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NATIONAL BUREAU OF STANDARDS REPORT

10 156

OUTDOOR PERFORMANCE OF PLASTICS
IV. SIGNIFICANCE OF CLIMATE

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OUTDOOR PERFORMANCE OF PLASTICS
IV. SIGNIFICANCE OF CLIMATE

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ABSTRACT

This is the fourth in a series of reports on outdoor weathering of plastics in three climates. Non-linear regression analysis has been used to fit an exponential model describing the "wear-out" process, as measured by three years of ultimate tensile elongation data.

Since the parameters (b_i) of the exponential model have physical significance, we have attempted to relate them to the weather causing the deterioration. A linear relation was hypothesized between the b_i or "characteristic life" (t_f) and the five climatic variables: langleys, ultraviolet radiation, relative humidity, inches of rainfall and sol-air temperature. The latter is a calculated surface temperature of the exposed plastic.

The simultaneous linear equations relating b_i or t_f to climate were solved by computerized multiple linear regression. Three climatic variables, or less, explained most of the variance in "characteristic life", with the factors most significant to ultimate tensile elongation being:

a) for polyethylene, clear PVC or white PVC -- sol-air temperature and UV;

b) for polyethylene terephthalate -- humidity, temperature and rain.

Rainfall is a significant, but less important variable for PVC. Rainfall and humidity appear to have separate and distinct effects on polyethylene terephthalate.

Given frequent measurements of a plastic's property at a small number of exposure sites, its behavior at other sites can be predicted by such mathematical techniques with a known degree of confidence.

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OUTDOOR PERFORMANCE OF PLASTICS
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1. BACKGROUND

The overall objective of this cooperative industry-government study is to develop rapid methods to accurately predict the weatherability of plastics.

This is the fourth in a series of reports on the outdoor performance of plastics. Three previous NBS Reports have discussed the measured behavior of 20 plastics in 3 climates:

I. INTRODUCTION & COLOR-CHANGE (#9912)

II. TENSILE & FLEXURAL PROPERTIES (#10 014)

III. STATISTICAL MODEL FOR PREDICTING WEATHERABILITY (#10 116)

A large bank of data has been accumulated on clear and white-pigmented plastics exposed in Phoenix (Arizona), Miami (Florida), and Washington, D. C. Computer-assisted analysis of physical-property data has shown that ultimate tensile elongation is a meaningful "early-detector" of physical deterioration.

A Weibull-type model, analogous to that used for fatigue and failure analysis, fitted these data well. Parameters of the model are related to "characteristic life" and other measures of the "wear-out" process.

A computer-based method of non-linear regression was used for fitting data from 3 years exposure. Model parameters, their confidence intervals, and measures of goodness-of-fit were given in NBS Report #10 116. The observed data and the predicted 5-year behavior are shown in the Appendix to this report.

2. INTRODUCTION

Plastics exhibit different degrees of weatherability in different climates. Type, as well as degree, of deterioration may vary with climate. Attempts to explain these differences quantitatively have met with little success.

This report summarizes an approach we have used to relate physical-property change to weather data.

As detailed in our NBS Report #10 116, a Weibull-type model is useful for describing the decrease of ultimate tensile elongation caused by weathering:

$$P = b_1 \exp\left[-\left(\frac{t+b_2}{b_3}\right)^{b_4}\right] + b_5 \qquad (1)$$

P is the value of the property at time t, and the b's are parameters determined by non-linear regression. The 5 parameters completely describe the degradation curve, and furthermore, have physical significance:

b_1 is related to maximum property value ($b_1 + b_5$ = max.)

b_2 is related to pre- or post-aging ($b_2 = 0$, for most cases)

b_3 is related to "characteristic life" (time to reach 37% of initial property value)

b_4 is related to the shape of the curve ($b_4 \leq 1$ shows rapid initial decay; $b_4 > 1$ indicates induction period)

b_5 is related to the asymptotic value of the property.

3. WEATHER VARIABLES

Since the parameters of the Weibull-type model have physical significance, we have attempted to relate them to the weather causing the deterioration. It is generally considered that significant weather factors in weathering of polymeric materials are:

SOLAR RADIATION (actinic and thermal)
TEMPERATURE
MOISTURE (especially humidity and rainfall)
OXYGEN
AIR CONTAMINANTS (especially O_3, NO_x, SO_x, particulates)
WIND

Stress and biological factors are non-climatological, and will not be considered here. Thickness of the exposed material is an easily measured variable which can be studied.

Data on the above variables can be treated in several ways. The problem is to reach optimum balance between a minimum number of variables and adequate description of weather variation. It is frequently stated in discussions of weatherability that weather is not reproducible --- from day to day, hour to hour, or year to year. This is certainly true. On the other hand, we can generalize that climate in regions of the country is quite stable --- on the average, Arizona is hot and dry, Florida is warm and moist.

According to Webster, the WEATHER is the "state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness". Furthermore, he defines CLIMATE as the "average course or condition of the weather at a place over a period of years as exhibited by temperature, wind velocity, and precipitation".

Thus it is reasonable to describe the climates for exposure in terms of average weather. We have selected annual averages of total solar radiation (langleys), ultraviolet radiation ("Coblentz langleys"), relative humidity, inches of rainfall and sol-air temperature. The constancy of climate is confirmed by the close averages over 2 and 3 years.

Where available, actual data from the exposure sites in Miami and Phoenix were used to calculate averages. For Washington, D. C. the climatological Data Summaries of the Weather Bureau were the source of data. Averages were calculated from both 24 months and 36 months of observations.

3.1 Sol-air Temperature

Environmental engineers use a factor known as "sol-air temperature" [1] to estimate the temperature of an exposed material:

$$T_S = T_A + \frac{a \cdot I}{h} \qquad (2)$$

where T_A is ambient air temperature,

- a is a constant for the material called solar absorptivity. It is closely related to color, varying from about 0.9 for black materials such as asphalt to about 0.2 for white polyvinyl fluoride film.
- I is total solar radiation, and
- h is a constant for the specific material and climate surrounding, called surface conductance. It is the time rate of heat exchange by radiation, conduction and convection of a unit area of a surface with its surroundings. It increases approximately linearly with wind velocity.

Thus, a typical bright summer day with air temperature about 90°F and a 5 mph breeze could yield a sol-air temperature for a black material of about 120°F. This calculation of 120°F for a black material should be compared with the experimental value [7] for black asphalt measured as 166°F during summer exposure. The difference between 120° and 166°F is probably due to allowance for wind-cooling in the calculated case. If the absence of wind is assumed, the calculated value is about 165°F. Temperatures of this range are probably not high enough to cause purely thermal decomposition, but they are likely high enough to increase the rate of hydrolytic, oxidative and secondary photochemical processes.

To calculate average maximum sol-air temperature, we used the average of maximum daily air temperature.

Averages were calculated over both 24 and 36 months of exposure, in order to compare with parameters of the Weibull-type model estimated for both 24 and 36 months of data.

No measurements were found for solar absorptivity, a, of our 20 plastics. Therefore, we measured an approximate value for each specimen by exposing the specimen to a pyrex-filtered xenon arc. Clear specimens were interposed between the arc and a radiometer, so that radiation absorbed by the specimen could be observed. Total reflectance of opaque specimens was measured in a Zeiss "Elrepho" electric reflectance photometer, which utilizes a white integrating spherical reflectance head. The observed values for estimated solar absorptivity are given in TABLE 1.

Surface conductance depends primarily on wind speed, for a particular material [1]. Average wind speed at the 3 sites over 36 months was:

A (Phoenix) - 2.0 miles per hour

F (Miami) - 4.2 miles per hour

W (D. C.) - 2.8 miles per hour

For wind speeds up to 5 miles per hour, surface conductance for many different materials is about 2.5 BTU per hour per square foot of surface per degree Fahrenheit temperature difference. Thus, a value of 2.5 was adopted for all our plastics.

Inserting h = 2.5 and the values of a, I and T_A shown in TABLE 1 into equation (2), we calculated the average maximum sol-air temperatures, T_S, given in the last two columns of TABLE 1. Note that for this calculation, I must <u>not</u> be in langleys but in BTU per square foot per hour.* The material's surface temperature is seen to be from 1° to 15°F higher than ambient temperature.

3.2 Radiation: Total and UV

For total solar radiation, monthly totals of langleys were averaged. The 2- and 3-year averages for the 3 sites are given in TABLE 2.

"Coblentz langleys" of ultraviolet radiation below 315 millimicrons were calculated by multiplying the above langley values by monthly correction factors published by Coblentz [2] See TABLE 2.

* 1 langley/minute = 1 calorie per cm^2 per minute = 221 BTU per ft^2 per hour.

3.3 Rainfall and Humidity

For rainfall, monthly total inches of rainfall was averaged.

For humidity, monthly averages of daily relative humidity were averaged.

See TABLE 2, for the 2- and 3-year averages.

4. RELATION OF WEIBULL-TYPE PARAMETERS TO CLIMATE

As noted previously, the Weibull-type model of equation (1) was computer-fitted to observed ultimate tensile elongation data. This was carried out separately for both 24- and 36-months of data. Thus, two slightly different sets of b's were obtained, corresponding to each period of time. This was done to increase the number of equations available for the approximate linear relation:

$$b_i = C_i + C_{iL} L + C_{iU} U + C_{iH} H + C_{iR} R + C_{iT} T + E_i \qquad (3)$$

where the b_i are the parameters fitted to the ultimate tensile elongation data, L is langleys, U is ultraviolet radiation ("Coblentz langleys"), H is relative humidity, R is inches of rainfall and T is sol-air temperature. E_i is the residual or unexplained variation. The 24- and 36-month fitted b's were related to the corresponding 24- and 36-month climate data of TABLES 1 and 2.

The climatological data were used in the 5-variable linear model (3) in their standardized form:

$$W = \frac{W' - \bar{W}}{s} \qquad (4)$$

where W is the standardized weather variable, W' is the observed weather variable, $\bar{W}$ is the average of the weather variable for the time under study, and s is the standard deviation from the mean. By using such dimensionless weather variables, the solution is unaffected by whether one uses, for example, temperature in °C, °F, or °K.

This approach is analogous to the second stage of Kamal's analysis [3]. That is, a mathematical relationship is postulated between the fitted parameters (b's) and the exposure variables. He had sufficient different exposures to give data for a complete quadratic form. Our experiments were not designed to give extensive data of the type necessary for weather analysis. Thus, we use a simpler linear form which the following results show to be moderately satisfactory.

4.1 "Characteristic Life" vs Climate

The "characteristic life", t_f, is the time it takes for a material to lose 63.2% of its original property value. At t_f, the plastic retains 36.8% (or 1/e) of the original value of the property. It is perhaps the single most significant measure of a material's life.

If we take the Weibull-type model equation (1), substitute 36.8% for P, and solve for t, we can define this time-to-failure:

$$t_f = b_3 \left[\ln\left(\frac{b_1}{36.8 - b_5}\right) \right]^{1/b_4} -b_2 \qquad (5)$$

Once the b's are known, t_f can be calculated from equation (5). It is apparent that for $b_2 = b_5 = 0$, $b_1 = 100$ and $t_f = b_3$. This corresponds to the classic Weibull case.

Because of the physical significance of this parameter, we have also calculated its relation to the climatic variables.

The pertinent values of t_f and the b's are listed in TABLE 3.

4.2 Multiple Linear Regression

The simultaneous equations relating the b's and t_f to the climatic variables were solved by computerized multiple linear regression. There are 5 basic methods [4] for selecting the climatic factors and determining the coefficients C: 1) all possible regressions, 2) backward elimination, 3) forward selection, 4) stagewise regression and 5) stepwise regression.

The stepwise regression procedure was adopted as optimum since it consists of forward selection of the most significant variables with a "backward glance" to eliminate statistically insignificant variables. The variable added is the one which makes the greatest reduction in the unexplained variance. Variables are automatically removed when they become statistically insignificant, as calculated by the F-test.

A computer program was available at NBS for carrying out this stepwise regression: BMD-02R from the UCLA Biomedical Computer Programs [5]. This program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Variables are automatically removed when their F-values become too low. The algorithm [6] for the program is analogous to the stepwise regression procedures of Draper and Smith [4].

