.09370(3)	0.07361(5)	125.59	98.67	350(2)	252(4)	12.68	8.81	22.33	19.74
E10	0.09378(3)	0.07568(2)	125.70	101.44	324(2)	322(2)	12.41	9.16	21.84	19.98
C11	0.09308(2)	0.08069(3)	124.76	108.16	315(2)	315(2)	10.63	9.92	18.85	20.29
D11	0.09764(1)	0.08043(3)	130.88	107.81	320(1)	270(1)	9.12	7.92	15.41	16.24

Average Mass, Thickness, % Elongation and Load for each Blanket Specimen (3.47 cm2)
(number in parentheses shows number of individual data points used to obtain average)

The thermo-optical data obtained at Boeing is presented in this table. The atomic oxygen fluence is from the original calculation made at Boeing in early 1990. Values determined using more precise orbit routines have lead to an increase in the calculated values of between about three and five percent, depending on location. These slight corrections do not change the essential conclusions in any way.

BOEING DATA

Blanket Nr	UV (ESH)	AO (at/cm3)	Alpha Exp	Eps Exp	Alpha Unexp	Eps Unexp
D1	7500	1.22E+17	0.062	0.804	0.063	0.804
A2	9600	1.37E+09	0.073	0.805		
E2	9600	1.37E+09	0.067	0.800		
F2	9600	1.37E+09	0.062	0.803		
A4	10400	2.99E+05	0.087	0.803		
F4	10400	2.99E+05	0.064	0.791		
B5	8200	1.09E+13	0.062	0.804		
C5	8200	1.09E+13	0.065	0.807		
D5	8200	1.09E+13	0.062	0.804	0.064	0.799
C6	6500	4.93E+19	0.061	0.799		
B7	7200	3.16E+21	0.059	0.789		
D7	7200	3.16E+21	0.060	0.793		
C8	9400	6.63E+21	0.062	0.777		
A10	10700	7.78E+21	0.070	0.776	0.061	0.803
E10	10700	7.78E+21	0.072	0.779		
C11	8600	5.16E+21	0.066	0.786		
D11	8600	5.16E+21	0.064	0.799		

Thermo-optical Data
(Each value is the average of three measurements)

Mass and thickness data for the FEP layer of the thermal control blankets obtained at ESTEC are shown in this chart.

ESTEC DATA

Blanket Nr	Mass Exposed (g)	Thickness (μm)	Blanket Nr	Mass Exposed (g)	Thickness (μm)	Blanket Nr	Mass Exposed (g)	Thickness (μm)
D01 M B	0.136646	132.39	C05 M B	0.132608	128.48	A10 M B	0.102977	99.77
D01 M M	0.130383	126.33	C05 M M	0.136600	132.35	A10 M M	0.106467	103.15
D01 M T	0.123777	119.93	C05 M T	0.129454	125.43	A10 M T	0.096813	93.80
A02 M B	0.133275	129.13	D05 M B	0.128098	124.11	E10 M B	0.105835	102.54
A02 M M	0.130525	126.46	D05 M M	0.133538	129.38	E10 M M	0.107047	103.72
A02 M T	0.123354	119.52	D05 M T	0.134969	130.77	E10 M T	0.100538	97.41
E02 M B	0.134030	129.86	C06 M B	0.133128	128.99	C11 M B	0.110334	106.90
E02 M M	0.129889	125.85	C06 M M	0.129548	125.52	C11 M M	0.118949	115.25
E02 M T	0.123589	119.74	C06 M T	0.127089	123.13	C11 M T	0.110886	107.44
A04 M B	0.129243	125.22	B07 M B	0.118297	114.62	D11 M B	0.111878	108.40
A04 M M	0.129904	125.86	B07 M M	0.125845	121.93	D11 M M	0.114802	111.23
A04 M T	0.131158	127.08	B07 M T	0.124966	121.08	D11 M T	0.116304	112.69
F04 M B	0.127139	123.18	D07 M B	0.126953	123.00			
F04 M M	0.132623	128.50	D07 M M	0.123657	119.81			
F04 M T	0.134668	130.48	D07 M T	0.117955	114.28			
B05 M B	0.132259	128.14	C08 M B	0.109739	106.32			
B05 M M	0.132414	128.29	C08 M M	0.108617	105.24			
B05 M T	0.133841	129.68	C08 M T	0.106192	102.89			

