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NATIONAL BUREAU OF STANDARDS REPORT

10 179

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OUTDOOR PERFORMANCE OF PLASTICS
V. SURFACE ROUGHNESS

Sponsored
by
Manufacturing Chemists' Association

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

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OUTDOOR PERFORMANCE OF PLASTICS
V. SURFACE ROUGHNESS

by

Joseph E. Clark*

C. Bal Krishna*

Henry C. Gunst**

John R. Dagon**

Sponsored by Manufacturing Chemists' Association

* Research Associate of Manufacturing Chemists' Association

** Plastics Division, Union Carbide Corp., Bound Brook, N.J.

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ABSTRACT

This is the fifth in a series of reports on outdoor performance of plastics. Surface roughness of specimens was measured with a diamond-stylus type roughness meter. The number of "peaks" per inch of surface was found to be more sensitive for early detection of changes than the classic Arithmetic Average (AA).

Two-years' data on changes in peaks per inch indicated a cyclic roughening-smoothing behavior. Scanning electron micrographs of selected samples gave excellent confirmation of the data.

As reported previously with discoloration and loss of tensile elongation, Arizona was generally found to be the most severe exposure, followed by Florida and Washington, D. C.

OUTDOOR PERFORMANCE OF PLASTICS

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1. BACKGROUND

This is the fifth in a series of reports on the outdoor performance of plastics. Appearance, physical and "early-detection" properties of 20 plastics have been measured periodically for the last several years. This has yielded a large coherent bank of data on clear and white-pigmented films and sheets. Four previous NBS Reports have documented and analyzed the measured behavior in Phoenix, Miami and Washington, D. C.:

I.	INTRODUCTION & COLOR-CHANGE	(#9912)
II.	TENSILE & FLEXURAL PROPERTIES	(#10 014)
III.	STATISTICAL MODEL FOR PREDICTING WEATHERABILITY	(#10 116)
IV.	SIGNIFICANCE OF CLIMATE	(#10 156)

2. INTRODUCTION

The purpose of this report is to present and analyze data on the surface texture of weathered plastics.

Preliminary studies [1, 2] indicated that novel techniques were available to measure physical surface changes precisely. Several commercial devices were investigated, these being analogous to a phonograph player with diamond-stylus. Parameters can be taken from the resulting surface roughness recordings, and one parameter in particular was found to be very sensitive for "early-detection" of surface texture changes in the weathered surface.

Such techniques appear very useful for quantitatively describing phenomena such as fiber-bloom on glass-reinforced plastics, cracking and crazing. Furthermore, others have established correlations between surface texture and gloss, painted appearance and adhesion of coating to metals [3,4,5].

3. EXPERIMENTAL

For preliminary studies at NBS [1], a Brush Surface Analyzer was borrowed from the Brush Instrument Division of Clevite Corporation, Cleveland, Ohio. Unless otherwise indicated all data in this report are from measurements made at Plastics Division of Union Carbide

Corporation, Bound Brook, New Jersey -- using a Brush Surfanalyzer Model MS-5000, with MS-1000 stylus.

Component parts of the Brush system are as follows: electrohydraulic-driven diamond stylus, amplifier, signal analyzer, and recorder. This system detects surface variations by driving the diamond stylus pickup across the surface of the test object. An electromagnetic element in the pickup senses deflections of the stylus tip and generates a signal proportional to the profile of the test surface. The dual-channel Brush recorder gives a running record of surface profile and the arithmetical average of surface irregularities of the test material. Sensitivity of this system is 1/2 micro-inch of surface deviation.

The ASA (now American National Standards Institute)method was followed [6]. Equipment was operated at Scale of 10 micro-inches per chart division, Speed of 0.5 cm per second, and Roughness-Width Cutoff of 0.030 inch. (The latter can be understood by considering that only irregularities having a spacing less than the value of the Roughness-Width Cutoff are included in the measurement.) Sensitivity adjustment was the same for all samples.

All measurements were made normal to the natural grain or "lay" of the plastic, to preclude a channeling effect which would mask roughness changes caused by weathering.

3.1 ROUGHNESS PARAMETERS

According to the ASA definition, roughness consists of the finer irregularities in surface texture usually including those irregularities which result from the inherent action of the production process. These are considered to include traverse feed marks and other irregularities within the limits of the roughness-width cutoff. For a thorough understanding of the complex character of surface texture, study of the ASA standard is recommended.

Two primary parameters are used herein to characterize surface roughness:

AA = Arithmetic Average deviation, in micro-inches, from a hypothetical smooth line defining the surface.

PEAKS/INCH = Number of peaks per inch of surface, when a peak is defined as an increase of X micro-inches from the previous minimum, followed by a decrease of at least X micro-inches.

AA was taken directly from the charts. For peak count, any peak which was more than X micro-inches higher, peak to valley, than its corresponding two adjacent valleys, was counted. This was counted by eye at NBS, since an automatic peak counter which is often used for this purpose was not available.

The surface profile of a series of plastics was studied to determine minimum arbitrary "peak height" values that would best show a significant change from the unexposed samples. TABLE 1 gives the pertinent data for the original samples.

4. RESULTS

4.1 PRELIMINARY STUDIES

Preliminary studies were done at NBS [1] on original and weathered specimens of unreinforced and glass-reinforced polyester, polypropylene, PVC, and polymethyl methacrylate. In addition to Miami and Washington, D. C. exposures, these also included northern Ohio, New Mexico and Xenon-arc exposures. "Peaks" were defined in slightly different manner in these early studies, therefore the detailed results will not be presented herein. However, the conclusions from these explanatory studies are in good agreement with our later findings.

The preliminary results indicated that peaks per inch was a more sensitive parameter for plastics than Arithmetic Average (AA). AA includes waviness and lay of the material in addition to surface flaws that are to be isolated. The peak count method minimizes the irregularities caused by processing, thus stressing degradation changes. The following observations can also be made from study of the changes with time in peaks per inch:

Polyesters (both clear and reinforced) showed a somewhat cyclic increase in roughness with time. The reinforced polyesters were about ten-fold rougher than the un-reinforced. Of all the plastics examined, the glass-fiber reinforced polyesters showed the greatest change in roughness.

Polypropylene roughness increased almost linearly with time of exposure.

Polymethyl methacrylate appeared as smooth after the fourth year of exposure in Washington as it was initially, experiencing a rise in roughness up to the third year.

PVC specimens sometimes became rougher, and sometimes smoother. Cyclic roughening-smoothing was evident in many of the samples.

4.2 INITIAL ROUGHNESS

TABLE 1 shows data on the original specimens for the major study before exposure in Phoenix, Miami and Washington, D. C. Study of this table shows that Arithmetic Average (AA) of the plastics ranged from 0.0 to 6.0 micro-inches, the smoothest plastics being the acrylic, polyethylene terephthalate, and the thick 60-mil PVC's. Thinner PVC's of the same composition are seen to be comparatively rough.

Arbitrarily assigned peak-heights ranged from 30 to 200 micro-inches. No attempt was made to assign peak-heights on the basis of measured AA. However, it was later found that the higher the peak-height assigned the larger the AA was measured, generally. In hindsight, it is suggested that future work employing this technique should include a search for a useful relation between original AA and assigned peak-height.

Scanning electron micrographs in the APPENDIX appear to indicate weak points for attack on the surface of several original materials. Detailed study of original surface texture would probably be fruitful for suggesting ways to improve weatherability of plastics.

4.3 WEATHERED SURFACE TEXTURE

Figures 1 to 20 present the change of peak count with time of exposure, up to 2 years. Similar plots of AA versus time showed very few consistent trends, confirming the preliminary observation (see Section 4.1) that peaks per inch was a more sensitive and meaningful parameter than Arithmetic Average roughness.

The plots of peaks per inch versus time indicate the same general behavior for most plastics: a) an induction period of very little measurable change in texture, then b) very rapid increase in roughness, followed by c) gradual smoothing of the surface. This is shown strikingly in FIGURE 21, which was constructed by plotting the grand-averages of TABLES 2, 3 and 4.

TABLE 5 presents data for further analyzing the effects of exposure site and time. An analysis-of-variance [7,8] of this table showed that variation <u>between sites</u> is statistically significant (90% confidence) and variation <u>within sites</u>, including time, plastic, etc. is even more statistically significant (99% confidence). Examining the average peak count at each site:

Arizona = 20.5 peaks per inch
Florida = 19.1 peaks per inch
Washington, D.C. = 16.7 peaks per inch

we see that, on the average for all the plastics, Arizona exposure caused the most roughening and Washington exposure caused the least. This is the same order of severity that was noted in our earlier reports for discoloration and loss of tensile elongation.

Further examination of TABLE 5 and FIGURE 21 shows clearly that maximum roughening was observed in 6-12 months (keeping in mind that these exposures began in April). Further progress of roughening - smoothing is open to speculation, however it seems reasonable to postulate a gradual cyclic increase in roughness.

5. CONCLUSIONS & RECOMMENDATIONS

Novel techniques are available to measure physical surface changes precisely and quickly. Roughness meters produce useful parameters for quantitatively characterizing early changes in surface texture of weathered plastics. The number of "peaks" per inch of surface was found to be a more sensitive parameter for plastics than the classic Arithmetic Average (AA).

Initial roughness of 20 plastics varied from 0-6 micro-inches AA, with assigned peak-heights ranging from 30-200 micro-inches. Plots of peaks per inch versus exposure time indicate the same general behavior for most plastics: a) an induction period of very little measurable change in texture, then b) very rapid increase in roughness followed by c) gradual smoothing of the surface. Maximum roughness was observed at about 6-12 months, with exposures beginning in April. Future weathering would probably result in a gradual cyclic increase in roughness.

As with discoloration and loss of tensile elongation, Arizona was generally found to be the most severe exposure, followed by Florida and Washington, D.C.

Scanning electron micrographs of selected samples confirmed the peak count of roughness. The micrographs appeared to indicate weak points for attack on the surface of some original materials.

It is recommended that roughness meters be used to study quantitatively the surface changes in weathered plastics. Scanning electron micrography should be employed to elucidate physical mechanisms of attack.

6. ACKNOWLEDGEMENTS

We appreciate the advice and assistance with the instrumentation of Phil White of Brush Instruments and James Moriarty of L.A. Benson Company.

James A. Slater and John L. Herndon, MCA Research Associates, are thanked for their help in data reduction.

7. REFERENCES

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[7] "Statistics in Research", B. Ostle, State College Press, Ames, Iowa, 1956.

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LIST OF TABLES

TABLE 1

INITIAL SURFACE ROUGHNESS

Plastic	Arithmetic Average	Peaks/Inch	@ Peak Height
PE-1	1.0 micro-inch	0	@ 150 u in.
-60	1.5	0	@ 150
PMMA-60	0.0	2	@ 30
PVF-1	0.75	4	@ 80
PETP-5	0.0	0	@ 30
RP-60	2.4	0	@ 150
PVC-B4	4.75	4	@ 200
10	3.25	4	@ 200
60	0.0	0	@ 30
PVC-C4	6.0	18	@ 200
10	2.5	10	@ 150
60	0.0	0	@ 200
PVC-N60	0.5	2	@ 30
PVC-A4	1.25	0	@ 100
10	4.0	2	@ 200
60	0.0	0	@ 30
PVC-D4	2.5	8	@ 200
10	1.5	6	@ 150
60	0.0	0	@ 30
PVC-M60	0.50	2	@ 80

TABLE 2

PEAKS PER INCH VS EXPOSURE TIME (Phoenix, Arizona)

Plastic	Time in Months 0	3	6	9	12	16	20	24
1	0	0	32	-	-	-	-	-
2	0	4	24	8	32	46	22	0
3	2	0	10	4	20	12	0	2
4	4	0	30	22	24	0	-	14
5	0	2	8	22	16	16	22	16
6	0	0	24	30	16	38	32	58
7	4	2	64	64	64	6	18	0
8	4	2	6	18	24	10	10	12
9	0	0	4	2	18	6	12	22
10	18	0	14	54	46	-	-	22
11	10	4	38	38	60	34	30	12
12	0	-	-	-	6	-	-	-
13	2	0	2	18	10	2	6	12
14	0	0	10	16	24	16	16	11
15	2	6	26	44	52	44	18	16
16	0	-	-	-	4	-	4	-
17	8	10	52	48	50	10	20	-
18	6	22	76	72	66	66	28	20
19	0	0	22	18	10	22	10	6
20	2	2	50	76	24	126	60	56
Grand Average	3	3	27	38	30	27	19	17

TABLE 3

PEAKS PER INCH VS EXPOSURE TIME (Miami, Florida)

Plastic	Time in Months							
	0	3	6	9	12	16	20	24
1	0	0	32	2	22	-	-	-
2	0	2	12	8	18	34	12	10
3	2	0	6	18	8	6	16	12
4	4	2	14	26	32	12	-	10
5	0	2	14	24	22	30	16	16
6	0	0	26	16	16	48	50	132
7	4	2	58	60	28	6	26	12
8	4	0	18	8	22	12	14	18
9	0	2	18	10	8	10	8	50
10	18	0	16	46	50	-	-	-
11	10	6	54	28	38	54	36	8
12	0	-	-	-	6	-	-	-
13	2	2	6	6	12	8	4	8
14	0	0	16	26	20	4	-	14
15	2	0	18	52	62	44	28	14
16	-	-	-	-	-	-	-	-
17	8	16	66	50	52	12	-	38
18	6	26	80	72	74	56	30	34
19	0	0	10	10	6	12	14	12
20	2	2	40	52	28	0	40	16
Grand Average	3	4	28	29	27	22	22	18

TABLE 4

PEAKS PER INCH VS EXPOSURE TIME (Wash., D.C.)

Plastic	Time in Months							
	0	3	6	9	12	16	20	24
1	0	0	36	2	22	-	10	-
2	0	0	24	18	30	36	14	6
3	2	0	4	2	6	0	2	0
4	4	6	18	16	34	2	10	2
5	0	2	20	20	10	14	6	6
6	0	2	18	20	10	24	32	40
7	4	2	60	88	78	6	46	12
8	-	-	-	-	-	-	-	-
9	0	0	10	12	4	14	2	0
10	18	18	52	50	58	6	34	22
11	-	-	-	-	-	-	-	-
12	0	-	6	2	-	-	-	-
13	2	0	4	12	16	0	8	18
14	0	0	18	26	22	0	22	10
15	-	-	-	-	-	-	-	-
16	0	0	4	8	-	64	-	12
17	8	12	54	56	54	48	28	30
18	-	-	-	-	-	-	-	-
19	0	0	4	14	14	10	4	24
20	2	14	34	42	40	0	54	26
Grand Average	3	4	23	24	28	16	19	15

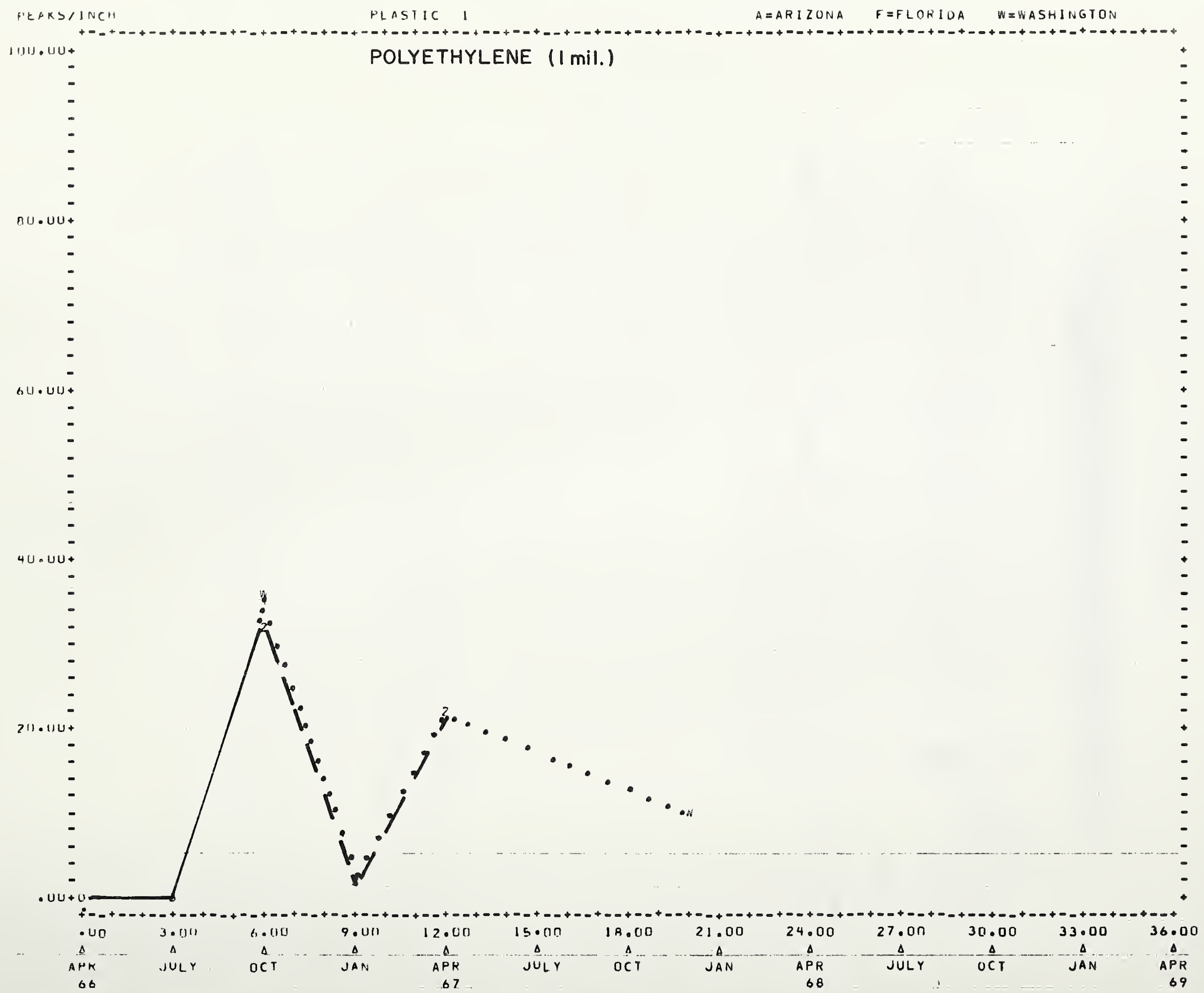
TABLE 5

VARIANCE OF PEAK COUNT WITHIN AND BETWEEN SITES

Site \ Time (Months)	0	3	6	9	12	16	20	24	$\bar{S}$
Arizona	3	3	27	38	30	27	19	17	20.5
Florida	3	4	28	29	27	22	22	18	19.1
Wash., D.C.	3	4	23	24	28	16	19	18	16.7
$\bar{t}$	3.0	3.7	26.0	30.3	28.3	21.7	20.0	16.7	

$\bar{S}$ = Average Peak Count for each site.

$\bar{t}$ = Average Peak Count for each time.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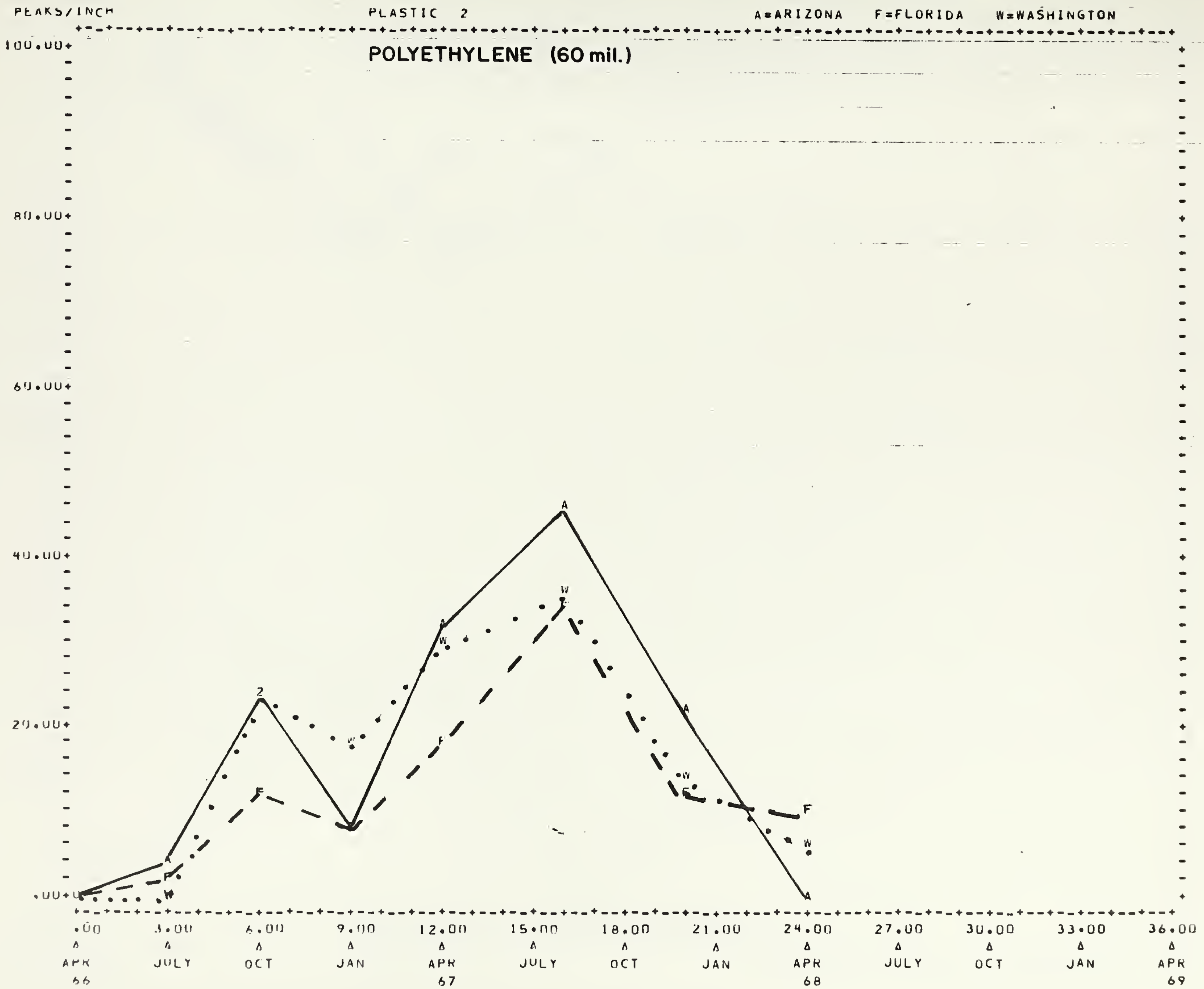
20.00
.00
.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00 27.00 30.00 33.00 36.00
APR 66 JULY OCT JAN APR 67 JULY OCT JAN APR 68 JULY OCT JAN APR 69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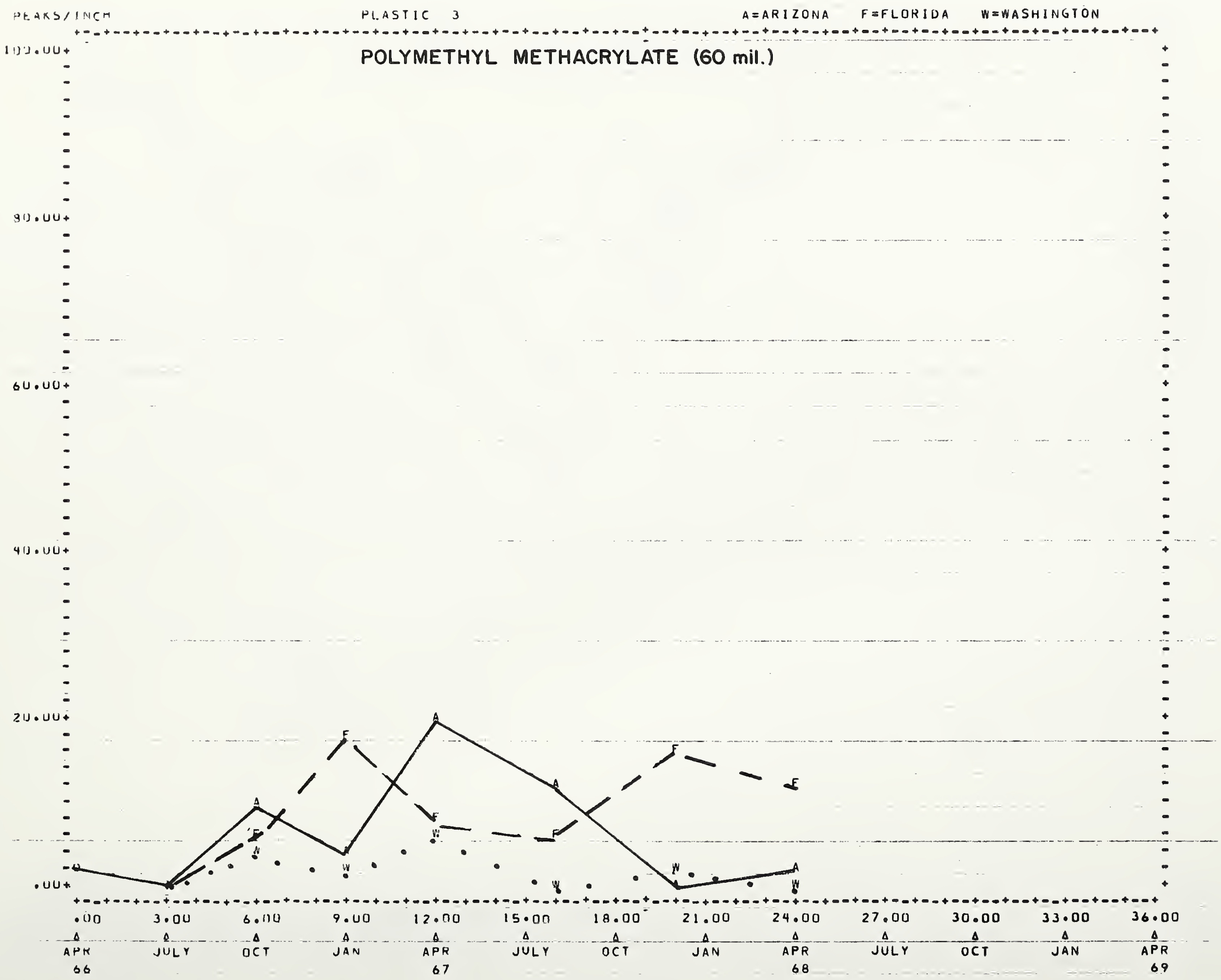
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20.00
.00
.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00 27.00 30.00 33.00 36.00
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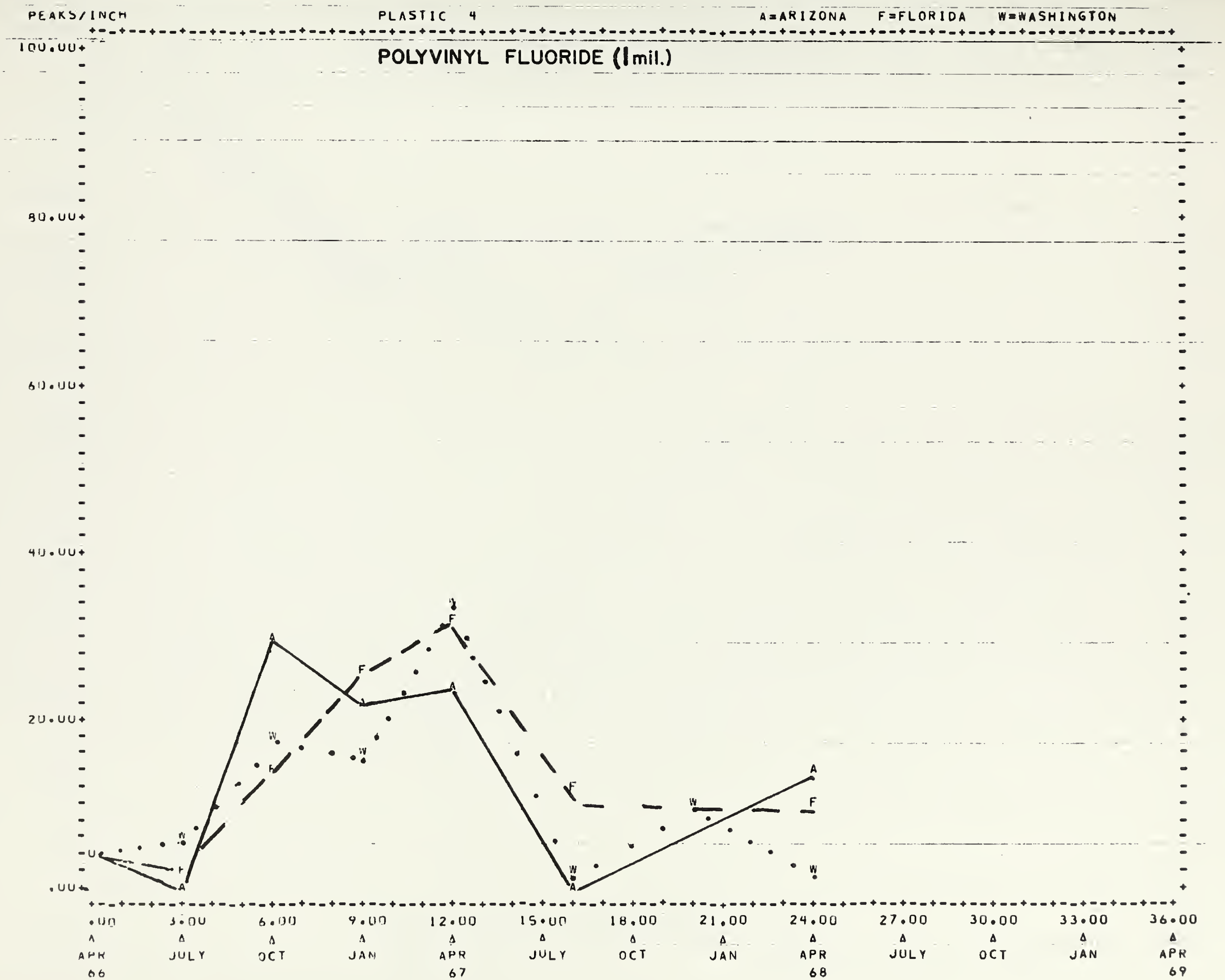
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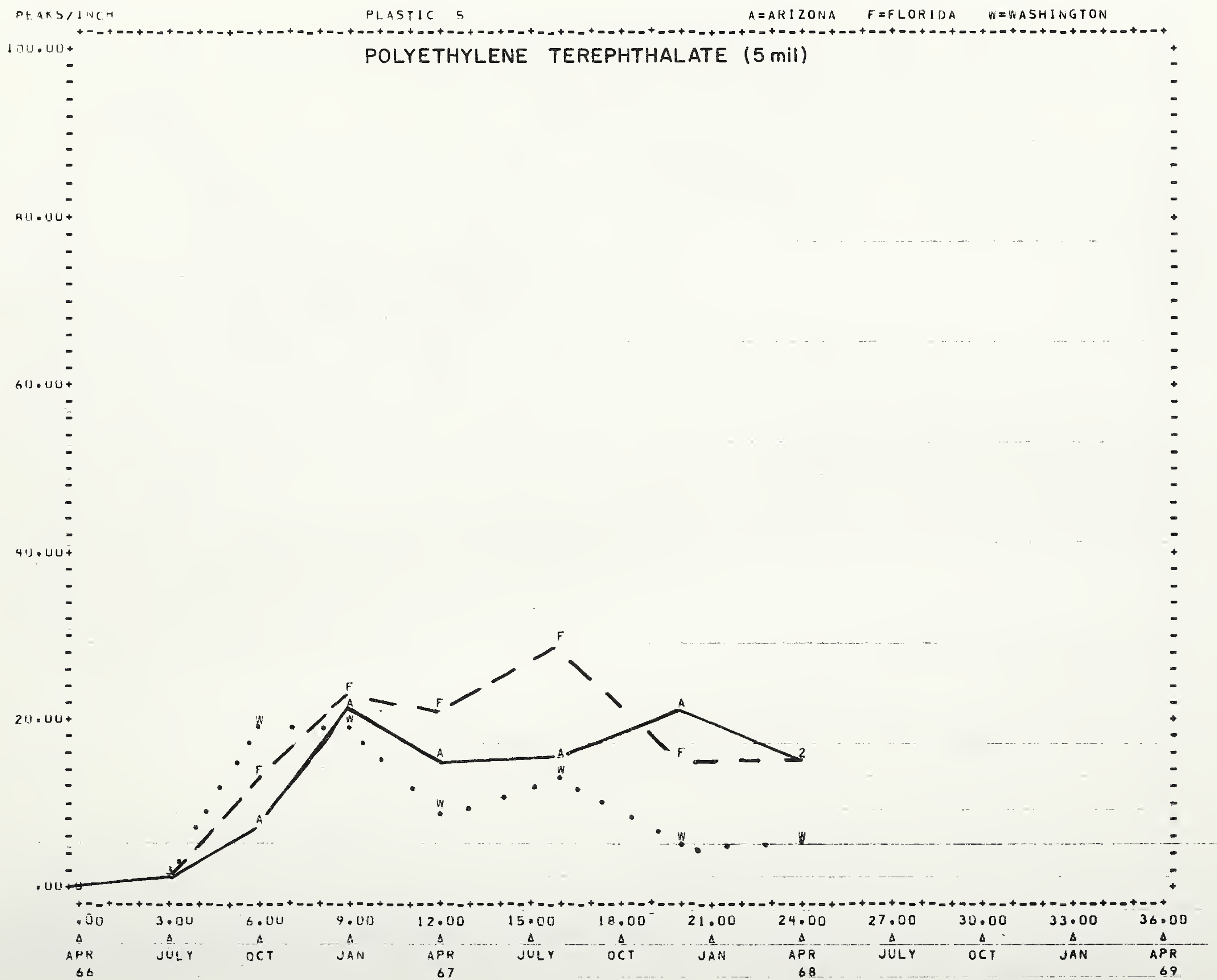
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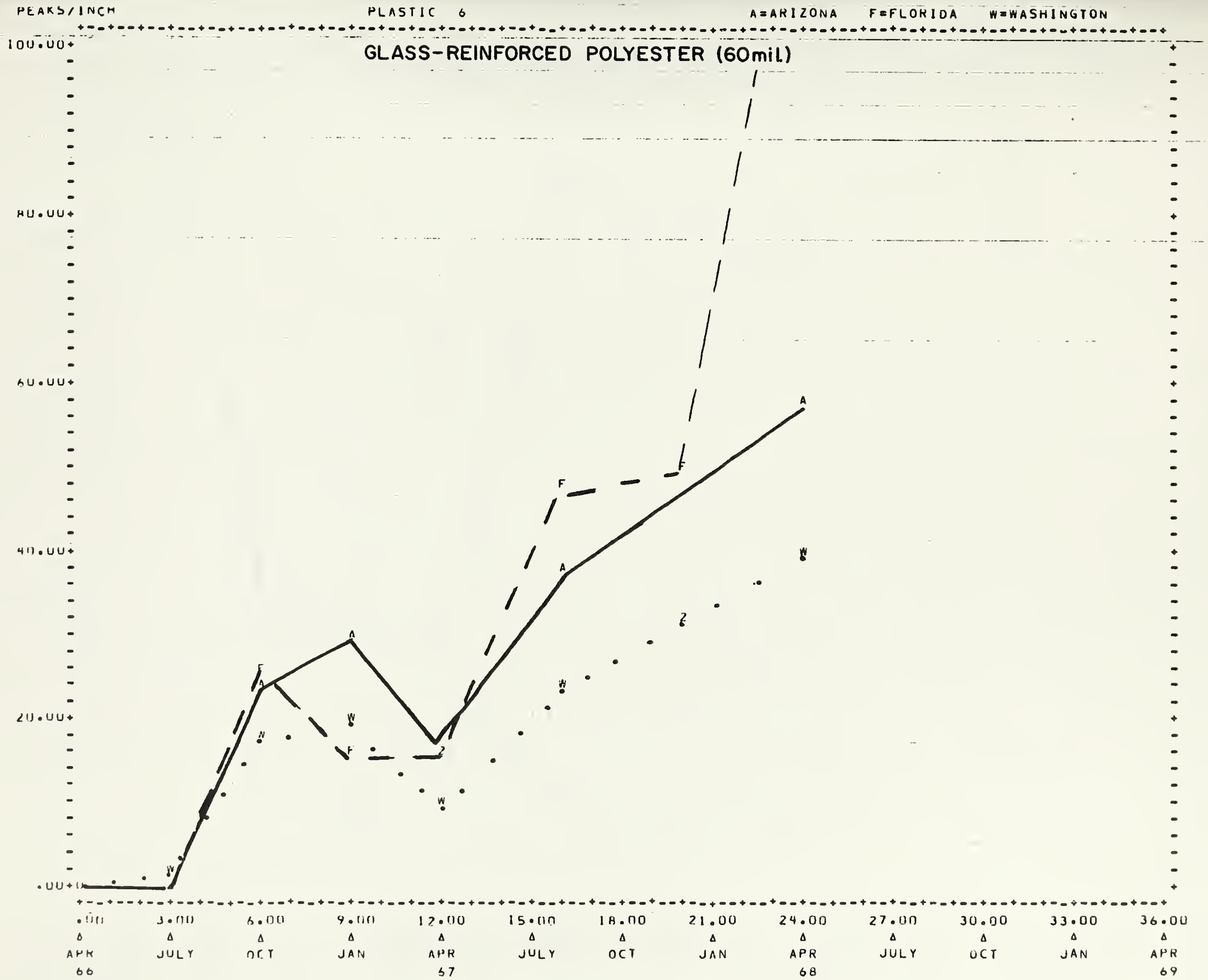