4.3 Multiple Correlation Coefficient

Closely associated with the multiple regression equation

$$\hat{b}_i = C_i + C_{iL} L + C_{iU} U + C_{iH} H + C_{iR} R + C_{iT} T$$

is the quantity r which is known as the coefficient of multiple correlation. The r may be thought of as the simple coefficient of linear correlation which measures, in the sample, the degree of linear associations between $\hat{b}_i$ and b_i, that is, between the estimated and observed values of the dependent variable. Another way of looking at r is to say that it measures the degree of joint linear association among all the variables both dependent and independent under discussion. Mathematically it can also be related to the amount of variation of the dependent variable explained by the following relation:

$$r^2 = \frac{\text{Amount of variation explained for some } b_i}{\text{Total amount of variation for that } b_i}$$

5. RESULTS

The results of the multiple linear regressions are given in TABLES 4, 5, 6 and 7. These results are considered a significant improvement over preliminary results communicated previously. The number of data points varied from 5 to 16 for different types of plastics studied. In most cases the first three entries of independent variables explained most of the variation in the dependent variable for each of the plastics. In other cases, the analysis would have been more justified and satisfactory if there were more data points.

5.1 Correlation Between Weibull-type Parameters and Climate

TABLES 4 and 5 present the multiple correlation coefficients, r, between t_f or b_i and the climatic factors of langleys, Coblentz langleys, relative humidity, inches of rainfall and sol-air temperature. The order in which the climatic variables entered the model is shown, along with the corresponding correlation coefficient up to its entry. Thus, each pair of columns shows the climatic variable accepted in the model, and its corresponding multiple correlation coefficient, r. The square of the correlation coefficient times 100 is the percent variance explained up to the entering variable.

For example, TABLE 4 shows that for polyethylene (PE) langleys, sol-air temperature, and rainfall combine to explain 97.5% (0.987^2) of the variance in its characteristic life, t_f. Similarly, for polyethylene terephthalate, PETP, relative humidity, sol-air temperature and rainfall together explain 85.4% of the variance in its characteristic life.

Clear PVC's -B, -C and -N are shown by TABLE 4 to be very sensitive to sol-air temperature and ultraviolet radiation, and slightly sensitive to langleys and rainfall. For PVC-B, the small increase in correlation coefficient from 0.79 to 0.81 on entry of rainfall into the model indicates a small but significant effect of rainfall on the tensile elongation of this plastic. For PVC-C, ultraviolet radiation is seen to be the major determinant of its characteristic life.

White PVC's -A, -D and -M lose elongation primarily because of sol-air temperature and ultraviolet radiation, according to TABLE 4. However, TABLE 5 indicates some involvement of moisture factors (rainfall and humidity) in determining the b's for the Weibull-type model for white PVC's.

Further study of TABLE 5 reveals that b_3, b_4 and b_5 have quite different relations to the climatic factors. Since these b's are mathematically and implicitly related to one another, interpreting their relation to climatic factors is difficult. Since the correlation coefficients of TABLE 4 are generally higher than those of TABLE 5, we feel that the linear model used may be better for characteristic life than it is for the b's. The linear model may be quite useful, however, for synthesizing deterioration curves for climates other than the one in which exposures were actually made.

5.2 Constants for Estimating Weibull-Type Parameters

TABLES 6 and 7 present the estimated constants for the linear relation between t_f or b_i and the climatological factors. These constants resulted from the computer's solution to the simultaneous equations. The b's or t_f for each plastic in any climate may be estimated by substituting these constants into the linear model, along with the corresponding climatic average for that climate.

The constants have the dimensions of t_f or b_i. The sign of the constant indicates whether the corresponding climatic factor increases or decreases the weatherability of the plastic. The magnitude of the constant reflects the variability (standard deviation in equation (4)) of the climatic factor, as well as its relative effect on b_i or t_f.

For example, the estimated value of characteristic life for PVC-B-4 is given by the equation

$$t_f = 11.319 - 32.141\ U - 30.275\ R - 7.115T. \qquad (6)$$

For the case of 36 months exposure in Arizona we have UV = 6.95 Coblentz langleys, Rain = 0.64 inch , Sol-air temp = 88.61°F. Because the corresponding means and standard deviation for these three variables are

Means: $\bar{U} = 6.159$ $\quad\bar{R} = 3.270$ $\quad\bar{T}_S = 82.735$

Standard Deviations: $s_U = 0.767$ $\quad s_R = 2.446$ $\quad s_{T_S} = 7.816$

The standarized values of these variables are

$$U = \frac{6.95 - 6.159}{0.767} = \frac{0.791}{0.767} = 1.031$$

$$R = \frac{0.64 - 3.27}{2.446} = \frac{-2.63}{2.446} = -1.075$$

$$T_S = \frac{88.61 - 82.735}{7.816} = \frac{5.875}{7.816} = 0.752$$

The estimate of characteristic life is therefore from equation (6)

$$t_f = 11.319 - 32.141 \times 1.031 + 30.275 \times 1.075 - 7.115 \times 0.752$$
$$\approx 5.40 \text{ months}.$$

In the case of Washington the corresponding weather information is:

UV = 5.18 Coblentz langleys Rain = 6.35 inches Sol-air temp = 84.30°F

and the corresponding standardized values are

$$U = \frac{5.18 - 6.159}{0.767} = \frac{-0.979}{0.767} = -1.276$$

$$R = \frac{6.35 - 3.27}{2.446} = \frac{3.08}{2.446} = 1.259$$

$$T_S = \frac{84.30 - 82.735}{7.816} = \frac{1.565}{7.816} = 0.200$$

Using again equation (6) we get the estimate

$$t_f = 11.319 + 32.141 \times 1.276 - 30.275 \times 1.259 - 7.115 \times 0.200$$
$$\approx 12.8 \text{ months}.$$

5.3 Variation Unexplained (Residue)

Analysis of the data is based on the limited information of 5 to 16 data points. The amount of variation explained for the dependent variable is the square of the multiple correlation coefficient. In some cases a significant amount of variation was explained by the first variable entering the model; for example in TABLE 4 we have the multiple correlation coefficient as high as 0.991 for PVC-C. So the amount of variation explained by the single entry of UV is $(0.991)^2 = 98.3\%$ for PVC-C. The amount of variation is not significant even up to the entry of the third variable in some cases; for example, b_5 for PVC-D (TABLE 5) is explained only $(0.390)^2 = 15.2\%$. The validity of the model depends upon the amount of variation explained up to a certain number of entries which depends on the number of data points. To have n entries in the model, we need at least (n + 1) independent data points. The greater the variation explained by a given number of variables in the model, the more reliable is the model and hence its validity.

TABLE 8 summarizes the unexplained variation between $\hat{t}_f$ estimated from the linear climatic model (3) and t_f fitted to the data by the Weibull-type model. Thus, the tabulated residues are the differences between the value of characteristic life, t_f, as given by stage I using Marquardt's algorithm and the estimated characteristic life, $\hat{t}_f$, as obtained by stepwise regression in stage II.

This table shows that estimated values of t_f are, at best, exact for PVC-M and at worst, too high by a factor of 4 for PE-1. The PE-1 case is by far the worst due to scarcity of data points and insufficient replicates for more than one climate.

Coming back to the example of Sec. 5.2 we had the estimated characteristic life, $\hat{t}_f$, for PVC-B-4 at Arizona as 5.4 months and at Washington as 12.8 months. TABLE 3 gives the characteristic life from stage I, t_f, as 8.3 months in Arizona and 13.41 months in Washington. Hence,

$$t_f - \hat{t}_f = E$$

8.3 - 5.4 = 2.9 months (Arizona)

13.4 - 12.8 = 0.6 months (Washington, D. C.)

6. CONCLUSIONS

Within the limitations of the ultimate tensile elongation data and the linear model, several useful observations may be made:

1. Three climatic variables, or less, explained most of the variance in "characteristic life" of the plastics' tensile elongation.

2. The relation between "characteristic life" of the plastics and average climate indicates that the most significant factors:

   a) for polyethylene, are temperature and UV;

   b) for polyethylene terephthalate, are humidity, temperature and rain;

   c) for PVC, are temperature and UV.

3. Rainfall is a significant, but less important variable for PVC. Rainfall and humidity appear to have separate and distinct effects on polyethylene terephthalate.

4. Given frequent measurements of a plastic's property at a small number of exposure sites, its behavior at other sites can be predicted with a known degree of confidence. The more measurements are made, the more confident the prediction: "You get what you pay for".

5. "Characteristic life" is perhaps the single most significant and useful measure of a plastic's outdoor life.

7. RECOMMENDATIONS

To forecast outdoor life of plastics, industry and government should adopt established mathematical techniques such as those applied in this study.

To determine the usefulness of accelerated tests, these same mathematical models should be fitted and compared to accelerated-test data.

8. ACKNOWLEDGMENTS

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LIST OF TABLES

TABLE 1

Sol-Air Temperature, T_S

Plastic	Total Radiation: I $(BTU)(Ft)^{-2}(Hr)^{-1}$	Solar Absorptivity: a	a/h* $(BTU)^{-1}(Ft)^{2}(Hr)(°F)$	I a/h (°F)	Average Max.Temp.: T_A (°F) 24 Mos.	Average Max.Temp.: T_A (°F) 36 Mos.	Average Sol-Air Max.Temp.: T_S** (°F) 24 Mos.	Average Sol-Air Max.Temp.: T_S** (°F) 36 Mos.
PE-1-W	66.45	.14	.056	3.72	66.50	66.83	70.22	70.55
-60-A	78.88	.48	.192	15.14	85.54	85.14	100.68	100.28
-F	58.01	.48	.192	11.14	81.83	81.75	92.97	92.89
-W	66.45	.48	.192	12.76	66.50	66.83	79.26	79.59
PETP-5-A	78.88	.15	.060	4.73	85.54	85.14	90.27	89.37
-F	58.01	.15	.060	3.48	81.83	81.75	85.31	85.23
-W	66.45	.15	.060	3.99	66.50	66.83	70.49	70.82
PVC-B-4-A	78.88	.11	.044	3.47	85.54	85.14	89.01	88.61
-F	58.01	.11	.044	2.55	81.83	81.75	84.38	84.30
-W	66.45	.11	.044	2.92	66.50	66.83	69.42	69.75
-10-A	78.88	.11	.044	3.47	85.54	85.14	89.01	88.61
-F	58.01	.11	.044	2.55	81.83	81.75	84.38	84.30
-60-A	78.88	.15	.060	4.73	85.54	85.14	90.27	89.87
-F	58.01	.15	.060	3.48	81.83	81.75	85.31	85.23
-W	66.45	.15	.060	3.99	66.50	66.83	70.49	70.82
PVC-C-4-W	66.45	.08	.032	2.13	66.50	66.83	68.63	68.96
-10-A	78.88	.08	.032	2.52	85.54	85.14	88.06	87.66
-F	58.01	.08	.032	1.86	81.83	81.75	83.69	83.61
PVC-N-60-A	78.88	.08	.032	2.52	85.54	85.14	88.06	87.66
-F	58.01	.08	.032	1.86	81.83	81.75	83.69	83.61
-W	66.45	.08	.032	2.13	66.50	66.83	66.63	68.96
PVC-A-4-A	78.88	.13	.052	4.10	85.54	85.14	89.64	89.24
-W	66.45	.13	.052	3.46	66.50	66.83	69.96	70.29
-10-A	78.88	.09	.036	2.84	85.54	85.14	88.38	87.98
-F	58.01	.09	.036	2.09	81.83	81.75	83.92	83.84
PVC-D-4-A	78.88	.12	.048	3.78	85.54	85.14	89.32	88.92
-F	58.01	.12	.048	2.78	81.83	81.75	84.61	84.53
-W	66.45	.12	.048	3.19	66.50	66.83	69.69	70.02
-10-A	78.88	.06	.024	1.89	85.54	85.14	87.43	87.03
-60-A	78.88	.09	.036	2.84	85.54	85.14	88.38	87.98
-F	58.01	.09	.036	2.09	81.83	81.75	84.67	84.59
-W	66.45	.09	.036	2.39	66.50	66.83	68.89	69.22
PVC-M-60-A	78.88	.05	.020	1.58	85.54	85.14	87.12	86.72
-F	58.01	.05	.020	1.16	81.83	81.75	82.99	82.91
-W	66.45	.05	.020	1.33	66.50	66.83	67.83	68.16

* h is the surface conductance equal to 2.5 BTU $(Ft)^{-2}(Hr)^{-1}(°F)^{-1}$

** $T_S = T_A + I\ a/h$ (see Section 3.1)

TABLE 2

Averages of Climatological Factors

Site	24 months Langleys (x100)	24 months UV (x100)	24 months Humidity %	24 months Rain (inches)	36 months Langleys (x100)	36 months UV (x100)	36 months Humidity %	36 months Rain (inches)
Arizona (Phoenix)	144.24	6.90	41.0	0.6	140.65	6.95	41.2	0.6
Florida (Miami)	115.41	5.30	75.1	5.8	112.85	5.18	74.3	6.4
Washington (D.C.)	132.59	6.42	62.3	3.0	129.55	6.35	61.8	3.0

TABLE 3

Results of Nonlinear Regression on Normalized Elongation Data

Plastic	24 months b_1	b_5	b_3	b_4	t_f	36 months b_1	b_5	b_3	b_4	t_f
PE-1-W	100.00	0.00	3.24	0.66	3.24	100.00	0.00	3.24	0.66	3.24
-60-A	44.22	55.78	19.91	85.30	-	94.66	5.34	25.01	5.57	25.45
-F	59.22	40.78	16.55	10.55	-	60.40	39.60	16.64	9.55	-
-W	100.00	0.00	119.35	1.70	119.35	100.00	0.00	167.11	1.62	167.10
PETP-5-A	100.00	0.00	40.55	1.56	40.55	100.00	0.00	50.87	1.22	50.87
-F	100.00	0.00	31.71	2.33	31.71	100.00	0.00	39.17	1.63	39.17
-W	100.00	0.00	39.86	1.77	39.86	100.00	0.00	67.74	1.11	67.74
PVC-B-4-A	97.07	2.93	8.22	6.25	8.29	97.60	2.40	8.24	6.23	8.30
-F	92.73	7.27	12.96	4.90	13.32	95.79	4.21	13.19	4.60	13.41
-W	88.88	11.12	17.43	2.52	19.00	97.66	2.34	19.02	2.32	19.36
-10-A	99.66	0.34	9.35	2.21	9.37	99.21	0.79	9.29	2.94	9.35
-F	100.00	0.00	18.03	1.54	18.03	100.00	0.00	17.66	1.73	17.66
-60-A	100.00	0.00	0.34	0.24	0.34	100.00	0.00	0.31	0.24	0.31
-F	100.00	0.00	8.62	0.49	8.62	100.00	0.00	8.70	0.48	8.70
-W	100.00	0.00	13.83	0.81	13.83	100.00	0.00	13.22	0.97	13.22
PVC-C-4-W	96.41	3.59	3.17	1.57	3.30	97.01	2.99	2.59	1.15	2.71
-10-A	100.00	0.00	1.28	0.28	1.28	100.00	0.00	1.32	0.29	1.32
-F	83.21	16.79	7.50	2.50	8.64	86.30	13.70	7.75	2.29	8.74
PVC-N-60-A	93.06	6.94	1.08	0.71	13.28	93.46	6.54	0.72	0.56	0.89
-F	100.00	0.00	4.98	0.61	4.98	97.29	2.71	4.65	0.65	5.01
-W	100.00	0.00	11.05	0.68	11.05	100.00	0.00	11.06	0.81	11.06
PVC-A-4-A	97.29	2.71	1.46	0.85	1.54	97.67	2.33	0.77	0.57	0.83
*W	92.31	26.37	11.45	4.00	21.81	105.28	15.84	12.30	3.33	22.05
-10-A	94.00	6.00	6.26	2.17	6.59	95.59	4.41	6.34	1.96	6.60
-F	83.94	16.06	11.40	5.45	12.12	82.20	17.80	11.34	5.51	12.15
PVC-D-4-A	98.50	1.50	0.91	1.00	0.93	98.57	1.43	0.97	1.00	0.99
-F	100.00	0.00	10.97	1.32	10.97	100.00	0.00	10.98	1.31	10.98
-W	100.00	0.00	14.23	8.01	14.23	100.00	0.00	14.23	8.01	14.23
-10-A	97.23	2.77	4.54	1.76	4.67	97.38	2.62	4.53	1.74	4.65
-60-A	90.04	9.96	2.72	0.73	3.53	89.88	10.12	2.77	0.75	3.59
-F	80.88	19.12	4.51	1.43	6.05	84.20	15.80	4.23	0.99	5.90
-W	97.98	2.02	8.89	0.60	9.43	89.08	10.92	6.90	0.71	9.30
PVC-M-60-A	92.71	7.29	1.90	6.98	1.94	92.41	7.59	1.90	6.98	1.94
-F	74.36	25.64	7.26	2.00	10.02	79.12	20.87	7.78	1.39	10.92
-W	75.54	24.46	6.47	1.86	13.04	82.13	17.87	10.59	1.55	13.57

* For PVC-A-4 at Washington b_2 = - 7.89 (24 months) b_2 = - 7.85 (36 months)

TABLE 4

Multiple Correlation Coefficients (r) Between t_f and Climatic Factors

Plastic	Number of Data Points	First Entry Variable	First Entry r	Second Entry Variable	Second Entry r	Third Entry Variable	Third Entry r
PE	5	L	.321	T	.805	R	.987
PETP	6	H	.710	T	.858	R	.924
PVC-B	16	T	.685	U	.794	R	.812
-C	6	U	.991	T	.996		
-N	6	T	.479	L	.602	U	.897
PVC-A	8	T	.960	U	.980		
-D	14	T	.784	U	.873		
-M	6	T	.820	U	.999		

L = Langleys H = Humidity T = Temperature

U = Ultraviolet R = Rainfall

TABLE 5

Multiple Correlation Coefficients (r) Between b's and Climatic Factors

Plastic		Number of Data Points	First Entry Variable	r	Second Entry Variable	r	Third Entry Variable	r
PE	b_3	8	T	.191	U	.239	R	.641
	b_4	8	T	.576	L	.700	U	.906
	b_5	8	T	.721	U	.802	L	.950
PETP	b_3	6	H	.711	T	.858	R	.924
	b_4	6	H	.862	U	.970	T	.997
PVC-B	b_3	16	T	.670	U	.789	R	.811
	b_4	16	T	.184				
	b_5	16	T	.322	H	.413		
PVC-C	b_3	6	U	.993				
	b_4	6	R	.977	H	.993		
	b_5	6	U	.976	H	.986		
PVC-N	b_3	6	T	.978	U	.996		
	b_4	6	T	.607	H	.648		
	b_5	6	T	.762	U	.955	H	.970
PVC-A	b_3	8	R	.766	T	.918	U	.931
	b_4	8	R	.948	T	.959	H	.965
	b_5	8	L	.905	T	.916	H	.924
PVC-D	b_3	14	T	.728	R	.801		
	b_4	14	T	.554	U	.562		
	b_5	14	U	.285	R	.369	T	.390
PVC-M	b_3	6	T	.851	L	.996		
	b_4	6	R	.824	T	.999		
	b_5	6	R	.826	T	.937	H	.989

L = Langleys H = Humidity T = Temperature

U = Ultraviolet R = Rainfall

TABLE 6

Estimated Constants (C_i) Relating t_f to Climatic Factors

$$\hat{t}_f = C + C_L L + C_U U + C_H H + C_R R + C_T T$$

Plastic	Data Points	Constant C	Coefficient of Total Radiation C_L	Coefficient of Ultraviolet C_U	Coefficient of Humidity C_H	Coefficient of Rain C_R	Coefficient of Sol-Air Temp C_T
PE	5	63.676	-28.061			170.650	189.170
PETP	6	44.483			-8.000	- 4.140	- 6.200
PVC-B	16	11.319		-32.141		-30.275	- 7.115
PVC-C	6	4.332		- 3.438			0.320
PVC-N	6	7.712	27.459	-25.815			- 4.782
PVC-A	8	10.459		- 1.646			- 7.475
PVC-D	14	7.104		- 1.716			- 3.318
PVC-M	6	8.577		- 3.032			- 4.371

L = Langleys H = Humidity T = Temperature
U = Ultraviolet R = Rainfall

TABLE 7

Estimated Constants (C_i) Relating b's to Climatic Factors

$$\hat{b}_i = C_i + C_{iL} L + C_{iU} U + C_{iH} H + C_{iR} R + C_{iT} T$$

Type	b_i	Number of Data Points	Constant C_i	Coefficient of Total Radiation C_{iL}	Coefficient of UV C_{iU}	Coefficient of Humidity C_{iH}	Coefficient of Rain C_{iR}	Coefficient of Sol-Air Temp. C_{iT}
PE	b_3	8	46.384		632.83		630.62	80.163
	b_4	8	14.501	134.74	-123.83			2.076
	b_5	8	17.687	89.619	- 96.680			7.075
PETP	b_3	6	44.483			- 8.000	- 4.140	- 6.200
	b_4	6	1.603		- 0.200	0.343		0.101
PVC-B	b_3	16	11.151		- 33.709		- 31.841	- 7.088
	b_4	16	2.361					0.377
	b_5	16	1.962			0.829		- 0.942
PVC-C	b_3	6	3.935		- 2.930			
	b_4	6	1.347			0.177	0.895	
	b_5	6	6.178		- 6.843	1.052		
PVC-N	b_3	6	5.590		- 0.878			- 4.489
	b_4	6	0.670			- 0.020		- 0.055
	b_5	6	2.698		1.780	- 0.568		2.463
PVC-A	b_3	8	7.665		- 20.899		-19.004	- 5.153
	b_4	8	2.980			0.204	1.665	- 0.279
	b_5	8	8.931	- 5.667		- 0.811		- 1.050
PVC-D	b_3	14	6.527				1.557	- 2.998
	b_4	14	2.097		0.229			- 1.426
	b_5	14	5.447		- 36.815		- 35.545	- 3.059
PVC-M	b_3	6	6.483	- 1.943				- 3.019
	b_4	6	3.458				- 2.071	1.557
	b_5	6	17.303			2.649	5.726	- 3.452

L = Langleys H = Humidity T = Temperature

U = Ultraviolet R = Rainfall

TABLE 8

Residues (Difference between t_f and $\hat{t}_f$)

Type	Thickness	Site	24 months: As obtained from Stage I t_f	24 months: As estimated by Stage II $\hat{t}_f$	24 months: Residue $=t_f-\hat{t}_f$	24 months: % Error	36 months: As obtained from Stage I t_f	36 months: As estimated by Stage II $\hat{t}_f$	36 months: Residue $=t_f-\hat{t}_f$	36 months: % Error
PE	1	W	3.24	-8.70	11.94	368.5	3.24	15.18	-11.94	368.5
	60	A	-	-	-		25.45	25.45	0.00	0.0
	60	F	-	-	-		-	-	-	
	60	W	119.25	131.19	-11.94	10.0	167.10	155.16	11.94	7.1
PETP	5	A	40.55	43.66	-3.11	7.7	50.87	47.91	2.96	5.8
	5	F	31.71	29.42	2.29	7.2	39.17	41.21	-2.04	5.2
	5	W	39.86	40.60	-0.74	1.8	69.14	68.51	0.63	0.9
PVC-B	4	A	8.29	7.01	1.28	15.4	8.30	5.40	2.90	34.9
	4	F	13.32	14.01	-0.69	5.2	13.41	12.80	0.61	4.5
	4	W	19.00	16.11	2.89	15.2	19.36	18.33	1.03	5.3
	10	A	9.37	7.01	2.36	25.2	9.35	5.40	3.95	42.2
	10	F	18.03	14.51	3.52	19.5	17.66	12.80	4.86	27.5
	60	A	0.34	5.86	-5.52	1623.5	0.31	4.25	-3.94	1270.9
	60	F	8.62	13.17	-4.55	52.8	8.70	11.95	-3.25	37.3
	60	W	13.83	14.94	-1.31	9.5	13.22	17.35	-4.13	31.2
PVC-C	4	W	3.30	3.33	-0.03	0.9	2.71	2.68	0.03	1.1
	10	A	1.28	1.41	-0.13	10.1	1.32	1.20	0.12	9.1
	10	F	8.64	8.55	0.09	1.1	8.74	8.82	-0.08	1.0
PVC-N	60	A	13.28	12.41	0.87	6.5	0.89	1.93	-1.04	116.8
	60	F	4.98	3.86	1.12	22.5	5.01	6.24	-1.23	24.5
	60	W	11.05	12.97	-1.92	17.4	11.06	8.85	2.21	20.0
PVC-A	4	A	1.54	3.48	-1.94	125.9	0.83	2.73	-1.90	228.9
	4	W	21.81	21.51	0.30	1.4	22.05	22.66	-0.61	2.8
	10	A	6.59	4.94	1.65	25.0	6.60	4.21	2.39	36.2
	10	F	12.12	12.40	-0.28	2.3	12.15	11.77	0.38	3.1
PVC-D	4	A	0.93	2.65	-1.72	184.9	0.99	2.70	-1.71	172.7
	4	F	10.97	8.32	2.65	24.1	10.98	8.63	2.35	21.4
	4	W	14.23	11.66	2.57	18.1	14.23	11.67	2.56	18.0
	10	A	4.67	3.41	1.26	26.9	4.65	3.46	1.19	25.6
	60	A	3.53	3.03	0.50	14.2	3.59	3.07	0.52	14.5
	60	F	6.05	8.29	-2.24	35.8	5.90	8.60	-2.70	45.8
	60	W	9.43	11.98	-2.55	27.0	9.30	11.99	-2.69	28.9
PVC-M	60	A	1.94	1.94	0.00	0.0	1.94	1.94	-0.00	0.0
	60	F	10.02	10.02	0.00	0.0	10.95	10.95	-0.00	0.0
	60	W	13.04	13.04	-0.00	0.0	13.57	13.57	0.00	0.0

APPENDIX

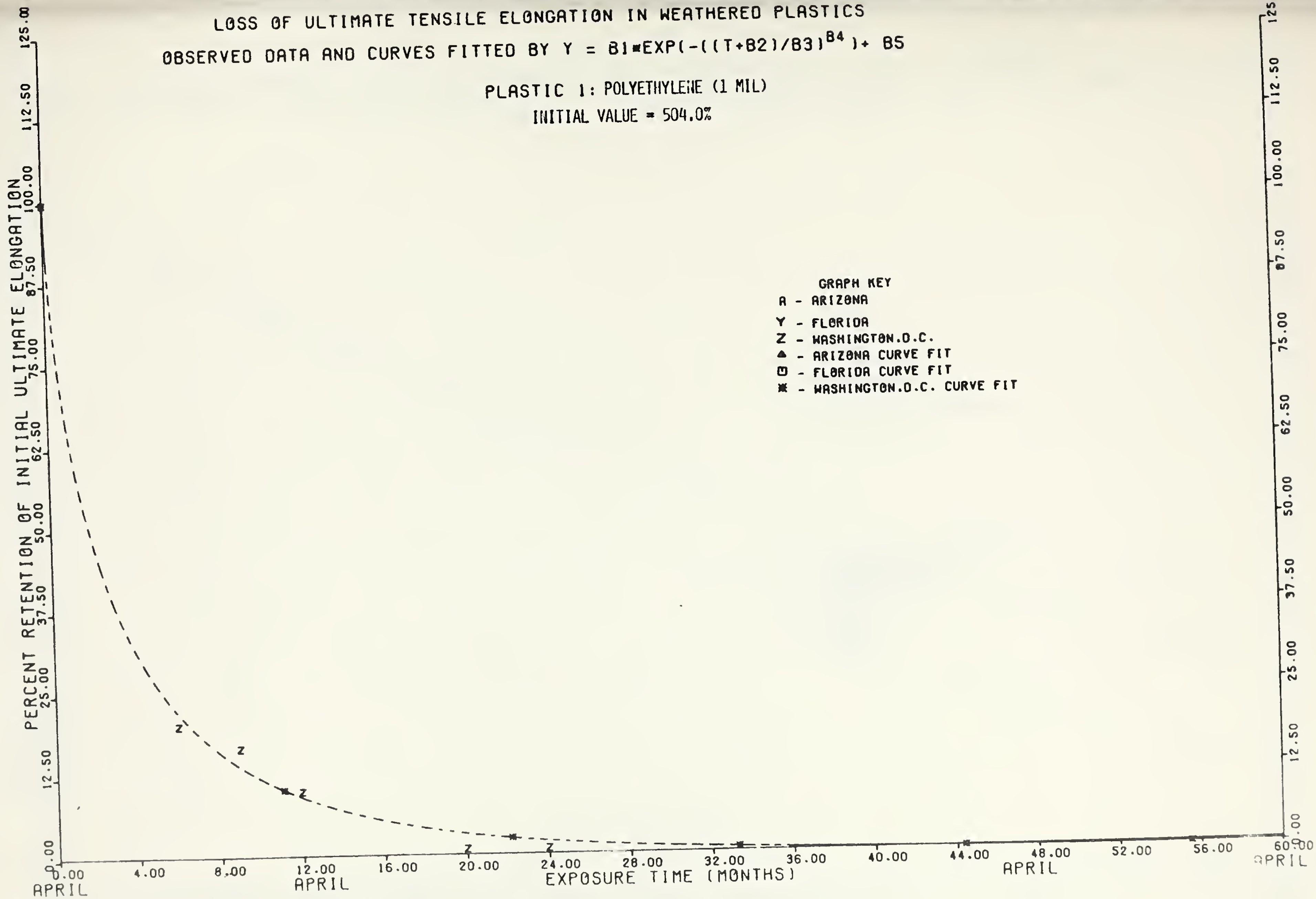
The graphs on the following pages present observed measurements of ultimate tensile elongation as a function of outdoor-exposure time in Arizona, Florida and Washington, D. C. The curves were fitted by non-linear regression to 3 years of data as explained in NBS Report #10 116. Thus, the 5-year behavior is quantitatively forecasted from 3-year observation.

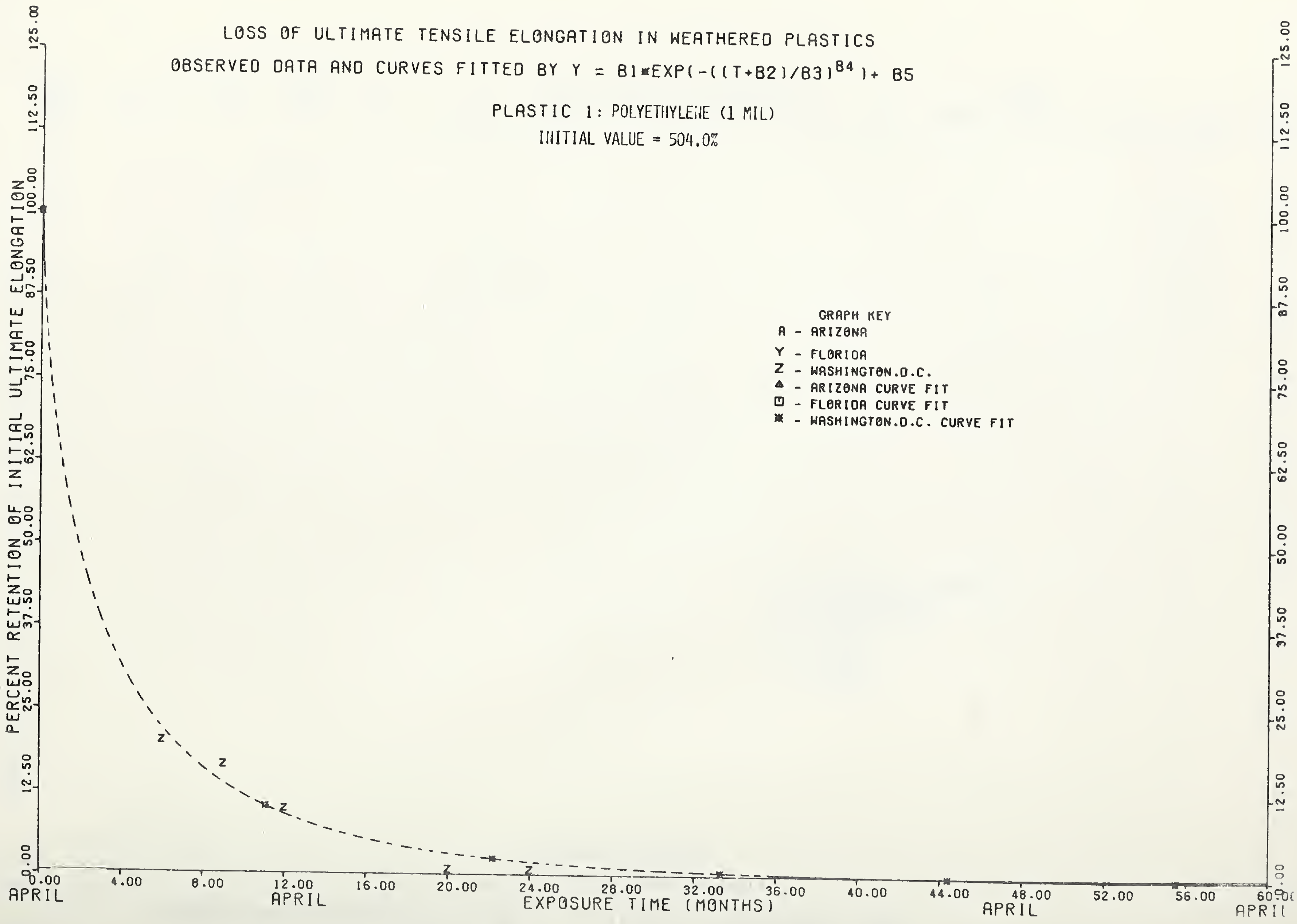
LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS

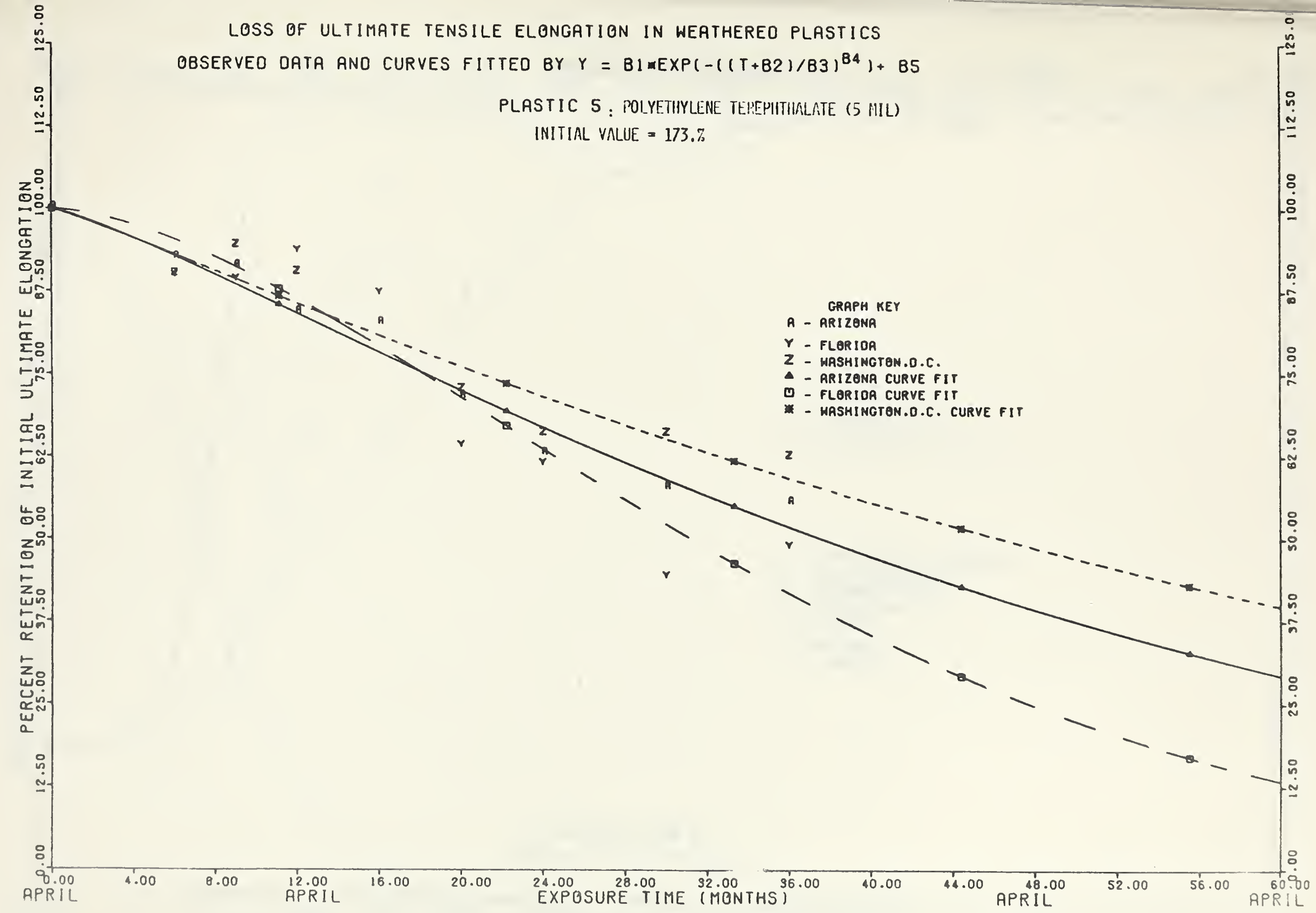
OBSERVED DATA AND CURVES FITTED BY $Y = B1*EXP(-((T+B2)/B3)^{B4}) + B5$