Mass and Thickness
for each Blanket Specimen (4.796 cm2)

Thermo-optical data obtained at ESTEC for the silvered Teflon thermal control blankets are shown in this chart.

ESTEC DATA

Blanket Nr	Absorptance	Emittance	Blanket Nr	Absorptance	Emittance	Blanket Nr	Absorptance	Emittance
D01 M B		0.802	C05 M B		0.799	A10 M B		0.770
D01 M M	0.073	0.796	C05 M M	0.075	0.802	A10 M M	0.087	0.775
D01 M T		0.789	C05 M T		0.796	A10 M T		0.761
A02 M B		0.800	D05 M B		0.794	E10 M B		0.774
A02 M M	0.082	0.799	D05 M M	0.079	0.800	E10 M M		0.776
A02 M T		0.790	D05 M T		0.801	E10 M T	0.102	0.768
E02 M B		0.801	C06 M B		0.799	C11 M B		0.776
E02 M M	0.087	0.796	C06 M M	0.071	0.796	C11 M M	0.079	0.788
E02 M T		0.790	C06 M T		0.792	C11 M T		0.781
A04 M B		0.796	B07 M B		0.783	D11 M B		0.777
A04 M M	0.079	0.798	B07 M M	0.073	0.791	D11 M M	0.082	0.781
A04 M T		0.799	B07 M T		0.790	D11 M T		0.784
F04 M B		0.795	D07 M B		0.794	Spare	0.077	0.795
F04 M M	0.082	0.802	D07 M M	0.068	0.789			
F04 M T		0.803	D07 M T		0.782			
B05 M B		0.798	C08 M B		0.775			
B05 M M	0.068	0.799	C08 M M	0.084	0.774			
B05 M T		0.800	C08 M T		0.771			

Thermo-optical Data

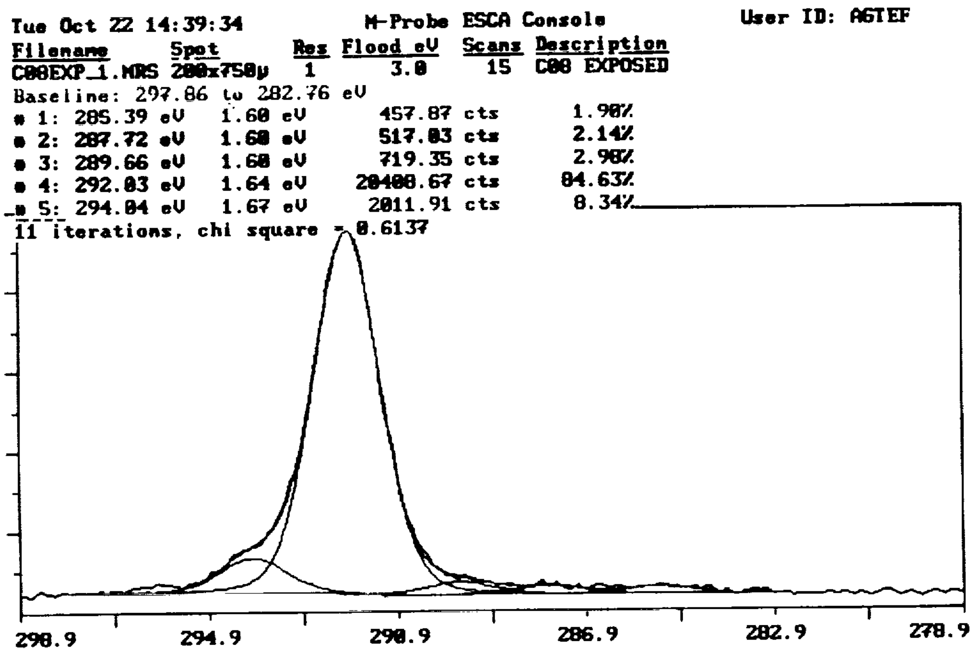
A comparison of total hemispherical and normal emittance is shown for a flight specimen from blanket E10, a ground control spare flight specimen, and a 1 mil silvered FEP Teflon sample. The increase in total hemispherical to normal emittance for the exposed specimen is due to a thickness decrease as confirmed by the 1mil sample. Slight changes in the total hemispherical and normal emittance for the flight specimen were observed after the specimen was polished.