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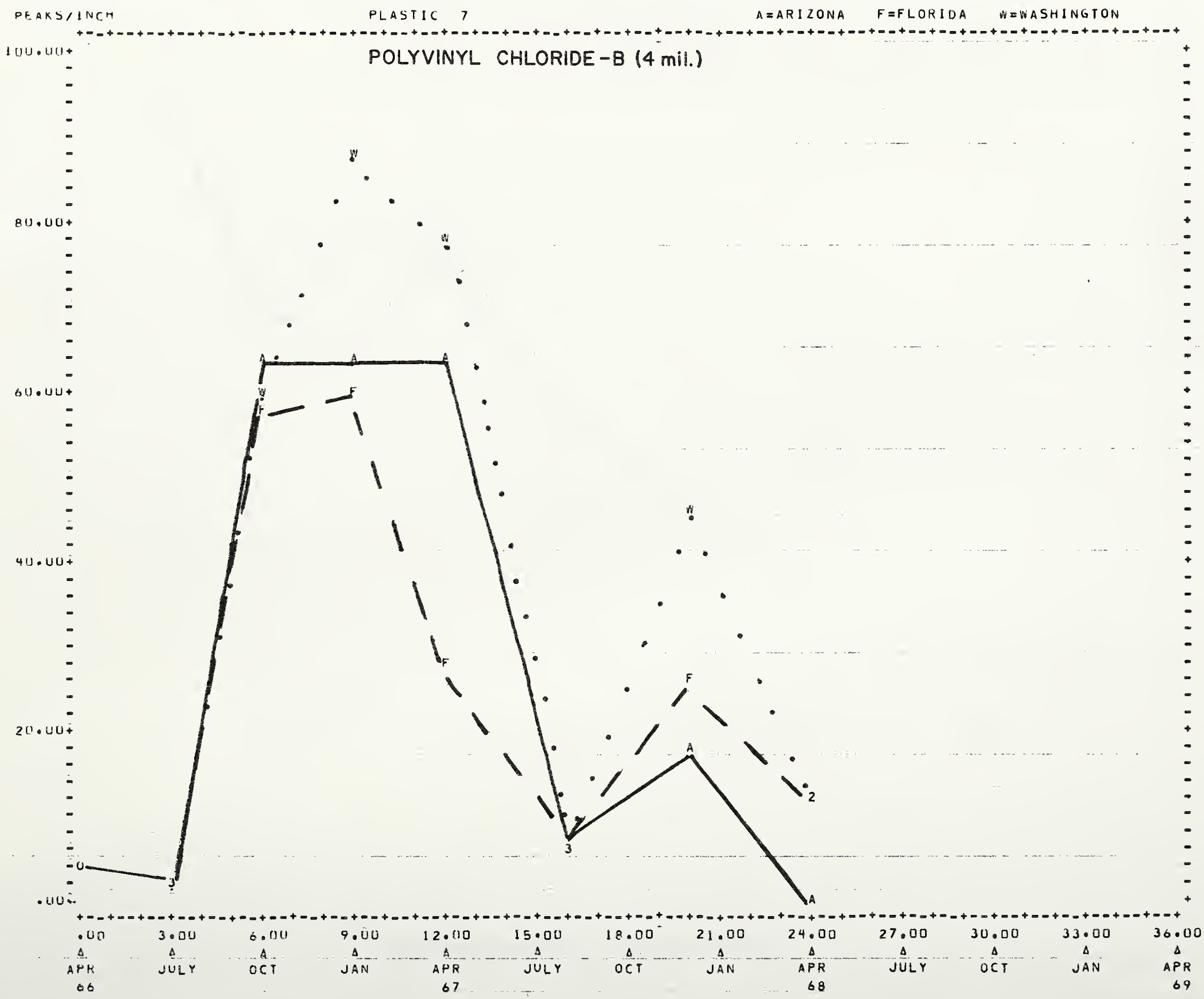
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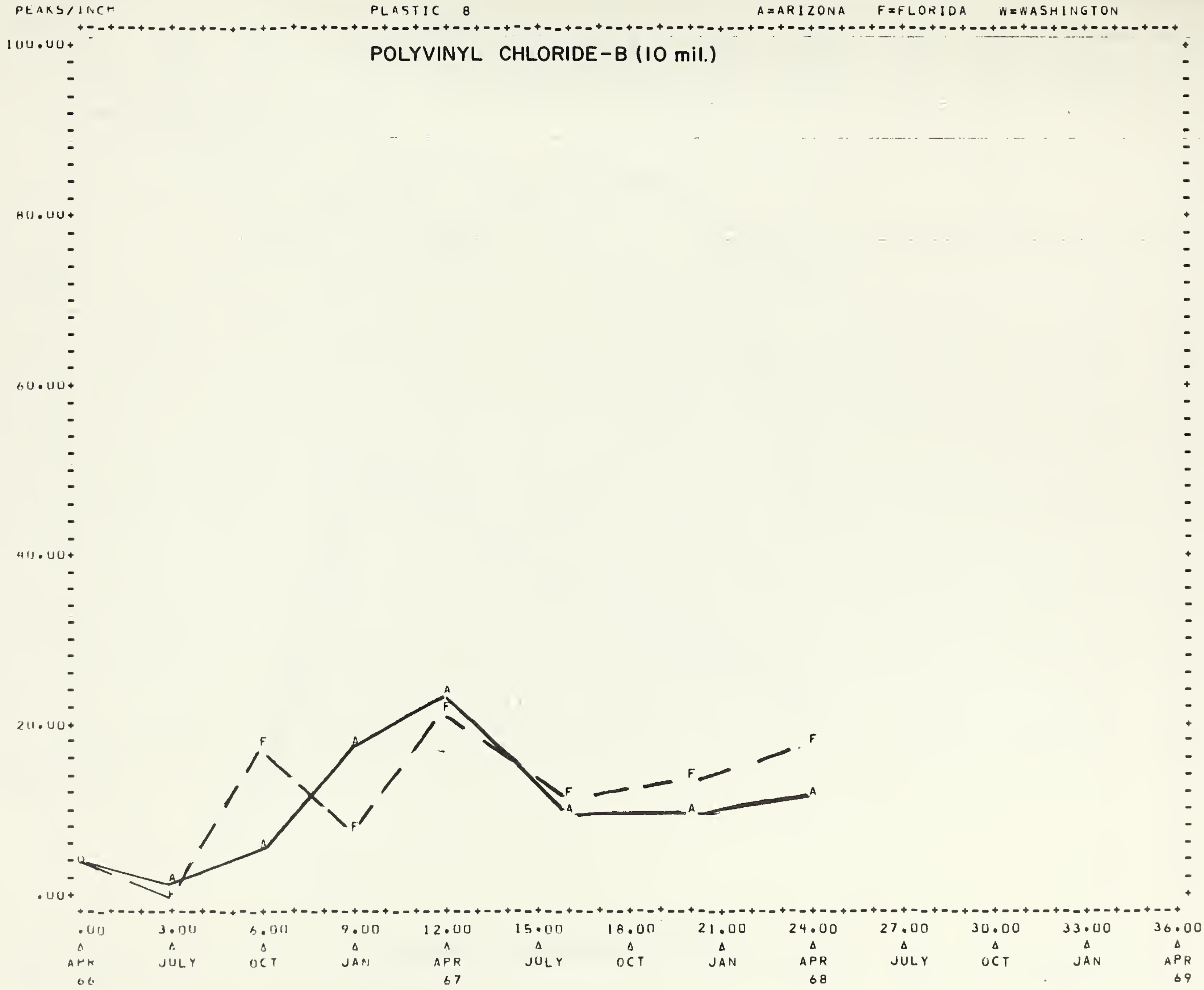
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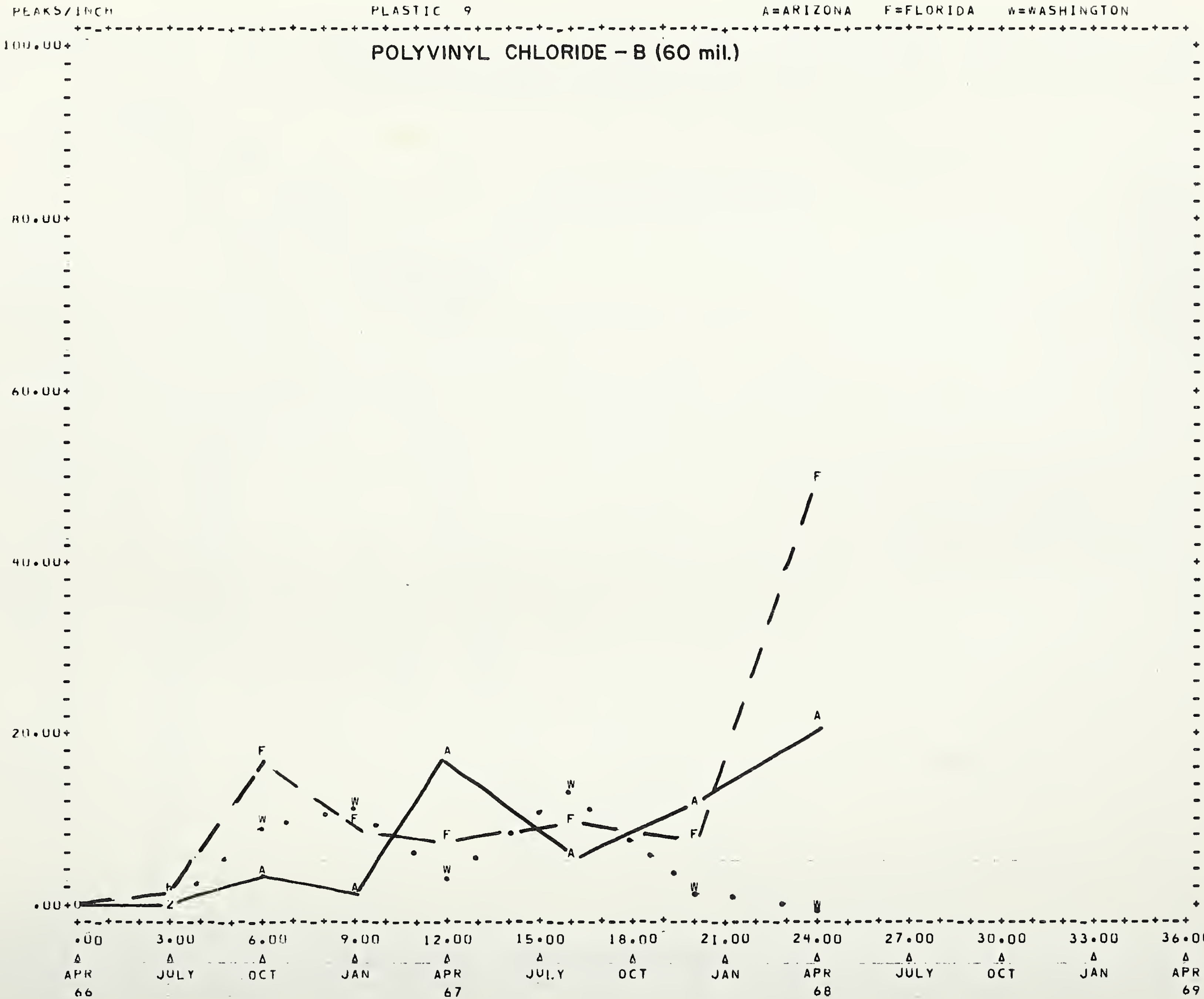
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APR 66
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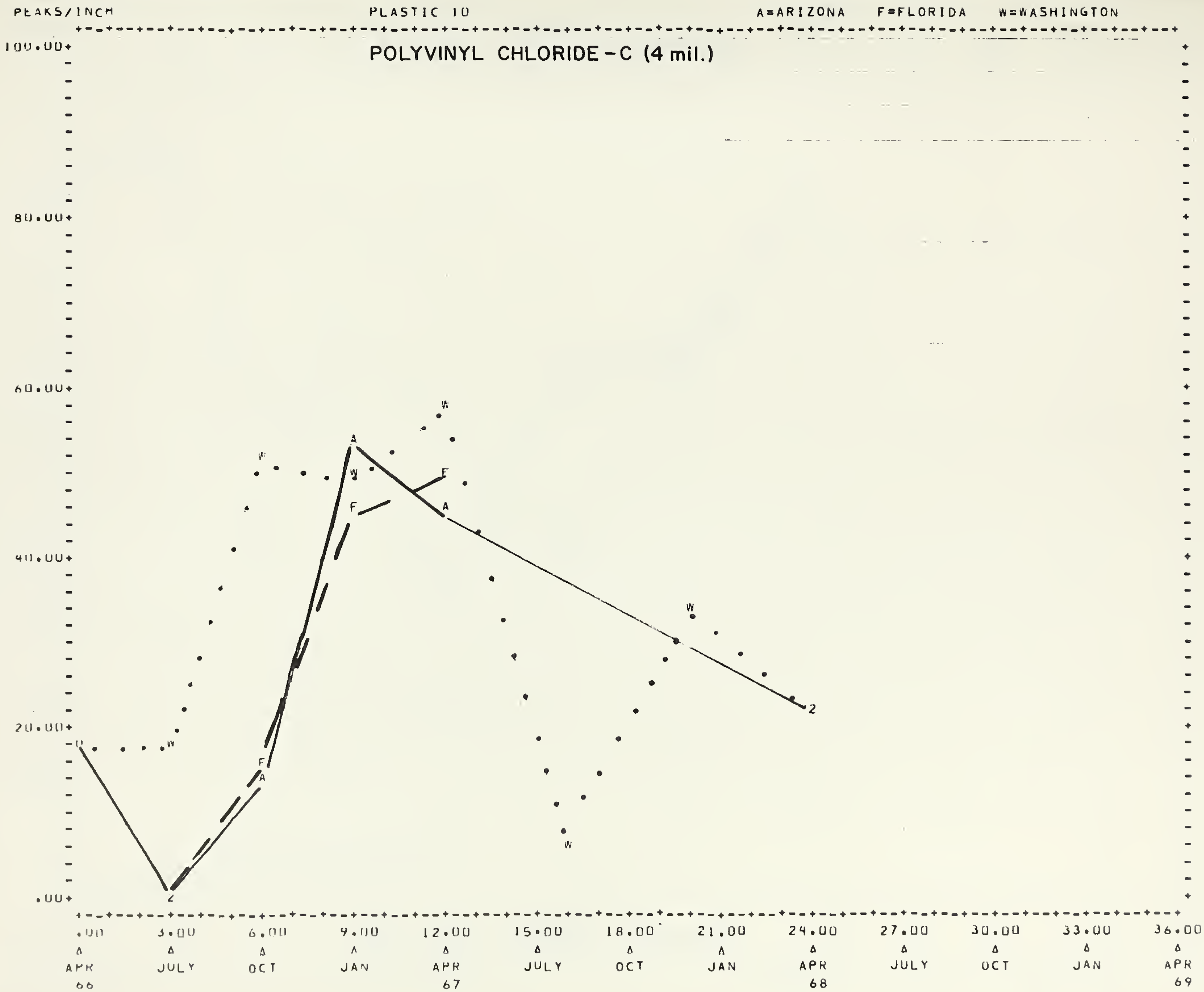
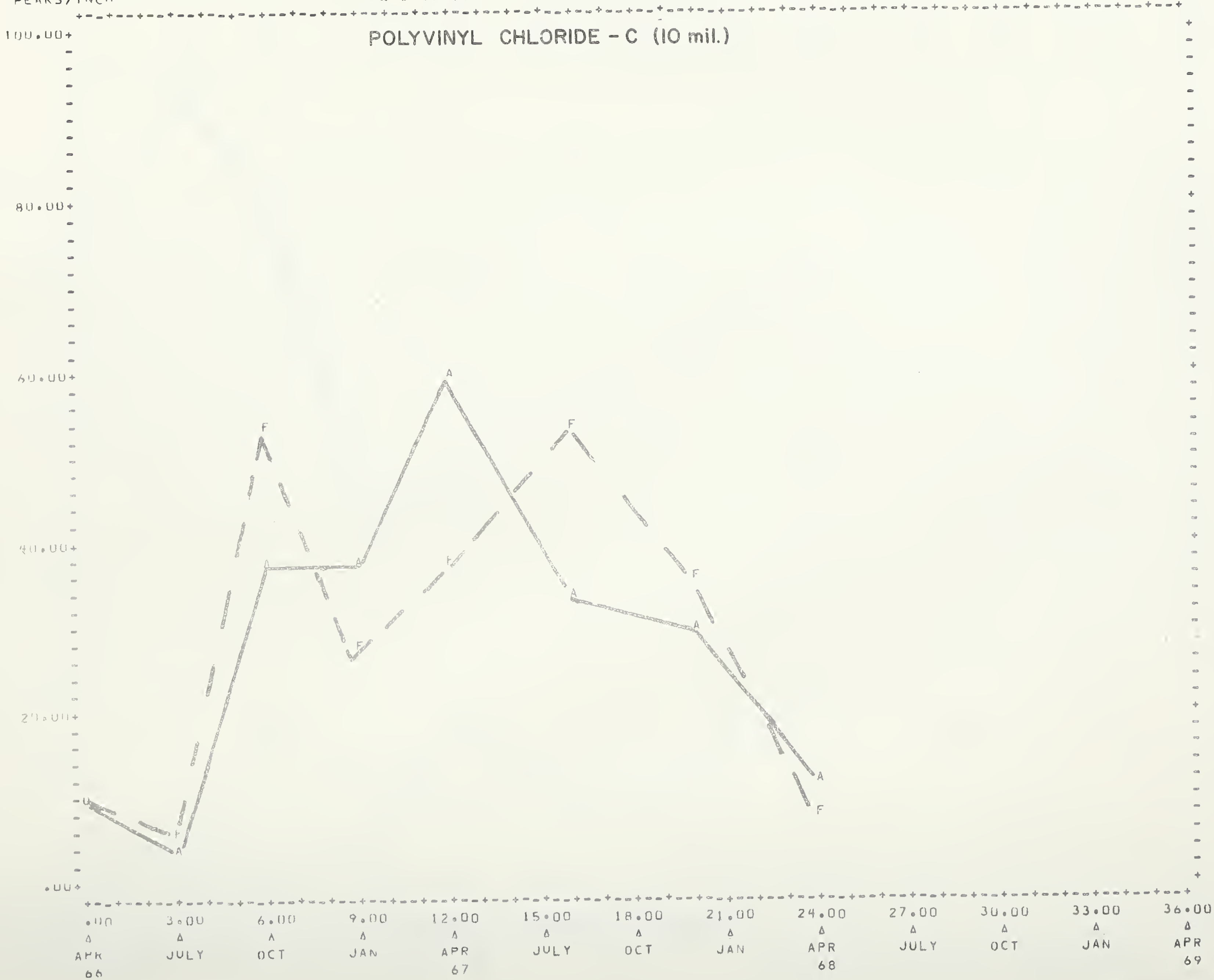
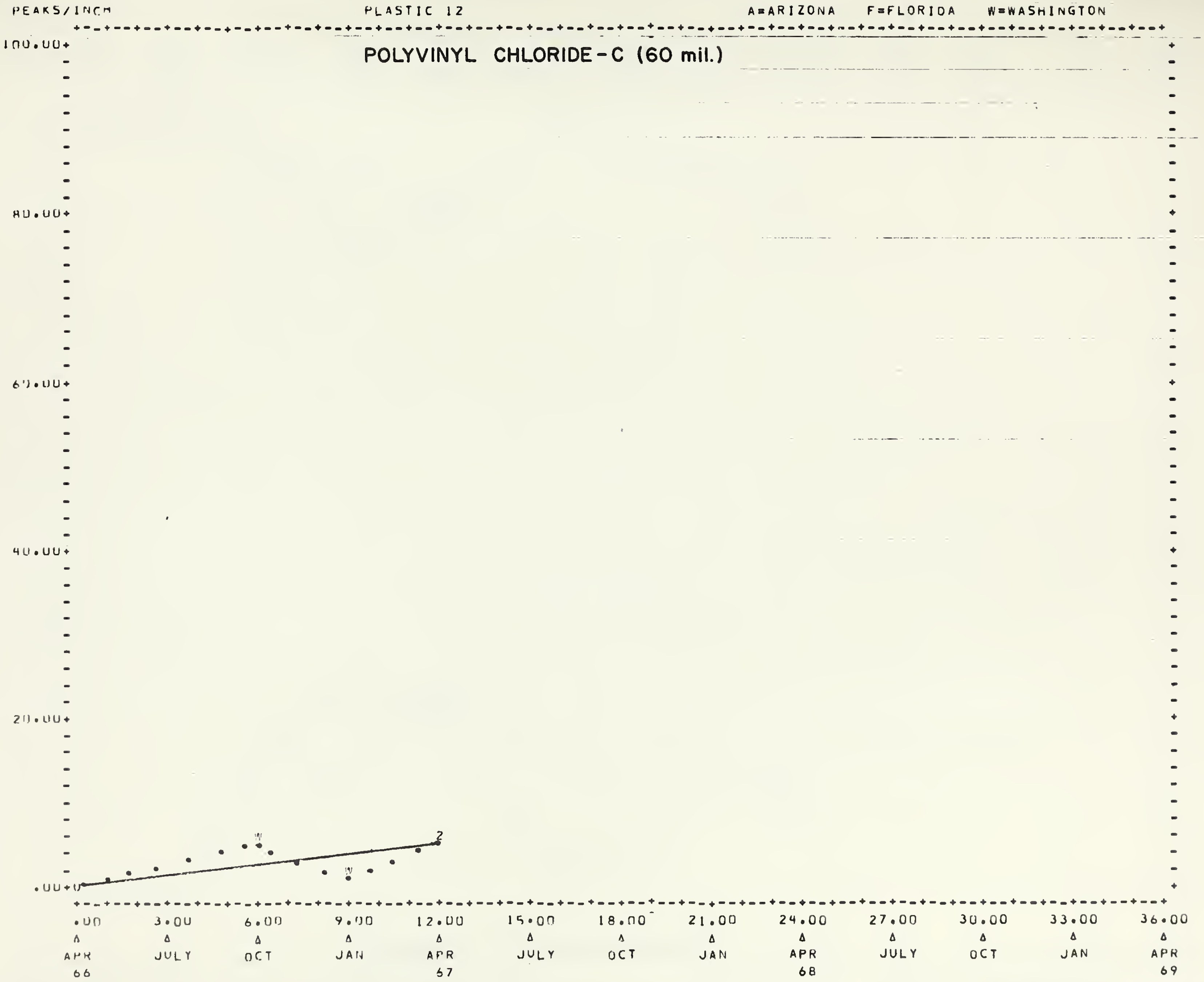
JAN
APR 69

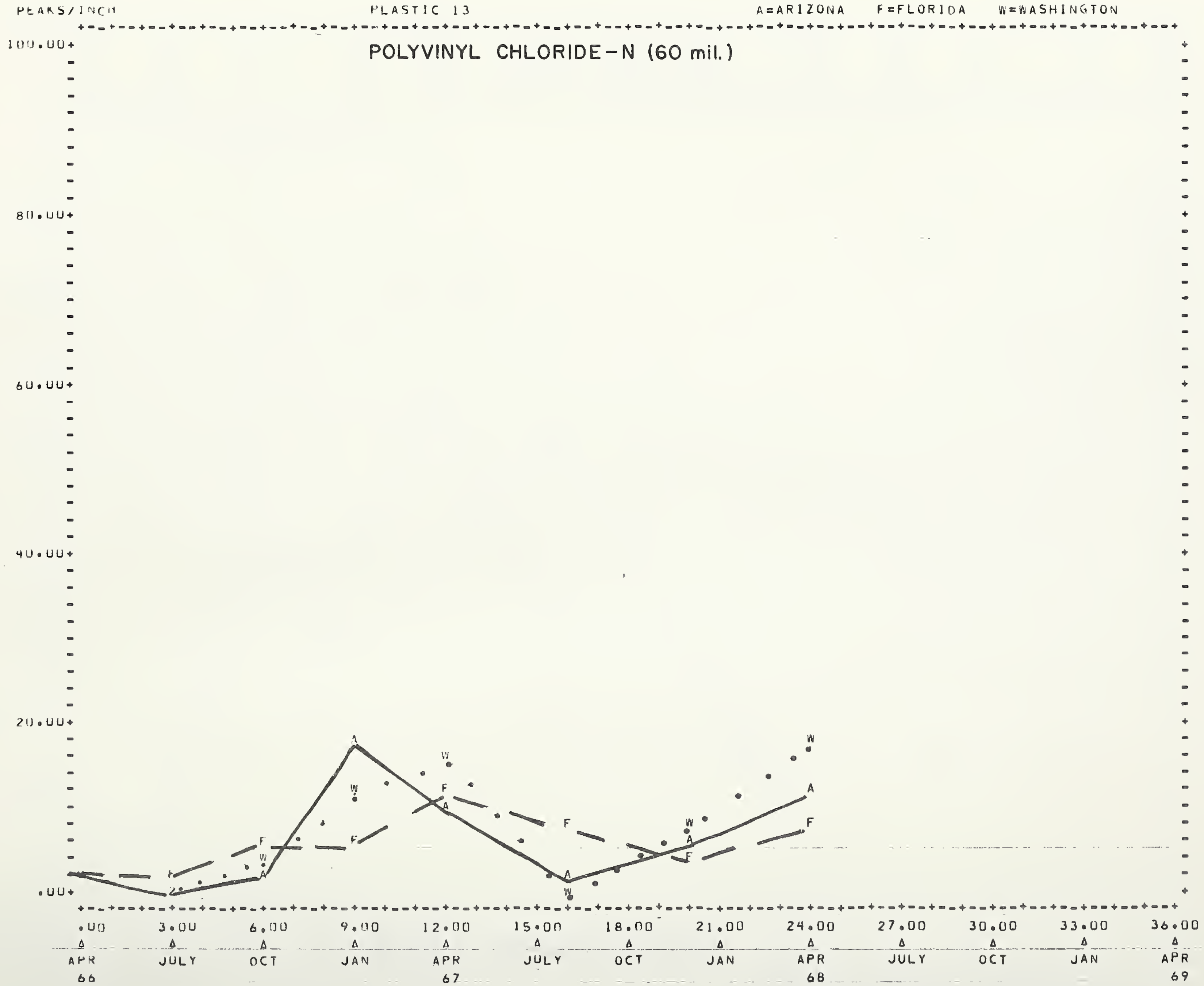

PEAKS/INCH
PLASTIC 10
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE - C (4 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69

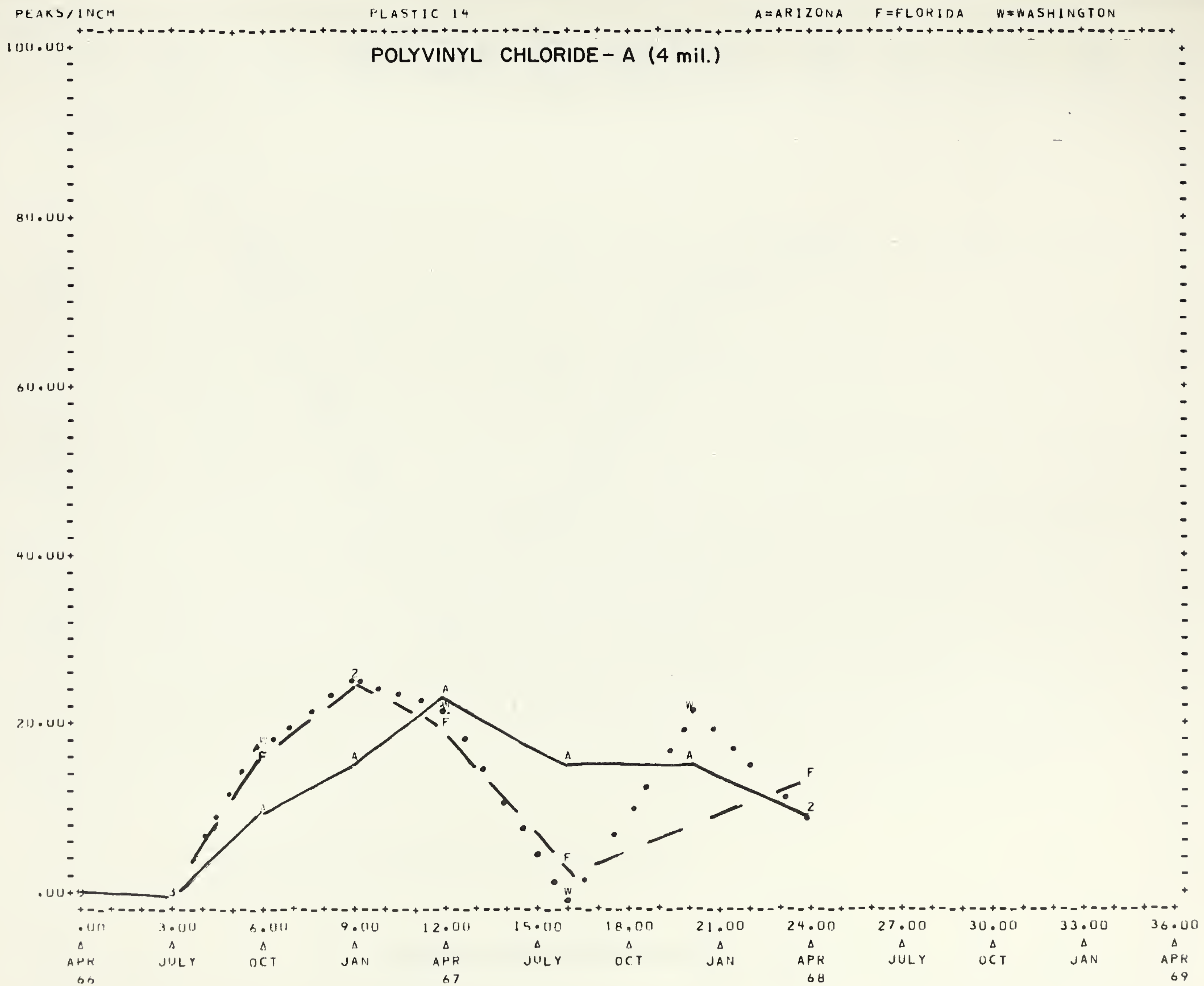
PEAKS/INCH PLASTIC 11 A=ARIZONA F=FLORIDA W=WASHINGTON

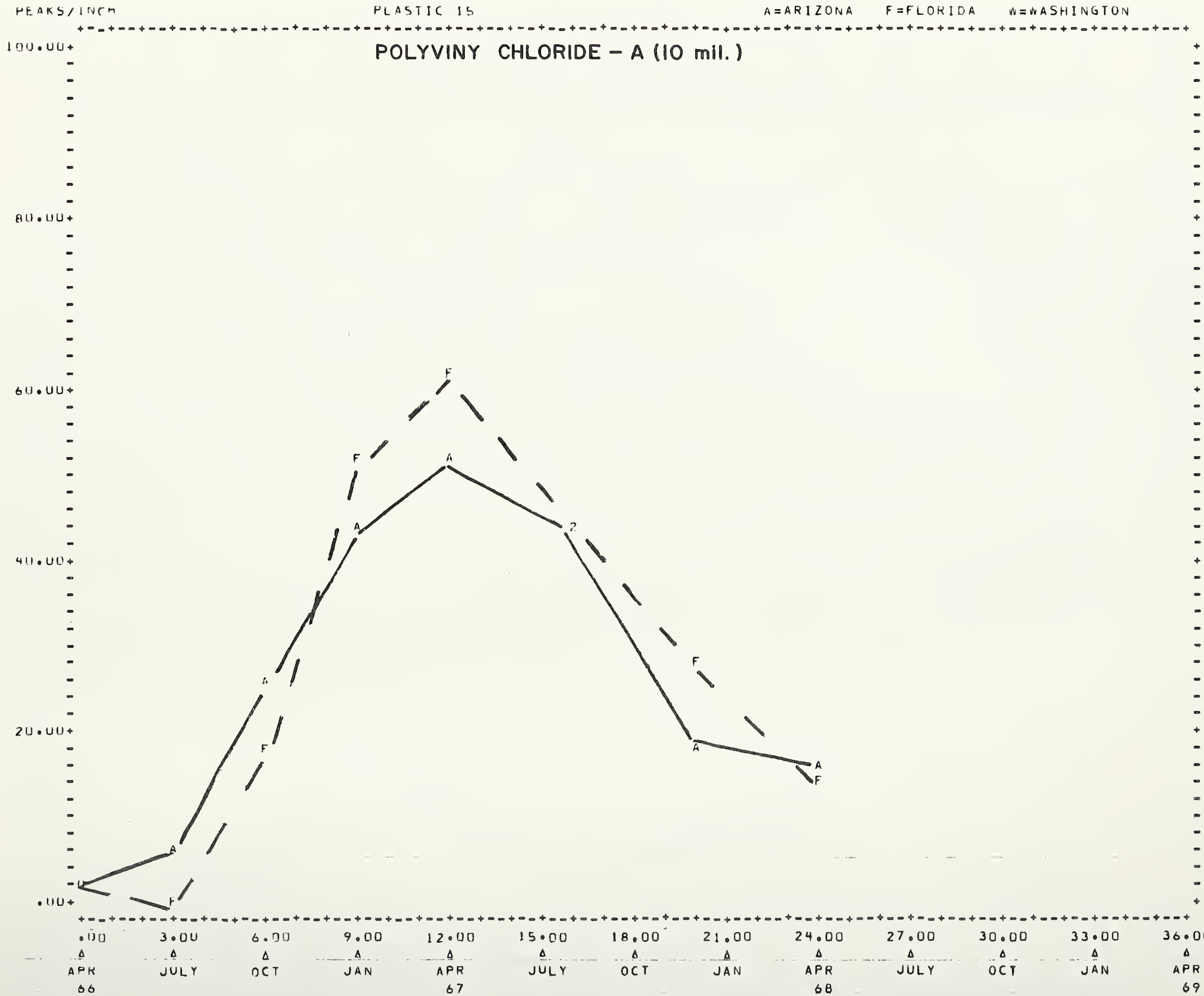


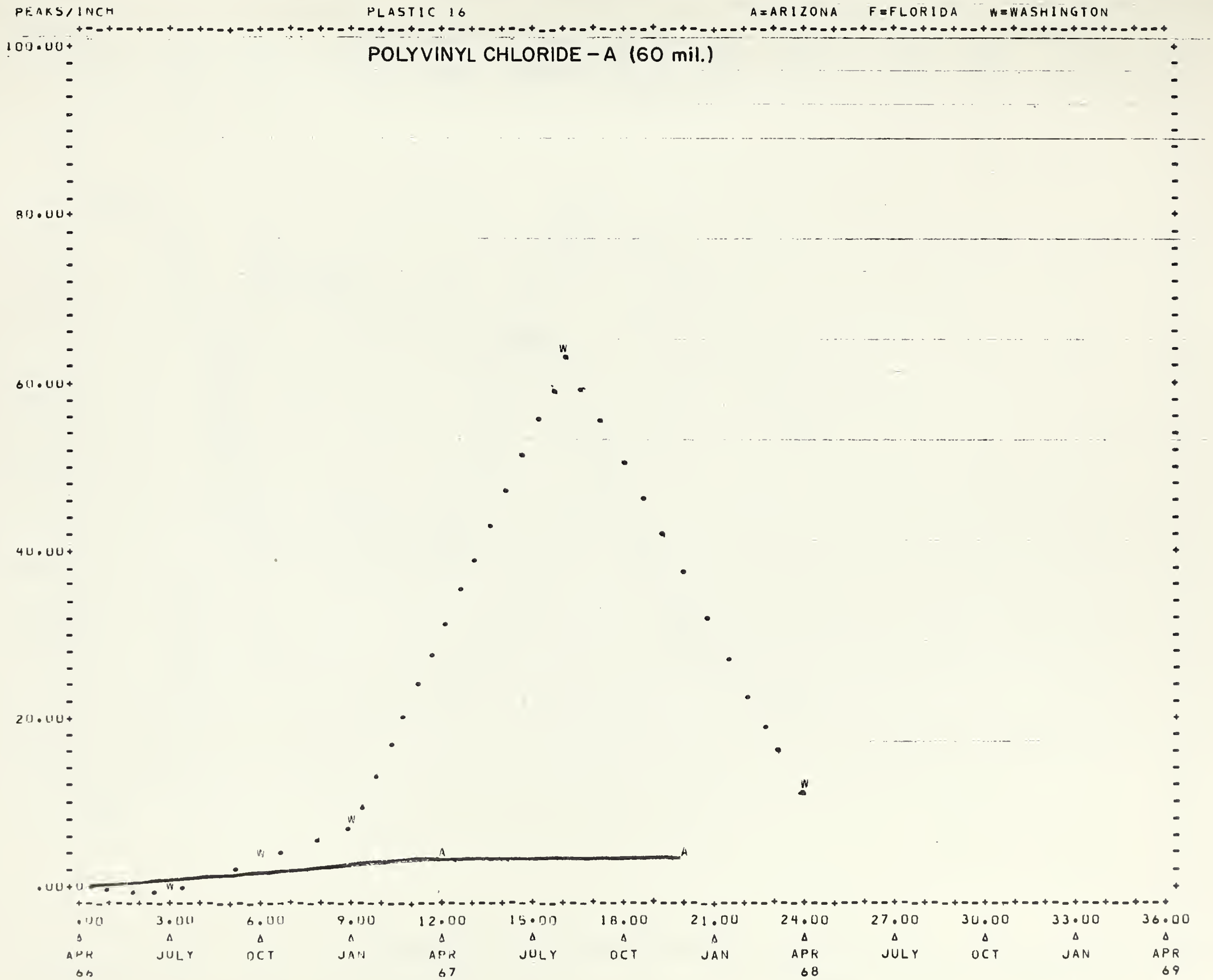

PEAKS/INCH
PLASTIC 12
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE-C (60 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69

POLYVINYL CHLORIDE-N (60 mil.)

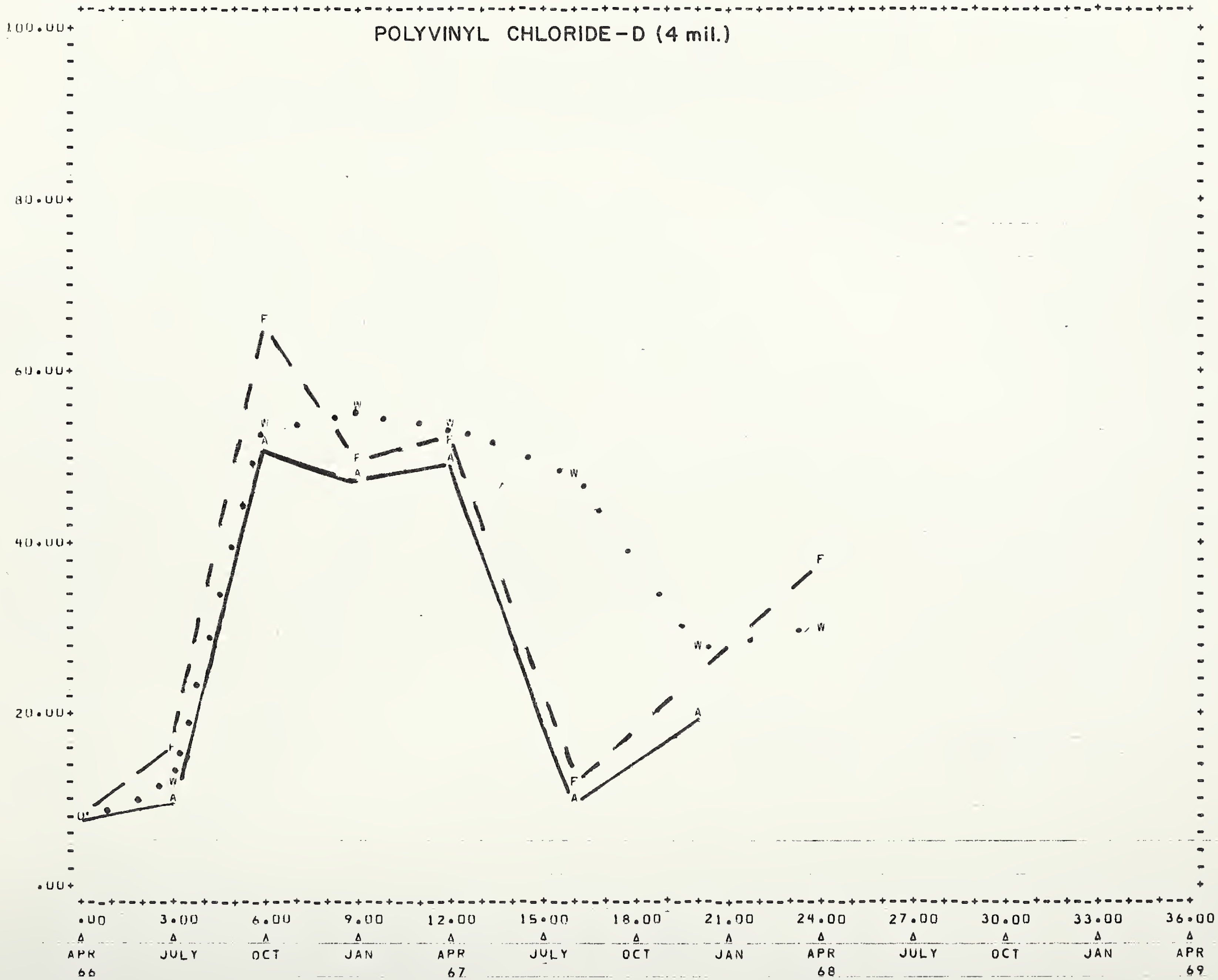


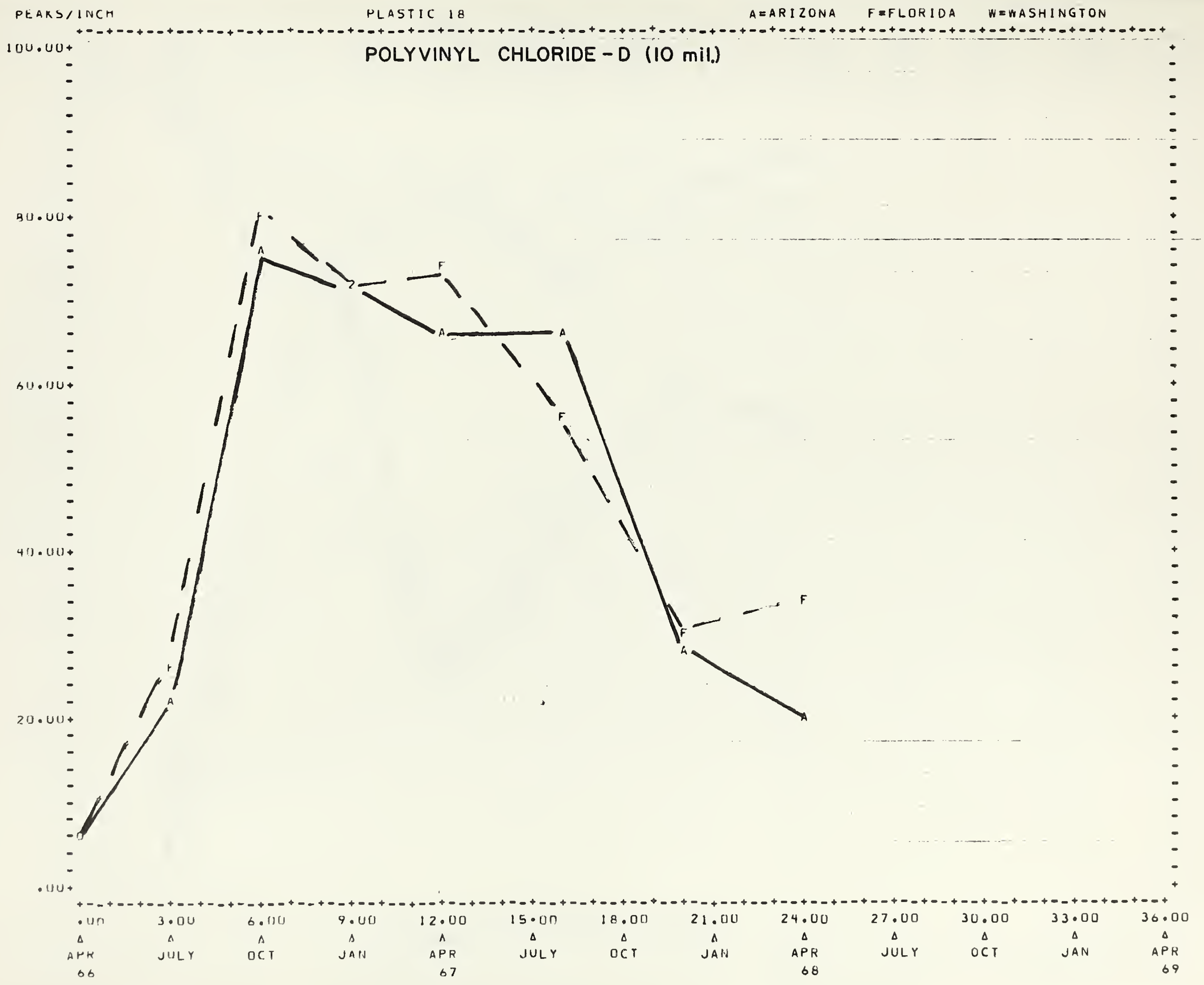

PEAKS/INCH
PLASTIC 14
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE - A (4 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69

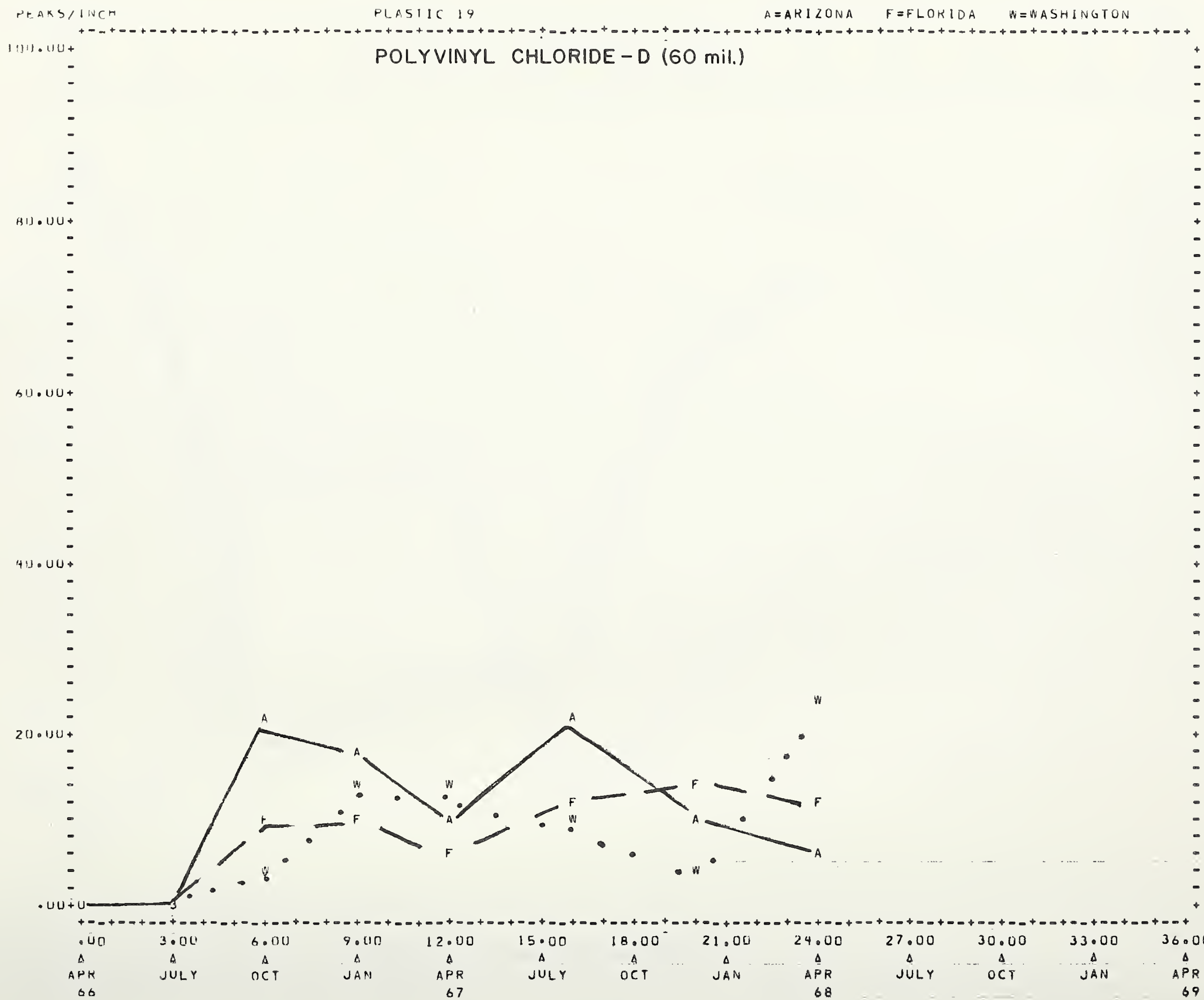

PEAKS/INCH
PLASTIC 15
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINY CHLORIDE - A (10 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69

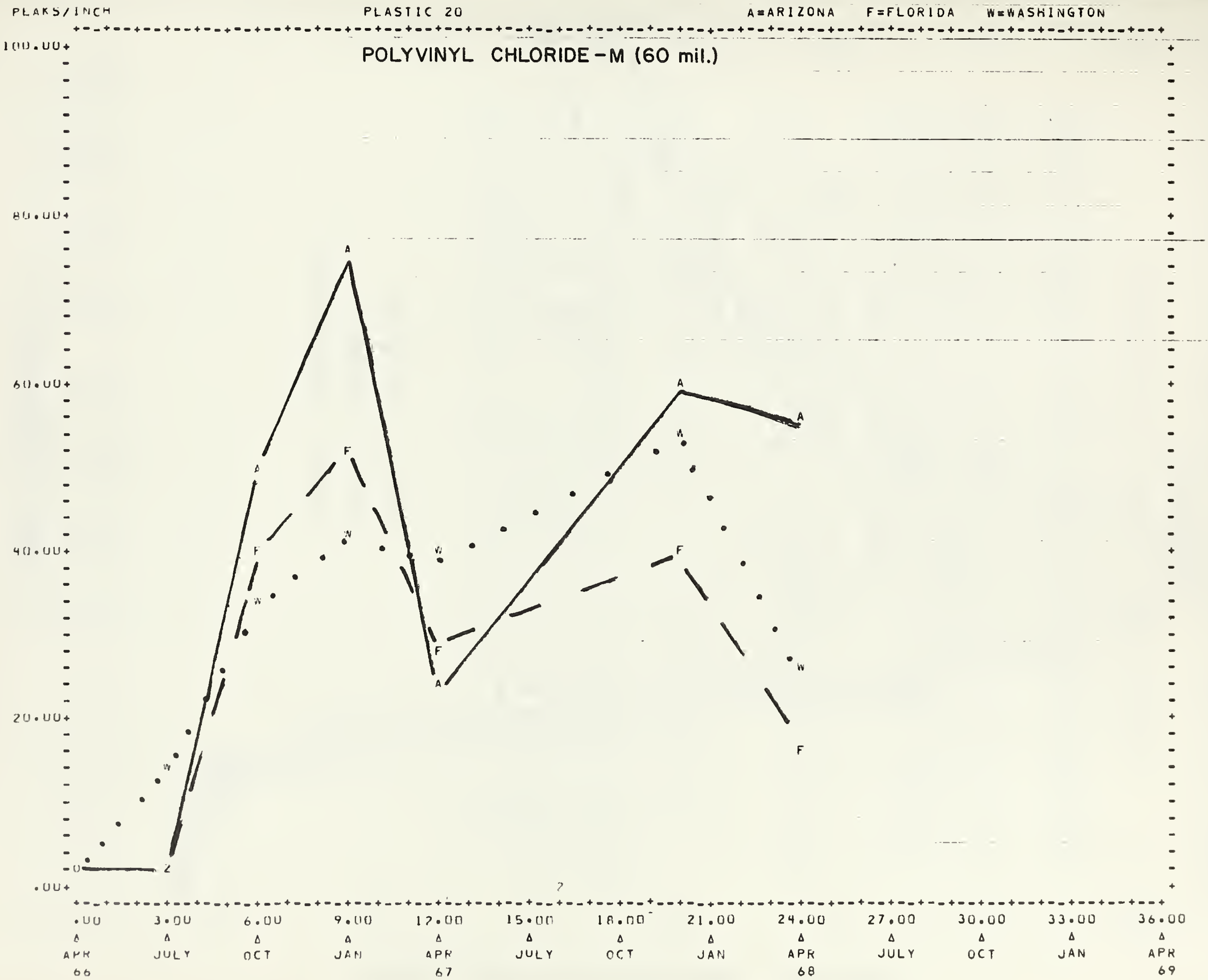

PEAKS/INCH
PLASTIC 16
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE - A (60 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00 27.00 30.00 33.00 36.00
APR JULY OCT JAN APR JULY OCT JAN APR JULY OCT JAN APR
66 67 68 69
W
A

PLASTIC 17


PEAKS/INCH
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE-D (4 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00 27.00 30.00 33.00 36.00
APR 66
JULY
OCT
JAN
APR 67
JULY
OCT
JAN
APR 68
JULY
OCT
JAN
APR 69


PEAKS/INCH
PLASTIC 18
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE - D (10 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69


PEAKS/INCH
PLASTIC 19
A=ARIZONA F=FLORIDA W=WASHINGTON
POLYVINYL CHLORIDE-D (60 mil.)
100.00
80.00
60.00
40.00
20.00
.00
.00 APR 66
3.00 JULY
6.00 OCT
9.00 JAN
12.00 APR 67
15.00 JULY
18.00 OCT
21.00 JAN
24.00 APR 68
27.00 JULY
30.00 OCT
33.00 JAN
36.00 APR 69



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

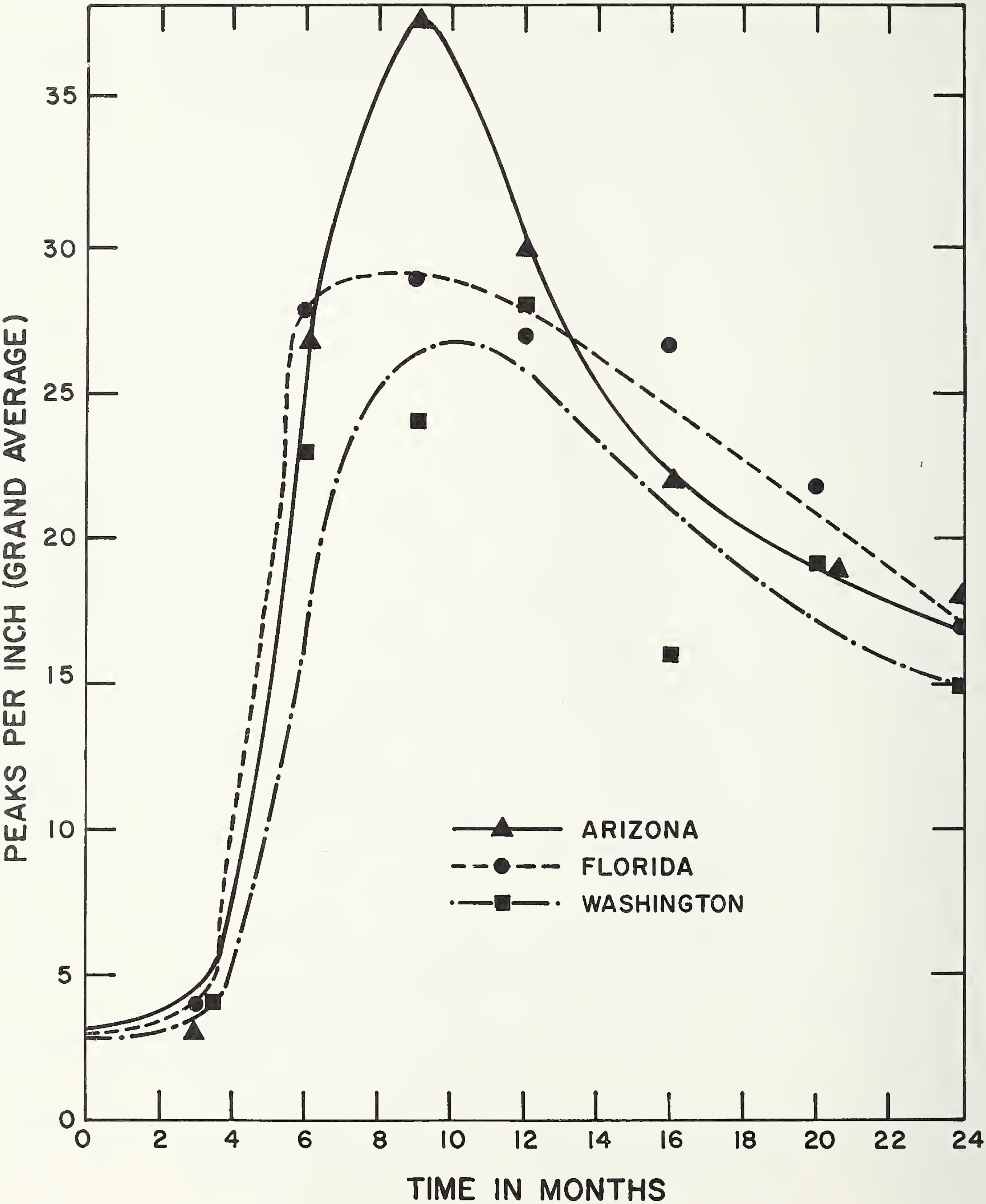


FIG. 21 PEAK COUNT VS EXPOSURE TIME
(GRAND AVERAGE FOR ALL 20 PLASTICS)

APPENDIX A

CONFIRMATION BY SCANNING ELECTRON MICROSCOPY

Scanning electron micrographs on the following pages were obtained through the courtesy of Dr. W. Calkins, E. I. duPont deNemours & Company, Experimental Station, Wilmington, Delaware.

The purpose of this high-magnification exploration of the surfaces was to qualitatively confirm the quantitative measurement of surface texture described herein. On the page facing each set of micrographs, the corresponding measured values of peak count are given. Excellent agreement is seen between the visual record and the number of peaks per inch of surface.

PVC-M, a commercial white vinyl siding, is seen to form pits which apparently enlarge until the entire surface takes on a grainy texture. We may speculate that the small holes seen in the original surface serve as initial points of attack.

POLYETHYLENE does not undergo so drastic a change in surface texture, but high magnification does show moderate generalized roughening followed by smoothing.

GLASS-REINFORCED POLYESTER shows a striking erosion of polyester from the top of the fiber, leaving crevices for "wicking" of moisture under the surface. This is soon followed by uncovering of the top layers of fibers to give "fiber bloom", as well as extensive cracking of the entire surface. It is tempting to postulate initial attack of the original material at the stressed area around the fibers where the polyester has shrunk to a thin coating.

PVC - M

(Phoenix, Arizona)

Original	16 Months	24 Months
2	126	56 peaks/inch

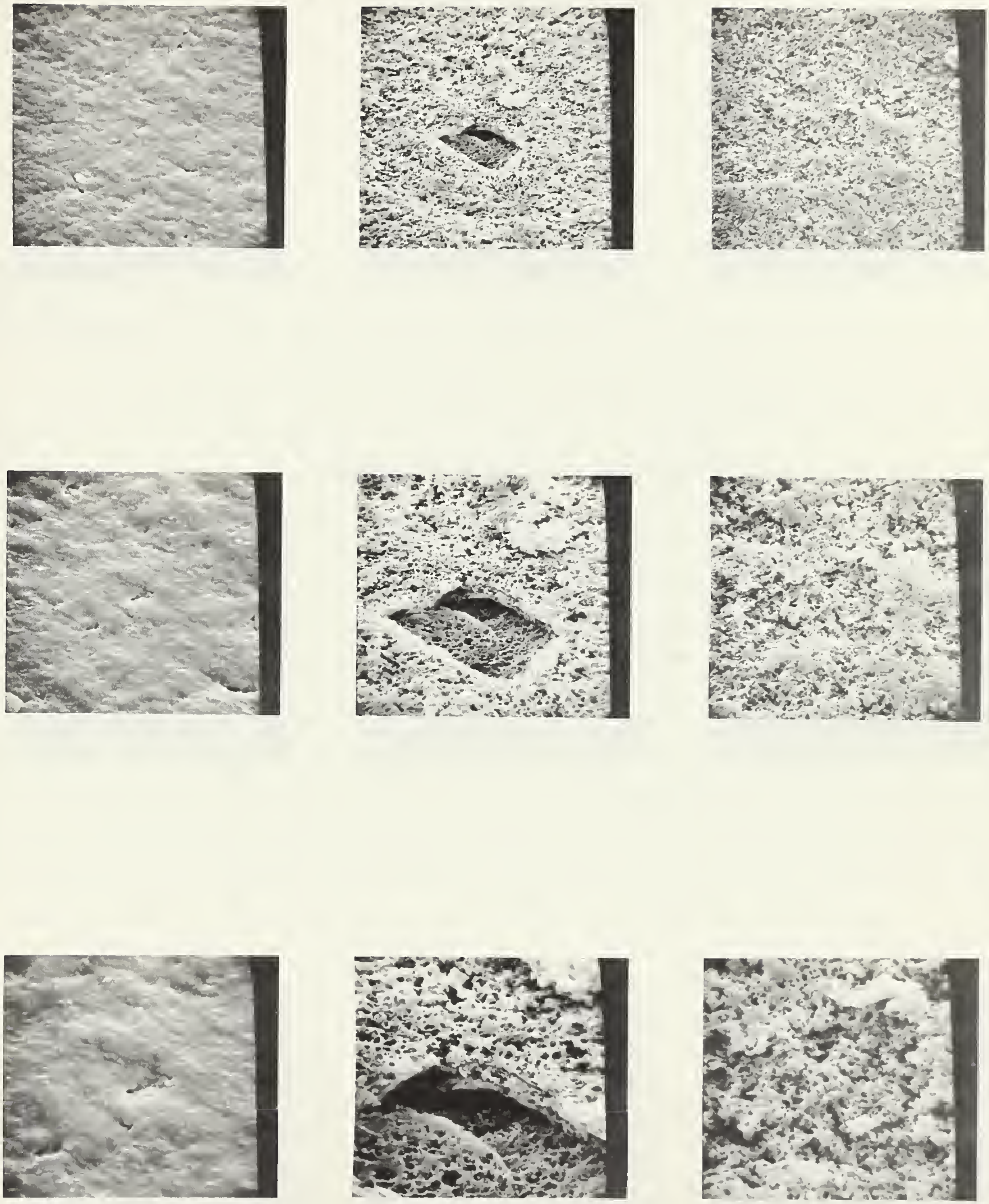
Peak Height = 80 micro-inches

PVC-M

PHOENIX, ARIZONA

ORIGINAL | 16 MONTHS | 24 MONTHS

MAGNIFICATION: 580X, 1200X, 2400X



POLYETHYLENE (60 mil)

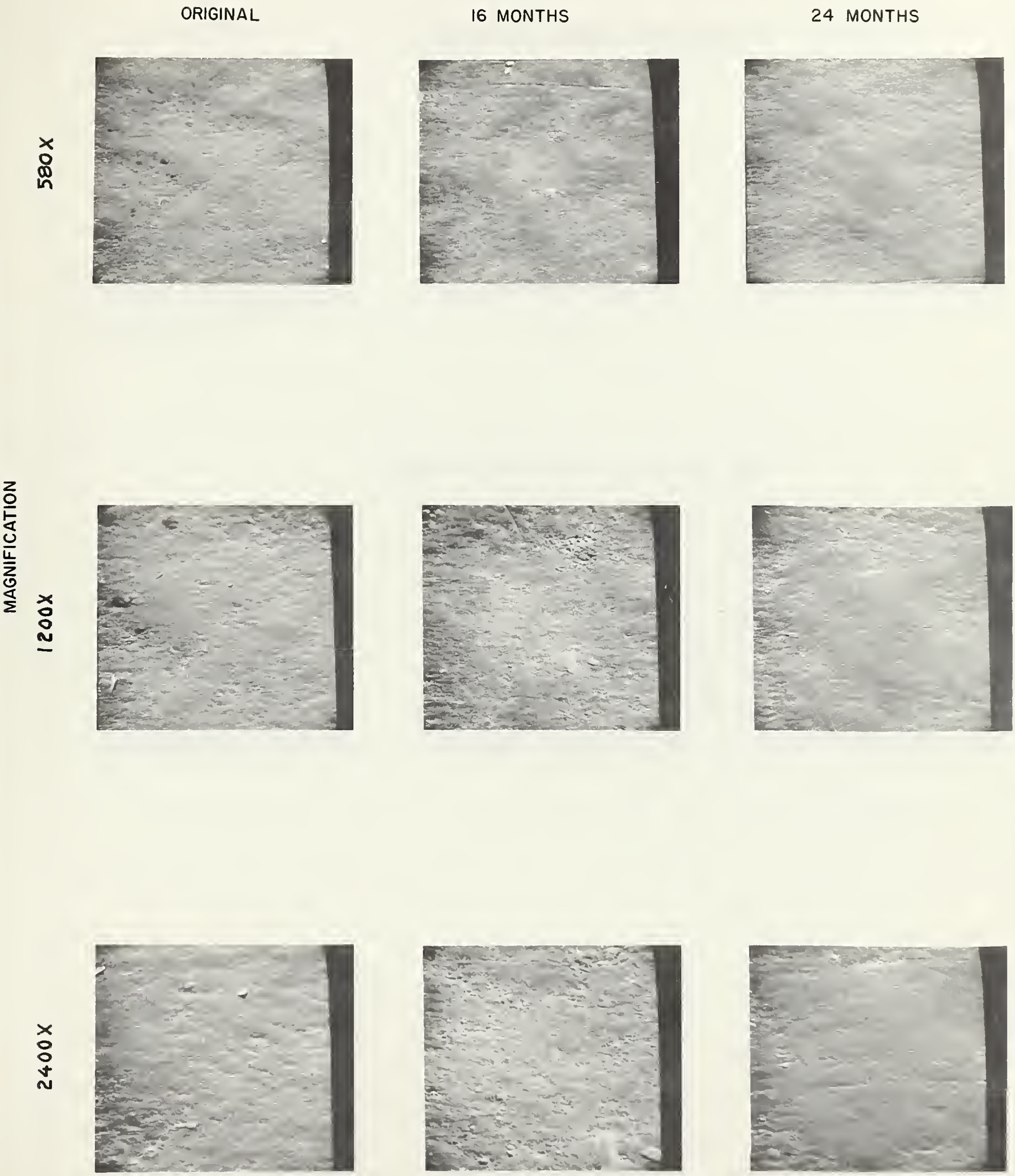
(Washington, D.C.)

Original	16 Months	24 Months
0	36	6 peaks/inch

Peak Height = 150 micro-inches

POLYETHYLENE (60 mil)

WASHINGTON, D.C.



GLASS-REINFORCED POLYESTER

(Miami, Florida)

Original	16 Months	24 Months
0	48	132 peaks/inch

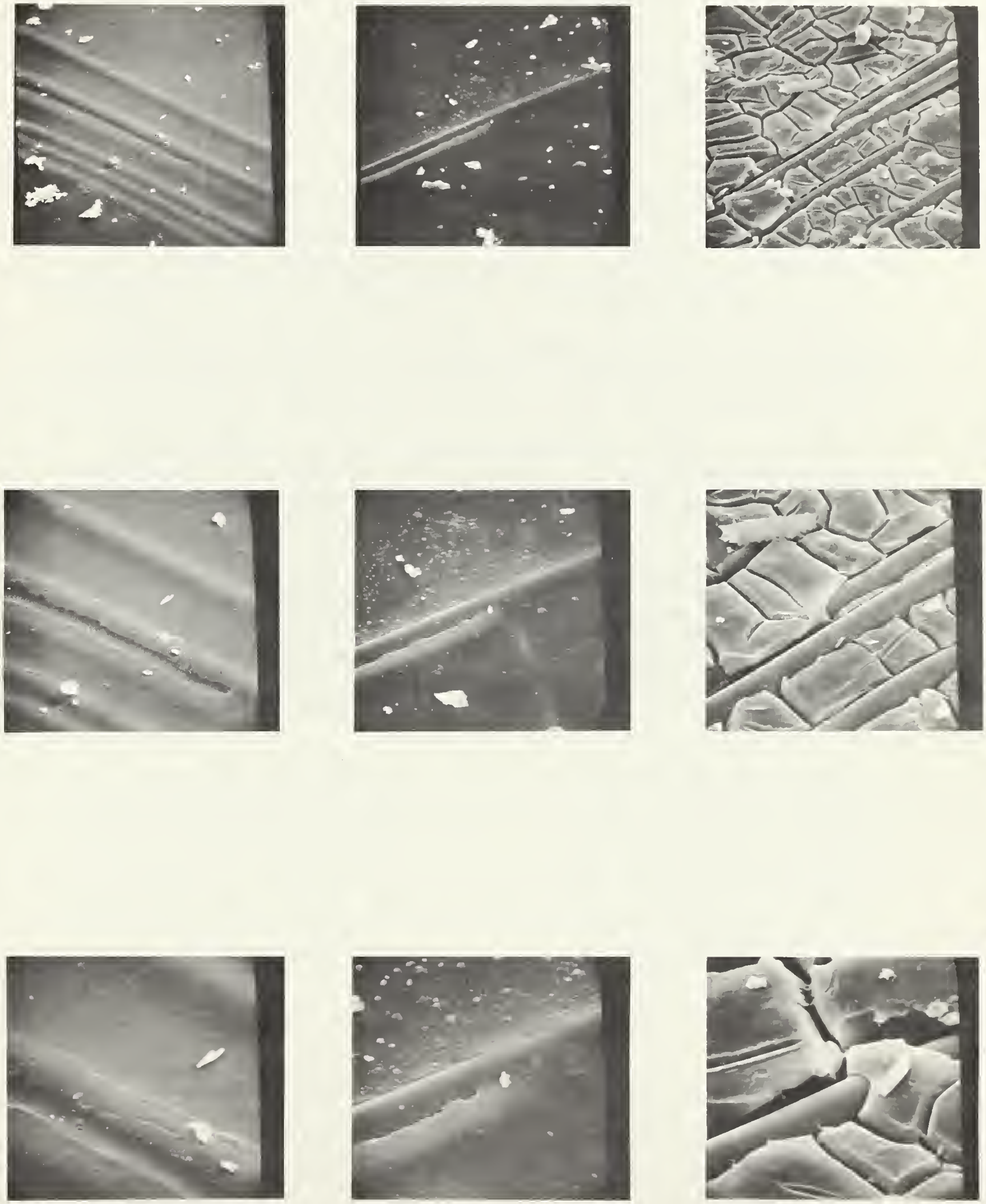
Peak Height = 150 micro-inches

REINFORCED POLYESTER

MIAMI, FLORIDA

ORIGINAL | 16 MONTHS | 24 MONTHS

MAGNIFICATION: 580X, 1200X, 2400X



APPENDIX B

SCANNING ELECTRON MICROGRAPHS OF GLASS-REINFORCED POLYESTER

The following micrographs were obtained at NBS through the effort of Margaret A. Baker (Research Associate of Porcelain Enamel Institute) assisted by Paul C. Gill (MCA Research Technician).

After the micrographs shown in APPENDIX A were found to confirm the roughness meter data, it was decided to further explore the surface texture of a most interesting case, viz., glass-reinforced polyester. On the page facing each set of micrographs, the corresponding measured values of peak count are given. Again, it can be seen that the data are in good agreement with the visual record.

Initiation of physical surface change appears to be similar at all 3 exposure sites. The initial change occurs during the first year by erosion of polyester from the top of the glass fiber.

Propagation of the surface deterioration seems very rapid, as witnessed by the extensive fiber bloom at all 3 sites by 16 months. Note that the roughness data at 9 months, at all 3 sites, gave an early indication of this change.

A phenomenon which does not appear in the Arizona micrographs is cracking of the polyester; such cracking is apparent in the Miami and Washington micrographs. It is possible that the polyester went through this cracking phase very rapidly between 9-16 months, then became smoother. Such roughening-smoothing of the polyester seems to have occurred in Miami at 20-36 months.

RP/PHOENIX, ARIZONA

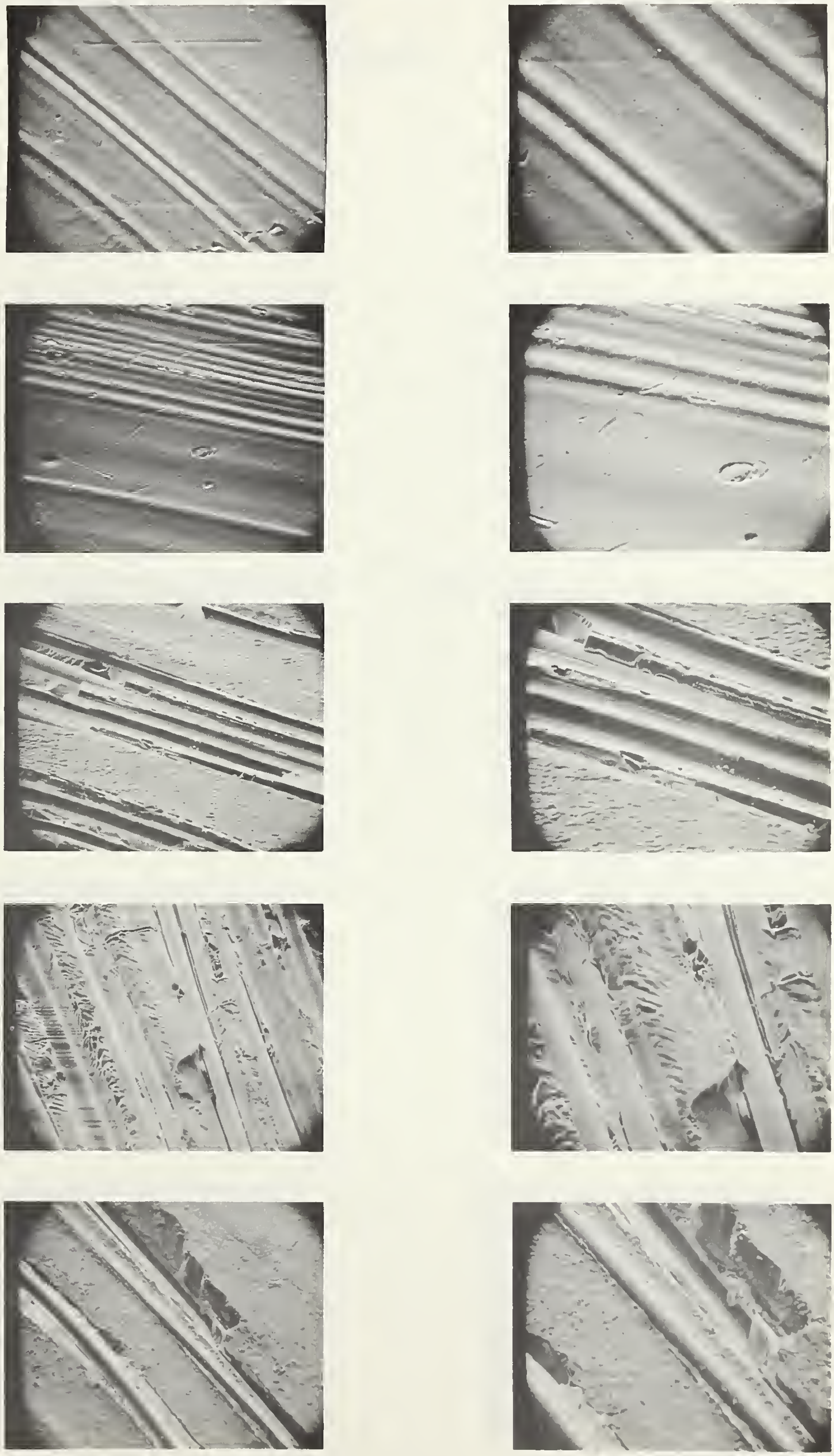
Original	0	peaks per inch
3 Months	0	peaks per inch
9 Months	30	peaks per inch
16 Months	38	peaks per inch
20 Months	32	peaks per inch
36 Months	--	

Peak Height = 150 micro-inches

REINFORCED POLYESTER

PHOENIX, ARIZONA

500 X, | 1000 X



3 mos.

9 mos.

16 mos.

20 mos.

36 mos.

RP/MIAMI, FLORIDA

Original	0	peaks per inch
3 Months	0	peaks per inch
9 Months	16	peaks per inch
16 Months	48	peaks per inch
20 Months	50	peaks per inch
36 Months	--	

Peak Height = 150 micro-inches

REINFORCED POLYESTER
WASHINGTON D.C.

500 X | 1000 X

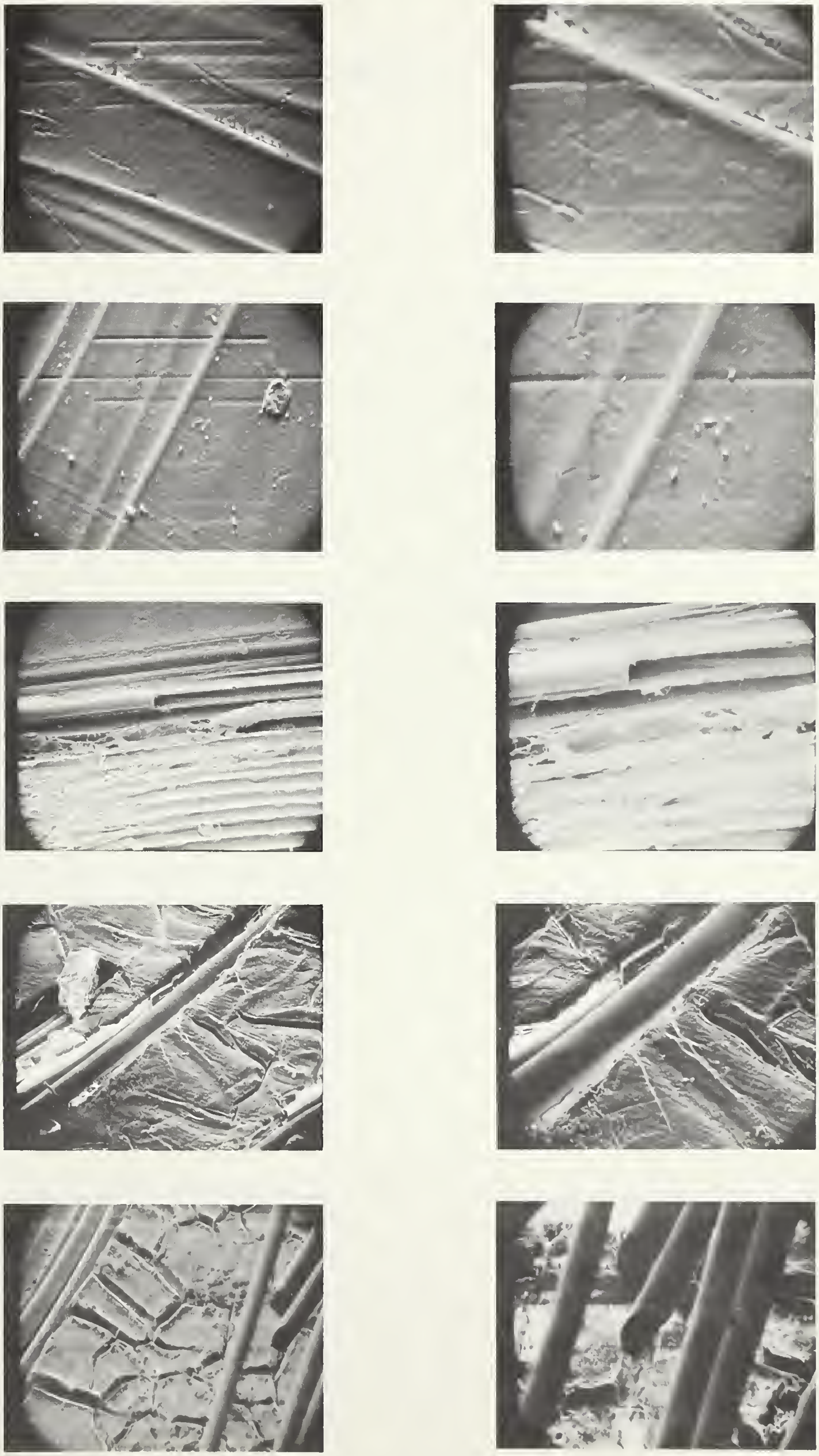
3 mos.

9 mos.

16 mos.

20 mos.

36 mos.



RP/WASHINGTON, D.C.

Original	0	peaks per inch
3 Months	2	peaks per inch
9 Months	20	peaks per inch
16 Months	24	peaks per inch
20 Months	32	peaks per inch
36 Months	--	

Peak Height = 150 micro-inches

REINFORCED POLYESTER

MIAMI FLORIDA

500 X — 1000 X

3 mos.

9 mos.

16 mos.

20 mos.

36 mos.

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS