BOEING ENGINEERING & CONSTRUCTION
THE BOEING ENERGY AND ENVIRONMENT DIVISION

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Unlimited Release

Plastic Film Performance Improvement for Heliostats

FINAL REPORT

Prepared for
Sandia Laboratories
Livermore, California
under Contract 83-0035D

July 1980

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FOR HELIOSTATS

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Under

Contract No. 83-0035D

by

Boeing Engineering and Construction Company
A Division of The Boeing Company
Seattle, Washington 98124

FOREWORD

This document is the final report issued under Sandia Laboratories Contract 83-0035D. The objective of this contract is to improve the Boeing Engineering and Construction (BEC) heliostat design and hence its overall performance and cost effectiveness through the development and test of improved enclosure and reflector plastic films. Work under this contract was initiated on April 9, 1979, and was completed July 31, 1980. This report complies with Task III-e as designated in the contract work statement. Technical management at Sandia was performed by Mr. Clayton Mavis. Program management at BEC was performed by Mr. Roger Gillette. Mr. Marcus Berry was project manager at BEC, and Mr. Harry Dursch performed the majority of work in the project

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1.0 INTRODUCTION AND SUMMARY

A plastic film improvement program was initiated to improve the BEC enclosed heliostat design and hence its overall performance and cost effectiveness. The initial overall plan for completing the program tasks and for accomplishing all its objectives is represented in the Event Logic Network shown in Figure 1-1.

An industrial survey was initiated in the early weeks of the contract. The initial list of potential film suppliers was expanded from a few to 30. Suppliers were urged to participate by providing samples of materials they felt had potential. Suppliers were visited for technical discussions about their products and to become knowledgeable in the processes of plastic film manufacture. The preliminary candidate materials were screen tested in Boeing laboratories. The materials showing promise were sent to Phoenix for desert exposure testing. After 3 months of accelerated exposure, coupons were withdrawn and tested for degradation. The data were used to eliminate candidates of obvious poor weatherability, and assist the supplier in making modifications for possible second iteration materials.

Exposure of first iteration materials continued while second iteration candidates (new materials and modified previously tested materials) were being made available. After 6 months of real time and accelerated exposure first iteration samples were withdrawn and returned for lab tests. Lab testing of second iteration materials were performed after 3 months of accelerated exposure. Exposure testing of the most promising materials will be continued after the end of this contract.

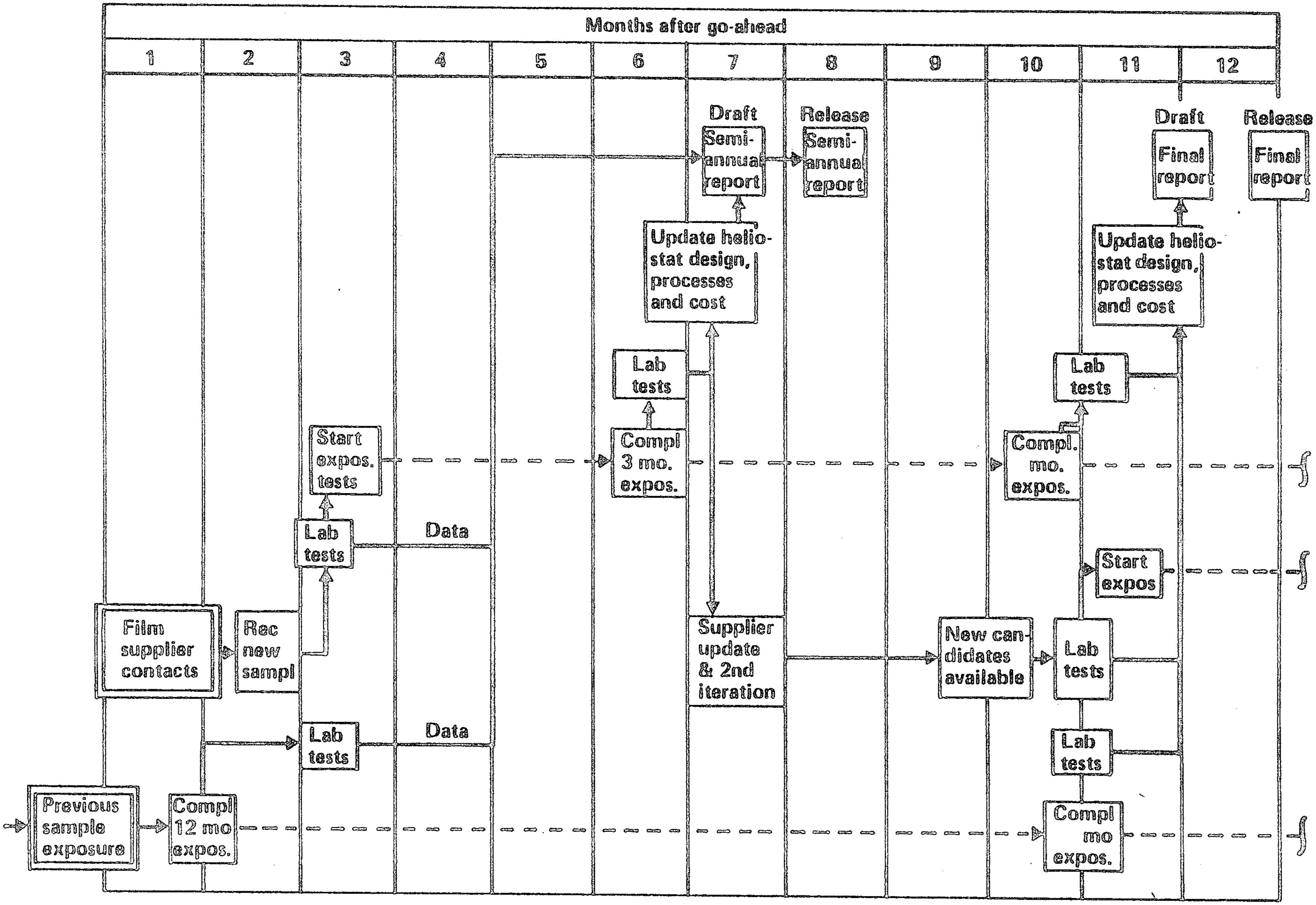

Figure 1-1. Event Logic Network

Response from the plastic film industry was slower than anticipated, causing a delay in the start of the outdoor testing. A major problem was that while many firms were interested, few of them could supply the material off the shelf. The majority required additional time to make special process runs. A 3 month contract extension permitted evaluation of materials after 6 months of exposure testing.

Plastic film exposure and testing initiated under a previous contract was continued in parallel with this contract, and these results are included in this report also. Outdoor exposure testing began in April, 1978. After an equivalent of over 15 years of solar exposure (24 months at $\simeq$ 7.6 suns), the two fluorocarbons, Kynar and Tedlar, have shown no appreciable degradation of mechanical or optical properties. During this period of time, the polyesters (weatherable and nonweatherable) and polycarbonate (weatherable) all exhibited severe loss of mechanical properties. Of the reflector material samples, only the OCLI* silvered UV stabilized polyester has shown promise after an equivalent of $\simeq$ 4 years solar exposure. The suppliers were notified of their respective material's exposure results.

Samples with improved weatherability characteristics were received during and after the industrial survey conducted in the early weeks of this contract. The most promising samples were sent to Arizona for exposure testing in August, 1979. While most materials displayed improved UV resistance, very few came close to meeting the mechanical and optical goals set by BEC and discussed in the following section. 3M** provided a highly specular transparent polyester (93%), but preliminary results show a roll off in properties after accelerated exposure. Dow Corning applied an anti-abrasive coating to the 3M material with the goal of improving its abrasive resistance and weatherability. The initial specularity fell to 89%; no exposure data is yet available to determine if longevity has been increased. Dunmore aluminized some ICI Melinex "OW" and achieved fairly high specular reflectance (89%), but the material showed a fairly substantial loss in ultimate elongation after 3 months of accelerated testing.

* Optical Coating Laboratories, Inc.

**Minnesota Mining and Manufacturing Co.

2.0 INDUSTRIAL SURVEY

2.1 Industry Contacts

At the initiation of the contract, suppliers were contacted by telephone to determine if mutual interest existed. If a supplier showed interest in participating in any way, a formal invitation letter and film performance specification was sent. Goals of 92% transmittance (.14^{o} cone angle) and 93% reflectance (.14^{o} cone angle) with minimal optical degradation and less than a 10% loss per year of mechanical properties were set. In cases where it appeared mutually beneficial, meetings and tours were held either at the supplier's plant or at BEC.

Thirty suppliers were contacted with 19 active responses. Some suppliers sent a variety of films and coatings. In many cases, the coupons were "first cut" laboratory-made materials that fell short of the program goals but showed promise for further improvement.

The flow of candidates was continuous for several months rather than the two as originally planned. Table 2.1-1 shows the 30 suppliers contacted and their respective responses.

SUPPLIER	PRODUCT LINE	RESPONSE
OPTICAL COATING LAB, SANTA ROSA, CA.	COATINGS	. COATED/SILVERED/POLYESTER . HIGH τ COATING (AR) FOR POLYESTER & KYNAR . COATED/SILVERED/KYNAR
3M ST. PAUL, MINN.	FILMS & COATINGS	. ACRYLIC COATED/ALUMINIZED/POLYESTER . HIGH τ COATING (AR) FOR KYNAR . ACRYLIC COATED/SILVERED/POLYESTER
SHELDAHL NORTHFIELD, MINN.	COATINGS	. 2ND SURF. SILVERIZED POLYCARBONATE . 2ND SURF. ALUMINIZED POLYCARBONATE
PENNWALT KING OF PRUSSIA, PA	RESINS	. BIAXIALLY ORIENTED KYNAR
DOW-CORNING MIDLAND, MICH.	COATINGS	. HIGH τ AND ABRASION RESISTANCE COATING FOR KYNAR, TEDLAR, POLYESTER
NATIONAL METALIZING CRANBURY, N.J.	COATINGS	. COATED/ALUMINIZED/POLYESTER . COATED/SILVERED/KYNAR
XCEL CORP. NEWARK, N.J.	FILM	. 3 MIL KORAD . ALUMINIZED KORAD
MORTON CHEMICAL WOODSTOCK, ILL.	COATINGS	. HIGH τ COATING FOR TEDLAR . ANTIOXIDANT COATING AND ANTIABRASION FOR ALUMINIZED POLYESTER
MOBAY PITTSBURGH, PA.	RESIN	. ALUMINIZED/POLYCARBONATE . STABILIZED POLYCARBONATE
DUNMORE NEWTOWN, PA.	COATINGS	. COATED/ALUMINIZED/MELINEX

Table 2.1-1 Vendors Contacted

77-K1803-NOV

SUPPLIER	PRODUCT LINE	RESPONSE
CELANESE GREER, S.C.	FILMS	. U/V STABILIZED CELANAR (POLYESTER)
ICI WILMINGTON, DE	FILMS	. INTERNALLY STABILIZED POLYESTER
MARTIN PROCESSING MARTINSVILLE, VA.	FILM DYEING	. U/V STABILIZED POLYESTER
CRYOVAC S.C.	LAMINATIONS/ COATINGS	. U/V STABILIZED POLYCARBONATE
BIXBY, INTERNATIONAL MASS.	COATINGS	. ACRYLIC COATING ON U/V STABILIZED POLYCARBONATE
EASTMAN CHEM. TENN.	FILMS	. POSSIBLE WEATHERABLE POLYESTER
CLOUDSLEY CINCINNATI, OHIO	FILMS	. NO LONGER MAKING POLYCARBONATE
ALLIED CHEMICAL MORRISTOWN, N.J.	UNORIENTED FILM	. POSSIBLE 2ND ITERATION U/V STABILIZED PETRA
CHEMPLAST SAN JOSE, CA.	SUPPLIER	. POSSIBLE LAMINATION SCHEME
PIERSON INDUSTRIES MASS.	EXTRUDER	. POSSIBLE COEXTRUSION FILM
BEE CHEMICAL CHICAGO, ILL.	COATINGS	. POSSIBLE U/V AND ABRASION RESISTANT COATING FOR METALLIZED FILM

Table 2.1-1 Vendors Contacted

77-K1803-NOV

SUPPLIER	PRODUCT LINE	RESPONSE
CROWN ZELLERBACH SAN FRANCISCO, CA.	COEXTRUDER	. POSSIBLE COEXTRUSION SCHEME
VAN LEAR HOUSTON, TEXAS	LAMINATION	. POSSIBLY TEAR RESISTANCE IMPROVEMENT THROUGH CROSS-LAMINATION
AMERICAN ENKA N.C.	FILMS	. NOTHING AT THIS TIME
DOW CHEMICAL MIDLAND, MICH.	FILMS	. NOTHING AT THIS TIME
OWENS ILLINOIS TOLEDO, OHIO	FILMS	. NOTHING AT THIS TIME
SUNTEC CA.	CONTROL COATINGS	. NOTHING AT THIS TIME
SPRINGBORN LABS ENFIELD, CONN.	RESEARCH, LAB	. NOTHING AT THIS TIME
UNION CARBIDE LONG BEACH, CA.	RESIN	. NOTHING AT THIS TIME
EXXON PASEDENA, TEXAS	FILM	. NOTHING AT THIS TIME

Table 2.1-1 Vendors Contacted

77-K1803-NOV

2.2 Screening Tests

As samples were received from various suppliers, they were given initial "screening" tests to determine if mechanical and optical properties were within acceptable range to warrant outdoor exposure testing. This determination was made within Boeing laboratories.

Microtensile coupons were tested per ASTM D1708 for determination of yield strength, ultimate strength, and ultimate elongation. The microtensile coupon is used because of the limited amount of test material that is usually available.

Specular reflectance or specular transmittance was measured on reflector or enclosure candidate films, respectively. Specularity is measured by using a modified bidirectional reflectometer utilizing a 633 nanometer wavelength laser source and a variable aperture system (0.08^{o} to 0.59^{o}) to determine scatter. In addition, specular transmittance can be measured using a Beckman DK-2A spectrophotometer and a Gier-Dunkle integrating sphere, to provide transmittance within an acceptance cone angle of $.5^{o}$ for wavelengths of 250 through 2500 nanometers. The results are integrated over an air mass 2 solar spectrum. The instrument accuracy of the transmittance and reflectance measurements is $\pm$ 0.5%.

At the start of exposure testing over 4 years ago, BEC's specularity measuring techniques determined specular transmittance on the Beckman DK-2A spectrophotometer and specular reflectance on the modified bidirectional reflectometer at aperture openings of 0.5^{o} (8.7 mr) and 0.14^{o} (2.5 mr) respectively. The same measurement techniques were used during this contract for the purposes of consistency and comparison.

Tables 2.2-1 and 2.2-2 show the samples that were selected for outdoor exposure testing under this contract and the material identification used in this document. Table 2.2-3 shows samples whose exposure was initiated under a previous contract.

ENCLOSURE FILMS

BEC IDENTIFIER	SUPPLIER	MATERIAL	THICKNESS (MILS)
FLUOROCARBON B	MORTON CHEMICAL	o FLUOROCARBON (TEDLAR)	1
FLUOROCARBON B (AR)		o ANTI-REFLECTIVE (AR) COATED TEDLAR	1
POLYESTER D	MARTIN	o UV STABILIZED POLYESTER	5
FLUOROCARBON C (ORIENTED)	PENNWALT	o BIAXIALLY ORIENTED FLUOROCARBON (KYNAR)	3
POLYESTER E	ICI	o INTERNALLY STABILIZED POLYESTER	3
POLYESTER F	CELANESE	o UV STABILIZED POLYESTER	3
POLYCARBONATE B	CRYOVAC	o UV STABILIZED POLYCARBONATE	6
POLYCARBONATE C	MOBAY	o UV STABILIZED POLYCARBONATE	2
ACRYLIC	XCEL	o ACRYLIC (KORAD)	3
POLYESTER G	3M	o AR COATED/INTERNALLY STABILIZED POLYESTER	4
POLYESTER H	DOW CORNING	o ABRASIVE RESISTANT COATED/AR COATED/ INTERNALLY UV STABILIZED/ POLYESTER	4

Table 2.2-1. Enclosure Films Sent to DSET

REFLECTOR FILMS

BEC IDENTIFIER	SUPPLIER	MATERIAL	THICKNESS (MILS)
SILVERED/POLYCARBONATE M	SHELDAHL	o SILVERED/UV STABILIZED/POLYCARBONATE	2.5
ALUMINIZED/POLYCARBONATE N		o ALUMINIZED/UV STABILIZED/POLYCARBONATE	2.5
ALUMINIZED/POLYCARBONATE O	MOBAY	o ALUMINIZED POLYCARBONATE	1
ALUMINIZED ACRYLIC	XCEL	o ALUMINIZED ACRYLIC	2
ALUMINIZED/POLYESTER P	DUNMORE	o ALUMINIZED POLYESTER	2
ALUMINIZED/POLYESTER Q		o COATED/ALUMINIZED/POLYESTER	2
ALUMINIZED POLYESTER R		o ALUMINIZED/UV STABILIZED/POLYESTER	2
ALUMINIZED POLYESTER S	3M	o ACRYLIC COATED/ALUMINIZED/POLYESTER	2
ALUMINIZED POLYESTER T	MORTON CHEMICAL	o COATED/UV STABILIZED/POLYESTER	2
ALUMINIZED POLYESTER U		o COATED/UV STABILIZED/POLYESTER (ALTERNATE COATING)	2
ALUMINIZED POLYESTER V		o COATED/UV STABILIZED/POLYESTER (ALTERNATE COATING)	2

Table 2.2-2. Reflector Films Sent to DSET

Table 2.2-3. Enclosure and Reflector Films Previously Under Test at DSET

BEC Identifier	Thickness (mils)	Supplier	Material
		Enclosure	
Fluorocarbon A	4	Du Pont	Fluorocarbon (Polished Tedlar)
Fluorocarbon C (Lab)	4	Pennwalt	Fluorocarbon (Kynar-made in laboratory)
Polyester A	6	Allied Chemical	Polyester (Petra A)
Polycarbonate A	8	W.R. Grace	UV Stabilized polycarbonate
Polyester B	3.5	National Metalizing	UV Stablized polyester
Polyester C	2	Martin Processing	UV stabilized polyester (Llumar)
		Reflector	
Silvered polyester J	2	Optical Coating Laboratory	Silvered/UV Stabilized/Polyester
Aluminized polyester K	2	National Metalizing	Coated/Aluminized/Polyester
Aluminized polyester P	2	Dunmore	Coated/Aluminized/Polyester

3.0 DESERT EXPOSURE TESTS

3.1 Apparatus

Plastic film samples that were selected for outdoor exposure tests were sent to Desert Sunshine Exposure Testing Facility (DSET) located in the Sonora Desert, 40 miles north of Phoenix, Arizona. Two exposure tests were conducted, accelerated and real time.

Real time exposure testing is performed on 45^o elevation, south facing racks providing 1 sun exposure. Accelerated testing is performed on EMMA (equatorial mount with mirrors for acceleration). EMMA acceleration factors average out to approximately 8 suns over a year's period of exposure. These machines track the sun equatorially and have an air distribution system that forces air past the samples so that their surface temperatures are approximately the same as that of a sample on a south facing rack. As EMMA machines are non-operational during periods of low insolation, the samples are protected from the environment during periods of inclement weather.

Plastic film materials were cut into 2 inch x 5 inch coupons. All reflective material coupons were placed inside of Kynar bags to simulate BEC's plastic film heliostat design. Figure 3.1-1 shows a close-up of two silvered polyester coupons inside of Kynar bags on a 45^o elevation south facing rack, and Figure 3.1-2 shows reflector material coupons undergoing exposure testing on EMMA. The same testing techniques that were used to screen test the samples were used to test the samples after outdoor exposure. The samples were optically measured before and after cleaning. The materials were cleaned by immersing them 5 minutes in an ultrasonic bath with detergent, rinsing them in distilled water, then air dried. All optical values presented in this report were measured after cleaning. Microtensile tests destroy the samples, so successive measurements are made on the same material, not the same sample.

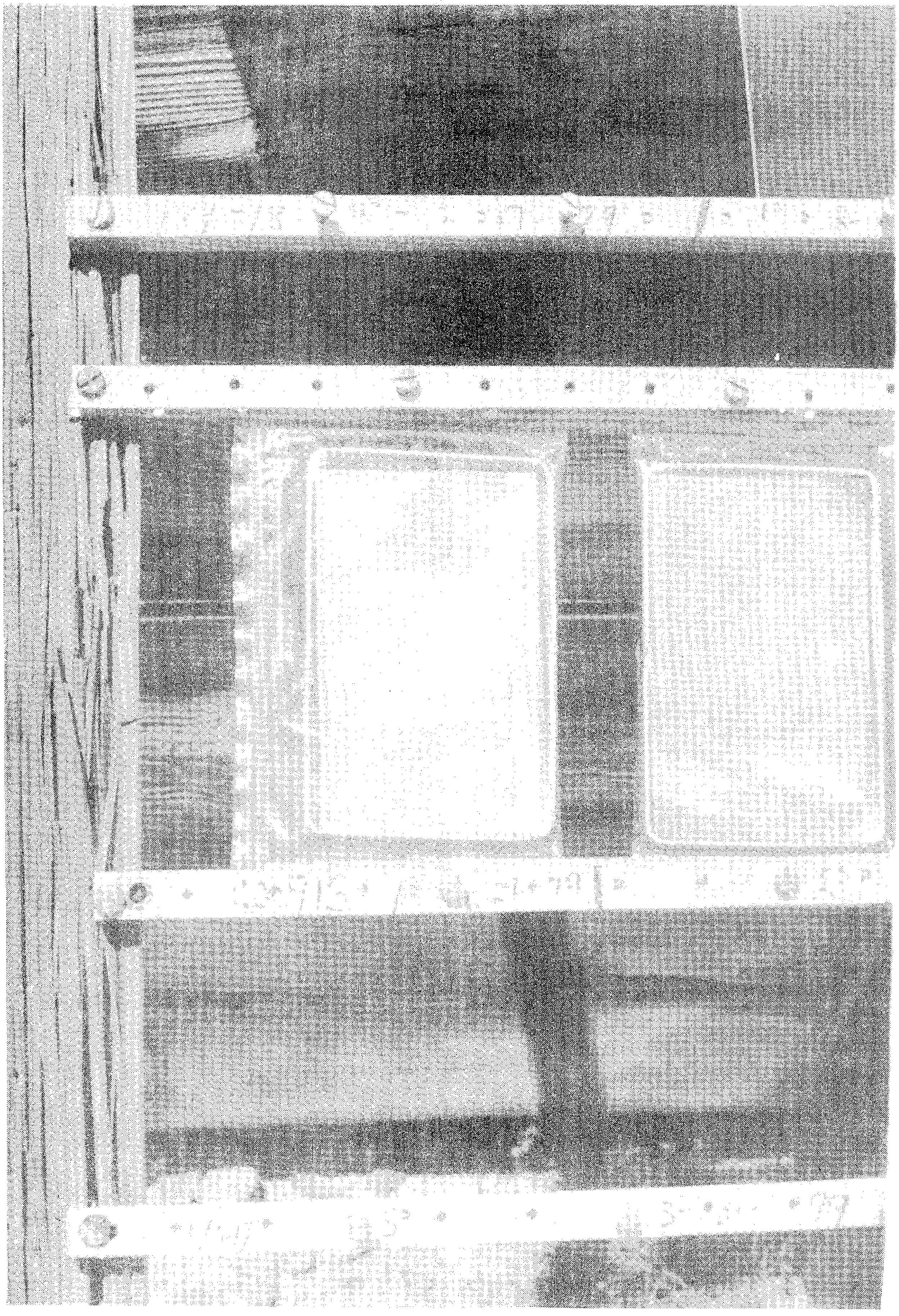

Figure 3.1-1. Reflector Coupons on Real Time Rack

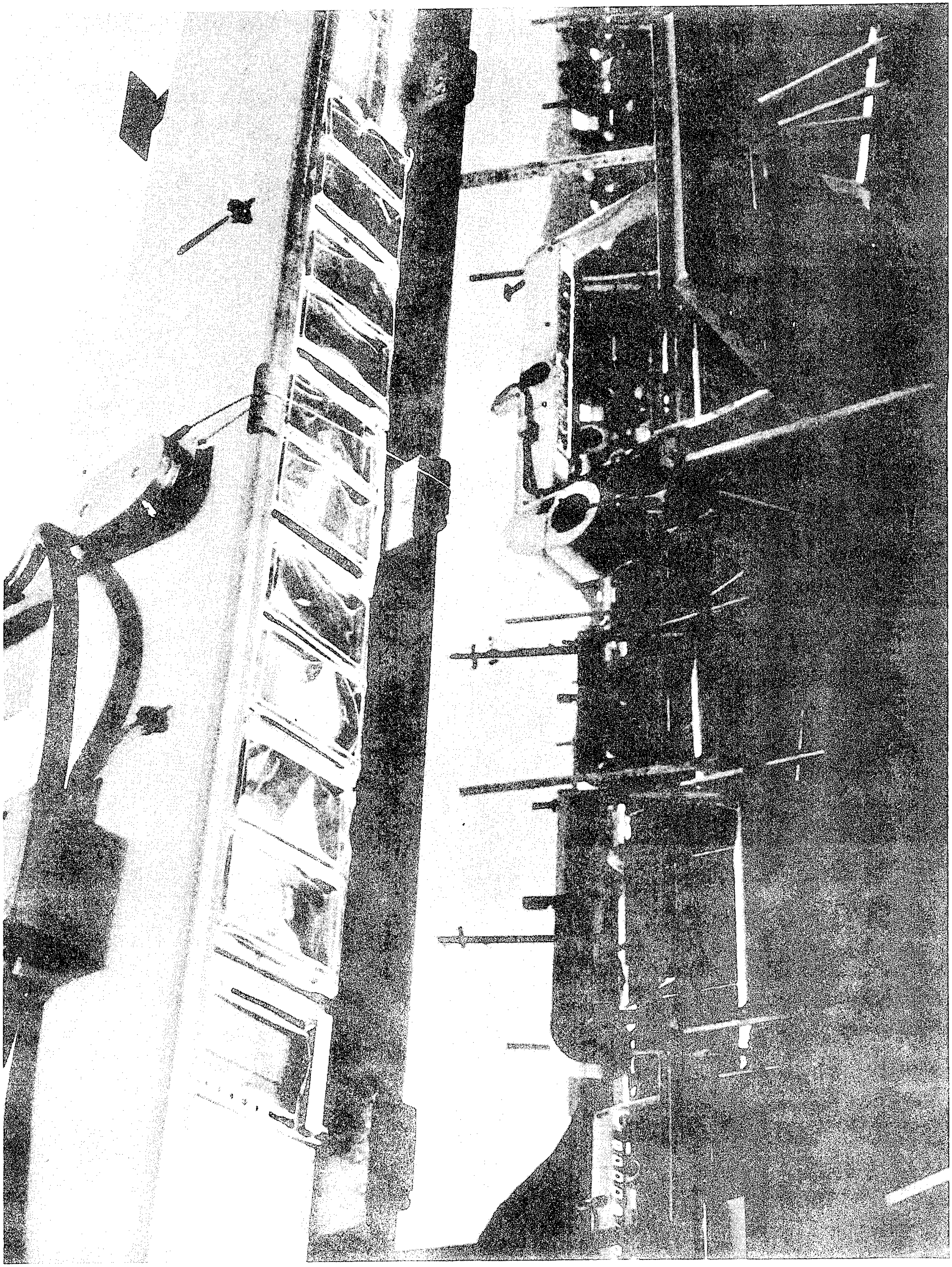

Figure 3.1-2. Reflector Coupons on EMMA

3.2 Test Results (Enclosure Films)

Shown in Table 3.2-1 are the transparent, thin film materials that have been or are currently being exposure tested at DSET. Materials whose exposure testing was initiated under a previous contract have had up to 24 months of solar exposure while the materials initiated under this contract have had 6 months exposure.

After 24 months of real time and an equivalent of over 15 years of accelerated solar testing, the fluorocarbons, Kynar and Tedlar, have proven to be the most promising of the enclosure films. Figures 3.2-1 and 3.2-2 give the ultimate elongation and specular transmittance of Kynar and Tedlar respectively. Experience has shown ultimate elongation to be the first mechanical property to exhibit signs of degradation. After an equivalent of 15.2 years solar exposure (2,781,000 langleys), Kynar exhibited a negligible loss of specularity (0.5° cone angle, air mass 2), and a 35% increase in elongation. During the same time, Tedlar decreased 4% in specularity and elongation. The results of real time testing after 2 years (368,000 langleys), show that Kynar had no change in specularity and a 36% increase in elongation. Tedlar had a 2% loss in specularity and a 5% loss of elongation.

The test results of plastic films exhibit scatter in both mechanical and optical properties as can be seen in Figure 3.2-1 and 3.3-2. This seems to be an inherent problem of thin film plastics and is probably due to non-uniformities in the orientation of the basic film and non-uniformities resulting from coatings and in the case of reflective films, the metalizing process.

Shown in Figure 3.2-3 and 3.2-4 are the results from exposure testing of three polyesters and one polycarbonate that was initiated over 2 years ago. All four materials lost considerable mechanical strength in EMMA after 6 months. In all cases, elongation was reduced to near zero. The losses in transmittance ranged from 27% for the Polyester A to 60% for the Polycarbonate A. It was decided to discontinue accelerated testing after 6 months.

Table 3.2-1. Enclosure Materials Undergoing Exposure Testing at DSET

IDENTIFIER	SOLAR SPECULAR TRANSMITTANCE, % @ .5° cone angle, (control value)
Polyester G	93
Fluorocarbon A	90
Fluorocarbon C (Lab)	89
Polyester H	89
Polyester A	89
Polycarbonate C	89
Acrylic	87
Fluorocarbon C (Oriented)	86
Polycarbonate A	86
Polyester B	86
Polyester D	85
Polyester F	85
Polyester E	84
Fluorocarbon B (AR)	83
Polyester C	82
Fluorocarbon B	79
Polycarbonate B	73

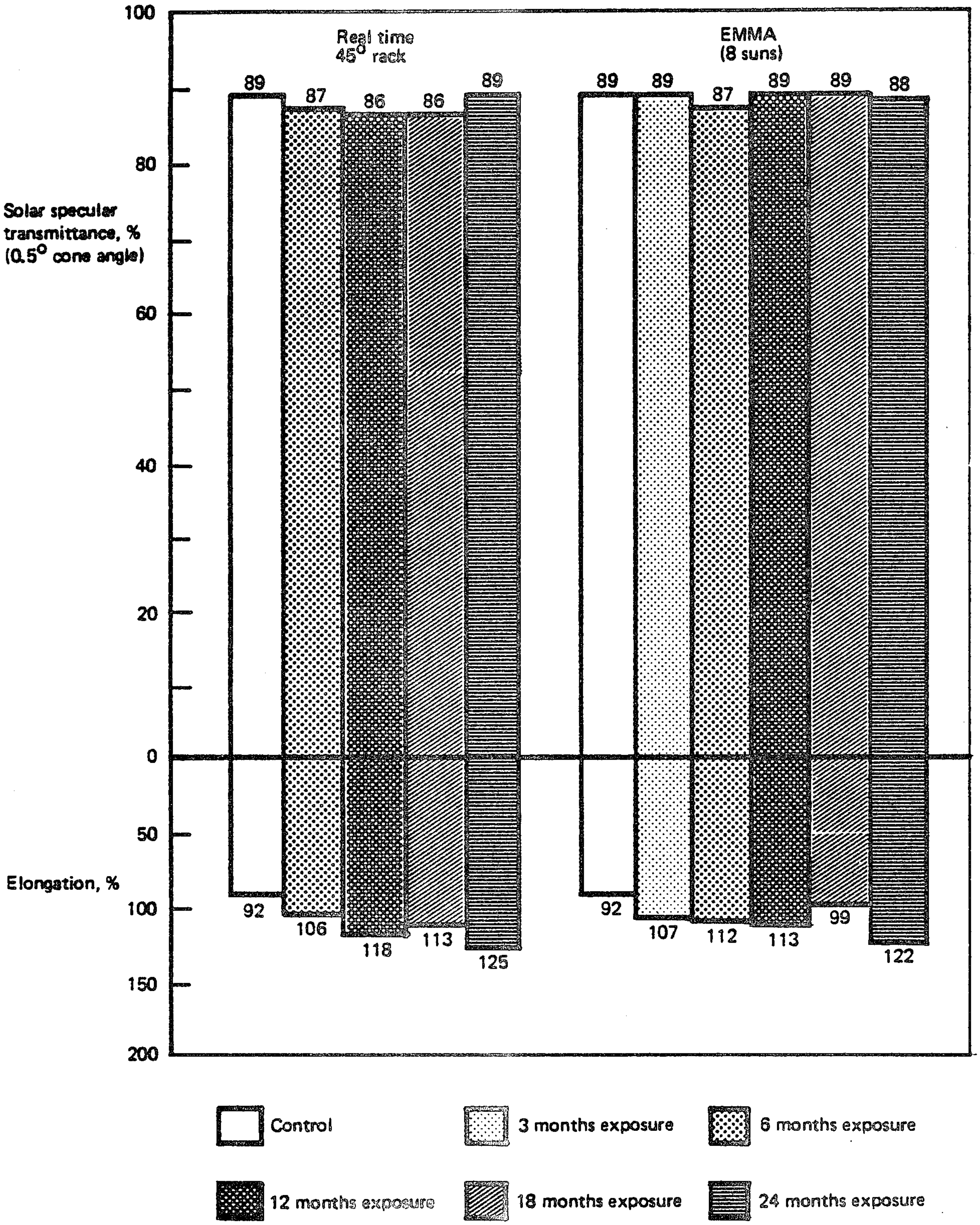

Figure 3.2-1. Fluorocarbon C (Lab Kynar) Exposure Testing Results

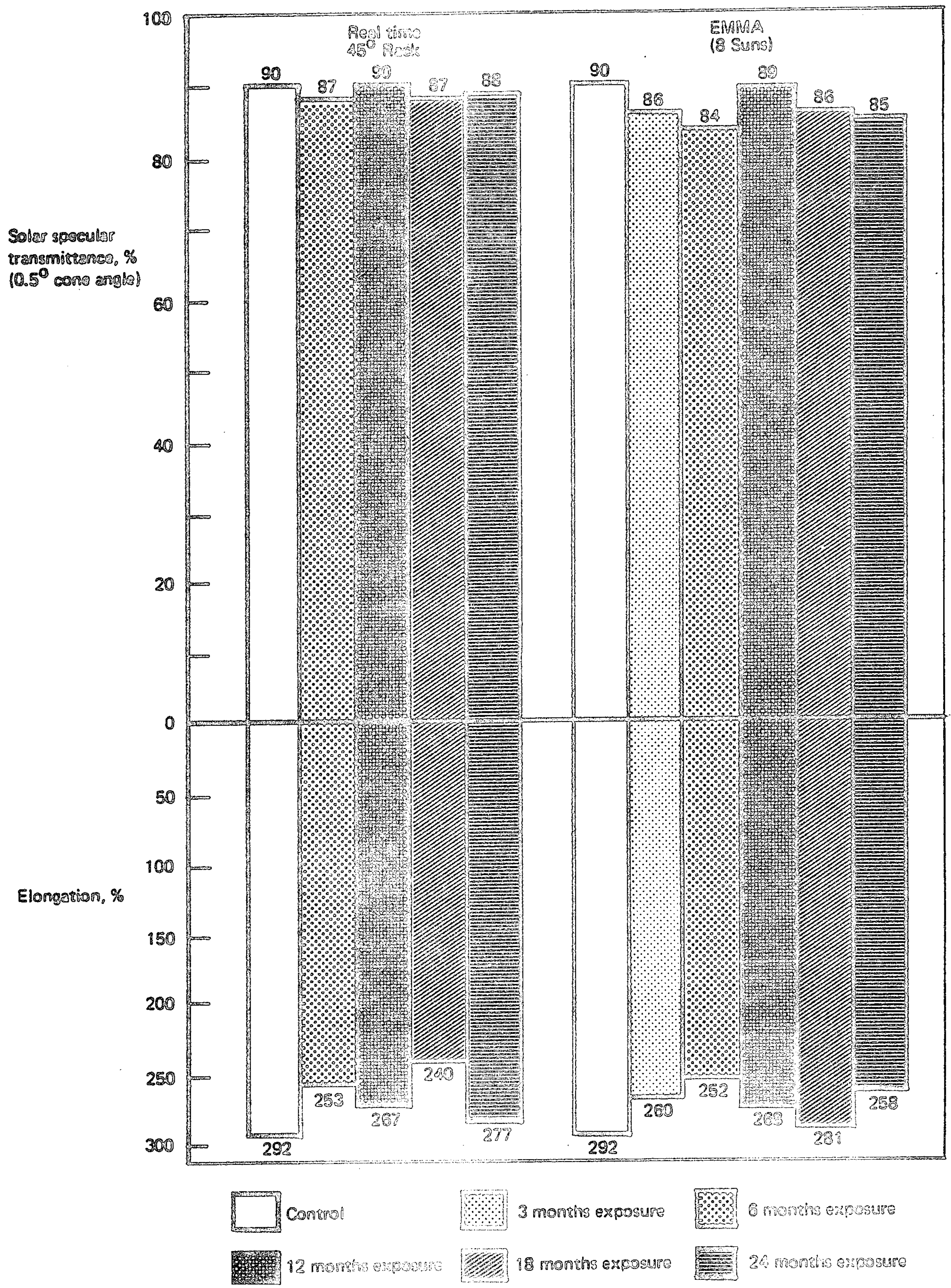

Figure 3.2-2. Fluorocarbon A (Tedlar) Exposure Testing Results

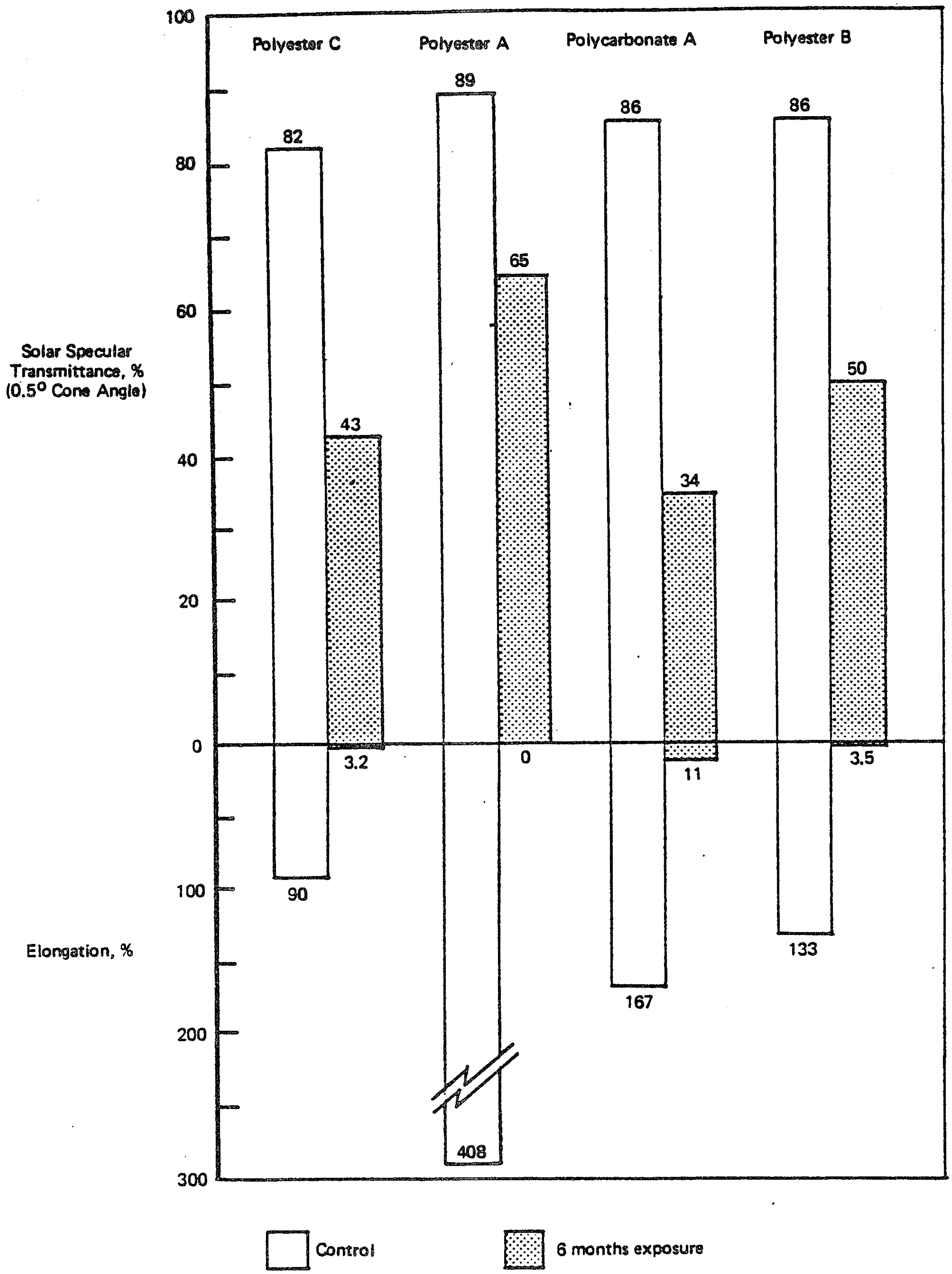

Figure 3.2-3. Enclosure Material Data - EMMA (8 Suns)

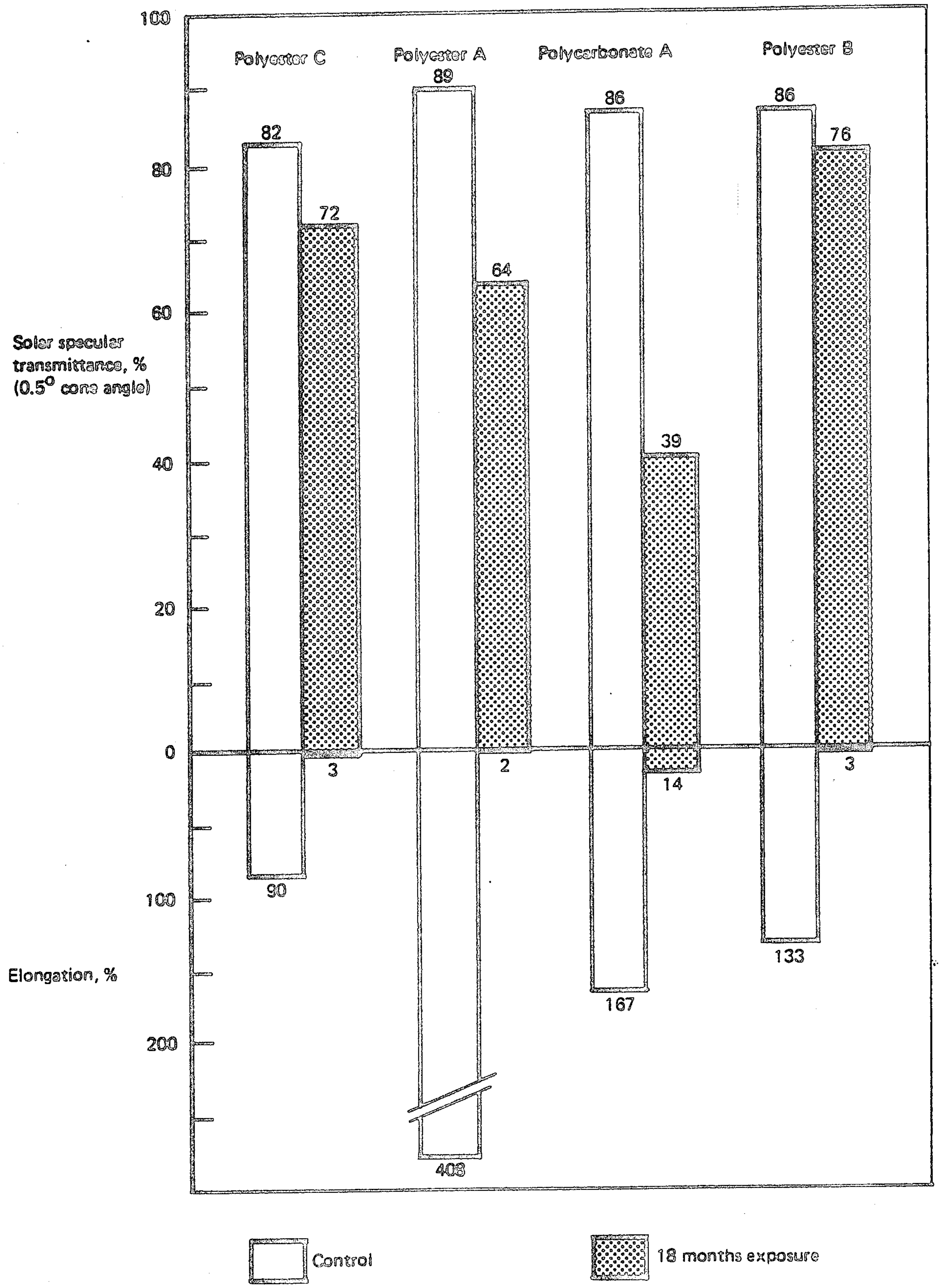

Figure 3.2-4. Enclosure Material Data - Real Time (45° Rack)

Polyester C, Polyester B and Polycarbonate A samples were UV stabilized but as results show, the stabilization techniques used were inadequate. The suppliers were notified and samples with second iteration stabilization techniques are now being evaluated.

The most promising of the transparent plastic films, whose exposure was initiated under this contract, are shown in Figures 3.2-5 and 3.2-6. Martin Processing provided 5 mil Llumar which is a UV stabilized polyester (Polyester D) The Llumar that was exposure tested before was 2 mil (Polyester C, Figures 3.2-3 and 3.2-4) and it was felt that by increasing the thickness, the weatherability would be enhanced. The exposure testing data shows no loss in specularity and a 22% drop in elongation after 6 months of real time exposure. After the same exposure time, the 2 mil Llumar had shown an 82% drop in elongation. This material is also very specular with no change in transmittance through the various aperture openings of .08^{o} to .59^{o} (1.4 mr to 10.3 mr).

Polyester E exhibited no loss of specular transmittance, but the elongation decreased by 47%, from 101% to 54%, after 6 months of real time testing. This degradation is quite typical of polyesters, as shown in Figure 3.2-5, and illustrates the importance of the ultimate elongation (% elongation at failure) values.

A 5.2 m (17 ft) diameter gore formed dome made out of the Polyester E material and fabricated by Sheldahl under contract with BEC, was installed in Boardman, Oregon on May 6, 1979. The dome has remained intact after 15 months, while surviving severe snow loading, 31 m/s (70 mph) wind storms and volcanic ash. The dome in the foreground on Figure 3.2-7 is the Polyester E dome installed at Boardman.

The Fluorocarbon C (oriented) shown in Figures 3.2-5 and 3.2-6 is part of a run of biaxially oriented Kynar made by Pennwalt under contract with BEC. The material exhibited little or no loss of mechanical or optical values after 6 months of accelerated or 6 months of real time exposure. A West German firm called Bruckner oriented some Kynar film provided by Pennwalt and achieved equivalent results.

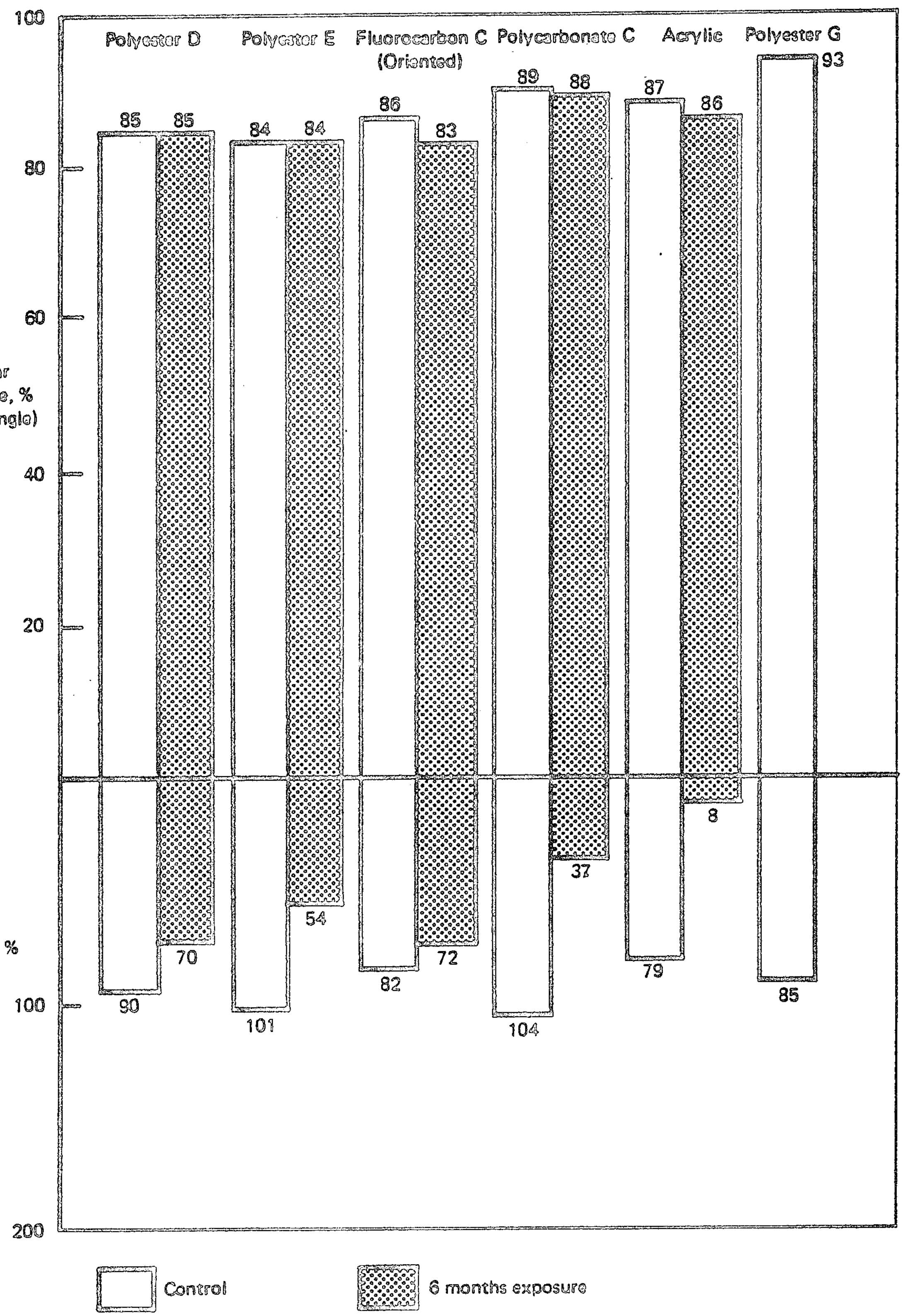

Figure 3.2-5. Enclosure Material Data - Real Time (45° Rack)

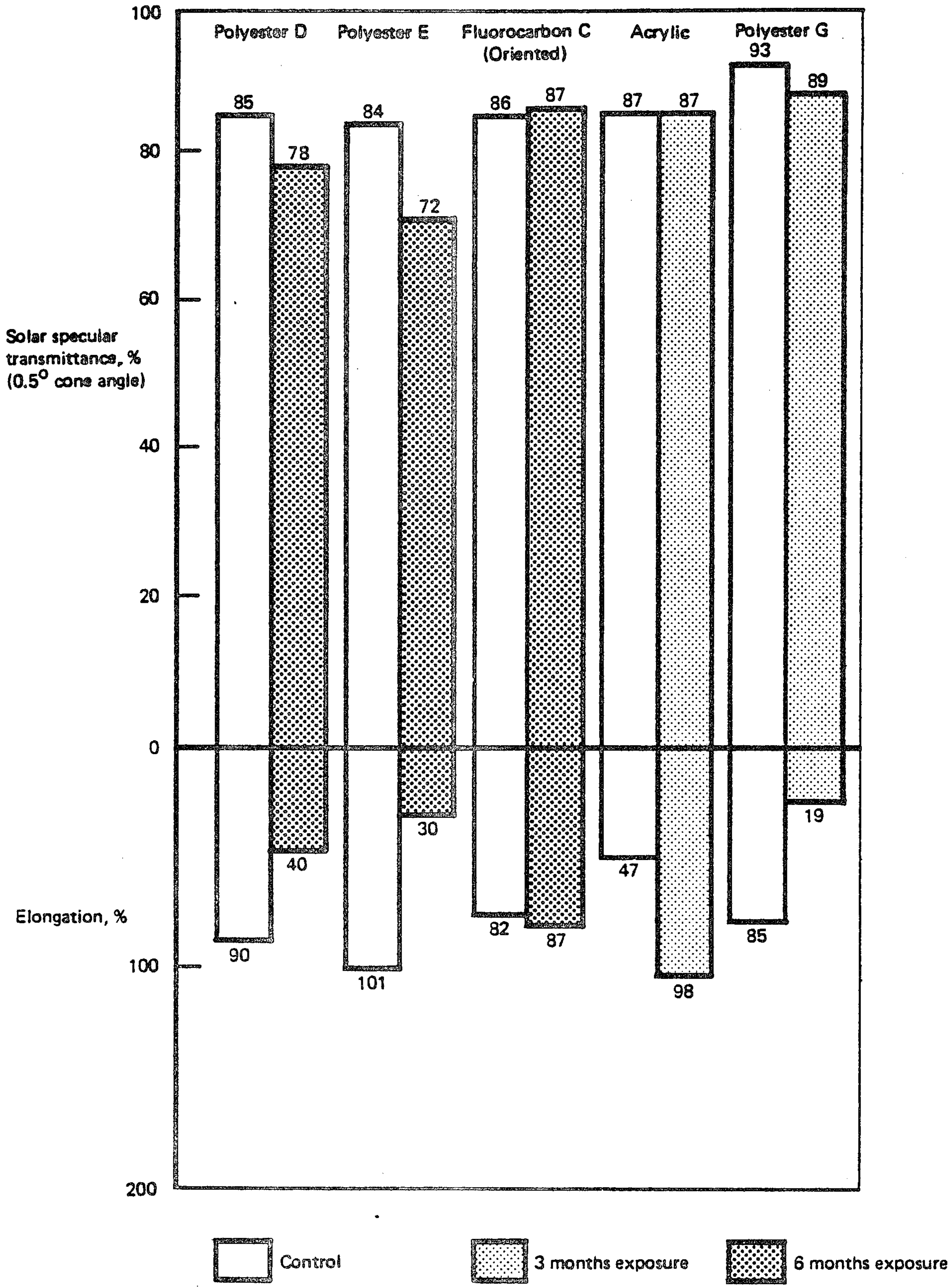

Figure 3.2-6. Enclosure Material Data - EMMA (8 Suns)

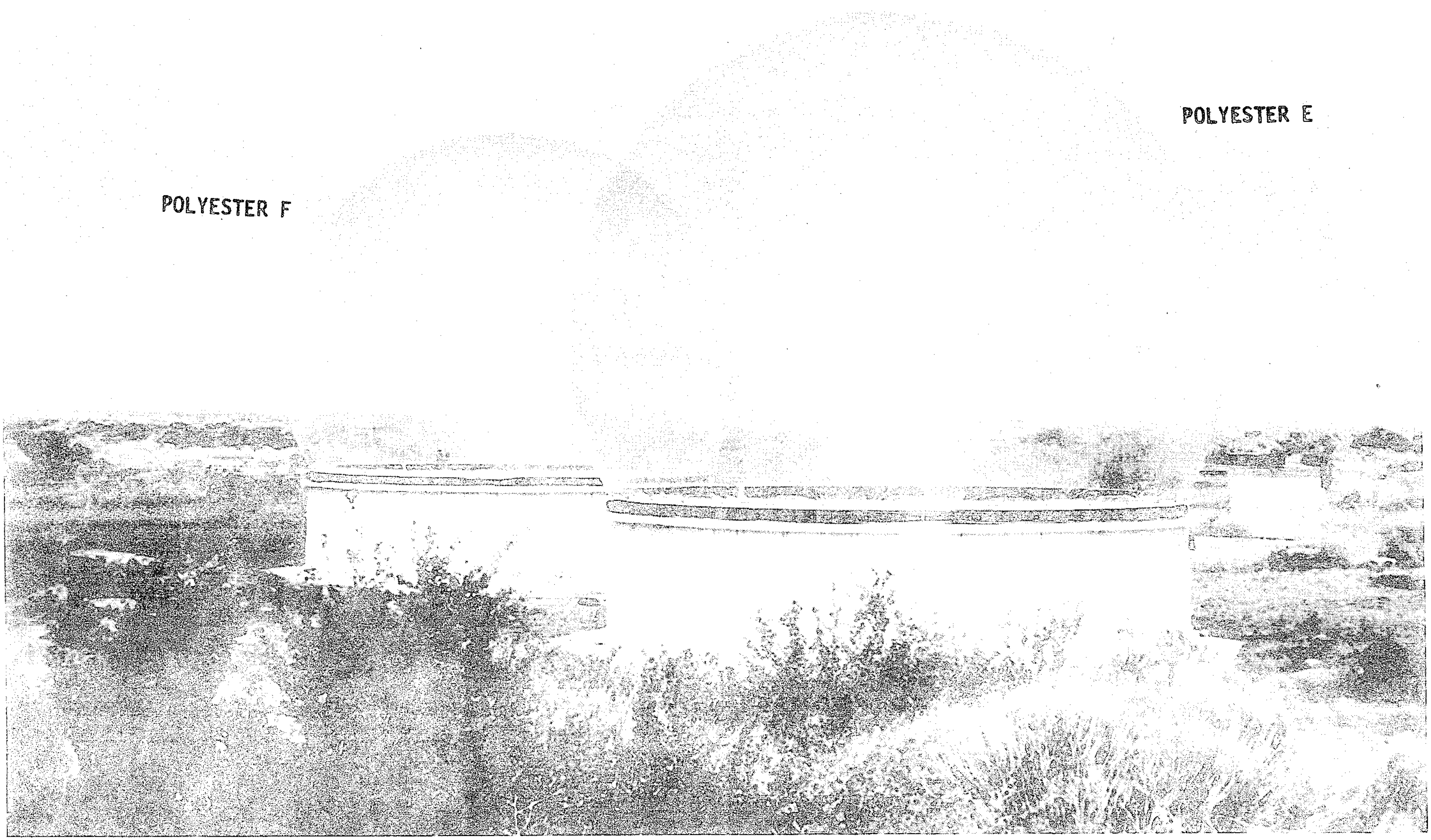

Figure 3.2-7. Polyester Domes Installed at Boardman, Oregon (5.2m Diameter)

The acrylic samples on the real time rack were the only materials that were damaged during a hailstorm. Samples on EMMA failed for an unresolved reason and then were probably destroyed by buffeting caused by the air distributing system on EMMA. New samples were sent to DSET and again some failed. A 3-month EMMA sample did survive and displayed no loss of specularity; it had an unexplained increase of 24% in elongation. The real time samples were returned after the hailstorm, and while a minimal loss of specular transmittance took place, the elongation values fell 89%. The material was probably buffeted by the storm after failure and this could explain the substantial decrease in elongation. Acrylic looked promising due to its low cost and fairly high specularity, but thicker material should be sent to DSET to see if the weatherability can be improved.

Polyester G had a very high specular transmittance of 96% at the 633 nanometer wavelength, but when integrated over an air mass 2 solar spectrum, it fell off to 93%. After 3 months on EMMA, the material decreased 4% in specularity and lost 78% of its elongation. No real time testing data is yet available. The anti-reflective (AR) coating possessed a very low abrasive resistance. Samples were sent to Dow Corning for application of an abrasive resistance coating. The coating decreased the specularity from 93% to 89%. The material, called Polyester H, was recently sent to DSET and exposure data was not available in time for publication in this report.

The Polycarbonate C material had fairly high specular values; and after 6 months of real time testing, the material exhibited a negligible loss of transmittance. The elongation decreased substantially from 104% to 37%. The samples did not survive the EMMA testing, and were not replaced because of the substantial decrease in elongation after 6 months of real time exposure.

Morton developed a coating that when applied to unpolished Tedlar, improved the specularity by 5% from 79% to 83% (Fluorocarbon B (AR)). After 6 months of real time and accelerated exposure, the coating retained its effectiveness. The Tedlar had an initial low specular transmittance (79%) and it will have to be seen if the coating is as effective when applied to roll polished Tedlar.

After 6 months of real time exposure, the elongation of Polyester F decreased 85% from 106% to 16%. The specularity decreased from 85% to 83%. The accelerated testing results showed a decrease of 90% in elongation and 12% in specularity. The samples tested at DSET were taken from the roll of Polyester F that was shipped to Sheldahl for fabrication of the dome shown in Figure 3.2-7. The dome was installed at the same time as the other dome, but after 10 months, a 10 cm tear was noticed in the polar cap, away from the seams. The tear was patched and the dome remained intact until 3 months later, when during the wind gusts of 8 - 10 m/s (18 - 23 mph), the dome failed. The dome will be returned and tested for specularity and mechanical properties at the polar cap, seams and base. It is somewhat surprising that the dome lasted as long as it did with the DSET results showing a substantial decrease in elongation after 6 months of real time exposure.

Polycarbonate B is a second iteration of UV stabilized polycarbonate that has shown surprising good weatherability characteristics. The material showed no change in elongation after 6 months of real time testing and an unexplained 10% increase in specularity from 73% to 82%.

Table 3.2-2 shows the results of the Beckman DK-2A spectrophotometer transmittance test integrated over an air mass 2 solar spectrum with an aperture opening of 0.5°. The control values of Polyester G and exposed Fluorocarbon C (Lab) after exposure of 2 years real time are shown. This table illustrates one of the main differences between fluorocarbons and polyesters or polycarbonates. The polyester G material has the highest transmittance of any material that has been received by BEC to date, but at the wavelength of 341 nanometers (UV), the polyester has no transmittance as opposed to the 77% transmittance that the fluorocarbon has. The absorption of the UV band wavelengths by the polyesters and polycarbonates helps explain why the longevity of the materials is inferior to that of fluorocarbons.

Thermophysics Lab.
Beckman DK-2A Spectrophotometer.
Air mass 2. (Reference handbook of Geophysics 1960)
For. HARRY DURSCH

Sample: 20-1 (1) AFTER WASH

Date 4-23-80

TRANSMITTANCE = 88.8

λ	100%	Sample	Correct	λ	100%	Sample	Correct
341	99.4	76.5	77.0	685	98.3	86.9	88.4
399	100.0	81.1	81.1	700	98.4	87.2	88.6
424	99.8	83.0	83.2	714	99.4	87.4	88.8
442	99.8	83.8	84.0	729	98.5	88.1	89.4
457	99.6	84.0	84.3	745	99.1	88.3	89.1
471	99.5	84.7	85.1	763	99.2	86.5	89.2
484	99.4	85.0	85.5	780	99.4	87.2	89.7
496	99.4	85.4	85.9	797	99.5	89.3	89.7
508		85.6	86.1	815	100.0	90.0	90.0
521		85.7	86.2	833		90.3	90.3
533		86.4	86.9	851		91.0	91.0
546			86.9	870		91.1	91.1
558			86.9	894		91.0	91.4
571			86.9	932		91.7	91.9
583			86.9	968			91.9
596			86.9	991			91.9
609	99.8		87.4	1015			91.9
621	98.4		87.8	1040		91.9	91.9
634	98.2		88.0	1067		92.0	92.0
647			88.0	1114			92.0
659		86.5	88.1	1171	99.9		92.1
672		86.9	88.5	1213	99.8		92.2

λ	100%	Sample	Correct
1253	99.5	92.0	92.5
1301	99.4		92.6
1437	99.3	91.9	92.5
1580	98.9	91.4	92.9
1660	99.4	90.1	92.8
1923	91.1	84.4	92.6

NBS #

Correction =

Total = 4438.52

Average = 88.76

Fluorocarbon C (Lab)

368,000 langleys

(2 years)

THE BOEING COMPANY
SEATTLE, WASHINGTON

SHEET 1 OF 5

Thermophysics Lab.
Beckman DK-2A Spectrophotometer.
Air mass 2. (Reference handbook of Geophysics 1960)
For.

Sample:

Date [illegible]-21-79

TRANSMITTANCE = 92.6

λ	100%	Sample	Correct	λ	100%	Sample	Correct
341	[illegible]	0	0	685	[illegible]	[illegible]	96.3
399	99.5	80.1	80.4	700	[illegible]	[illegible]	[illegible]
424	99.5	90.1	[illegible]	714	99.5	[illegible]	95.6
442	[illegible]	91.3	91.7	729	99.5	[illegible]	96.2
457	99.4	92.0	92.6	745	99.6	[illegible]	[illegible]
471	99.3	92.9	93.6	763	99.5	94.7	96.1
484	99.3	[illegible]	[illegible]	780	99.5	[illegible]	96.2
496	99.3	[illegible]	94.4	797	[illegible]	95.1	96.5
508	[illegible]	[illegible]	94.6	815	99.4	[illegible]	96.1
521	99.3	[illegible]	[illegible]	833	99.5		96.0
533	99.3	[illegible]	95.0	851	99.5		96.0
546	[illegible]	[illegible]	[illegible]	870	99.5		[illegible]
558	99.3	[illegible]	95.6	894	[illegible]		95.4
571	99.2	[illegible]	95.7	932	99.7		95.8
583	99.2	[illegible]	95.8	968	99.7	95.4	95.7
596	99.1	[illegible]	95.6	991	[illegible]	[illegible]	[illegible]
609	99.0	[illegible]	95.6	1015	[illegible]	95.1	95.3
621	99.0	[illegible]	95.7	1040	99.7	[illegible]	95.6
634	[illegible]	[illegible]	95.7	1067		94.6	94.7
647	99.5		95.9	1114		94.6	94.7
659	[illegible]	[illegible]	96.1	1171		[illegible]	94.5
672	[illegible]	[illegible]	96.1	1213		94.0	94.1

λ	100%	Sample	Correct
1253	99.8	93.9	94.1
1301	99.4	93.5	93.7
1437	99.6	[illegible]	93.9
1580	99.0	10.5	11.2
1660	[illegible]	77.7	[illegible]
1923	[illegible]	[illegible]	10.1

NBS #

Correction =

Total = 4[illegible]

Average = [illegible]

Polyester G

(Control Value)

THE BOEING COMPANY
SEATTLE, WASHINGTON

SHEET OF

Table 3.2-2 Typical Transmittance Data

3.3 Test Results (Reflector Films)

Shown in Table 3.3-1 are the reflector materials that have been or are being exposure tested at DSET and their respective specular reflectance control values. Of the three reflector materials whose desert exposure was initiated under the previous contract (Figures 3.3-1 and 3.3-2), only the silvered Polyester J shows promise. After an equivalent of almost 4 years solar exposure, the material exhibited the inherent problem of polyester. Its specular reflectance has remained the same (94% at .14^{o} cone angle) but, the ultimate strength has dropped from 168 MPa to 75.5 MPa (24,400 psi to 10.950 psi), and the ultimate elongation dropped from 79% to 8%. Accelerated testing of aluminized Polyester P and aluminized Polyester K was discontinued after 6 months due to low reflectance values. The suppliers were notified and a second iteration of aluminized Polyester P is currently being tested.

Figures 3.3-3 and 3.3-4 show the reflector films whose exposure was initiated under this contract. Aluminized Polyester R retained its specular reflectance of 88% after an equivalent of 2 years solar exposure, but decreased from 84% to 44% in ultimate elongation. No real time data is yet available.

Aluminized Polyester S is highly polished on one side, the polished side aluminized, and then coated with acrylic to protect the aluminum against moisture and oxidation. After an equivalent of almost 4 years solar exposure, it lost 5% of its specularity and the ultimate elongation decreased 12% (Figure 3.3-3). The 6 month real time was not available.

IDENTIFIER	REFLECTANCE, % @ .14° CONE ANGLE (control value)
Silvered Polyester J	94
Aluminized Polyester R	88
Aluminized Polyester K	86
Silvered Polycarbonate M	85
Aluminized Polyester T	83
Aluminized Polyester U	79
Aluminized Polyester P	76
Aluminized Polyester S	75
Aluminized Polyester V	73
Aluminized Polycarbonate N	66
Aluminized Polycarbonate O	58
Aluminized Polyester Q	43
Aluminized Acrylic	27

Table 3.3-1. Reflector Materials Undergoing Exposure Testing at DSET

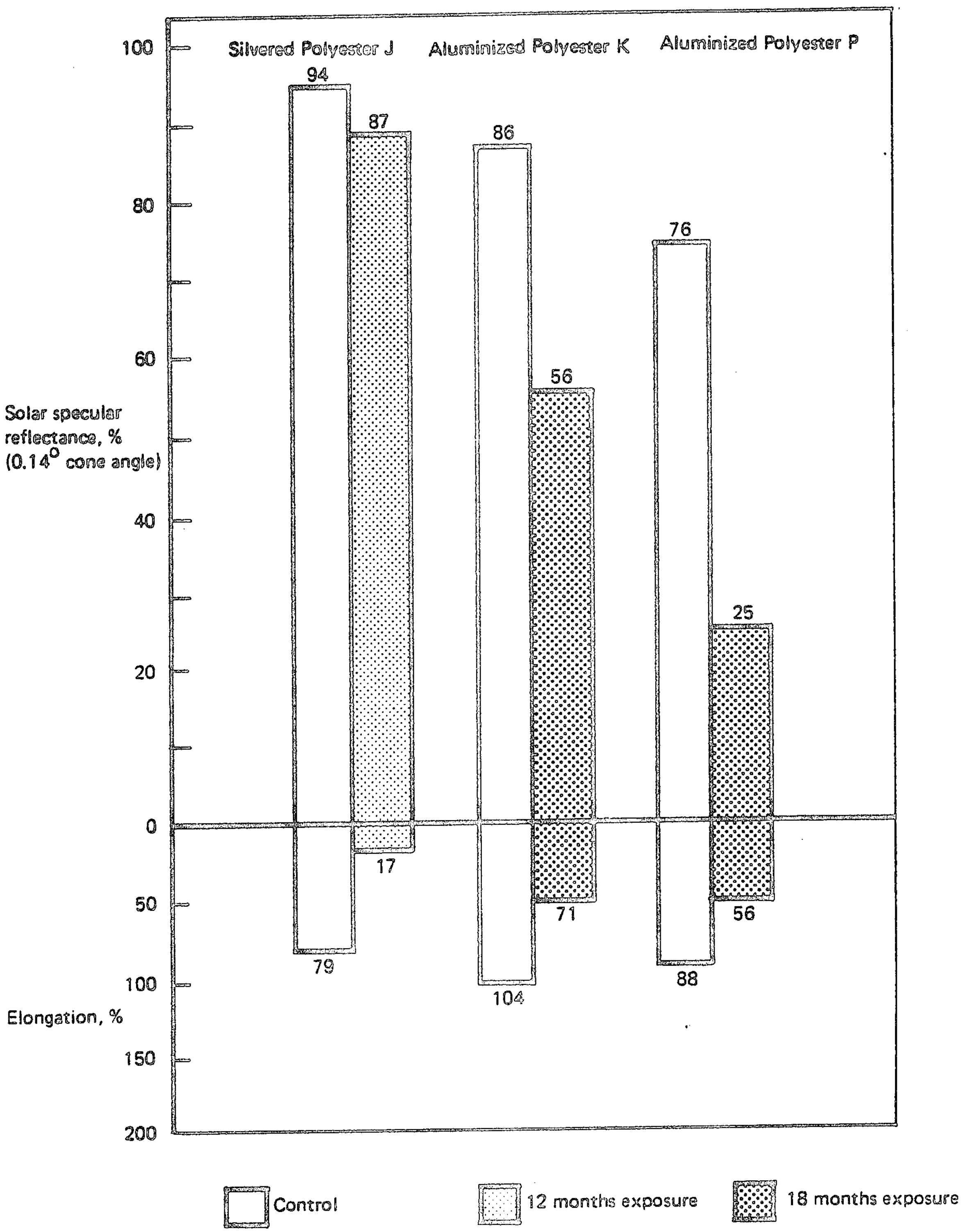

Figure 3.3-1. Reflector Material Data - Real Time (45° Rack)

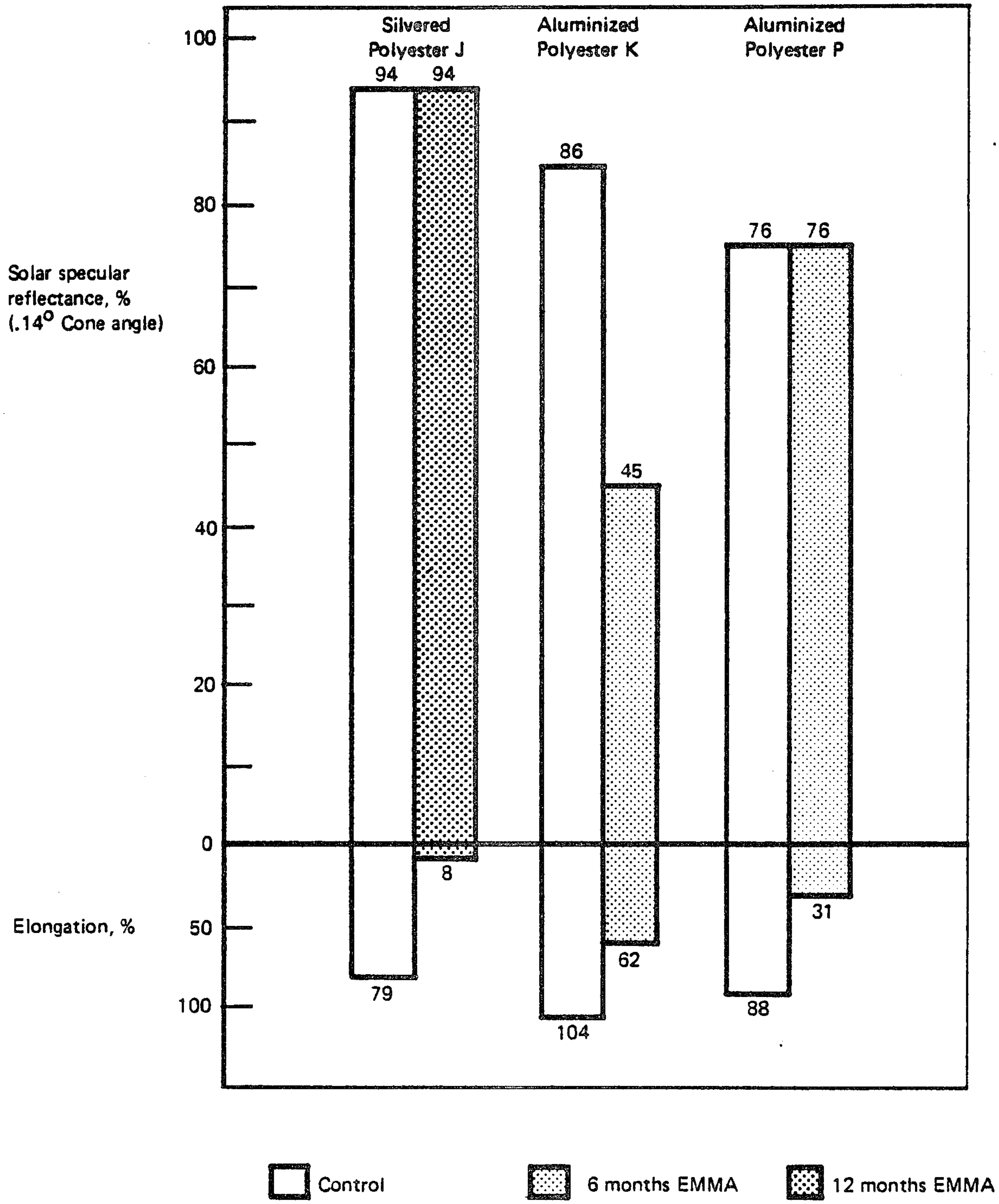

Figure 3.3-2. Reflector Material Data - EMMA (8 Suns)

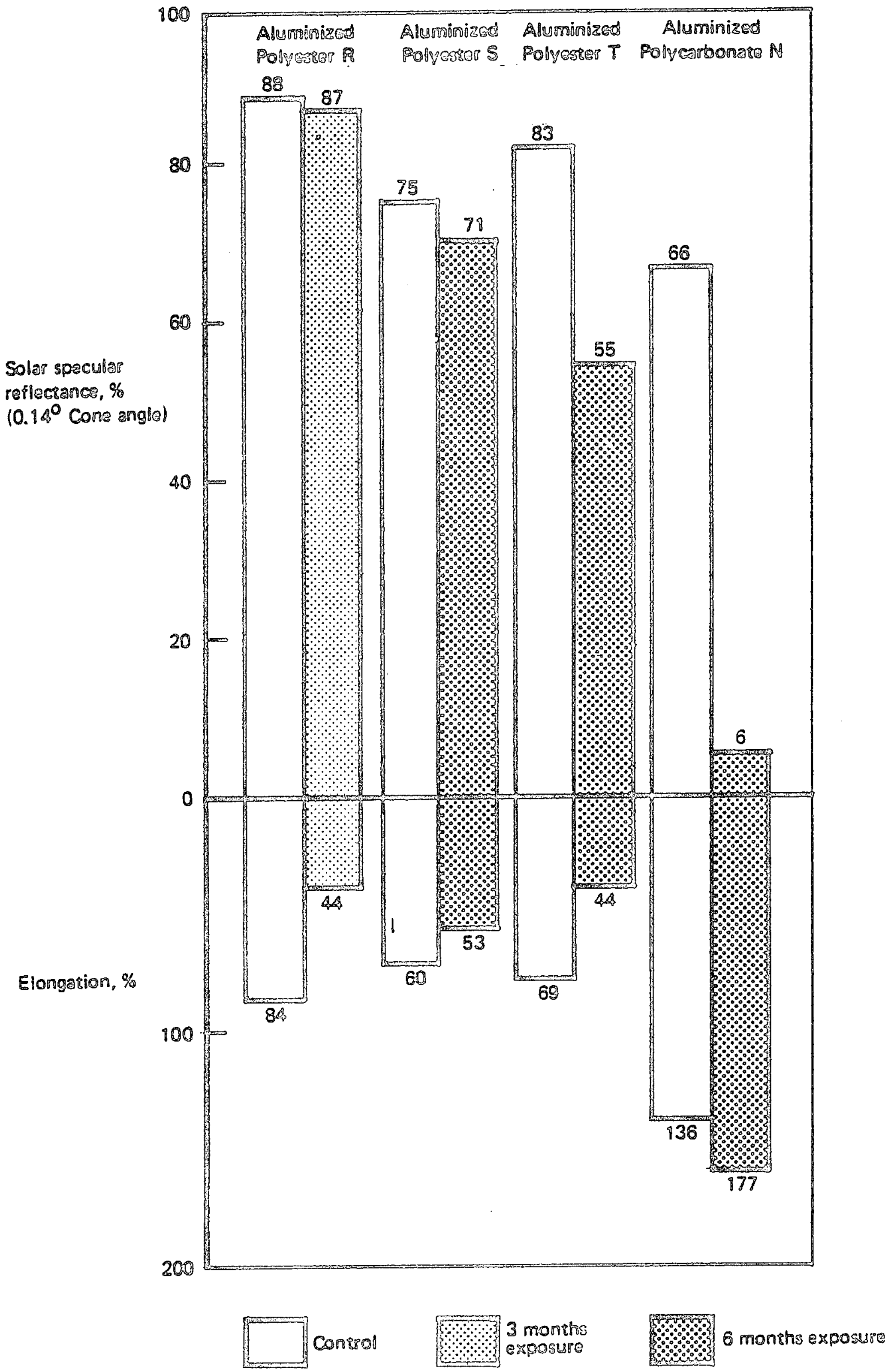

Figure 3.3-3. Reflector Material Data - EMMA (8 Suns)

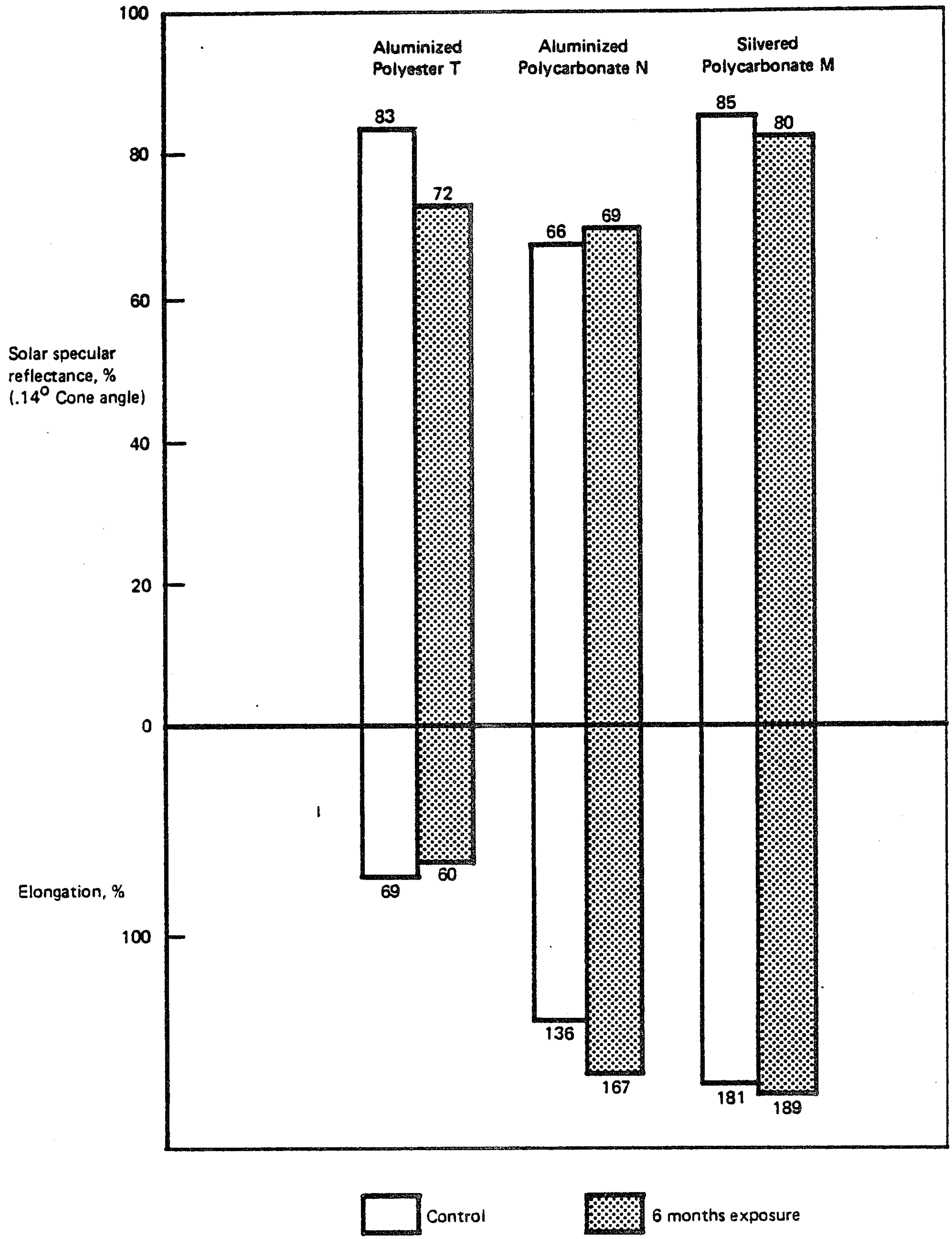

Figure 3.3-4. Reflector Material Data - Real Time (45° Rack)

Aluminized Polyester T, shown in Figures 3.3-3 and 3.3-4, experienced a loss in specular reflectance from 83% to 72% while the elongation decreased from 69% to 60% after 6 months of real time exposure. A second material (Polyester V, not shown in Figures 3.3-3 or 3.3-4) exhibited a substantial drop in elongation from 56% to 5% and its specular reflectance fell from 73% to 60%. The supplier was notified of the exposure results and since provided a third iteration material (Polyester U). The substrate is a second generation, Melinex "OW" which has improved UV resistance. Also, the material was aluminized to a high optical density which will eliminate the pin holes in the aluminum coating. The material had an initial specular reflectance of 79% and exposure testing has been initiated.

Silvered Polycarbonate M is composed of 2.5 mil, UV stabilized polycarbonate + silver + adhesive + 14 mil polyester. Aluminized Polycarbonate N is composed of 2.5 mil, UV stabilized polycarbonate + aluminum + adhesive + 14 mil polyester. The silvered material had an initial specular reflectance of 85% which decreased to 80% after 6 months of real time testing. During this same period of time, the aluminized material's specular reflectance increased a minimal amount from 66% to 69%. As Figure 3.3-3 shows, both elongation values increased. The aluminum and especially the silvered material showed substantial amounts of degradation for some unresolved reasons after being on EMMA for a couple of months. The silvered material had no reflectance and was too brittle to subject to a microtensile test. As Figure 3.3-3 shows, the specular reflectance of the aluminum fell from 66% to 6%, but the elongation increased from 136% to 177%. EMMA exposure of the materials has been discontinued.

Two more reflector films (not shown on graph) were sent to DSET to determine if aluminized acrylic or aluminized polycarbonate had good weatherability characteristics even though both their initial specular reflectance values were low. Aluminized acrylic had a very low initial specular reflectance of 27% and this decreased to 11% after 6 months of real time exposure. The elongation value increased for an unresolved reason from 19% to 52%. Elongation values decreased from 63% to 39% while the specularity showed a minimal increase for the aluminized polycarbonate.

4.0 CONCLUSIONS

The fluorocarbons, Kynar and Tedlar, continue to exhibit the best weatherability characteristics. Accelerated and real time exposure testing has shown them to be resistant to UV degradation. After an equivalent of over 15 years solar exposure, Kynar and Tedlar have shown little or no mechanical or optical degradation.

The polyesters, polycarbonates and acrylics to date have not demonstrated adequate UV degradation resistance. While changes made in UV stabilization techniques and weatherable coatings have improved the weatherability characteristics, the materials still fall short of the goal of a 10 year life.

The plastic industry recognizes the need for improving the weatherability of polyesters. For example, ICI has recently developed a second generation polyester that is expected to have substantially improved UV resistance. Several vendors are currently working on improving the longevity of reflective materials by coatings or increasing the density of the aluminum deposited on the substrate.

5.0 RECOMMENDATIONS FOR FUTURE WORK

The success of fluorocarbons in maintaining optical and mechanical properties during weather exposure is encouraging. These materials merit additional development in both the enclosure and reflector applications.

Further attempts should be made to improve production techniques of biaxially oriented Kynar. The first attempt produced material of marginal specular transmittance (86%). The Kynar had poor surface quality and non-uniformities in thickness which made bonding of gores difficult.

The use of silvered Kynar as a reflective surface has met with little success due to two principal problems. The material that BEC has provided to metalizers has had poor surface quality causing a problem in achieving a high specular reflectance. Accordingly, the Kynar should be roll polished before any future metalizing attempts. Also, there is an inherent problem of adhesion of metal to Kynar. One vendor solved this problem by ion-plating, but the finished product was very non-specular. Further R&D work is needed.

Additional work with silver on various substrates is needed. Materials such as 3M's YS-91 have shown minimal degradation after short term exposure, but have low initial specular reflectance values. Silvering would increase the specularity by a minimum of 4% to 5%.

Modifications to polyesters, polycarbonates, acrylics and other films should be screened and exposure tested as they become available from suppliers, since potential cost advantages are inherent.

Exposure testing should continue on those films currently under test at DSET until it is obvious that degradation rates are excessive or no useful information can be derived.

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U.S. Department of Energy
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R. N. Schweinberg
Solar 10-MW Project Office
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U.S. Department of Energy
Suite 210
9550 Flair Drive
El Monte, CA 91731

Elliott L. Katz
Solar Thermal Projects
Energy Systems Group
Aerospace Corporation
P. O. Box 92957
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Aerospace Corporation
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Dunmore Corporation
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1 River Road
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General Electric Company
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Schenectady, NY 12345

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Schenectady, NY 12345

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Plastic Division
ICI Petrochemicals & Plastics Company
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Herman Bank
Jet Propulsion Laboratory
Building 502-201
4800 Oak Grove Drive
Pasadena, CA 91103

William Carroll
Jet Propulsion Laboratory
Building 502-201
4800 Oak Grove Drive
Pasadena, CA 91103

Edward Cuddihy
Jet Propulsion Laboratory
Building 502-201
4800 Oak Grove Drive
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Schumacher & Associates
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Sacramento, CA 95825

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Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401

Holly Roberts
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401

John Thornton
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401

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