ESTEC DATA

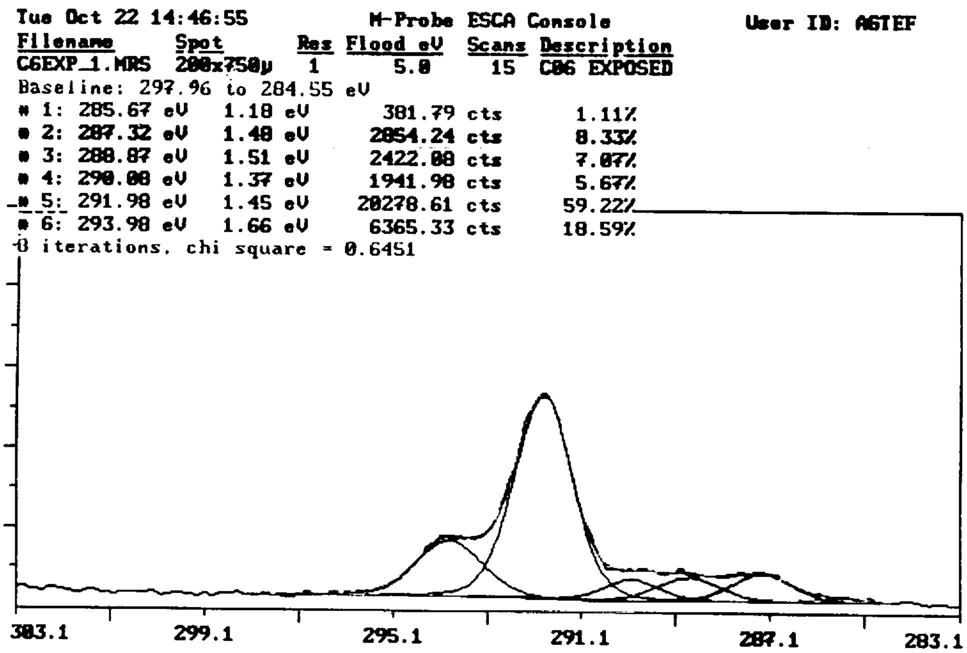
Sample	eH	eN	eH/eN
Spare	0.805	0.795	1.013
E10	0.795	0.770	1.033
E10 polished	0.792	0.763	1.038
1 mil FEP/Ag	0.547	0.487	1.128

Total Hemispherical Emittance

The ESCA spectrum for an exposed area on blanket C08 is essentially identical to a spectrum of unexposed FEP.



This spectrum for an exposed area from blanket C06 shows the competition between the effects of ultraviolet radiation and atomic oxygen exposure. As the UV breaks bonds and causes structural rearrangements, sites are created where the oxygen atoms can react and produce volatile products. The reactions with atomic oxygen occur on the surface but the UV damage extends into the material.



This ESCA spectrum for an exposed area on blanket C05 shows evidence of significant changes in the chemical structure of the FEP. The changes in this spectrum relative to the spectrum from C08 are representative of UV induced bond breaking and subsequent cross-linking.