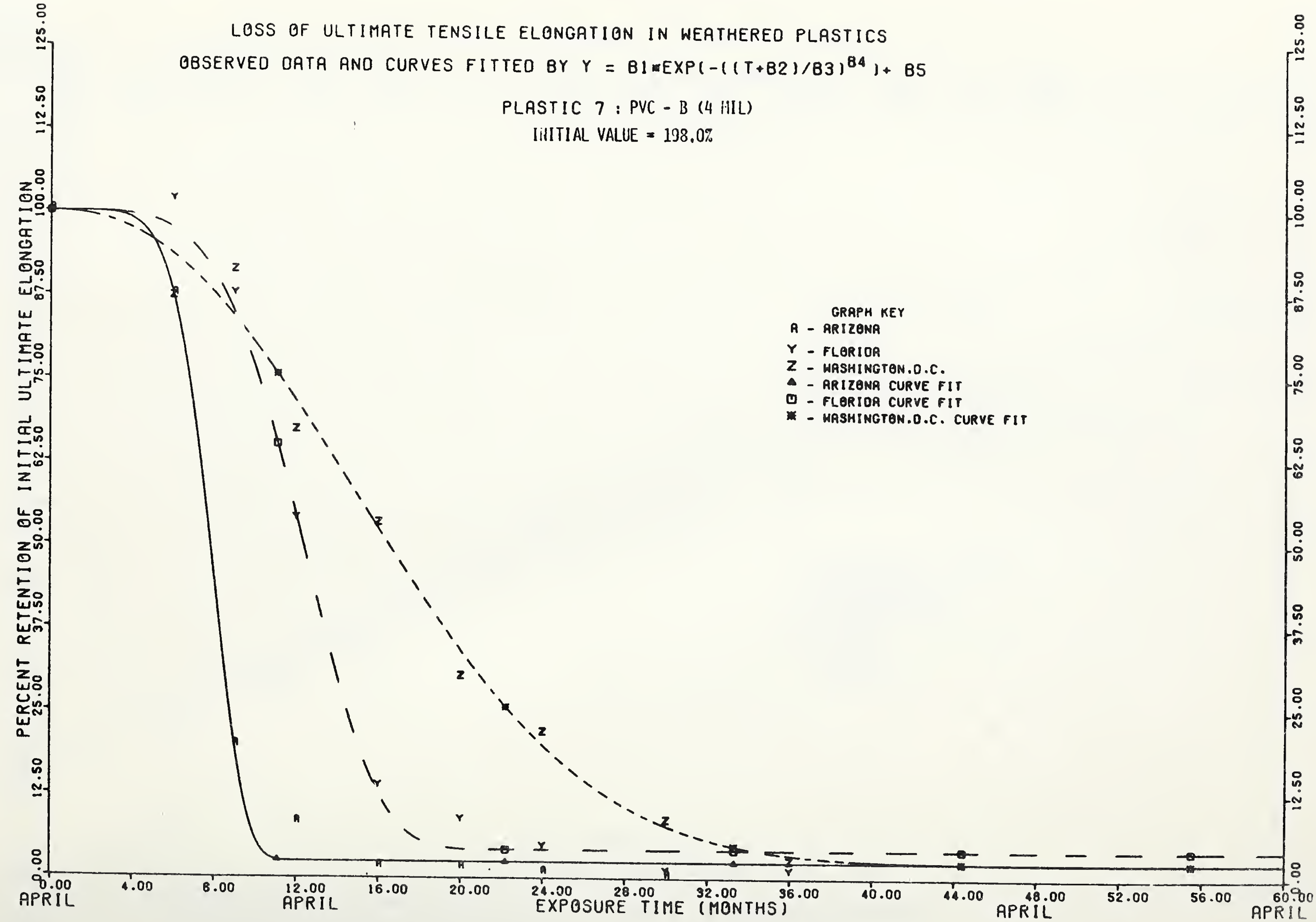
PLASTIC 1: POLYETHYLENE (1 MIL)

INITIAL VALUE = 504.0%




LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 1: POLYETHYLENE (1 MIL)
INITIAL VALUE = 504.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL


LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 5 : POLYETHYLENE TEREPHTHALATE (5 MIL)
INITIAL VALUE = 173.%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
□ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL
EXPOSURE TIME (MONTHS)

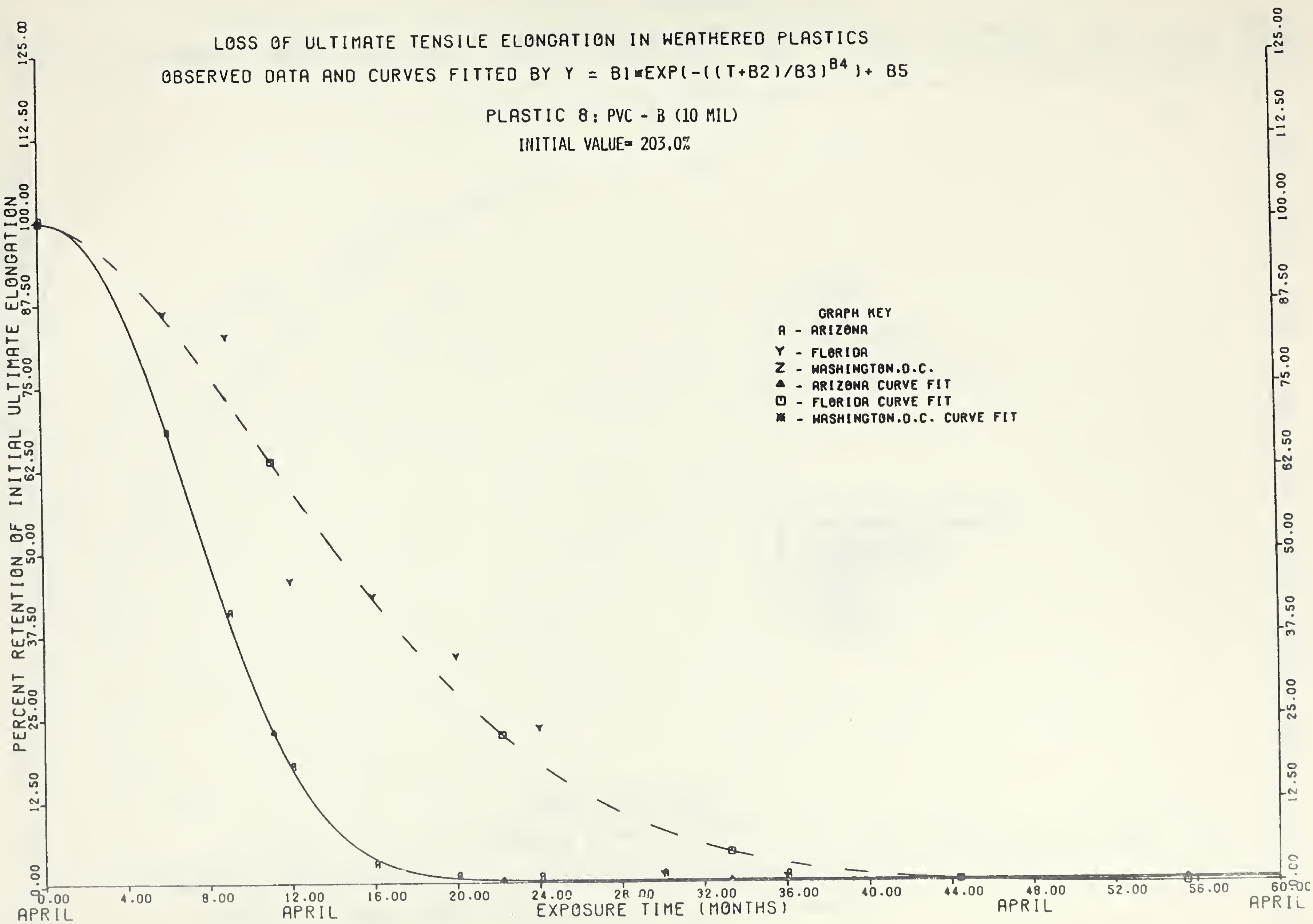

LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 7 : PVC - B (4 MIL)
INITIAL VALUE = 198.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
▢ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL

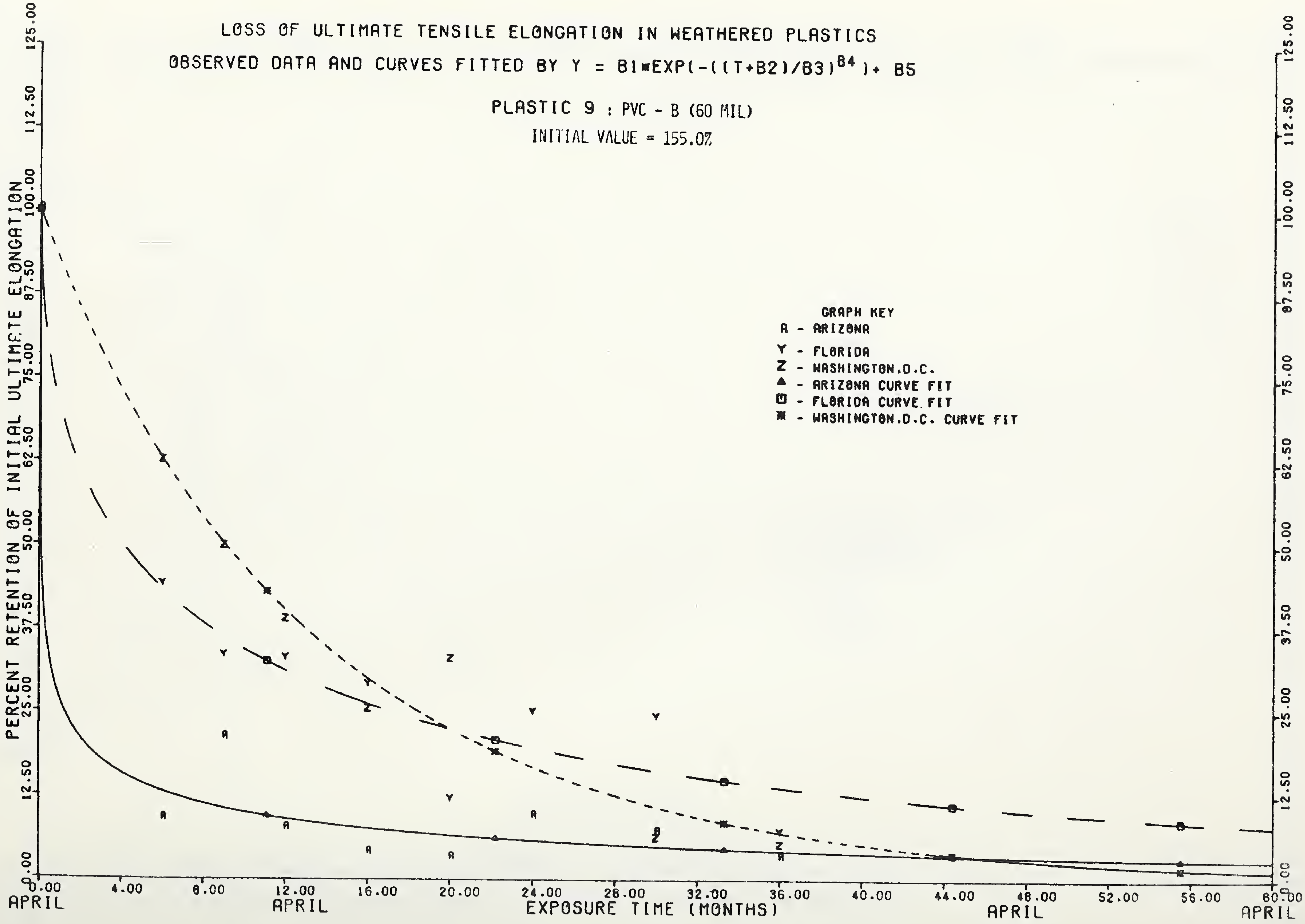
LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS

OBSERVED DATA AND CURVES FITTED BY $Y = B1*EXP(-((T+B2)/B3)^{B4}) + B5$

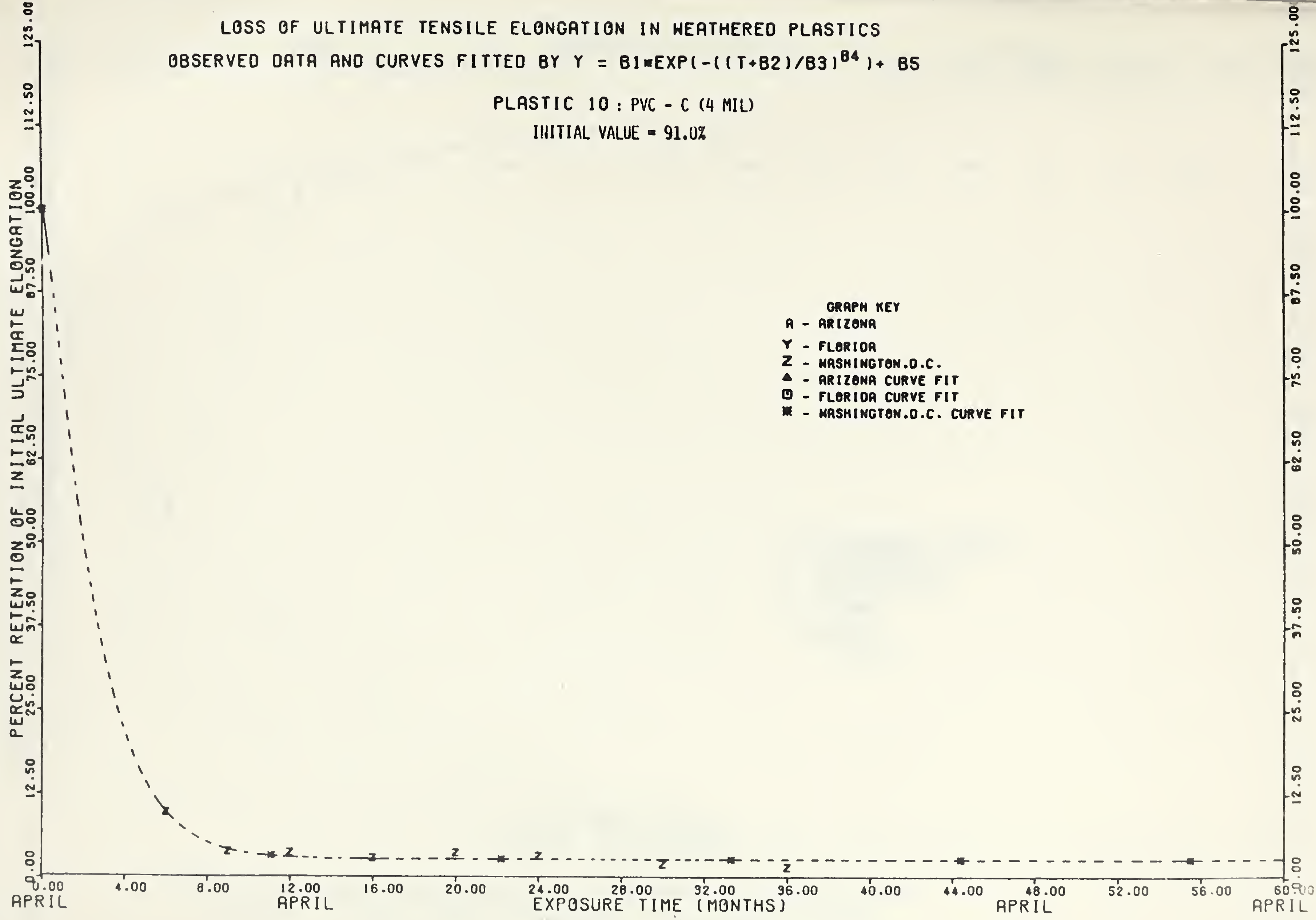
PLASTIC 8: PVC - B (10 MIL)

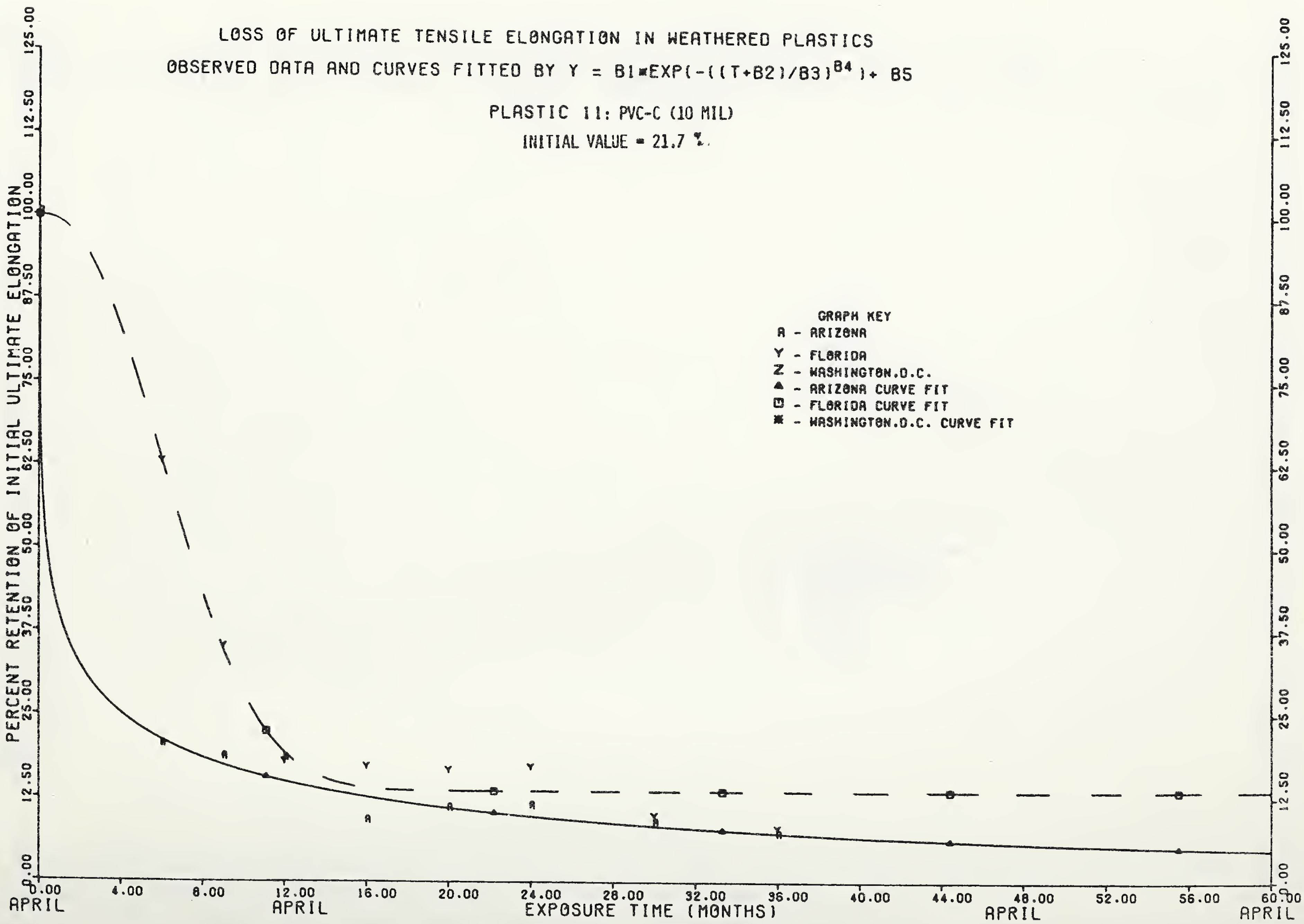
INITIAL VALUE= 203.0%





LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 9 : PVC - B (60 MIL)
INITIAL VALUE = 155.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
EXPOSURE TIME (MONTHS)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL


LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 10 : PVC - C (4 MIL)
INITIAL VALUE = 91.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL
EXPOSURE TIME (MONTHS)



LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 11: PVC-C (10 MIL)
INITIAL VALUE = 21.7 %
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
APRIL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
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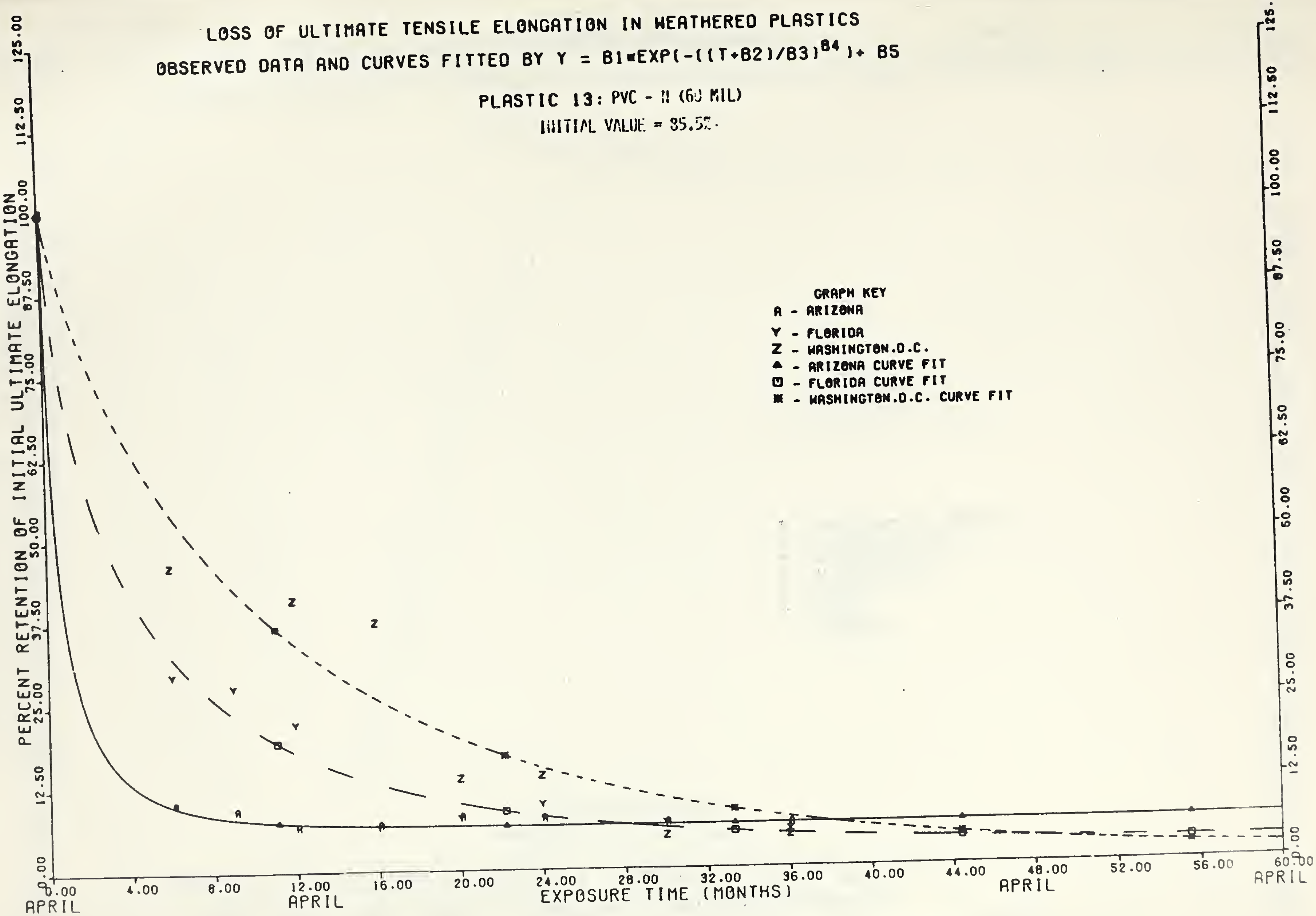
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00


LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 13: PVC - II (60 MIL)
INITIAL VALUE = 85.5%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
◻ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
APRIL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
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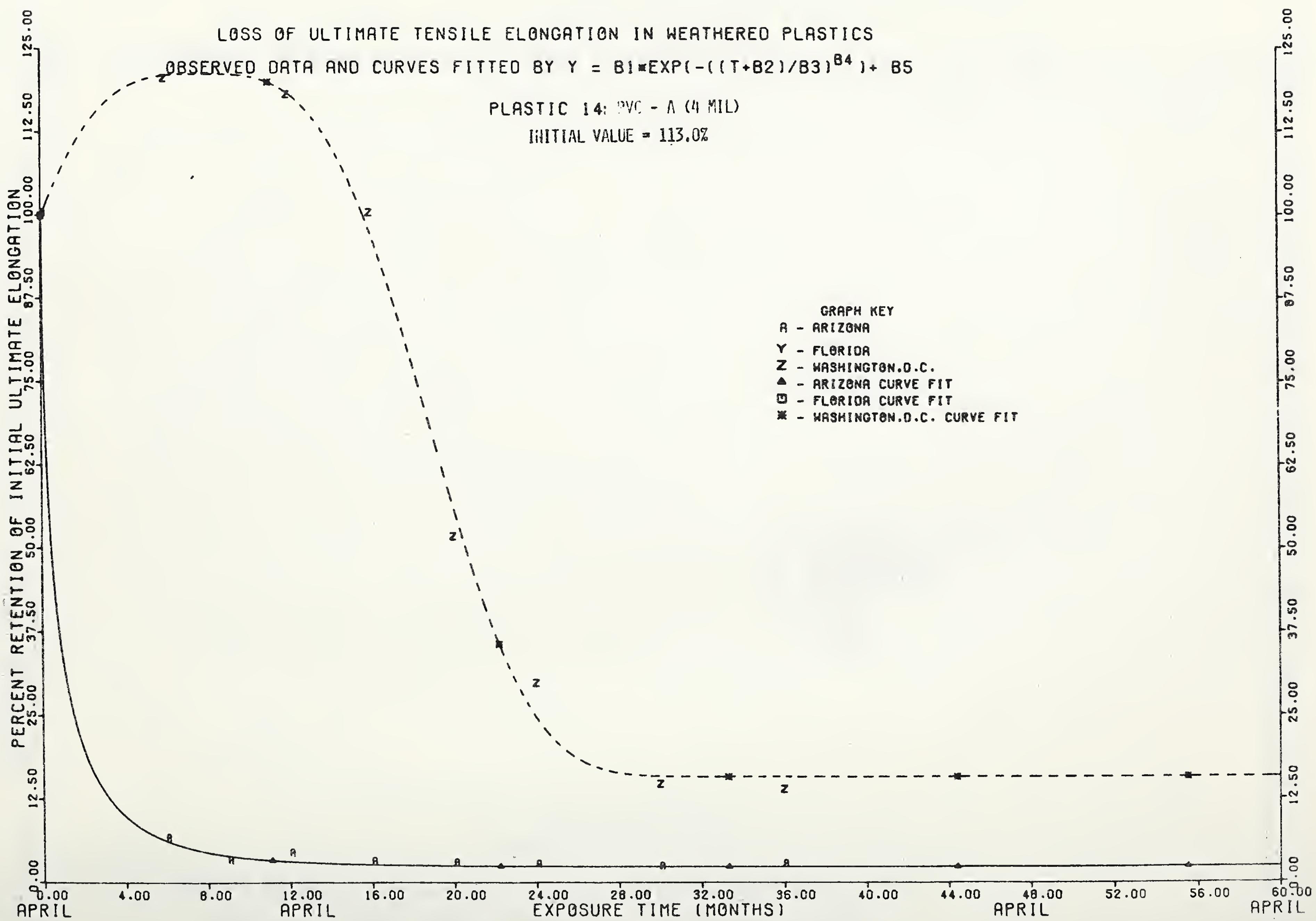
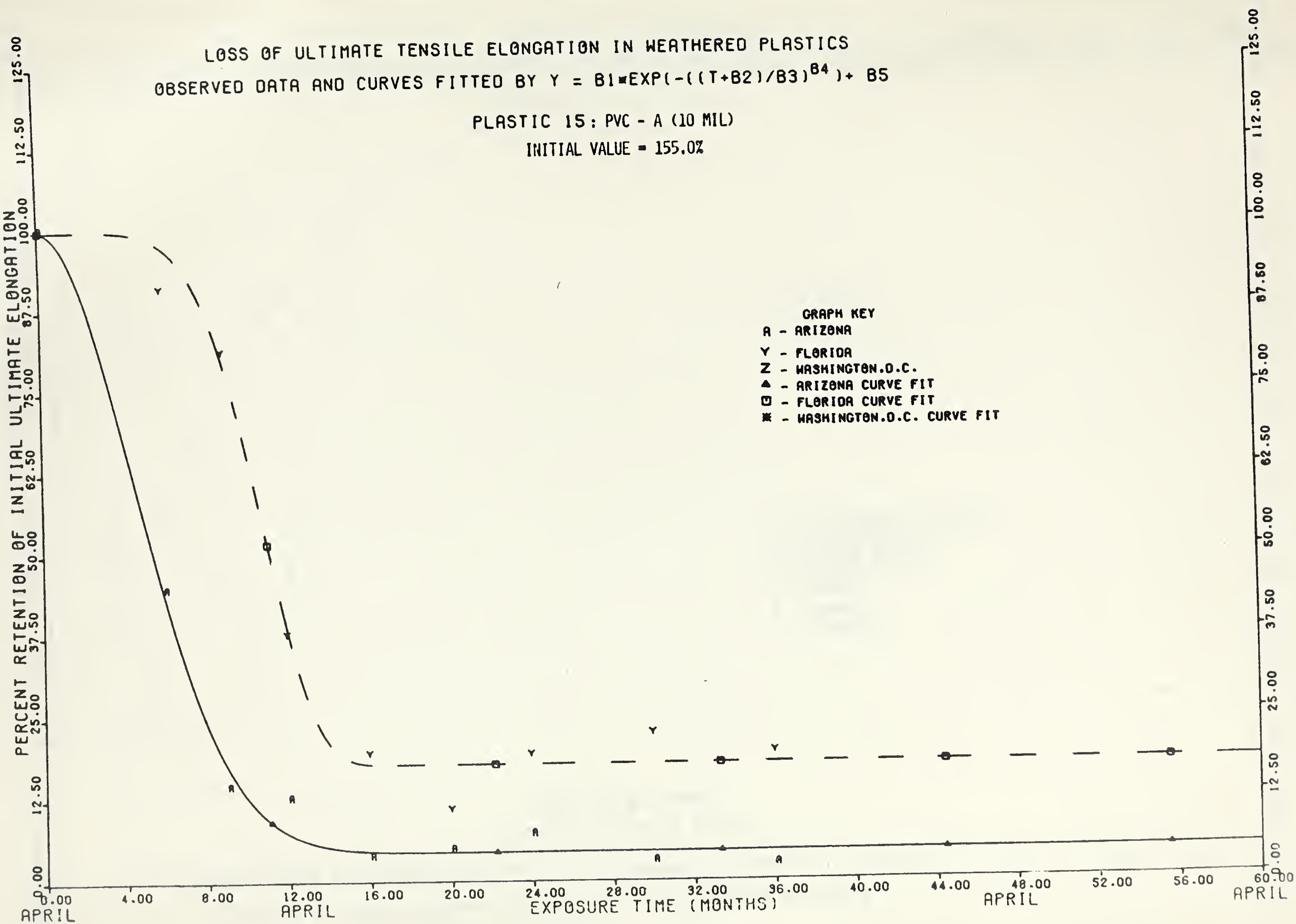
100.00
112.50
125.00



LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 14: PVC - A (4 MIL)
INITIAL VALUE = 113.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON,D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON,D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL
EXPOSURE TIME (MONTHS)


LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 15: PVC - A (10 MIL)
INITIAL VALUE = 155.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
▣ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
APRIL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
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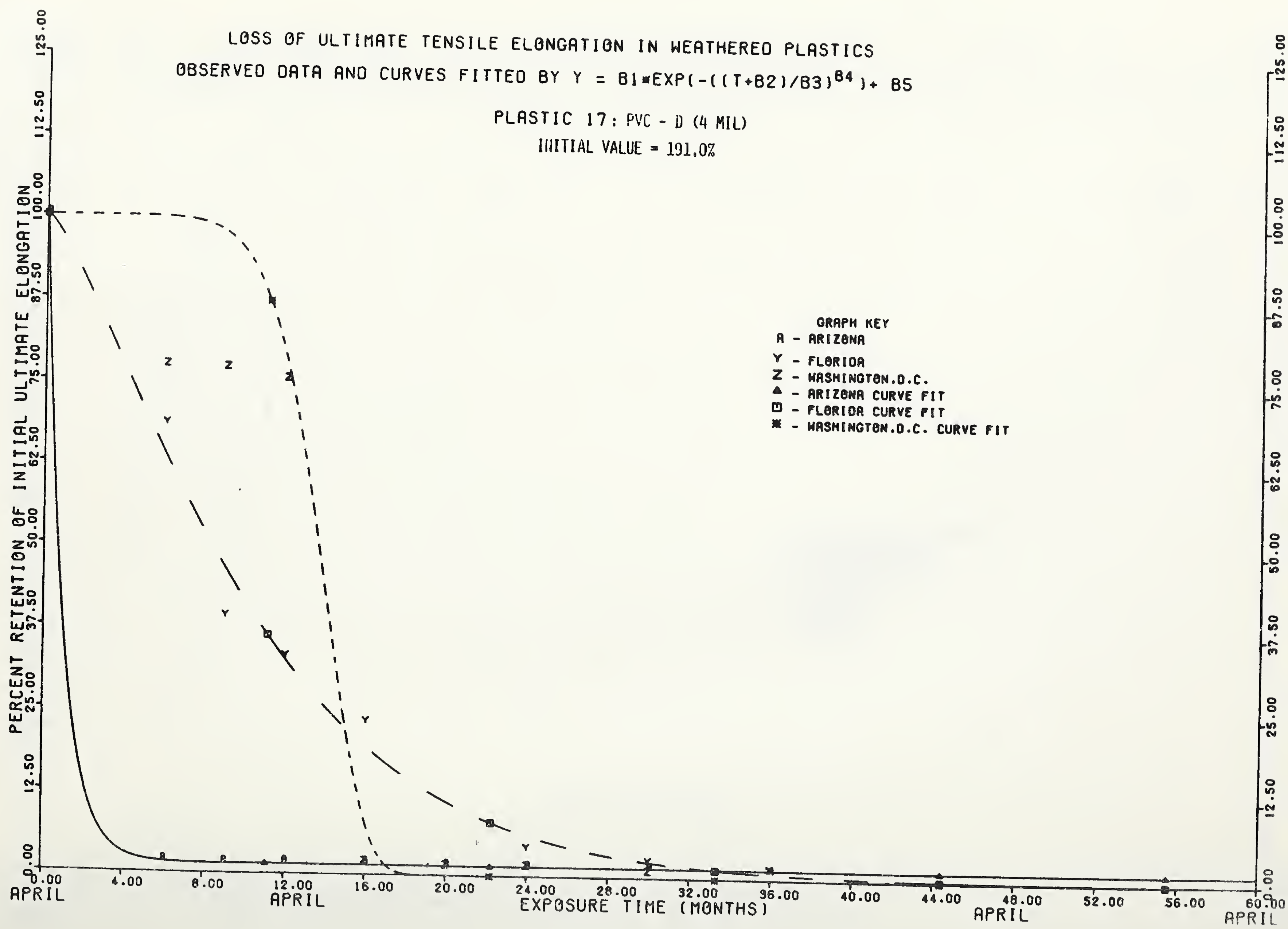
100.00
112.50
125.00



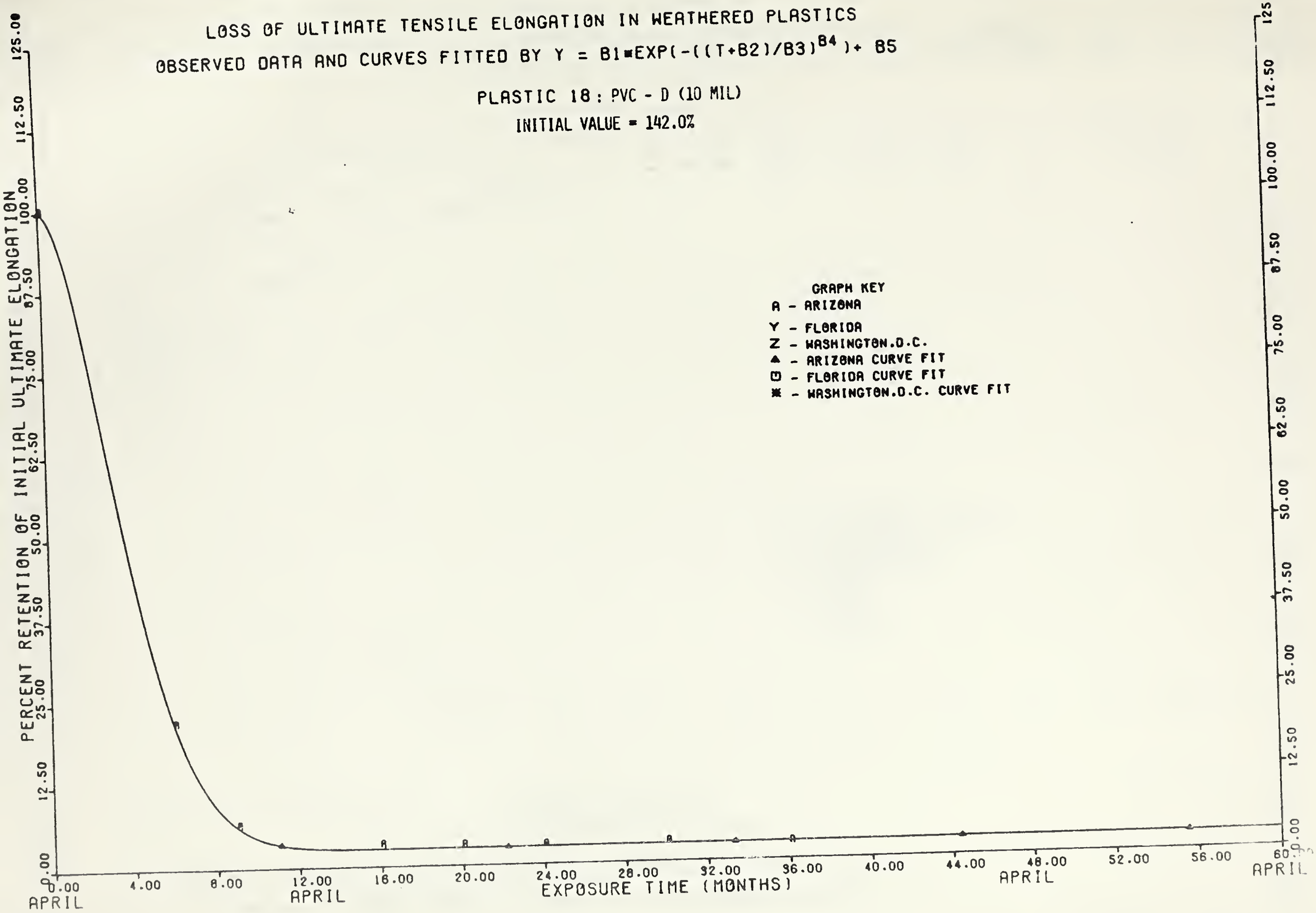
LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 17: PVC - D (4 MIL)
INITIAL VALUE = 191.0%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON.D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON.D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
EXPOSURE TIME (MONTHS)
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
APRIL
APRIL

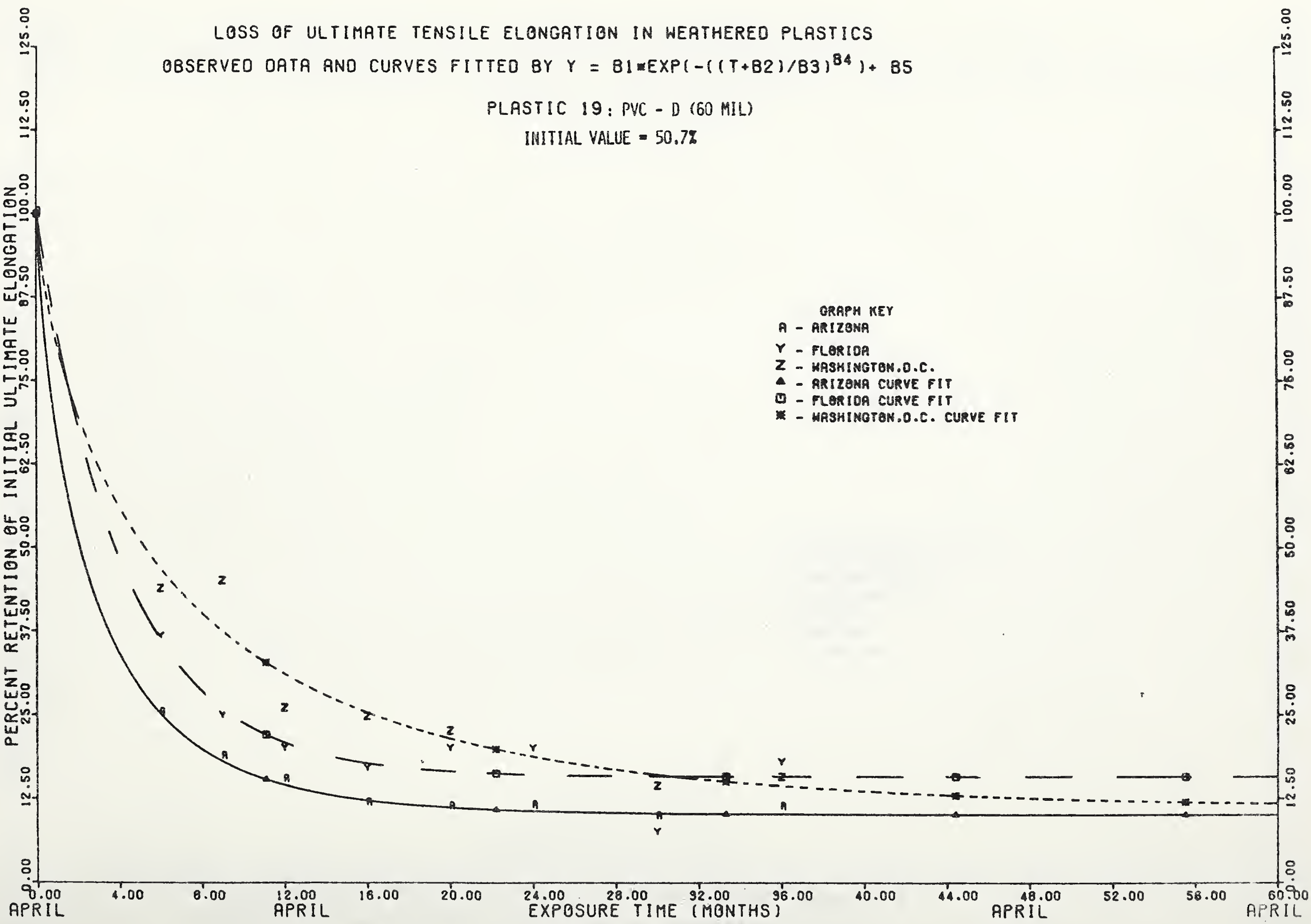
LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS

OBSERVED DATA AND CURVES FITTED BY $Y = B1*EXP(-((T+B2)/B3)^{B4}) + B5$

PLASTIC 18 : PVC - D (10 MIL)

INITIAL VALUE = 142.0%





LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS
OBSERVED DATA AND CURVES FITTED BY Y = B1*EXP(-((T+B2)/B3)^B4)+ B5
PLASTIC 19: PVC - D (60 MIL)
INITIAL VALUE = 50.7%
GRAPH KEY
A - ARIZONA
Y - FLORIDA
Z - WASHINGTON,D.C.
▲ - ARIZONA CURVE FIT
⊡ - FLORIDA CURVE FIT
✱ - WASHINGTON,D.C. CURVE FIT
PERCENT RETENTION OF INITIAL ULTIMATE ELONGATION
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
112.50
125.00
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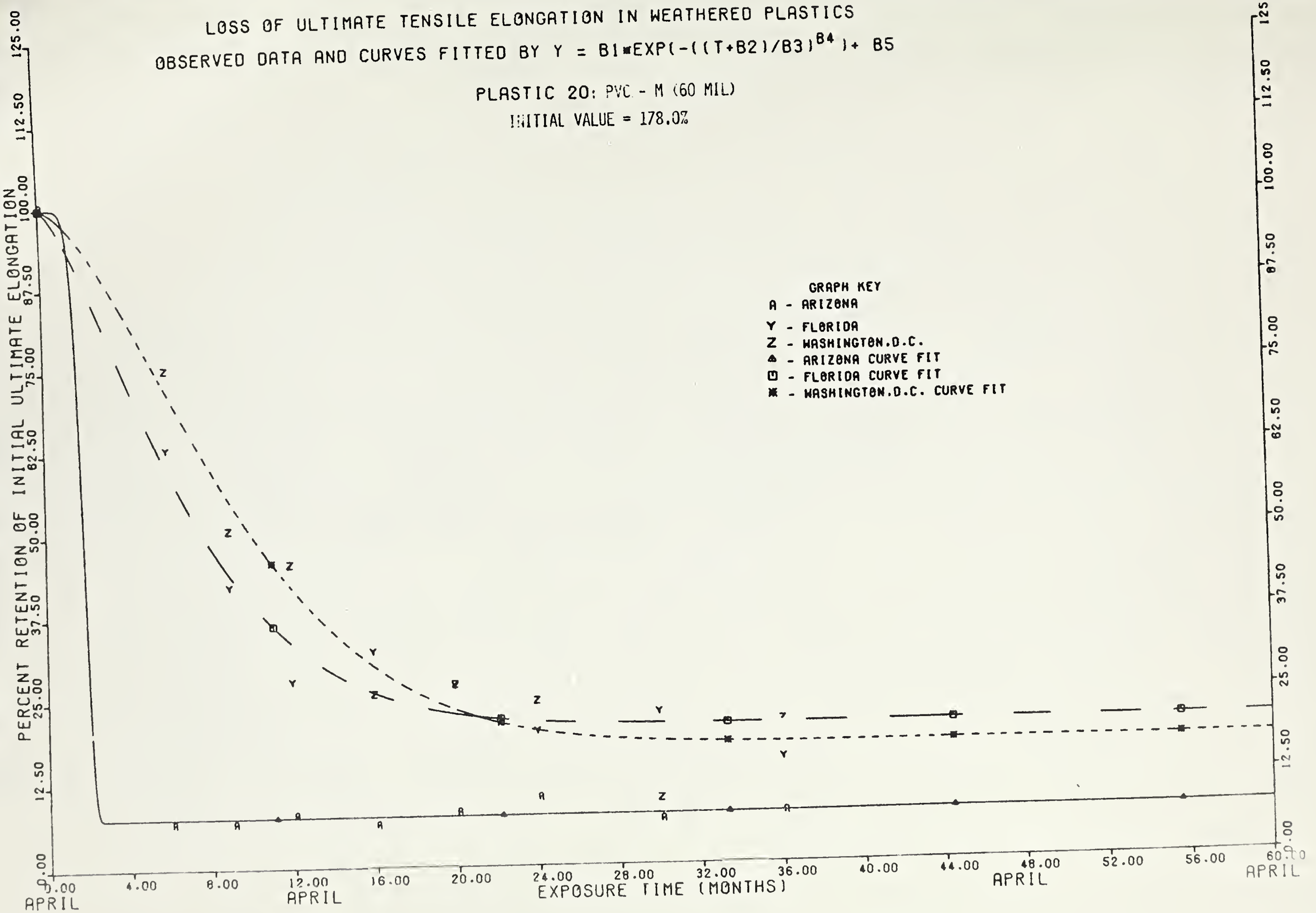
44.00
48.00
52.00
56.00
60.00
APRIL
APRIL
EXPOSURE TIME (MONTHS)
APRIL
APRIL

LOSS OF ULTIMATE TENSILE ELONGATION IN WEATHERED PLASTICS

OBSERVED DATA AND CURVES FITTED BY $Y = B1*EXP(-((T+B2)/B3)^{B4}) + B5$

PLASTIC 20: PVC - M (60 MIL)

INITIAL VALUE = 178.0%



DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS