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NATIONAL BUREAU OF STANDARDS REPORT

9912

OUTDOOR PERFORMANCE OF PLASTICS
I. INTRODUCTION AND COLOR-CHANGE

Sponsored
by
Manufacturing Chemists' Association

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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OUTDOOR PERFORMANCE OF PLASTICS

I. INTRODUCTION AND COLOR-CHANGE

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U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

ABSTRACT

This is the first in a series of reports on outdoor performance of 20 plastics. Computerized analysis and graphs of color data are presented. Reports on physical and other properties important to architectural performance are being prepared.

A coding system is given for computerizing more than 10,000 observations on the 8 properties.

Graphs are presented for Adams color-difference (E) versus time of exposure: 24 months in Arizona, Florida and Washington, D. C. Supporting tristimulus color data (L, a, b) are available on request.

Discoloration "failures" ($E > 25$) occurred only in Arizona, and only for 4 clear PVC's. Two other clear PVC films failed by embrittlement in Arizona. All clear PVC's followed similar patterns of sudden catastrophic discoloration. If any of the clear PVC's were slightly superior, it was PVC-B.

All white-pigmented PVC's discolored only slightly, averaging CLASS "B" color-fastness. If any of the white PVC's were slightly more color-fast, it was PVC-A.

PVF and PMMA were quite color-fast (CLASS "A") as expected. PE film (CLASS "A") and sheet (CLASS "B") did not discolor badly, but PE films embrittled in about a year, beginning in Arizona, then Florida, then Washington, D. C.

RP yellowed to color - CLASS "D" (E between 15 to 20 units) within 2 years. PETP discolored to CLASS "B" (E about 5 to 10 units).

Development of this color-fastness classification system is described. It is based on ranking plastics according to the highest color-difference (E) value attained at any time within a given period at any location.

The CLASS system is now being extended to the other properties.

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1. OBJECTIVE

This is the first in a planned series of reports on the outdoor performance of plastics. In this series, data will be graphically presented on 20 plastics exposed in Arizona (A), Florida (F), and Washington, D. C. (W).

Eight properties are being measured periodically. These are appearance, physical, and other properties related to architectural performance.

Computerized presentation and analysis of data will be emphasized.

This report considers the color of plastics. The next report, now in preparation, will concentrate on physical properties.

2. INTRODUCTION

Outdoor exposures have been conducted on 20 plastics formulated from 6 base polymers: polyethylene (PE), polymethyl methacrylate (PMMA), polyvinyl fluoride (PVF), polyethylene terephthalate (PETP), glass-reinforced polyester (RP), and polyvinyl chloride (PVC). Clear and white sheet and film have been exposed in Phoenix, Miami and Washington, D. C. for over 2 years.

This is part of an integrated exposure program in which the same plastics are being exposed to accelerated weathering in laboratory environmental chambers.

The goal is to forecast outdoor performance of plastics, by establishing the relation between such accelerated vs. outdoor exposures.

3. EXPERIMENTAL

Details may be found in our earlier NBS Report 9640, "Correlation of Accelerated and Outdoor Weathering Tests of Plastics" [1]1/. The summaries are given below for convenience of the reader.

3.1 Materials

Table 1 summarizes the 20 plastics formulated from 6 base polymers. These materials were selected and approved by the MCA Plastics Technical Subcommittee.

3.2 Exposures

Specimens were placed on supports at a 45° angle to the horizontal and facing the equator, at

South Florida Test Service Inc.
Miami, Florida (hot, wet)

1/ Figures in brackets indicate the literature references at the end of this paper.

Desert Sunshine Exposure Tests Inc.
Phoenix, Arizona (hot, dry)

Connecticut and Van Ness Streets
(Old NBS Site)
Washington, D. C. (temperate)

At regular intervals, samples are removed for testing. Samples are not put back on exposure after removal. Where possible, sufficient replicates were exposed initially to allow for 10-years of sampling.

3.3 Properties Measured

Table 2 lists the most common criteria for evaluation of plastics in architectural outdoor applications: appearance, physical and selected additional properties.

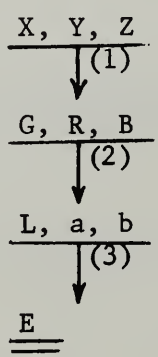
Also listed are member companies of MCA who volunteered to perform the indicated tests.

1. Color

Color of all original and outdoor-exposed specimens was measured under the direction of Mr. Paul Giesecke at American Cyanamid Company, Stamford, Connecticut. A GE spectrophotometer yielded the CIE color values of X, Y, Z.

Calculation of total color difference (E) was done by use of Reilly's modification of Glasser's cube-root formula, which is believed to be the best improvement of Adams chromatic-value formula [2]. This required conversion of X, Y, Z values to G, R, B values [2].

Schematically, this calculation of the Adams Color Difference (E) values plotted herein is:



where

(1) is $G = -0.10X + 100.05Y + 0.04Z$
$R = 110.84X + 8.52Y - 14.54Z$
$B = -0.62X + 3.94Y + 81.92Z$

(2) is $L = 25.29\ G^{1/3} - 18.38$
$a = 106.0\ (R'^{1/3} - G^{1/3})$
$b = 42.34\ (G^{1/3} - B^{1/3})$
$(R' = 0.8R + 0.2B)$

(3) is $E = [(\triangle L)^2 + (\triangle a)^2 + (\triangle b)^2]^{1/2}$

An added benefit of this method of calculation is direct comparison of tristimulus spectrophotometer readings with Colormaster tristimulus colorimeter readings. The Colormaster colorimeter is used by us at NBS to read color of specimens exposed to accelerated laboratory weathering.

It should be noted that some color-difference (E) values presented in our earlier NBS Report #9640 were given in the Hunter E system. The Hunter equations convert directly from X, Y, Z to L, a, b and complicate comparison with G, R, B colorimeter values. See Reference [2] for correction of the common reference [3] to the Hunter equation.

Calculations and plots were done on the NBS UNIVAC 1108 computer, using both the OMNITAB english-language program and FORTRAN V.

4. RESULTS

4.1 Computerization of Data

Over 10,000 observations now constitute the bank of data on outdoor performance: 20 plastics X 3 sites X 8 samplings, to-date X 22 property-parameters. To efficiently select, plot, analyze and correlate these data, computer handling was found necessary.

To retrieve any individual observation, or set of observations, from the computer memory all data were coded. The code is given in Table 3. Variables coded are type of exposure, time of exposure, plastic, property measured and value of that property.

For example, Arizona exposure for 3 months of plastic PE-60 mil, and the resulting value of color-difference (E) is coded:

1	3	.	2	111	4.77

The unexposed control specimen for this appears as:

0	0		2	111	0.0

The following conventions were adopted for special cases:

Missing data	8888.88	Value
Off-scale reading	9999.99	Value
Repeat exposure of plastic 1	101	Plastic
Repeat exposure of plastic 10	110	Plastic
Second repeat of plastic 10	210	Plastic

All available data can be obtained from the authors. At your request, it can be obtained in the following forms:

IBM punched cards
Computer listing of card-contents
Magnetic Tape

4.2 Color Code for Computer

A 3-numeral code is used for the property of color:

First numeral	1	Color
Second numeral	1	E (Adams color-difference)
	2	L (lightness-darkness)
	3	a (redness-greenness)
	4	b (yellowness-blueness)
Third numeral	1	GE Spectrophotometer
	2	Meeco Tristimulus Colorimeter

Only 111 data are presented in this report: Adams color-difference values calculated from measurements on the GE spectrophotometer.

As mentioned previously, the L, a, b values are available on request.

4.3 Graphic Results

In Figures 1 to 20, following, Adams color-difference (E) is plotted versus time of exposure. There is one graph for each of the 20 plastics. Results are given for exposure in Arizona (A), Florida (F) and Washington, D. C. (W).

Note that: a) Not all plastics are exposed in all locations. b) Color data on a plastic may not continue to 2 years because the plastic has completely deteriorated (e.g., Figure 1) or the supply of replicates is exhausted (e.g., Figure 12). c) For color-difference greater than 25 units (our arbitrary pre-set limit), the following note is printed below the graph: "**NOTE: #POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED".

5. OBSERVATIONS

5.1 Effect of Climate

Arizona exposure appeared to produce more discoloration for many plastics (e.g., Figures 2, 7, 8, 9, 11, 14, 15, and 18). This is most noticeable for clear PVC (Figures 7 to 13).

In no case did Washington exposure appear most severe.

In one case (Figure 5) Florida may have consistently caused slightly more discoloration.

5.2 Comparison of Plastics

Figures 21 to 30 group the plastics by discoloration at each site. In plots on which various plastics are compared, plastics are designated by the letter corresponding to their coded numbers.

TABLE 4

LETTER DESIGNATIONS FOR PLASTICS

A	1	PE-1	K	11	PVC-C10
B	2	PE-60	L	12	PVC-C60
C	3	PMMA	M	13	PVC-N
D	4	PVF	N	14	PVC-A4
E	5	PETP	O	15	PVC-A10
F	6	RP	P	16	PVC-A60
G	7	PVC-B4	Q	17	PVC-D4
H	8	PVC-B10	R	18	PVC-D10
I	9	PVC-B60	S	19	PVC-D60
J	10	PVC-C4	T	20	PVC-M

5.2.1 Clear PVC

Figures 21, 22, 23 group the 7 Clear PVC's by discoloration at each site. Three PVC-B's (G, H, I) are shown by solid lines; three PVC-C's (J, K, L) are shown by dotted lines; PVC-N (M) is shown by a dashed line.

All follow similar patterns of discoloration: initial discoloration, slight bleaching, then rapid discoloration. This harmonic (seasonal) behavior does not seem strongly dependent on formulation or thickness.

If any material showed slight superiority, it was PVC-B.

Note that only Arizona exposure failed some materials (color-change greater than 25 units) within 2 years. This is indicated by the "**NOTE" at the foot of Figure 21.

5.2.2 White-pigmented PVC

Figures 24, 25, 26 group the 7 white PVC's by discoloration at each site. Three PVC-A's (N, O, P) are shown by slashed lines; three PVC-D's (Q, R, S) are shown by dot-dash lines; PVC-M (T) is shown by widely-spaced dots.

These show generally similar patterns of mild discoloration. Slightly periodic (seasonal) behavior can be detected in most of the materials. As for Clear PVC's, harmonic behavior does not appear strongly dependent on formulation or thickness.

If any material showed slight superiority, it was PVC-A.

5.2.3 PVF and PMMA

Figure 27 is a composite comparison of two very good polymeric materials. Based on the polymer structures of polyvinyl fluoride and polymethyl methacrylate, their resistance to weathering should be excellent. These results, and industrial experience with these materials, confirm this prediction.

Both materials performed equally well, and were not affected by location.

5.2.4 Other Plastics

Figures 28, 29, 30 group the various plastics (except PVF and PMMA) by discoloration at each site.

Three white PVC's (N, O, T) were selected for comparison with the clear RP (F), polyethylene (B), and PETP (E). Glass-reinforced polyester (F) consistently discolored most in this group. In comparison, all three white PVC's did not discolor greatly.

Moderate effects of season and location were noted. In PE-60 (B) and RP (F), peaks occur around August in the period of maximum sunlight, and lows occur around January.

6. RANKING OF PERFORMANCE

It is highly desirable to be able to objectively rank the performance of architectural materials. The following section is a first step toward that goal.

6.1 Failures

Plastics with greater than 25 units of color-difference from the original were arbitrarily designated "failures". In fact, visual examination of such specimens confirms that they all discolored greatly.

Table 5 shows that discoloration "failures" to-date have occurred only in Arizona, and only for 4 clear PVC's. After 20-24 months, PVC-B4, B10, C10 and N60 severely discolored.

6.2 Classification

Of course, the acceptable degree of discoloration varies with application. For that reason, a performance ranking rather than a "pass-fail" designation is needed. Unfortunately, it is much more difficult to satisfactorily classify performance.

One system under trial is to arbitrarily create the classisfication:

Class	Adams (E) Color-Difference
A	0-5
B	5-10
C	10-15
D	15-20
E	20-25
F	Greater than 25

However, the performance rank of a plastic may change significantly with location and time selected for ranking. In fact, not only may a CLASS "A" material fall to lower class, but lower class materials may rise to higher class.

Table 6 presents the results of one solution to this problem. Plastics were ranked according to the highest E-value attained at any time (within 1 year, column 1 or within 2 years, column 2) at any location.

A weakness of this system is that it may lead to over-design (and probably higher cost) of plastics for less-demanding applications. However, small additional cost may be acceptable at this time to improve the "image" to the consumer of plastic construction materials.

Accuracy and precision of color-difference (E) values herein is about ± 1 unit. Therefore, borderline cases were given the better of the two ranks in question, in view of the above-described tendency to "over-design".

6.2.1 Classes of Plastics

A study of Table 6 shows that most of the plastics performed well, in color stability, for 1 year in all locations. Of the 20 plastics, 18 were CLASS "A" or "B" for 1 year. Over half were CLASS "A".

At 2 years, only 4 remained CLASS "A". Of the twenty, 13 were CLASS "A" or "B" for 2 years.

Furthermore, none were "failures" at 1 year, but 4 failed with 2 years.

Thus, 2-year exposure definitely separated the very good materials from the very bad. One-year exposure was much less effective in classifying the plastics.

6.2.2 Changes in Class

No material could better its class, with this system. Thus, the "bleaching" obstacle to ranking was overcome.

Some of the clear PVC's showed a drastic change in classification from 1 to 2 years:

PVC-B4	A to F
PVC-B10	A to F
PVC-B60	B to E
PVC-C10	A to F
PVC-N60	B to F

Of all the plastics exposed, only the clear PVC's have shown this exponential discoloration. Two clear PVC's remain, which are not in the above list: PVC-C4 and PVC-C60. As noted in Table 6, failure of PVC-C60 was likely at 24 months, but the supply of replicates for observation was exhausted. This leaves PVC-C4, which behaved similarly to PE-1: good color retention but total embrittlement of the film in about a year in Arizona and Florida. The Washington specimen of PVC-C4 was intact at 2 years. Thus, almost all clear PVC's failed by either discoloration or embrittlement within about 2 years.

Such examples of catastrophic failure are those which are most difficult to predict. Our other mathematical approaches to this forecasting problem may provide a solution.

7. SUMMARY

This is the first in a series of reports on outdoor performance of 20 plastics. Computerized analysis of color data and graphs are presented. Similar reports are underway for 2 physical properties and 5 other properties related to outdoor architectural performance.

A coding system is given for computerizing more than 10,000 observations on the 8 properties.

Color of all original and outdoor-exposed specimens was measured on a GE spectrophotometer, which yielded CIE color values of X, Y, Z. Total color-difference between original and exposed replicates was calculated in the Adams system from the computed L, a, b values.

Graphs are given of Adams color-difference (E) versus time of exposure: 24 months in Arizona, Florida and Washington, D. C. Supporting tristimulus color data (L, a, b) are available on request on magnetic tape, punched cards or computer listing.

Development of a weatherability classification system is described. This classifies performance as CLASS "A", "B", "C", "D", "E", or "F". It is based on ranking plastics according to the highest property value attained at any time within a given period at any location. Its successful application to the color-difference (E) data is presented. The CLASS system is now being extended to the other properties.

Discoloration "failures" (E>25) occurred only in Arizona, and only for 4 clear PVC's. Two other clear PVC films failed by embrittlement in Arizona.

All clear PVC's followed similar patterns of sudden catastrophic discoloration: initial color change, slight bleaching, then rapid discoloration. All but 1 of 7 clear PVC's failed by discoloration (E>25) or embrittlement (of films) within about 2 years. If any of these clear vinyls were slightly superior over the others, it was PVC-B.

All white-pigmented PVC's showed somewhat periodic slight discoloration. They averaged CLASS "B" color-fastness. If any of the white vinyls were slightly more color-fast, it was PVC-A.

For both clear and white PVC's, periodic discoloration does not appear strongly dependent on formulation or thickness.

PVF and PMMA were quite color-fast, as expected. Both materials performed equally well (CLASS "A"), and were not affected by location.

PE film (CLASS "A") and sheet (CLASS "B") did not discolor badly, but PE films embrittled in about a year, beginning in Arizona, then Florida, then Washington, D. C.

PETP discolored to CLASS "B" and RP yellowed to CLASS "D" within 2 years. In comparison with other intermediate-class plastics, RP consistently discolored most.

Moderate effects of season and location were usually noted, especially for PE-60 and RP.

In overall perspective, most of the plastics were fairly color-fast for 1 year in all locations, but by 2 years varying degrees of significant discoloration were measured. At 2 years, there were:

4 CLASS "A"
9 CLASS "B"
0 CLASS "C"
2 CLASS "D"
1 CLASS "E"
4 CLASS "F"

In CLASS "A", one of the four was PE-1 which retained good color but totally embrittled. Another was white PVC-A60 which was only exposed in Washington, D. C.; Arizona exposure would probably lower its assigned CLASS. Thus, the only 2 truly comparable members of CLASS "A" at 2 years were PVF and PMMA.

8. RECOMMENDATIONS

This series of reports should be completed, to record and summarize the bank of observations.

Graphic and mathematical analysis of the data should be continued and refined. Promising classification systems such as that described herein should be developed further, as an aid in objectively and simply comparing performance of new products.

MCA sponsor-companies should avail themselves of the data bank in the appropriate forms. With the aid of MCA Plastics Technical Subcommittee members, these data can provide a sound base for development of improved plastics.

9. ACKNOWLEDGMENTS

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W. C. Cullen, V. E. Gray and the staff of the National Bureau of Standards, Materials Durability and Analysis Section, for always lending helping hands when they were needed;

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10. REFERENCES

[1] "Correlation of Accelerated and Outdoor Weathering Tests of Plastics", J. E. Clark, NBS Report #9640, Second Printing, Dec. 1967.

[2] "Significance of Recent CIE Recommendations for Color Measurement", F. W. Billmeyer, Color Engineering 6, No. 1, 36, Jan.-Feb. 1968.

[3] "Color..." 2nd Edition, D. B. Judd and G. Wyszecki, Wiley and Sons, New York, 1963.

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TABLE

1	Twenty Plastics for Exposure Program
2	Evaluation Criteria for Architectural Plastics
3	Computer Code for Weathering Data
4	Identification Letters for Graphs of Plastics (see Text on page 5)
5	Discoloration "Failures" by 24-Months
6	Color-CLASS of Weathered Plastics

TABLE 1

TWENTY PLASTICS FOR EXPOSURE PROGRAM

BASE POLYMER	PLASTIC	DESIGNATION
Polyethylene	Translucent - 1 mil	PE-1
	- 60 mil	PE-60
Poly (methyl methacrylate)	Clear - 60 mil	PMMA-60
Poly (vinyl fluoride)	Clear - 1 mil	PVF-1
Poly (ethylene terephthalate)	Clear - 5 mil	PETP-5
Polyester/$_{\text{x-linked}}$	Clear - 60 mil	RP-60
Poly (vinyl chloride) Ba-Cd	Clear - 4 mil	PVC-B4
	- 10 mil	-B10
	- 60 mil	-B60
Sn	Clear - 4 mil	PVC-C4
	- 10 mil	-C10
	- 60 mil	-C60
	Clear - 60 mil	PVC-N60
Ba-Cd	White - 4 mil	PVC-A4
	- 10 mil	-A10
	- 60	-A60
Sn	White - 4 mil	PVC-D4
	-10 mil	-D10
	-60 mil	-D60
	White - 60 mil	PVC-M60

TABLE 2

EVALUATION CRITERIA FOR ARCHITECTURAL PLASTICS

PROPERTY	COMPANY
Color	American Cyanamid
Haze	Monsanto
Gloss	Hercules
Surface Roughness	Union Carbide
Tensile Properties	W. R. Grace B.F.Goodrich
Flexural Properties	W. R. Grace
Electrical Properties	Firestone Plastics
UV Spectra	E.I.duPont

TABLE 3

COMPUTER CODE FOR WEATHERING DATA

EXPOSURE	TIME	PLASTIC	PROPERTY	VALUE
0 Control	0	1 PE-1 mil	1 Color	#
1 Arizona	3 Months	2 PE-60	111 E (Adams)	
2 Florida	6 "	3 PMMA	121 L	
3 Wash. D.C.	9 "	4 PVF	131 a	
	12 "	5 PETP	141 b	
4 Atlas Xe	16 "	6 RP		
41 dry	20 "	7 PVC-B4	2 Haze	
42 spray	24 "	8 - 10	21 T at 420nm	
	30 "	9 - 60	22 T at 550nm	
5 Xenotest	36 "	10 PVC-C4		
51 dry, 30% RH, Light		11 - 10	3 Gloss	
52 wet, 30% RH, Light		12 - 60	31 45°	
53 dry, 30% RH, Lt/Dk		13 PVC-N		
54 wet, 30% RH, Lt/Dk		14 PVC-A4	4 Surface Rough.	
55 dry, 90% RH, Lt/Dk		15 - 10	41 AA	
56 wet, 90% RH, Lt/Dk	5 Hours	16 - 60	42 Peaks/inch	
	10 "	17 PVC-D4		
6 Enclosed Carbon	25 "	18 - 10	5 Electrical	
61 dry	50 "	19 - 60	51 D.C.) at 1 KC	
62 spray	100 "	20 PVC-M	52 D.F.)	
	500 "			
7 Sunshine Carbon	1000 "		6 Tensile	
71 dry	5000 "		61 Modulus x 10^5	
72 spray			62 Y Stress x 10^3	
			63 Y Strain %	
8 FS/BL			64 Tensile x 10^3	
			65 Ult. Elong. %	
9 Brucksch Device				
91 13,000 ppm SO_2			7 Flex	
92 18 ppm SO_2			71 Modulus x 10^5	
93 1400 ppm SO_2			72 Y Stress x 10^3	
			73 Y Strain x 10^{-2}	
			74 R Stress x 10^3	
			75 R Strain x 10^{-2}	
			76 5% Stress x 10^3	
			8 UV Spectra	
			81 Peak wavelength	
			82 Peak height	

TABLE 5

DISCOLORATION "FAILURES" BY 24 MONTHS*

PLASTIC	TIME OF OBSERVATION	ADAMS (E) COLOR-DIFFERENCE
PVC-B4	24 Months	28.32
-B10	24 Months	42.03
-C10	20 Months	26.59
-C10	24 Months	47.59

*ARIZONA only. No E-values greater than 25 were found in this period in Washington, D. C. or Florida

TABLE 6

COLOR-CLASS OF PLASTICS

CLASS	AT 1 YEAR	AT 2 YEARS
A	PE-1 (1) PMMA-60 PVF-1 PVC-B4 -B10 -C4 -C10 -A4 -A10 -A60 (2) -D60 -M60	PE-1 (1) PMMA-60 PVF-1 PVC-A60 (2)
B	PE-60 PETP-5 PVC-B60 -N60 -D4 -D10	PE-60 PETP-5 PVC-C4 -A4 -A10 -D4 -D10 -D60 -M60
C	RP-60 PVC-C60	-
D	-	RP-60 PVC-C60 (3)
E	-	PVC-B60
F	-	PVC-B4 -B10 -C10 -N60

(1) Film embrittled completely at all sites in 1/2 - 1 1/2 years.

(2) Washington, D. C. data only.

(3) Data to 16-months only. Based on comparison with others of its type, the 24-month prediction would be CLASS "E" or "F".

GRAPHS OF COLOR-DIFFERENCE VS. TIME

FIGURE	INDIVIDUAL PLASTICS
1	Polyethylene (1 mil)
2	Polyethylene (60 mil)
3	Polymethyl methacrylate (60 mil)
4	Polyvinyl fluoride (1 mil)
5	Polyethylene terephthalate (5 mil)
6	Glass-reinforced Polyester (60 mil)
7	Polyvinyl chloride -B (4 mil)
8	" " -B (10 mil)
9	" " -B (60 mil)
10	" " -C (4 mil)
11	" " -C (10 mil)
12	" " -C (60 mil)
13	" " -N (60 mil)
14	" " -A (4 mil)
15	" " -A (10 mil)
16	" " -A (60 mil)
17	" " -D (4 mil)
18	" " -D (10 mil)
19	" " -D (60 mil)
20	" " -M (60 mil)

INDIVIDUAL LOCATIONS

21	Arizona)	
22	Florida)	7 Clear PVC's
23	Washington, D. C.)	
24	Arizona)	
25	Florida)	7 White PVC's
26	Washington, D. C.)	
27	A, F, W	Exposures of PVF and PMMA
28	Arizona)	
29	Florida)	PE, PETP, RP, White PVC-A
30	Washington, D. C.)	

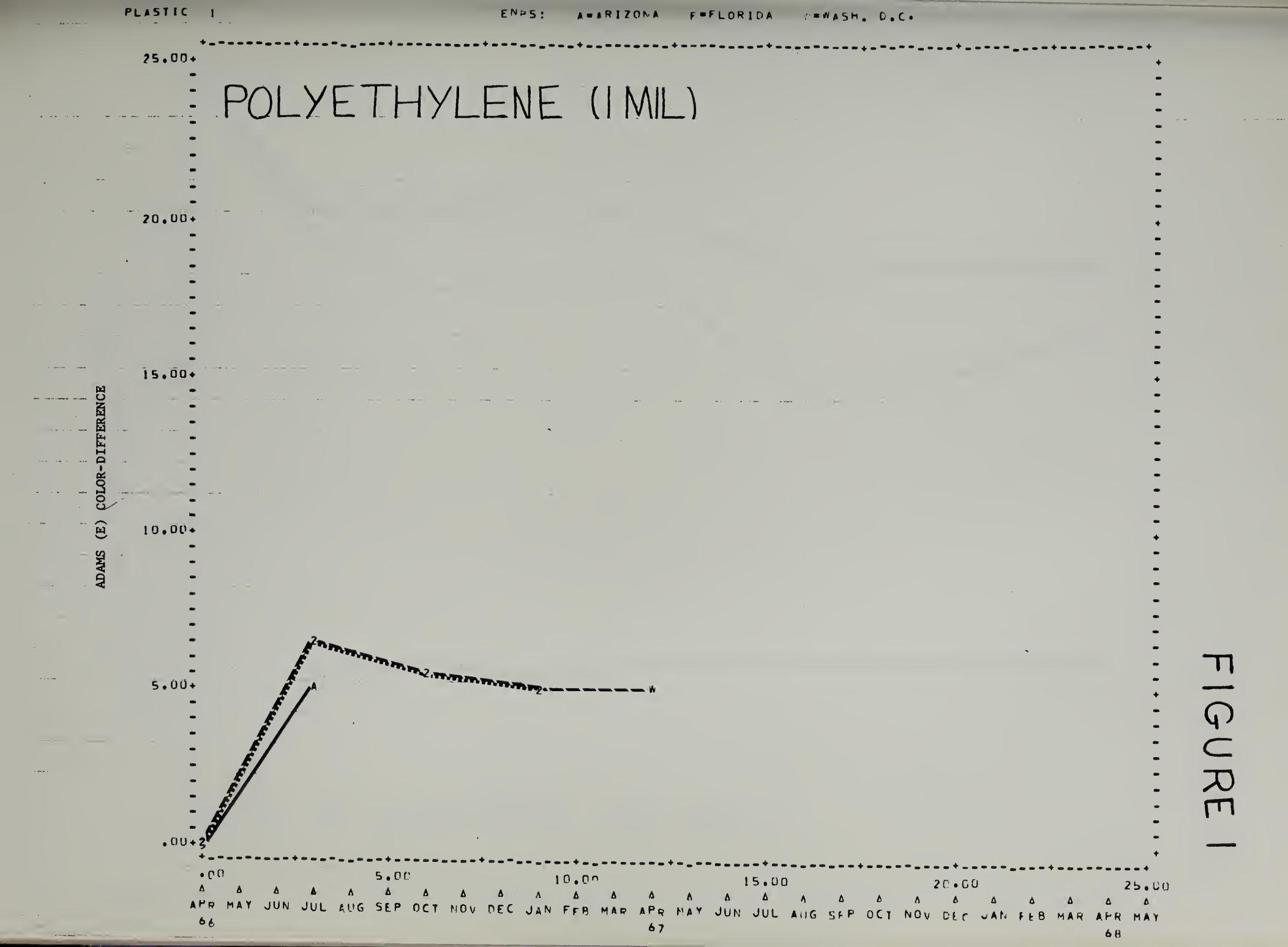

PLASTIC 1
ENPS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYETHYLENE (1 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 1

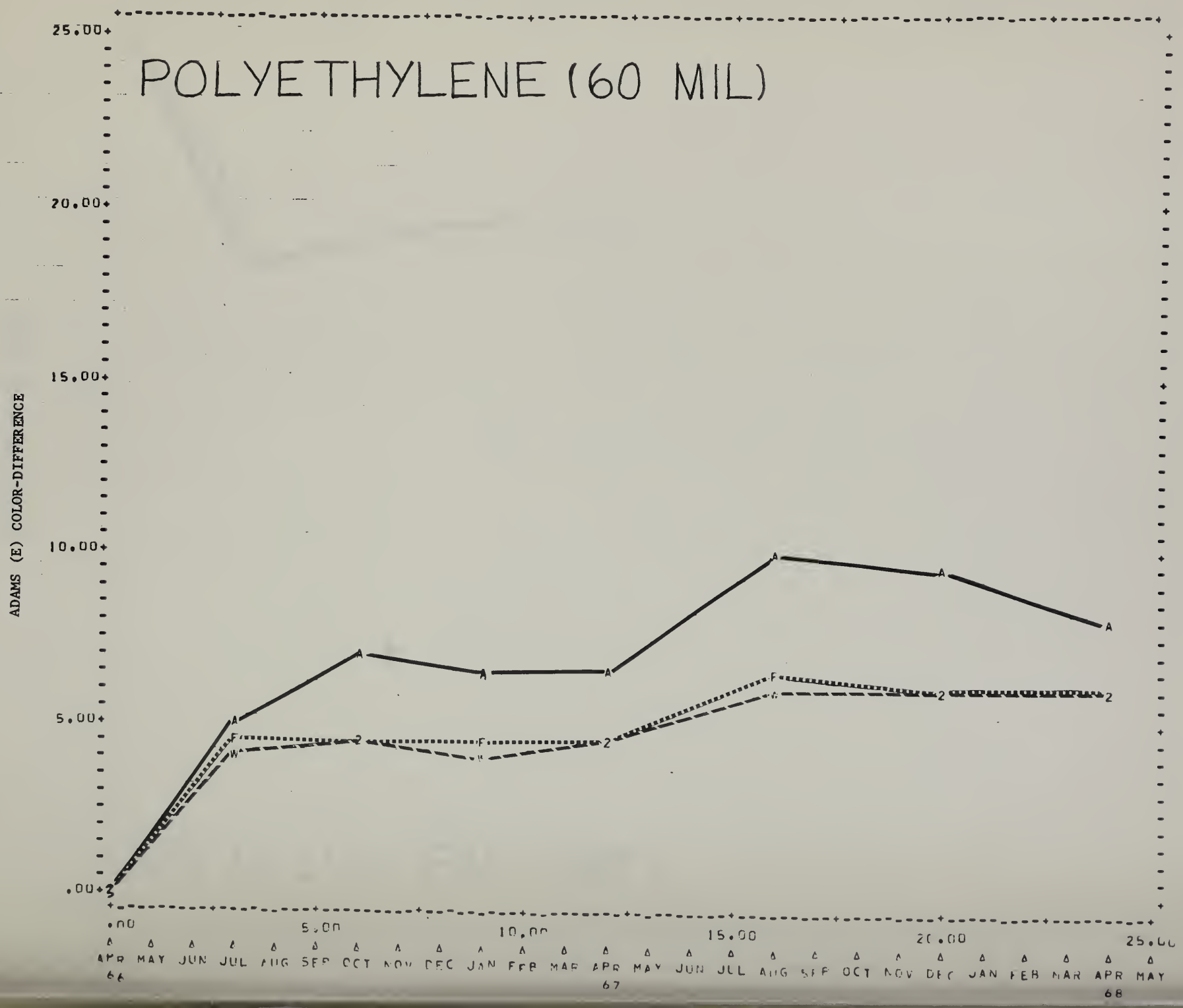

PLASTIC 2
ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYETHYLENE (60 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 2

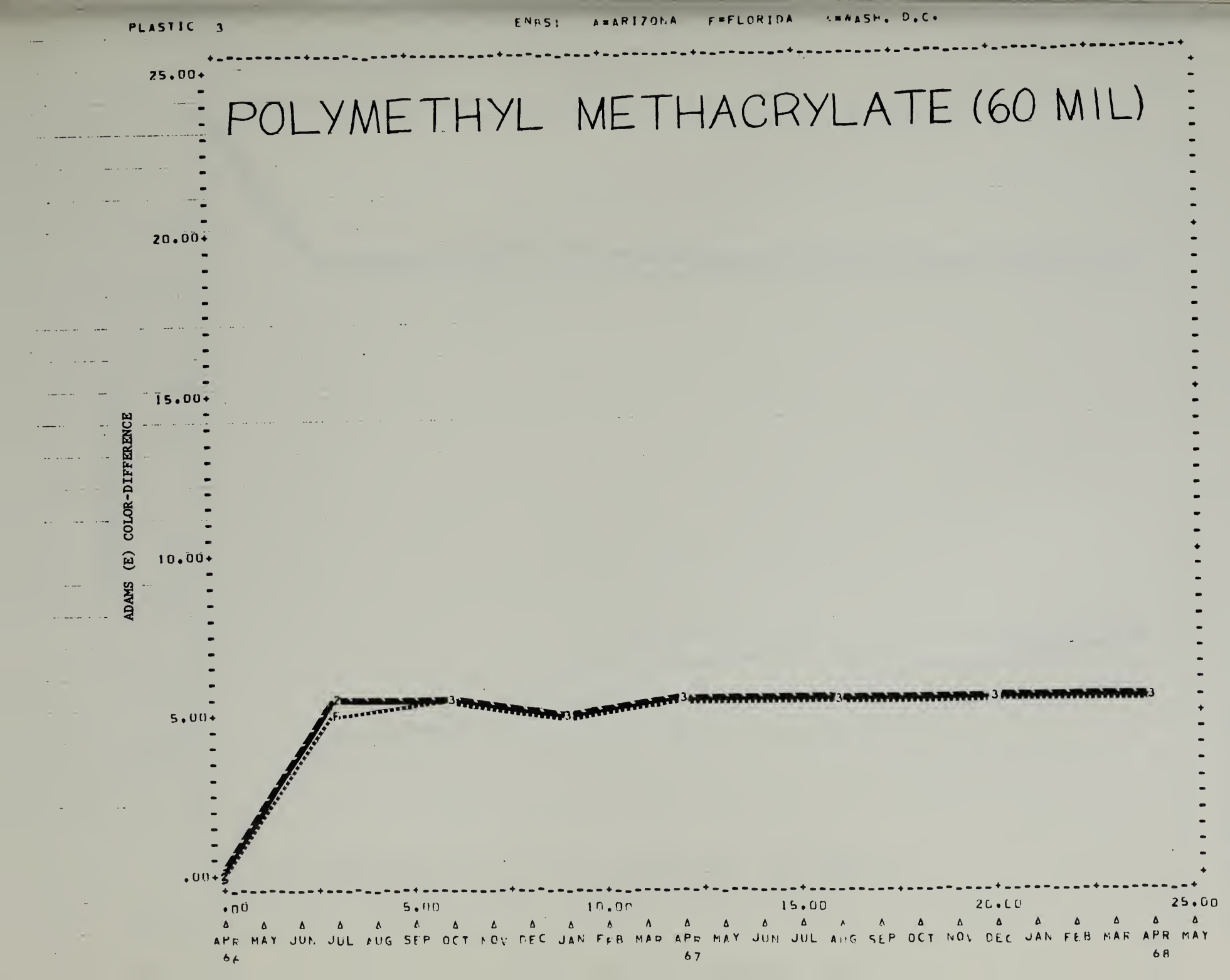
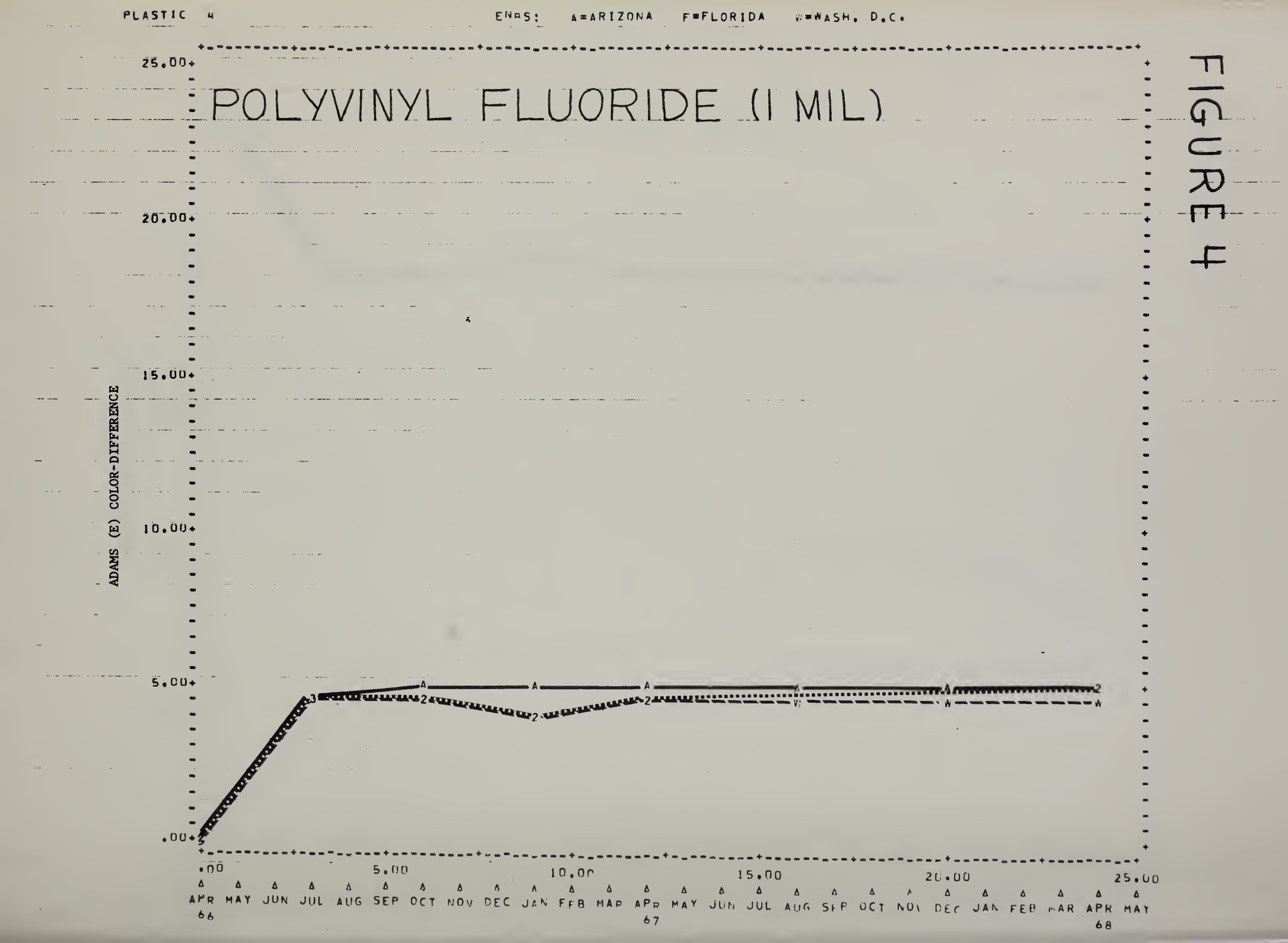

PLASTIC 3
ENAS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYMETHYL METHACRYLATE (60 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 3


PLASTIC 4
ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYVINYL FLUORIDE (1 MIL)
FIGURE 4
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

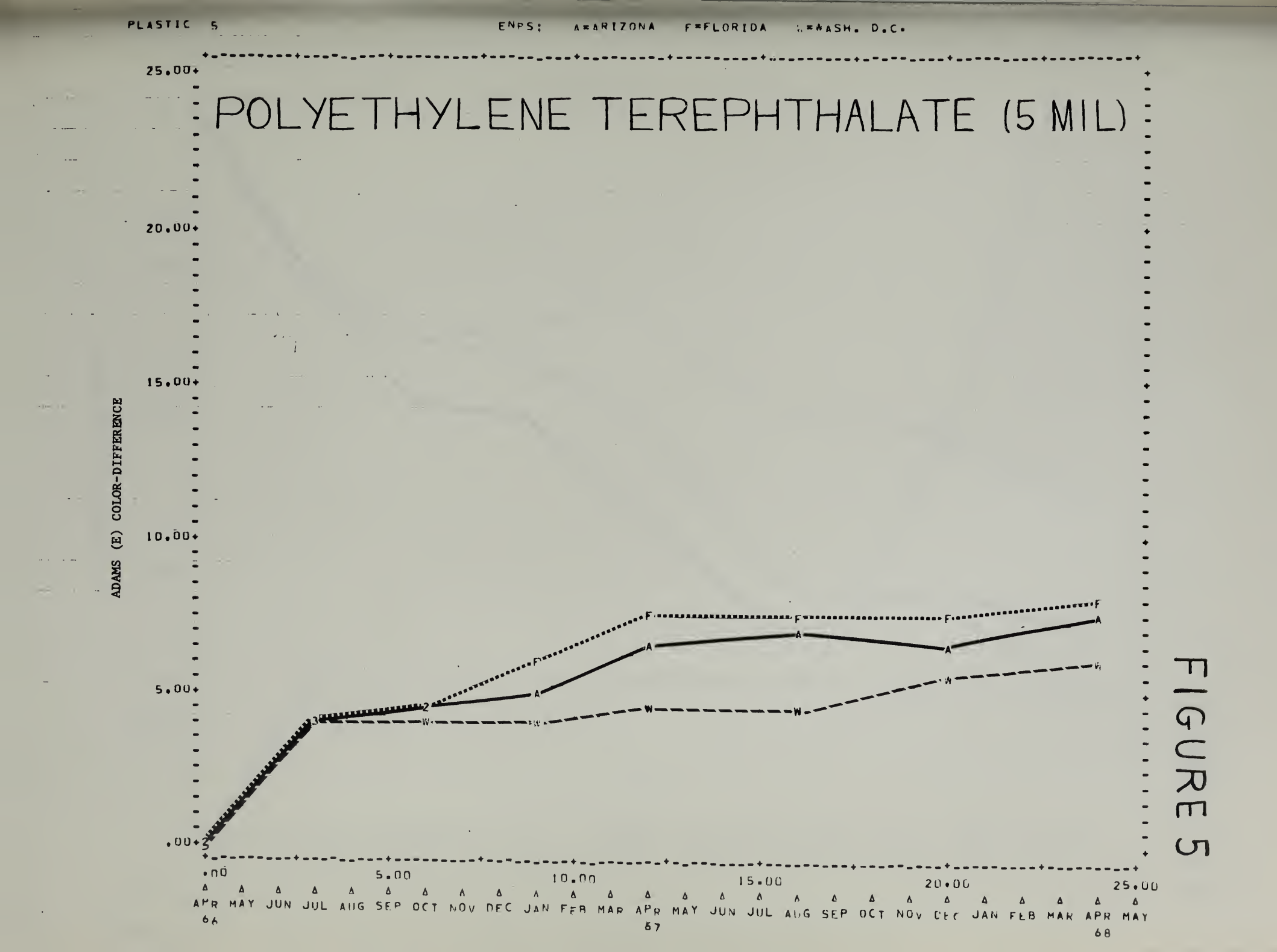

PLASTIC 5
ENPS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYETHYLENE TEREPHTHALATE (5 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 5

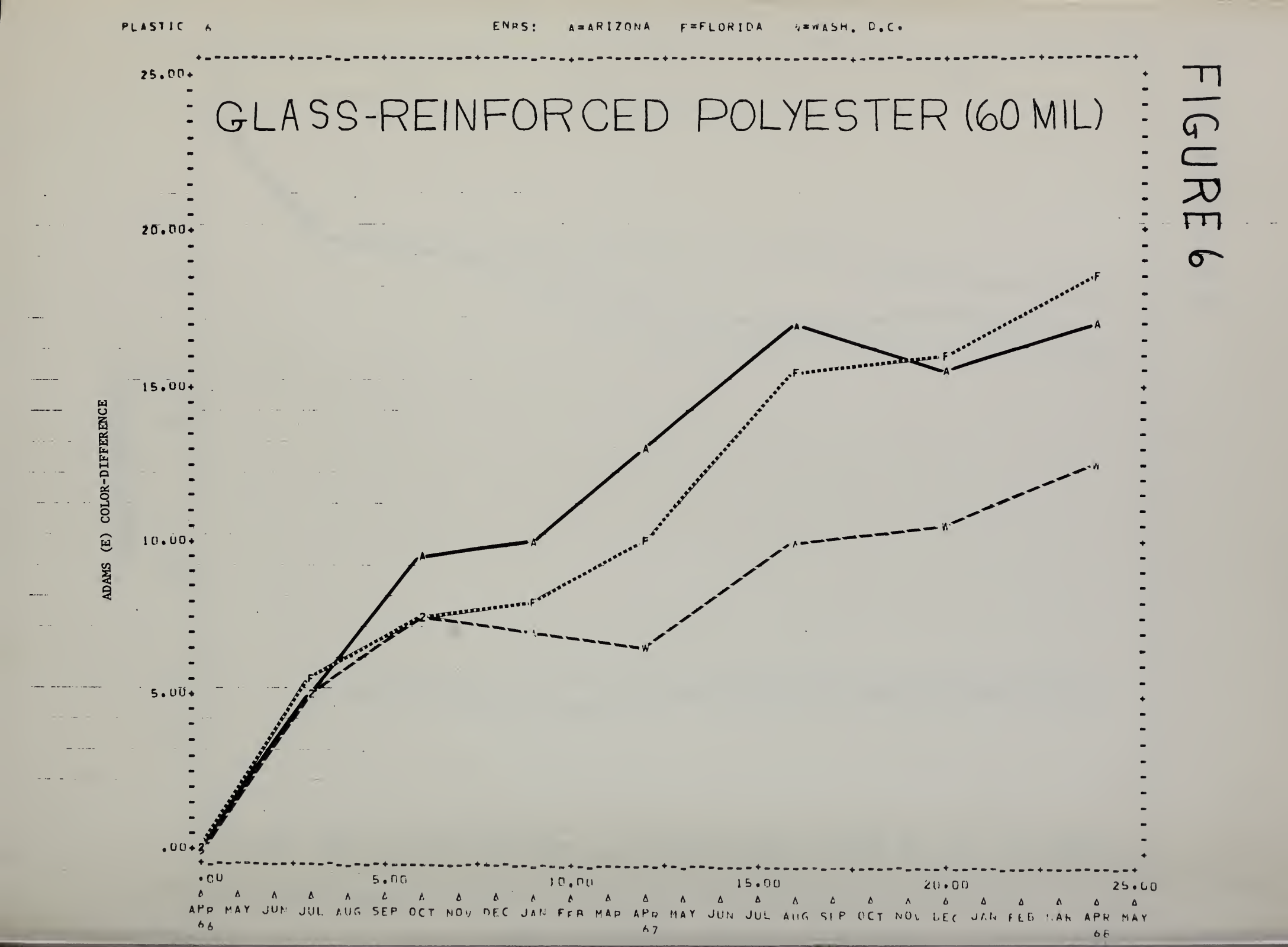

PLASTIC A
ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.
GLASS-REINFORCED POLYESTER (60 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR 66
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR 67 MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR 68 MAY

FIGURE 6

PLASTIC 7 ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.

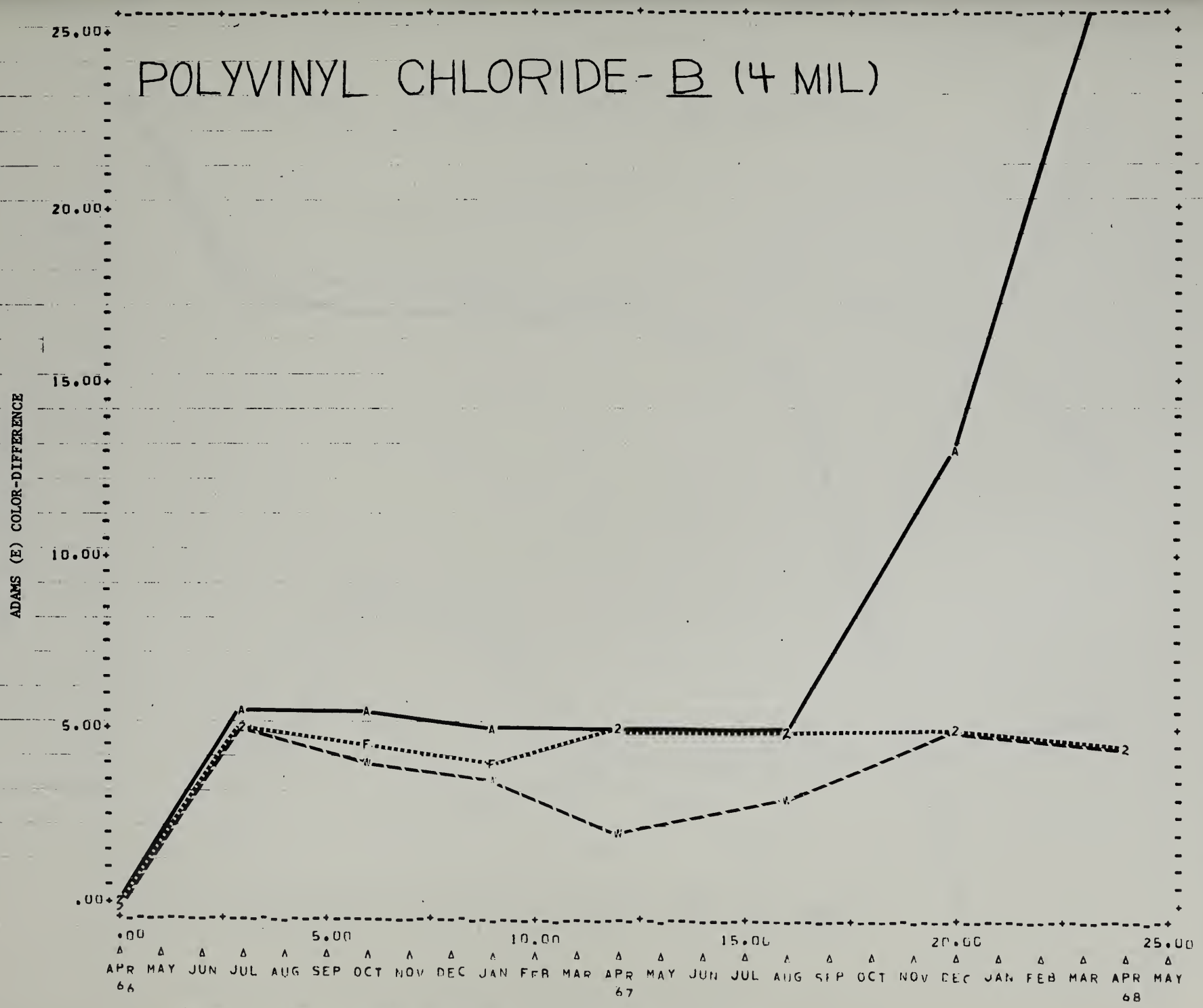


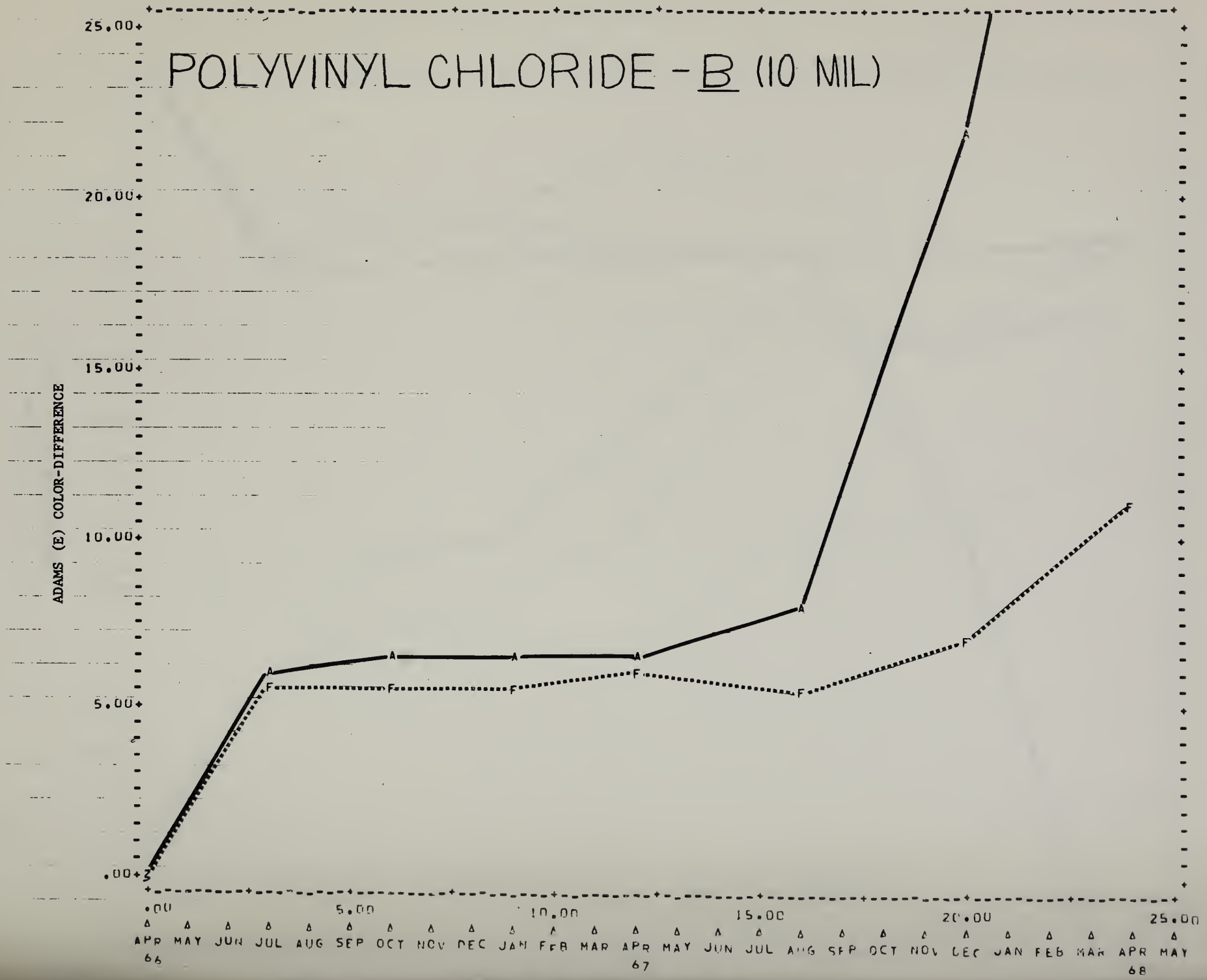
FIGURE 7

**NOTE: 1 POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED.

PLASTIC B

ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.

POLYVINYL CHLORIDE - B (10 MIL)



**NOTE: 1 POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED.

FIGURE 8

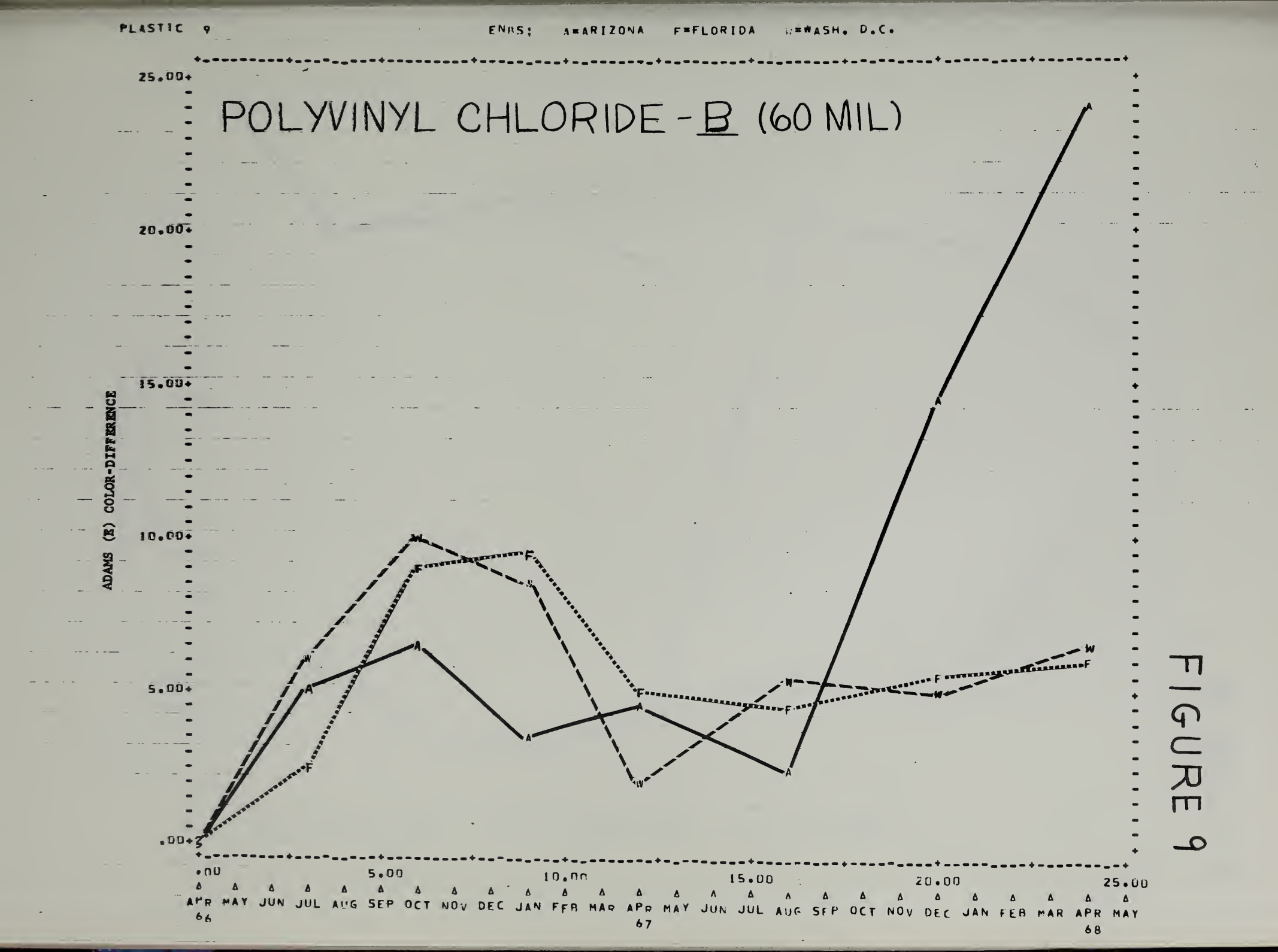

PLASTIC 9
ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYVINYL CHLORIDE - B (60 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 9

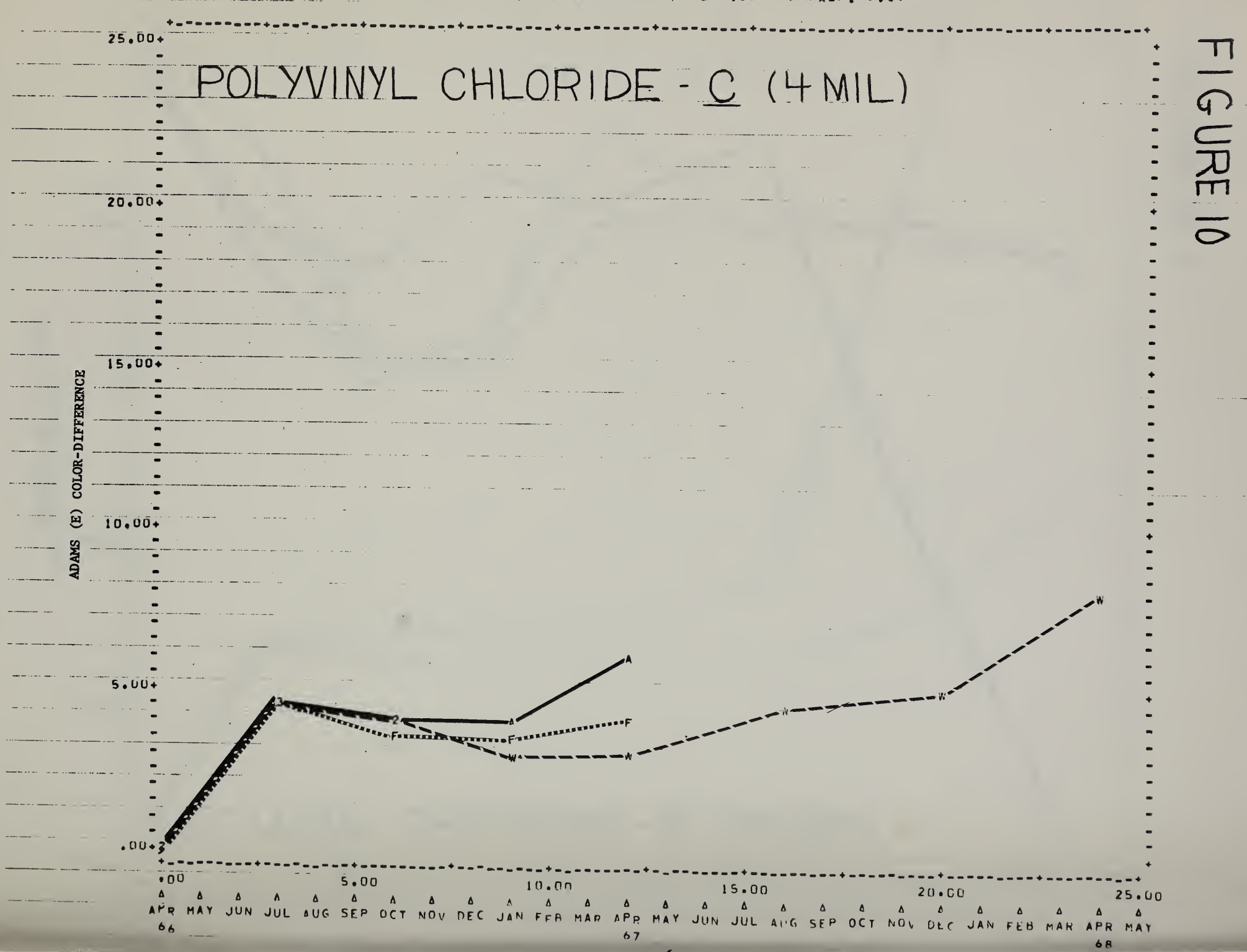

PLASTIC 10
ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYVINYL CHLORIDE - C (4 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 10

PLASTIC 1)

ENAS: A=ARIZONA F=FLORIDA W=WASH. D.C.

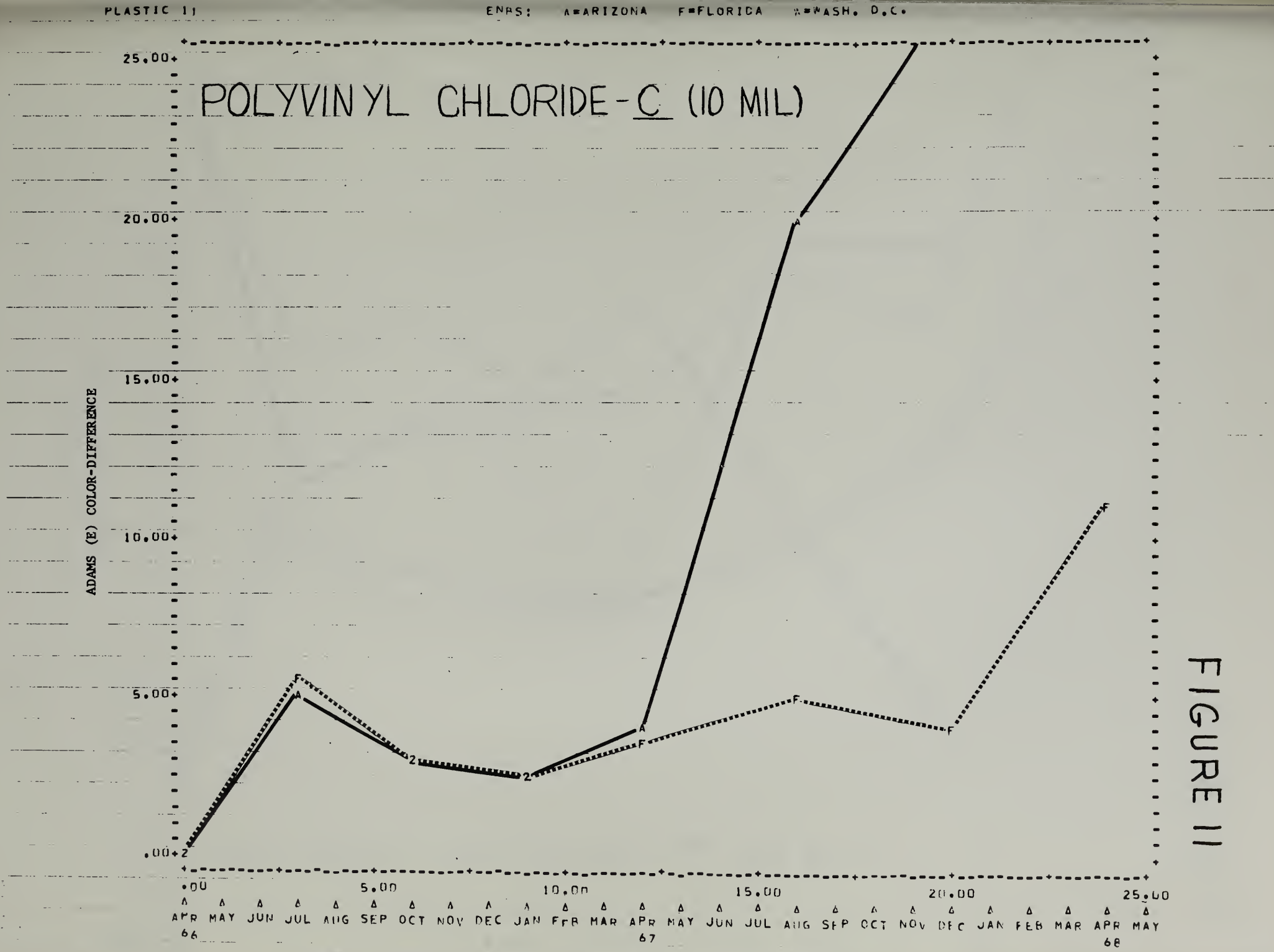


FIGURE II

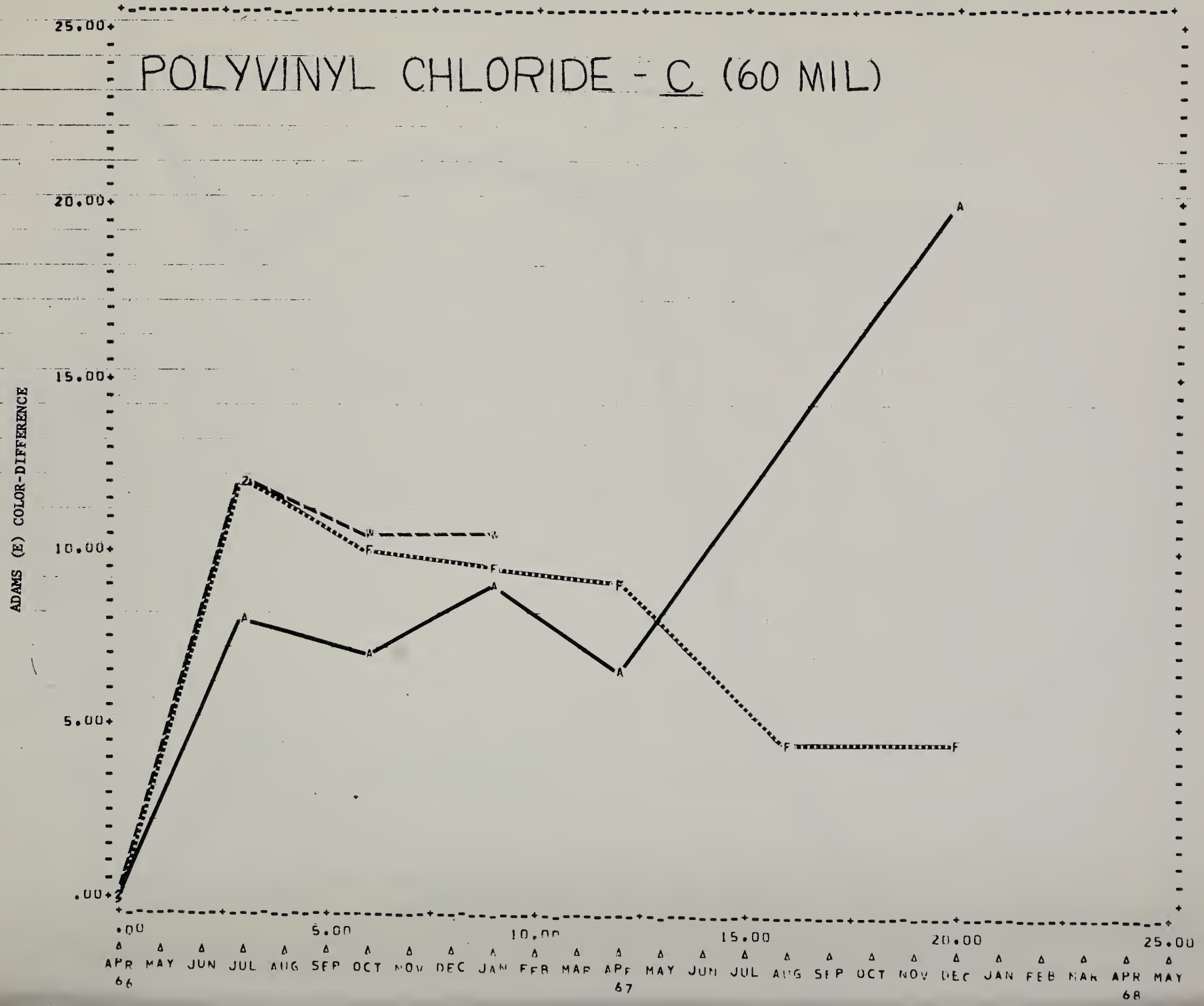
**NOTE: 2 POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED.

PLASTIC 12

ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.

POLYVINYL CHLORIDE - C (60 MIL)

FIGURE 12



PLASTIC 13 ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.

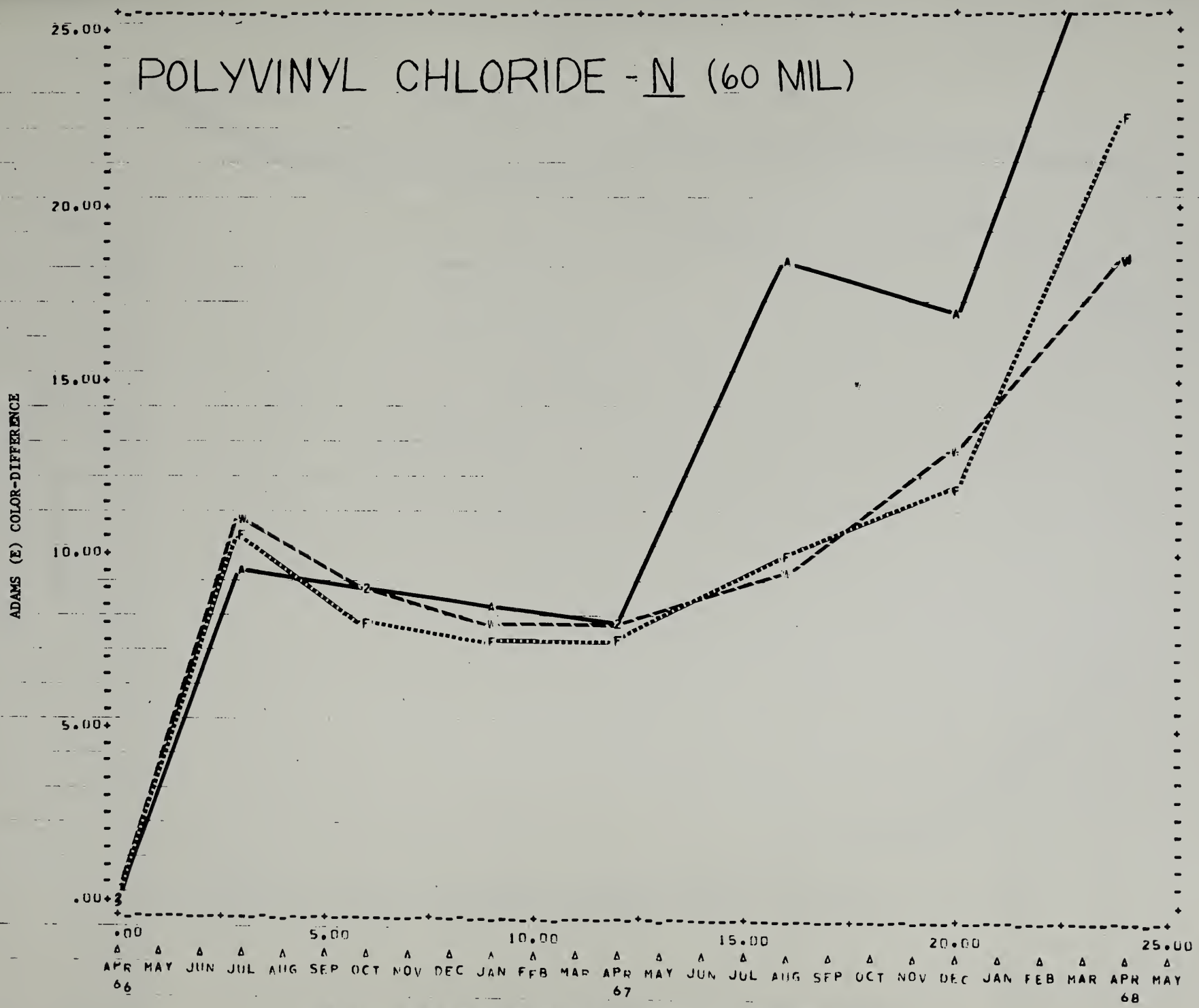


FIGURE 13

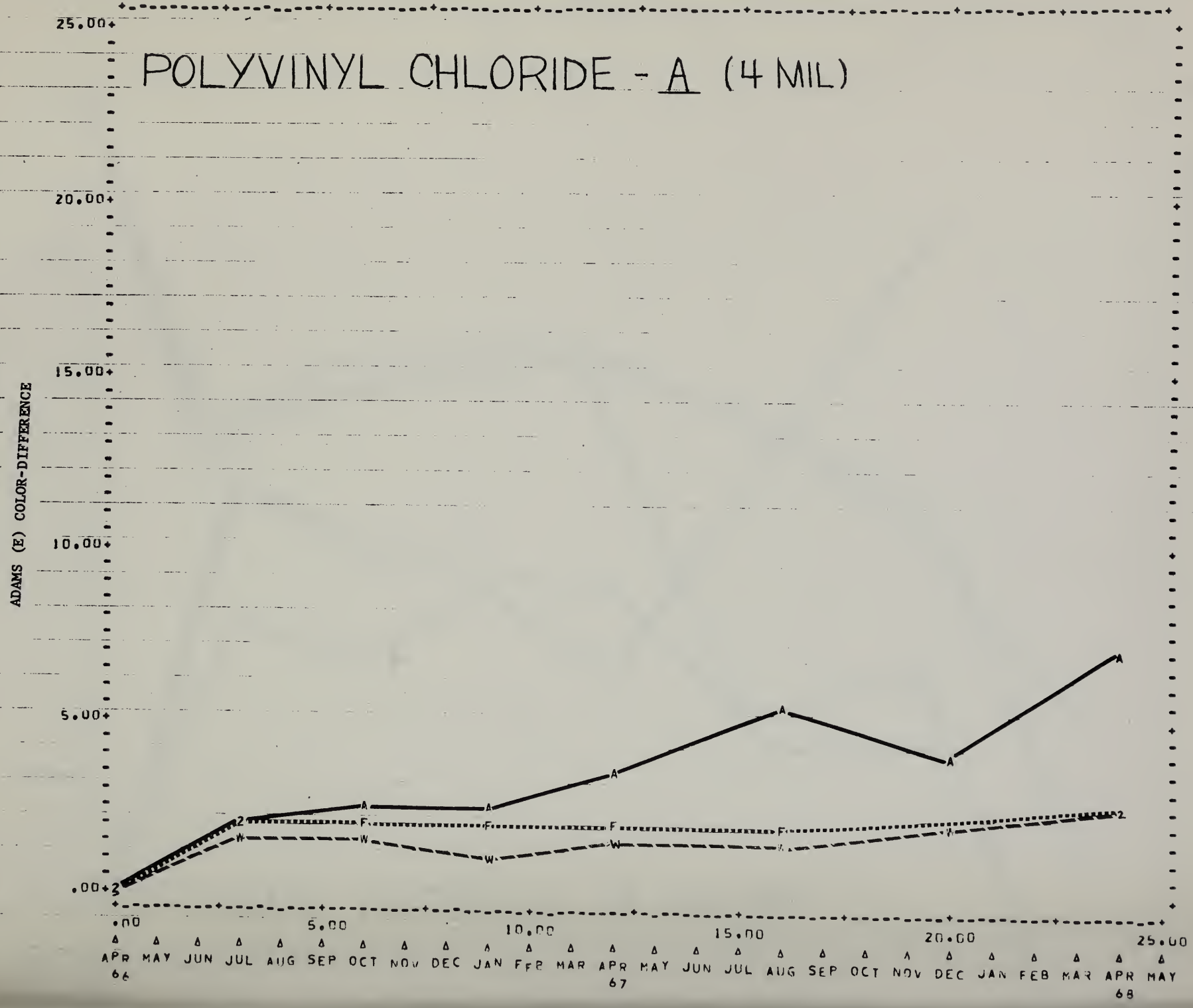
**NOTE: 1 POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED.

PLASTIC 14

ENBS: A=ARIZONA F=FLORIDA W=WASH. D.C.

POLYVINYL CHLORIDE - A (4 MIL)

FIGURE 14



PLASTIC 15 ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.

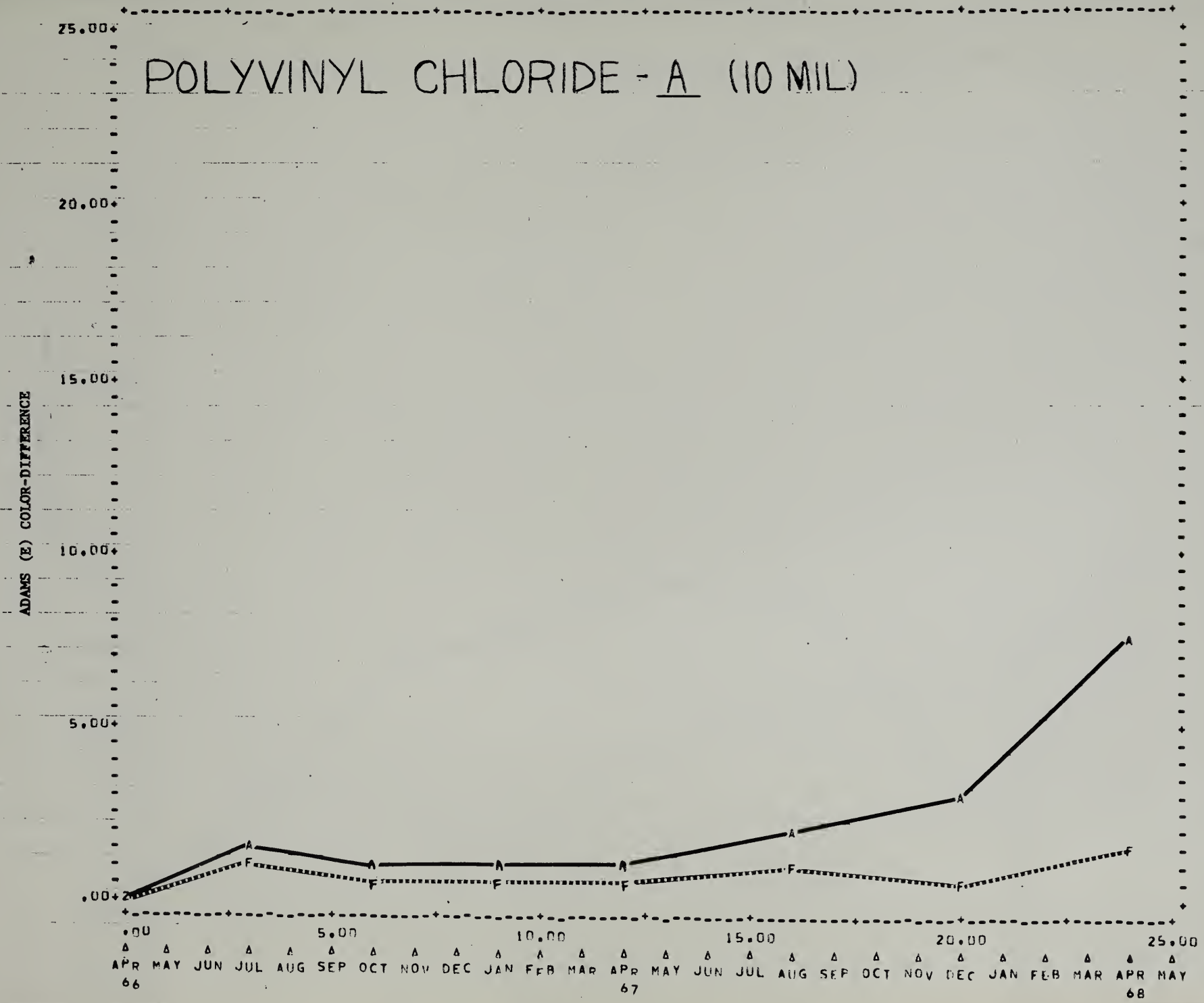
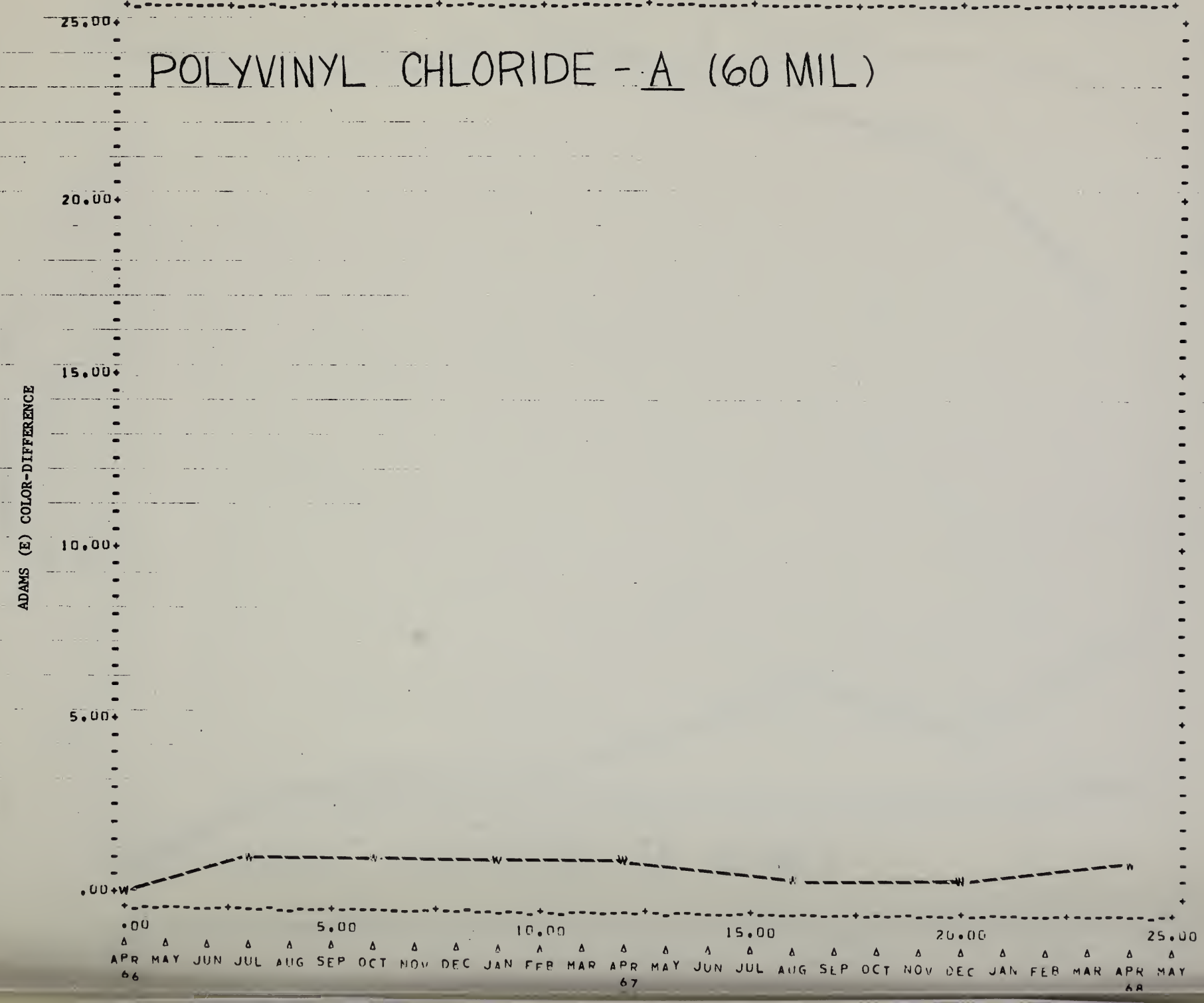


FIGURE 15

PLASTIC 16 ENBS: A=ARIZONA F=FLORIDA W=WASH. D.C.

POLYVINYL CHLORIDE - A (60 MIL)

FIGURE 16



PLASTIC 17 ENDS: A=ARIZONA F=FLORIDA W=WASH. D.C.

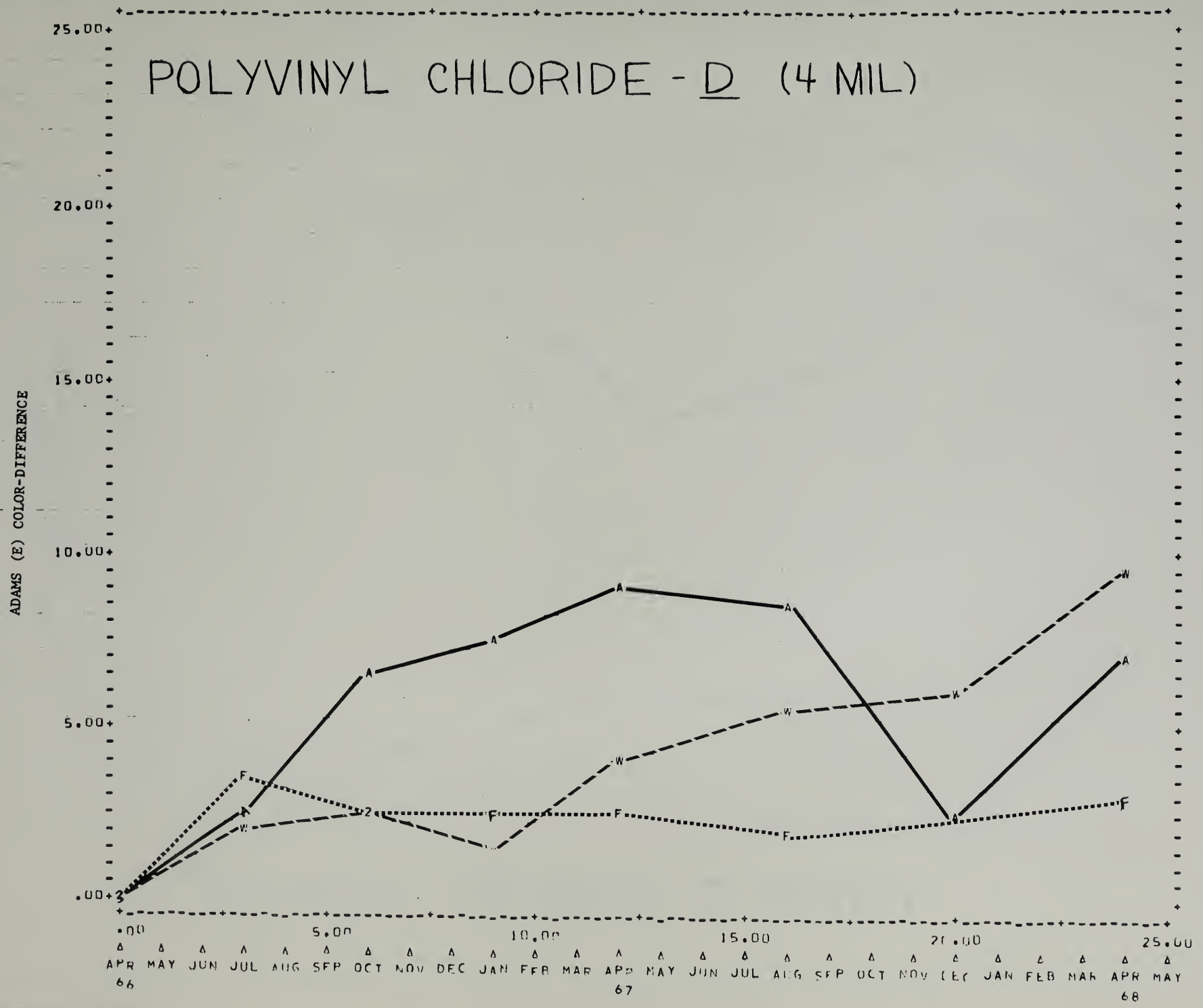
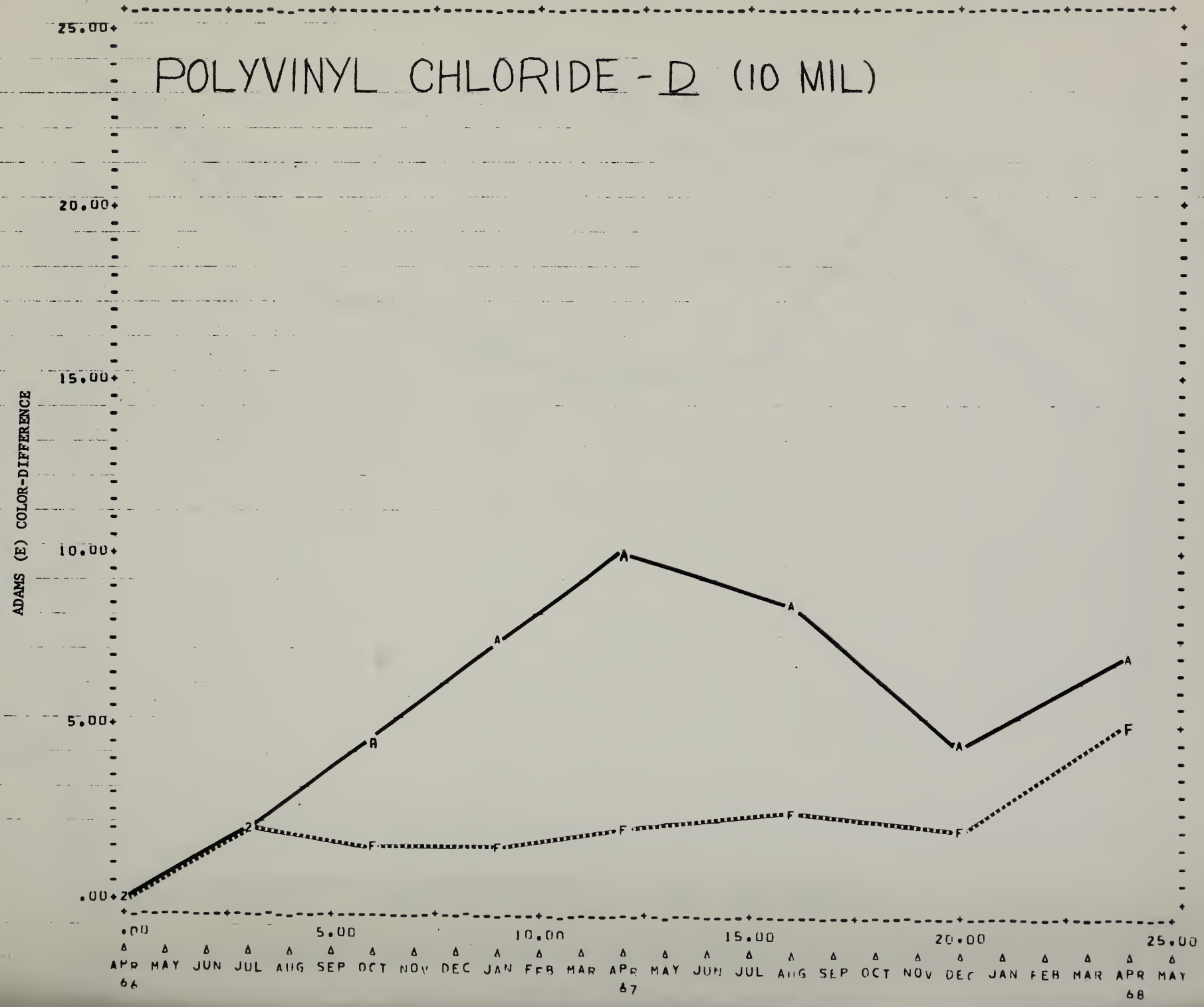


FIGURE 17

PLASTIC 18 ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.

POLYVINYL CHLORIDE - D (10 MIL)

FIGURE 18



PLASTIC 19 ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.

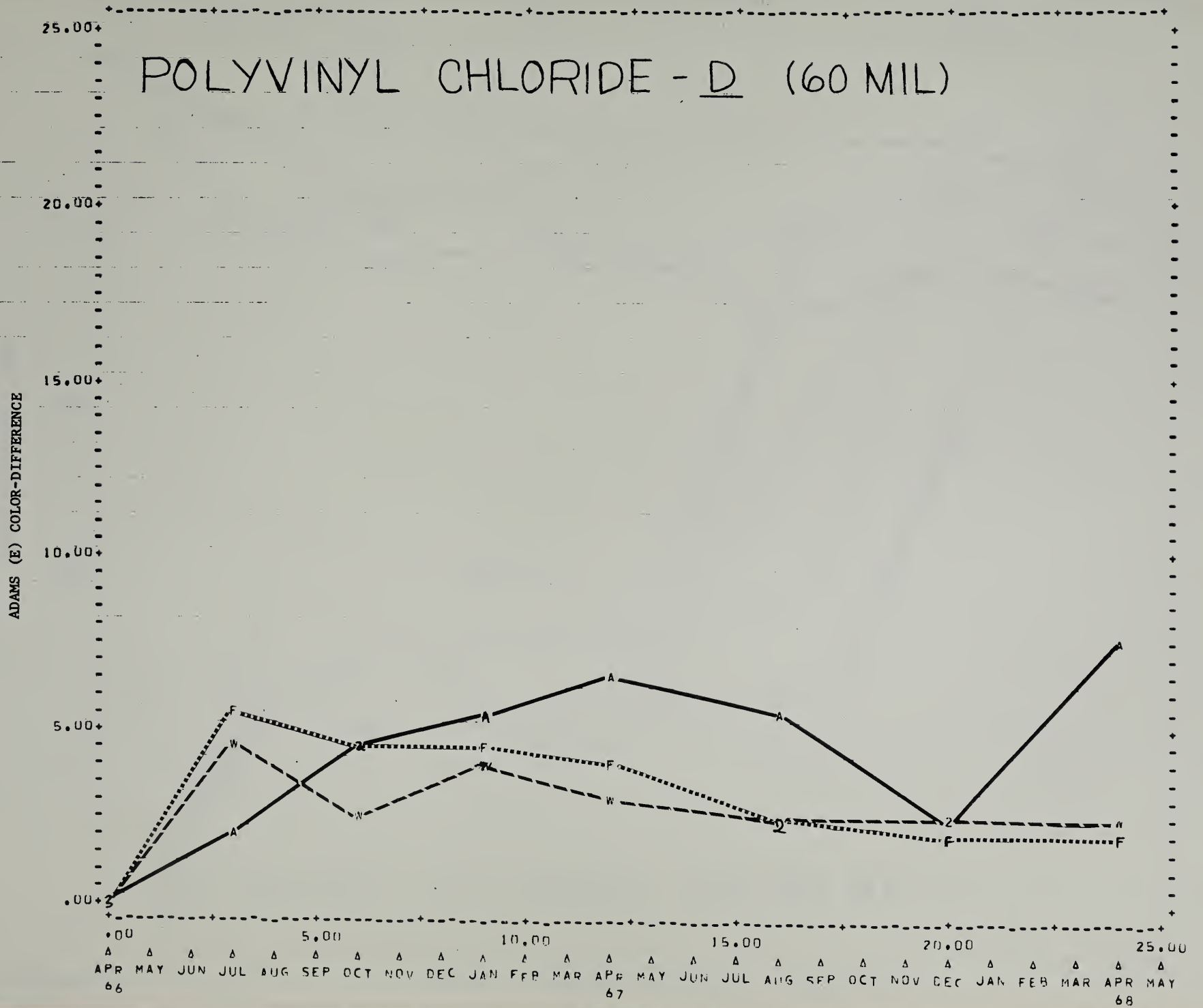


FIGURE 19

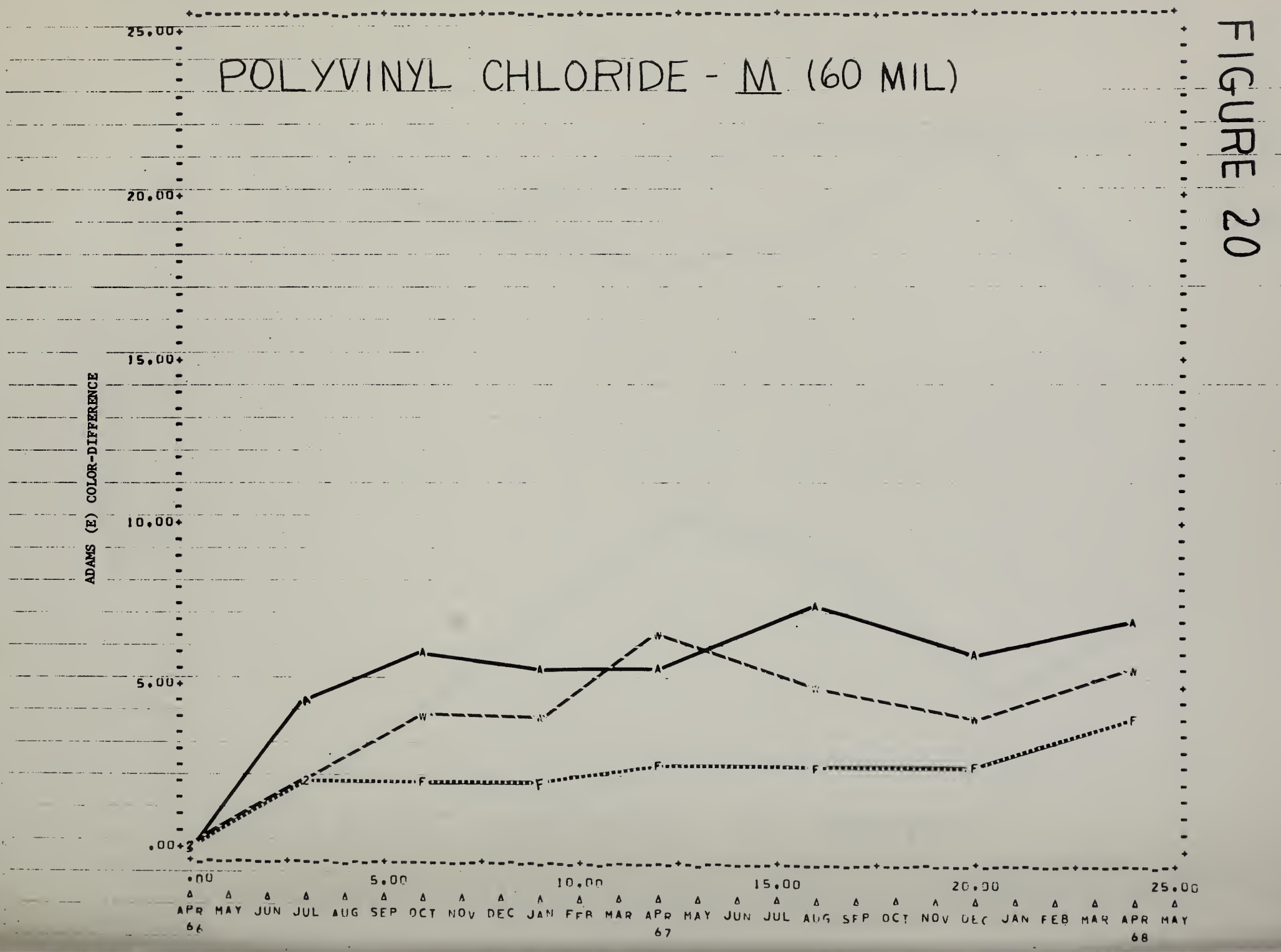
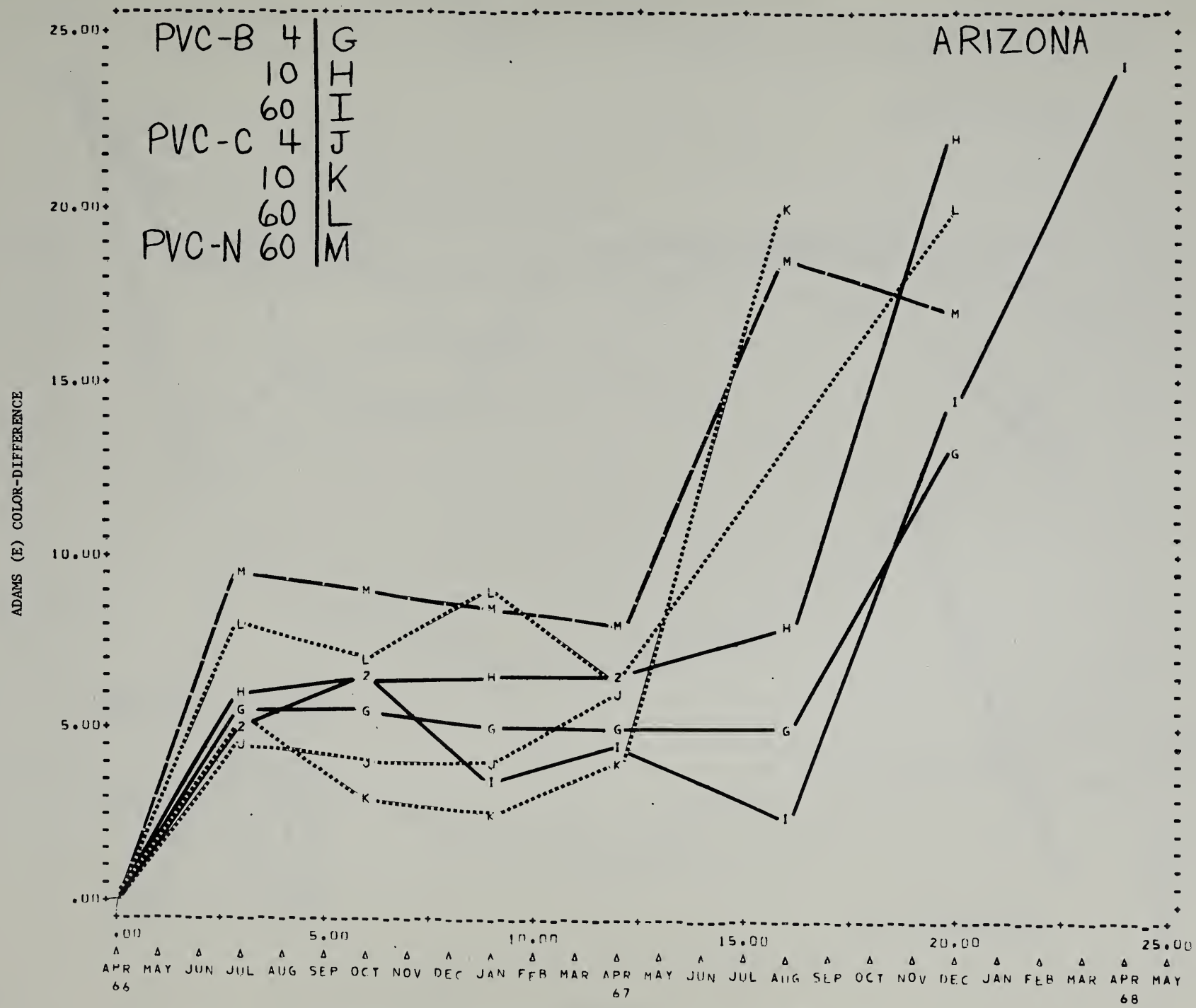

PLASTIC 20
ENRS: A=ARIZONA F=FLORIDA W=WASH. D.C.
POLYVINYL CHLORIDE - M (60 MIL)
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 20

EXPOSURE: 1 TIME: ALL PLASTIC: ALL CLEAR PVC PROPERTY: III

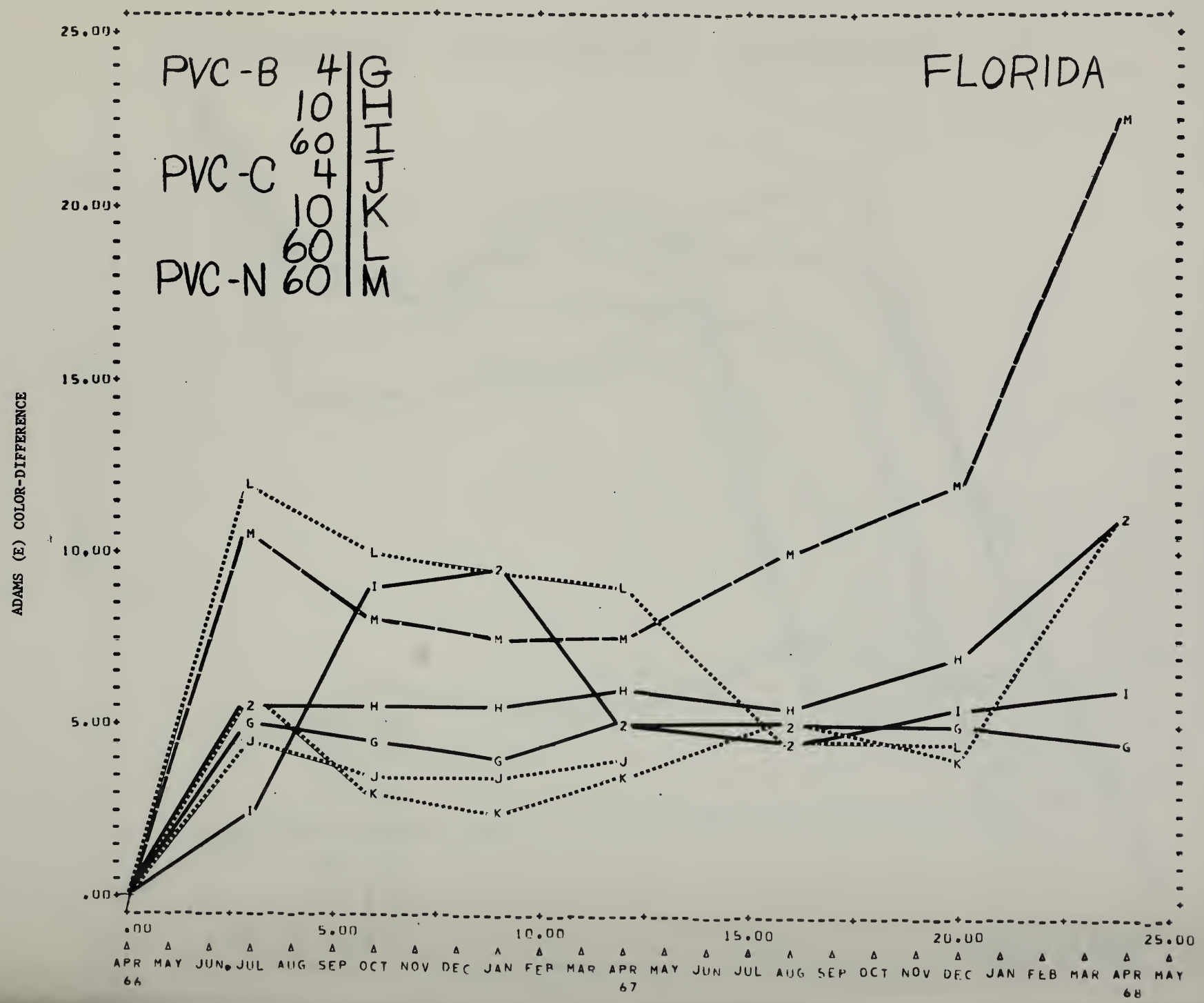


**NOTE. 5 POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED.

FIGURE 21

EXPOSURE: 2 TIME: ALL PLASTIC: ALL CLEAR PVC PROPERTY: III

FIGURE 22



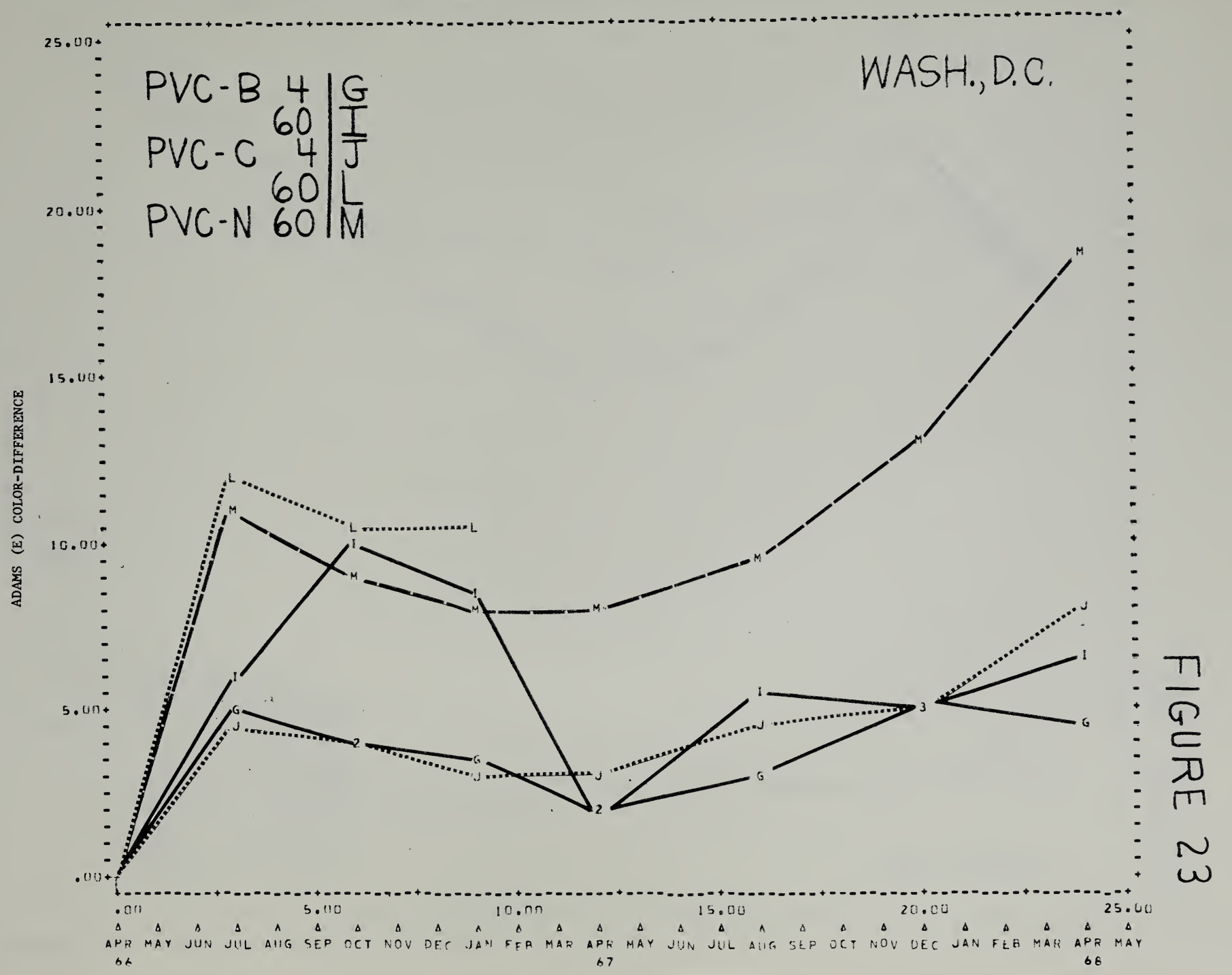
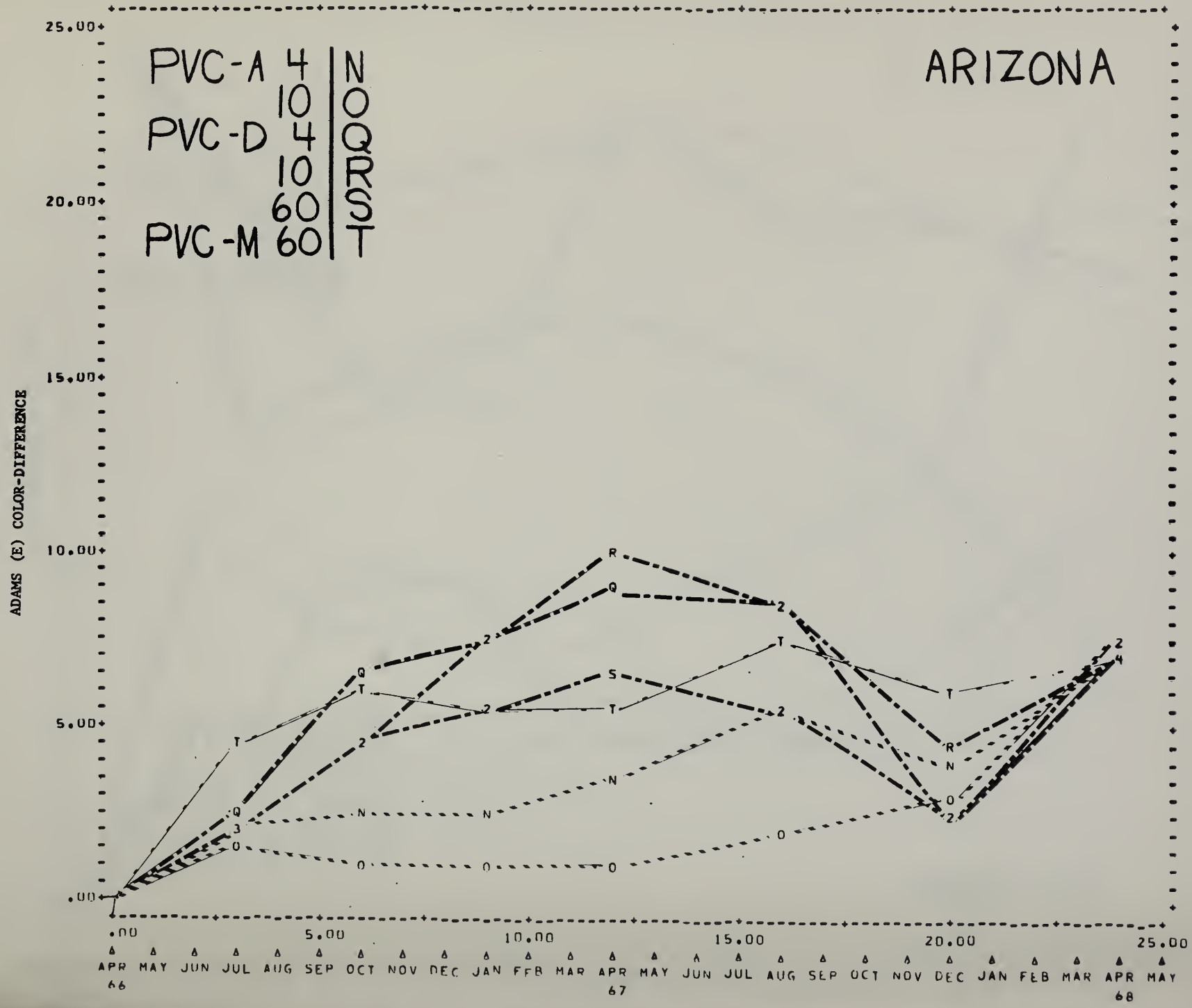

EXPOSURE: 3 TIME: ALL PLASTIC: ALL CLEAR PVC PROPERTY: III
WASH., D.C.
PVC-B 4 G
60 I
PVC-C 4 J
60 L
PVC-N 60 M
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 23

EXPOSURE: 1 TIME: ALL PLASTIC: ALL WHITE PVC PROPERTY: 111

FIGURE 24



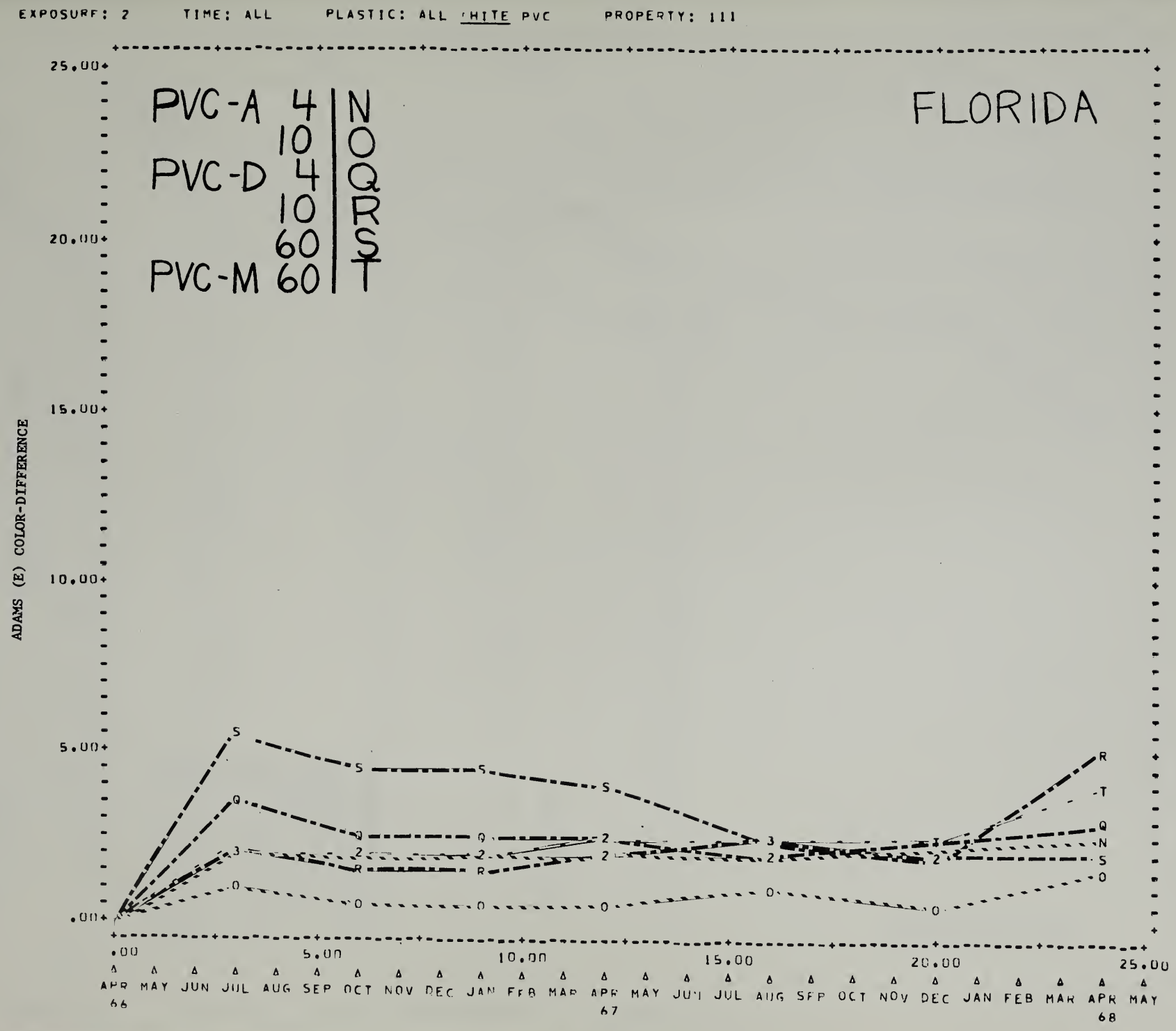

EXPOSURE: 2 TIME: ALL PLASTIC: ALL WHITE PVC PROPERTY: III
FLORIDA
PVC-A 4 N
10 O
PVC-D 4 Q
10 R
60 S
PVC-M 60 T
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 25

EXPOSURE: 3 TIME: ALL PLASTIC: ALL WHITE PVC PROPERTY: III

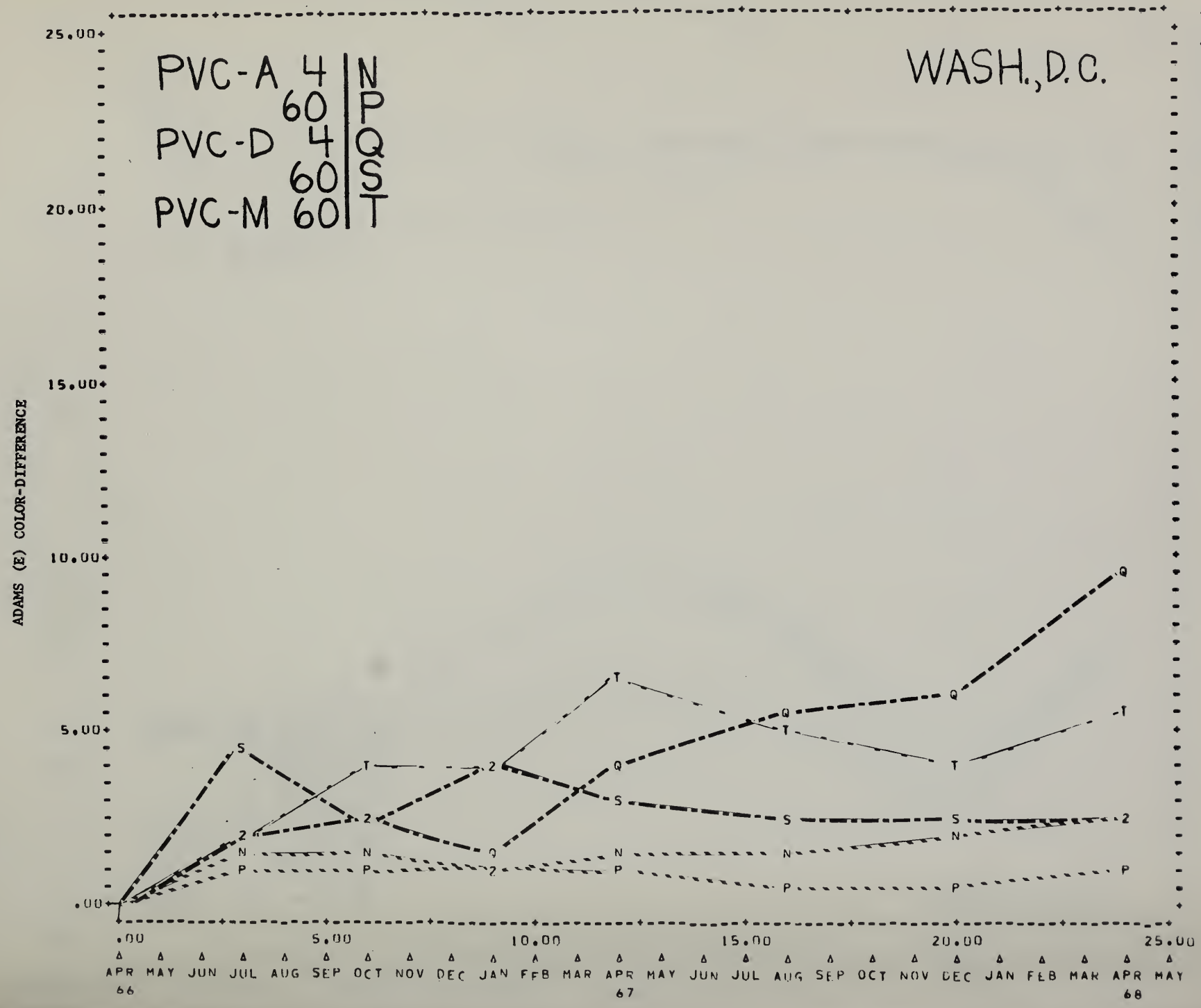


FIGURE 26

EXPOSURE: 1 TIME: ALL PLASTIC: 3,4 PROPERTY: III

FIGURE 27

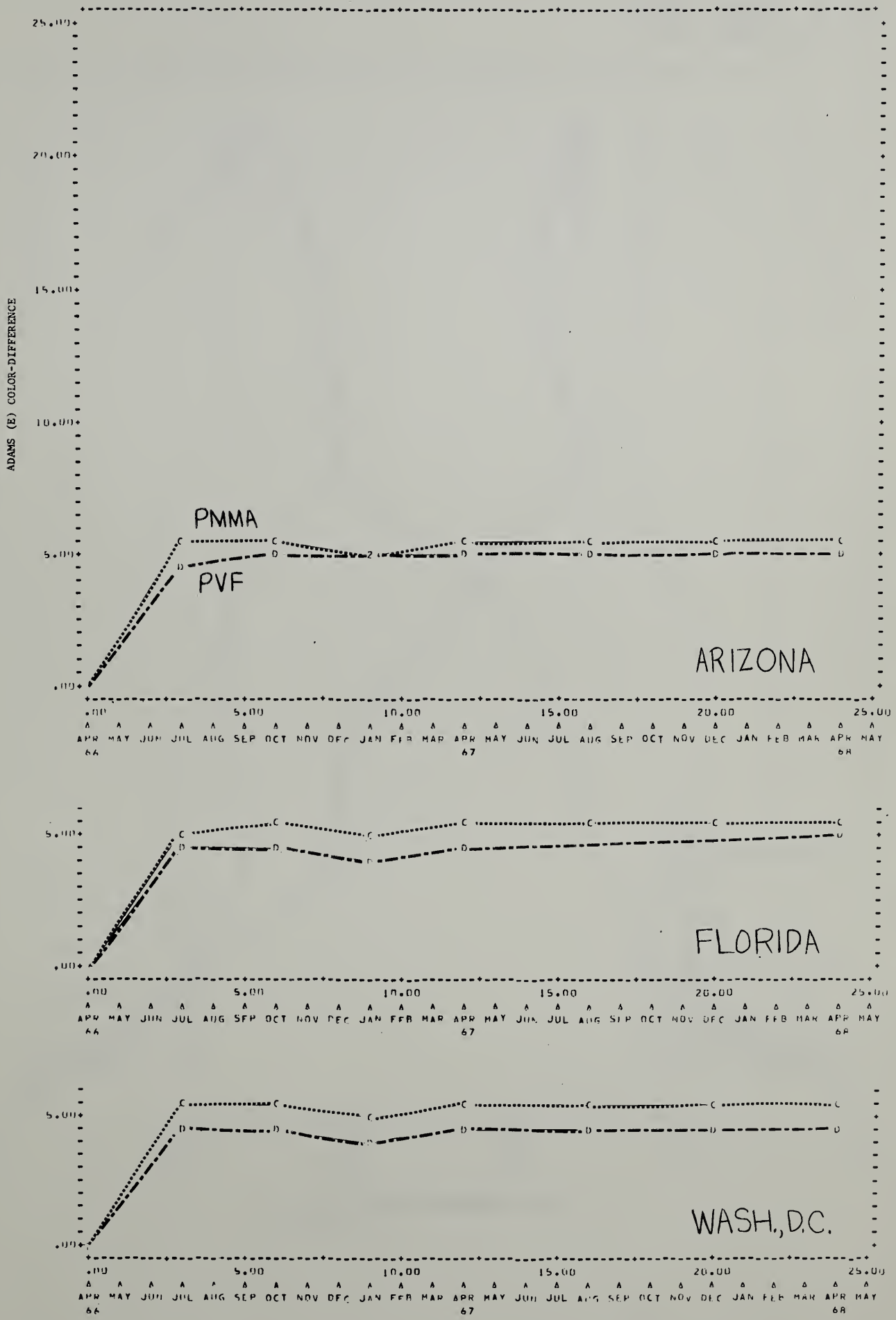


FIGURE 27

EXPOSURE: 1 TIME: ALL PLASTIC: 2,5,6,14,15,20 PROPERTY: 111

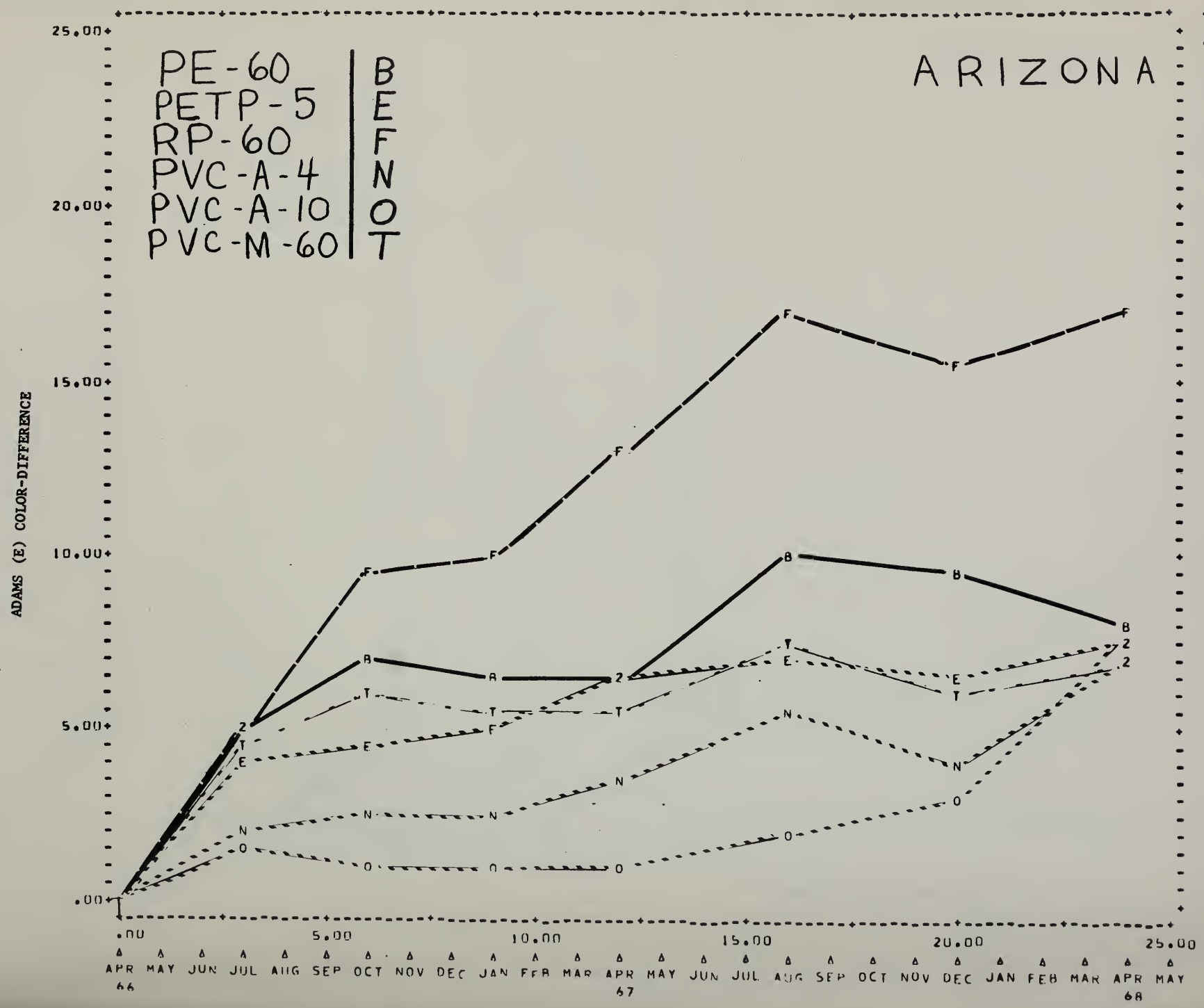


FIGURE 28

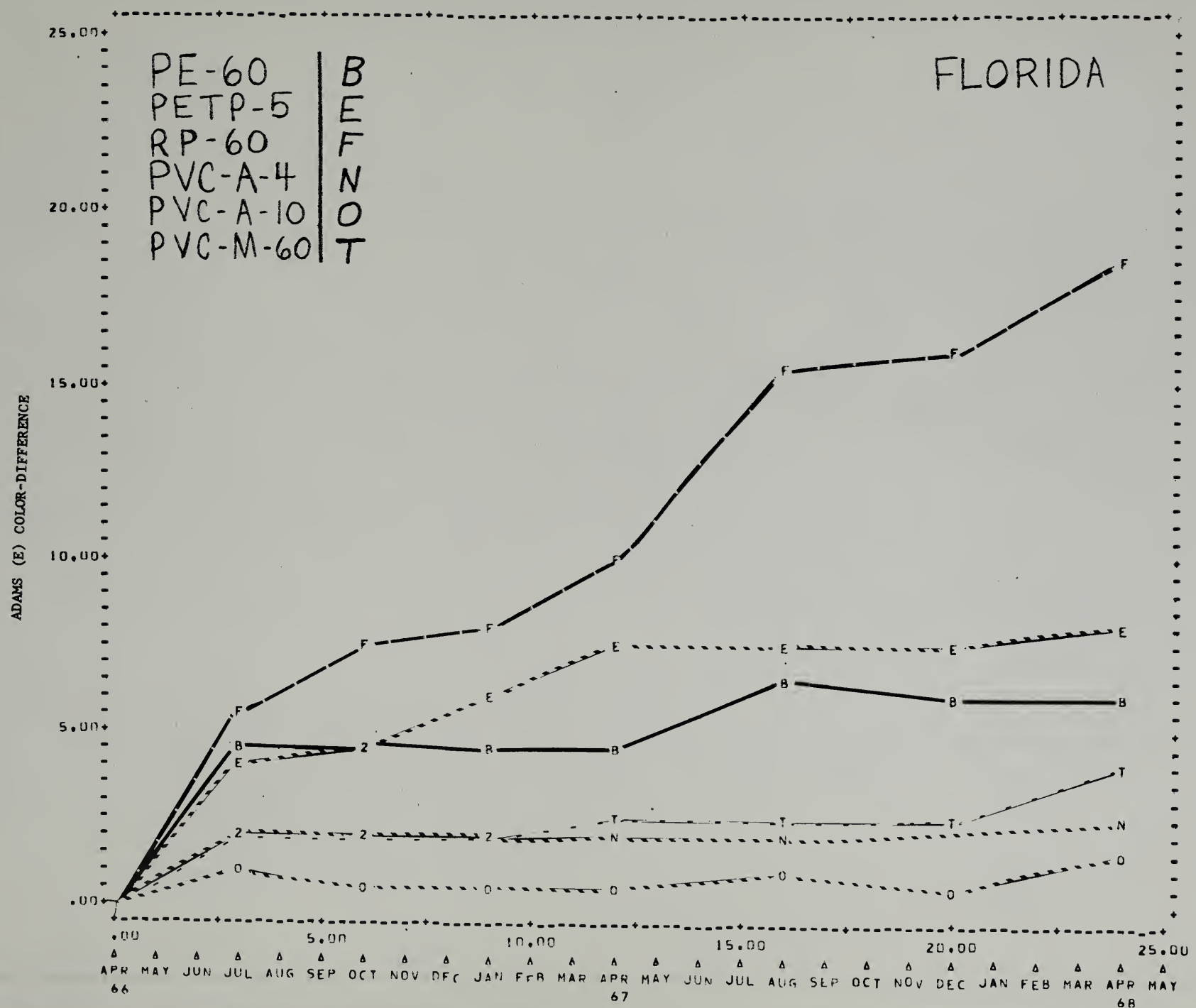

EXPOSURE: 2 TIME: ALL PLASTIC: 2,5,6,14,15,20 PROPERTY: III
FLORIDA
PE-60 B
PETP-5 E
RP-60 F
PVC-A-4 N
PVC-A-10 O
PVC-M-60 T
ADAMS (E) COLOR-DIFFERENCE
25.00
20.00
15.00
10.00
5.00
.00
.00
5.00
10.00
15.00
20.00
25.00
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
66
67
68

FIGURE 29

EXPOSURE: 3 TIME: ALL PLASTIC: 2,5,6,14,15,20 PROPERTY: III

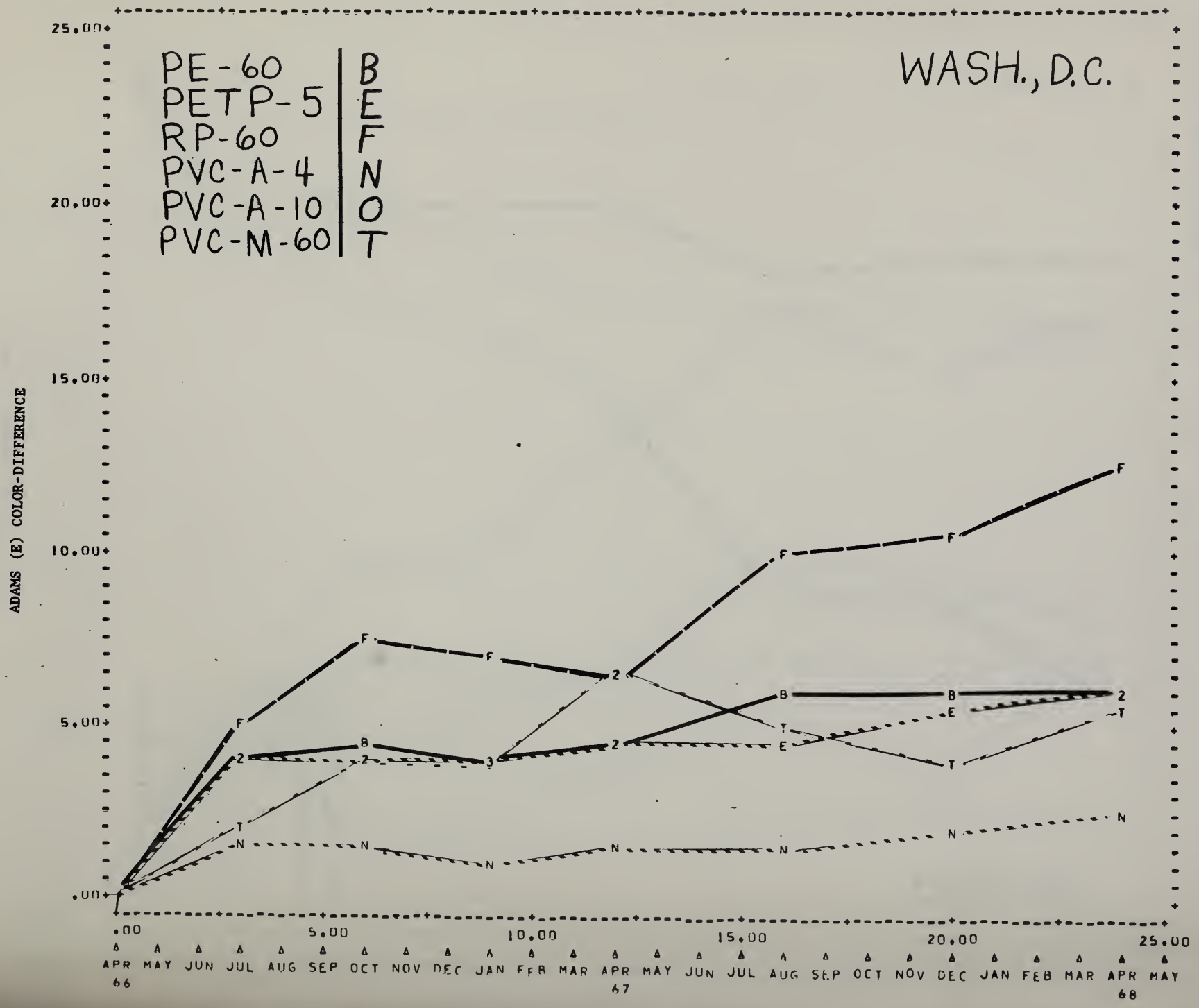


FIGURE 30

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS