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GEORGE C. MARSHALL SPACE FLIGHT CENTER

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VACUUM COMPATIBILITY OF ENGINEERING MATERIALS (SOLIDS)

By

J. B. Gayle, S. V. Caruso, and C. T. Egger

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ABSTRACT

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The effects of vacuum and elevated temperature on 54 solid materials are reported; similar results for liquids and semi-solids will be reported separately. Although the extrapolation of laboratory results to service conditions has not been demonstrated, preliminary results discussed herein suggest that such extrapolations are possible, at least for some materials.

Other preliminary results indicate that weight regains on exposure to air subsequent to vacuum testing are small for most materials and are not influenced by the temperature used for the vacuum test. Good correlation of total weight loss generally was noted for results with continuous weighing in standard vacuum systems and those for screening tests utilizing before-and-after-weighing from a vacuum oven. However, the screening tests provide little information regarding the rate of weight loss, and it was noted that some materials appear to undergo oxidation and, consequently, gain in weight during tests at elevated temperatures when the pressure in the test chamber is of the order of 10^{-1} to 10^{-2} Torr.

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MATERIALS DIVISION
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONCLUDED)

LIST OF TABLES

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MTP-P&VE-M-63-11

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INTRODUCTION

Vacuum compatibility is a major factor influencing the selection of materials for launch and space vehicle applications. Many materials lose weight when exposed to reduced pressure. Both the extent of this loss and any corresponding changes in material properties depend on a number of factors, including the temperature and radiation levels to which the material is subjected, as well as its chemical, physical, and mechanical characteristics. For this reason, specifications for acceptance or rejection of materials for space applications should take into account the environmental conditions associated with the intended application.

Weight loss is not an unambiguous criterion for selection of materials for space environments. For example, a grease may evaporate to a considerable extent but continue to function satisfactorily; on the other hand, some materials, such as potting compounds, may suffer only negligible weight losses while undergoing surface changes which could cause malfunction of either the particular component or some related component. It should be noted that materials which are susceptible to oxidation may perform more satisfactorily in vacuum than in air at normal atmospheric pressure. In any event, knowledge of the rate and extent of weight loss in vacuum together with information obtained by visual examination of the samples before and after testing can be used for preliminary screening, thus reducing the number of materials which must be subjected to altitude simulation tests in hardware configurations.

A program for testing the compatibility of materials in vacuum was initiated in the Engineering Materials Branch in 1959. The equipment used for this investigation, the test procedures, and limited results obtained for a number of materials have been discussed in previous reports (Ref. 1 and 2). This report presents additional results obtained for a variety of solid materials. Results for liquid and semi-solid materials will be presented in a separate report.

EXPERIMENTAL

STANDARD PROCEDURE WITH CONTINUOUS OR INTERMITTENT WEIGHING IN VACUUM

Three vacuum systems, designated 4A, 4B, and 4D, were used. All systems used 4-inch diffusion pumps and differed primarily in the degree of automatic operation and type of balance. Both weighing and pumping operations for the 4A system were manual. The 4D system (FIG 1) had an automatic balance and manually operated pumping equipment. Both weighing and pumping operations for the 4B system were automatic. The latter two systems were equipped with ceramic ovens (FIG 2) for elevated temperature experimentation.

An effort was made to standardize on circular samples approximately 5/8-inch diameter by 3/16-inch thick, but such factors as balance weight limitations, available sample configurations, and sample density resulted in the wide variations in size and shape noted in the tables. All samples were desiccated for 24 hours before being weighed and placed in the vacuum chambers.

Two types of balances were used for each run: an ordinary analytical balance for before-and-after weighing, and a Cahn magnetic electrobalance (FIG 3) for weighing in vacuum. In the 4B and 4D systems, the automatic balances provided continuous recording of weight. In the 4A system, the balance was operated manually. Most room temperature (R. T.) runs were made on this system, since it was not fitted with an oven and manual weighing was best suited for tests involving minimum weight loss. The zero settings and calibrations of the balances were checked between runs. By placing

thermocouples at various locations in the bell jar, it was determined that heating was confined largely to the ovens; consequently, thermal effects on the balances were small.

After a sample was placed in the vacuum chamber, a pressure of less than 10^{-4} Torr was achieved in approximately one hour, and then, when applicable, the specimen was heated to the selected test temperature in 15-30 minutes. Ultimate pressure in all cases was less than 10^{-5} Torr. Temperatures were governed by maximum anticipated service temperature, by the approximate upper temperature limit (for use in air) specified by the manufacturer, or by arbitrary selection.

In most instances, runs were terminated when the sample attained constant weight or exhibited less than 0.1 mg weight change in any eight-hour period. After cooling to room temperature, the specimens were removed from vacuum and weighed on the analytical balance.

This procedure has been described in somewhat greater detail in a previous report (Ref. 1). Experience has indicated that variations due to weighing errors and other causes normally do not exceed 0.3 milligrams. The corresponding percentage errors based on sample weights used in this investigation ranged from 0.9 to 0.01. Changes less than this value, therefore, were not considered significant.

SCREENING PROCEDURE WITH WEIGHING BEFORE AND AFTER EXPOSURE TO VACUUM

Groups of samples of approximately 20 materials were spaced on approximately 1.5-inch centers on a screen and placed in a one cubic foot vacuum oven. This oven was fitted with a mechanical pump capable of achieving an ultimate pressure of 10^{-1} to 10^{-2} Torr and had a conventional temperature control system. No precaution was taken to preclude cross-contamination of individual samples by gaseous constituents evolved from other samples. Samples were weighed on an analytical balance prior to placing them in the vacuum ovens, exposed for periods of approximately five days, cooled to room temperature while

still evacuated, removed to a desiccator, weighed, returned to the oven for an additional five-day period, and so on until weight losses became negligible.

Next, the samples were allowed to stand in air for several days until they achieved constant weight, after which they were desiccated for 24 hours and reweighed. Any regain in weight resulting from air exposure was taken to represent that portion of the total weight loss associated with moisture and other atmospheric constituents, rather than a loss of the material itself.

DISCUSSION

RESULTS OF STANDARD WEIGHT LOSS DETERMINATIONS

For convenience in discussion, results for the various materials have been divided into several groups.

1. Elastomers

Tests were carried out on 17 elastomeric materials. Some of these were obtained from commercial manufacturers; others were prepared in the Rubber and Plastics Section of this Branch. Specimens consisted of 1.588 cm diameter discs cut from 0.178 cm thick sheets, except for the fluorinated silicone elastomer (RA-27760) and Viton-B (a-495-VA) which were slightly thicker. Tests were carried out at two to four temperatures, ranging from room temperature to 150° or 200°C, depending on the approximate upper service limit recommended for the material. The results are summarized in Table 1 and presented graphically in FIG 4 through 20.

Table 1 lists the elastomers in increasing order of total percent weight loss at 100°C. In those cases in which the 100°C results did

not differ significantly, the 150° or 200°C results were used to establish the ranking. Inspection of the data indicates that the order of listing would not have changed greatly if results for some other temperature, for example 150°C, had been used as the basis for ranking.

FIG 4 through 20 illustrate the influence of temperature on the rate and extent of weight loss for each material. In general, the relationship is distinctly nonlinear, indicating the complex nature of the physical and chemical processes responsible for the loss of weight. The complexity of these processes is further indicated by the increases in total weight loss generally accompanying increases in temperature. These increases are suggestive of threshold temperatures corresponding to decomposition and/or evaporation of individual components of the various elastomers.

Because the results are dependent not only on the properties of the principle or characterizing component of each material, but also on any filler and/or plasticizing components which may be present, attempts to draw general conclusions regarding various types of elastomers should be undertaken with caution.

2. Plastics

Tests were carried out on six plastic materials. Except for the polyvinyl chloride film, all of the plastics were obtained from commercial manufacturers. Specimens varied widely in surface area, thickness, and weight, depending somewhat on the expected application for each material. Tests were carried out at two or three temperatures, generally room temperature, 100°C and 200°C. The results are summarized in Table 2 and FIG. 21 through 26. Results for polyvinyl chloride film are before-and-after weighings only, and the dashed curve represents the estimated weight history.

Table 2 lists the plastics in increasing order of percent weight loss at 100°C. Most of the total weight losses at this temperature failed to exceed appreciably the normal experimental variations associated with the determination. However, polyvinyl chloride film lost 3.41 percent at room temperature and 18.6 percent at 100°C and, therefore, exhibited trends similar to those noted for the elastomers discussed previously.

FIG 21 through 26 illustrate the influence of temperature on the rate and extent of weight loss for each plastic. Because of the wide variations in the physical dimensions of the various samples, comparisons of the different materials should be undertaken with caution. However, it should be noted that Teflon TFE, Mylar, and the polyimide tape were substantially unaffected under the conditions of the tests. Conversely, polyethylene melted at 100°C (as expected), and the polyvinyl chloride film and polyamide film lost significant weight at this temperature. The polyvinyl chloride film also exhibited surface cracking and decomposition. A sample of Mylar exposed to vacuum at 200°C for four hours melted without apparent decomposition.

3. Reinforced or Laminated Plastics

Seven materials were tested in this category. The Conolon 506 fiberglass laminate and Mobaloy AH-81 were tested (as 1.59 cm diameter discs approximately 0.04 cm thick) by continuous weighing in the usual manner. The other materials were tested as 2.54 cm square sheets, 0.318 cm thick, with the weight losses being determined by removing the samples from the system at appropriate intervals for weighing on an analytical balance. The results are summarized in Table 3 and presented graphically in FIG 27 through 33.

In general, weight losses at 100°C were small, and, except for slight darkening of the fiberglass laminate, no change in physical appearance was noted at this temperature.

4. Electrical Insulating Materials

Tests were made on a number of different types of electrical insulating materials. The specimens varied widely in size and shape due to variations in the physical characteristics of the material received for testing. The results are summarized in Table 4 and presented graphically in FIG 34 through 40.

Several varnish-coated magnet wires were tested to determine the effects of the test conditions on the integrity of the varnish coating. Because the distribution of total sample weight between the wire and the coating was not known precisely, calculations of percentage weight loss were not made, and graphs of the data were not prepared. However, visual inspection of the specimens after testing indicated that the coatings were substantially unaffected by the test conditions used.

One of three electrical tapes lost approximately two percent by weight at 90°C; whereas, the other two lost approximately four percent at this temperature. Inspection of the samples after testing indicated no visible change. However, before-and-after manual peeling indicated that the adhesion of the tapes exhibiting the greatest weight loss improved somewhat during the vacuum exposure.

Two types of polyolefin tubing were tested (one type in the three colors available from the manufacturer). Weight losses ranged from 12.3 to 16.4 percent at approximately 150°C. The close agreement between losses for the three colors of MS-7308 tubing is indicative of the reproducibility of test results.

5. Miscellaneous Materials

Included in this category are a variety of materials which were not tested in sufficient numbers to warrant separate discussions. The results are summarized in Table 5 and presented graphically in FIG 41 through 53.

The two epoxy-based materials were not affected appreciably by vacuum exposure at 100°C. However, it was noted that some delamination occurred when the copper-clad glass epoxy was tested at 200°C.

Results for the two lithium alloys were unusual in that each gained a small amount (approximately 0.5 percent) of weight, probably due to a gettering effect. Consistent with this view, a dull-gray, water-soluble surface layer which formed during the tests was qualitatively identified by X-ray diffraction as a mixture of the oxides and nitrides of the alloy constituents.

Weight losses for the four inorganic papers ranged from 4 to 8 percent and were not greatly dependent on the test temperatures. This suggested that most of the weight loss consisted of moisture and was confirmed by the fact that the samples regained most of the loss on exposure to normal temperature and humidity prevailing in the laboratory.

Also included in the tables and figures are results for two foam-type materials, one conductive gasket material, one lacing tape, and one nylon tying cord.

6. Samples of Buna-N Rubber Having Varying Size and Surface Area

The extrapolation of laboratory results to hardware applications should always be undertaken with caution. In the present instance, this is particularly important because the mass and shape of material required for a particular application usually will differ tremendously from that for samples used for testing, and because no adequate correlation of weight loss with the physical characteristics of the sample has been established.

To obtain preliminary information on this problem, a batch of Buna-N rubber was compounded and molded into sheets of 0.1", 0.2", 0.3", 0.4", and 0.5" thicknesses. Specimens representing a range of surface-to-volume ratios then were cut from each sheet and exposed to vacuum at 100°C, the weight losses being determined in the usual manner.

The results are summarized in FIG 54. The first sample exhibited a total weight loss of 7.72 percent after 70 hours. The other samples were not carried to completion because of the excessive amounts of time required. However, tests on a duplicate set of samples were carried out using intermittent weighing; the results (not shown) indicated that, for this material, the total percentage weight loss was independent of moderate variations in sample size and shape.

It would be expected that the amount of time required to effect a given percentage weight loss would be directly proportional to some function of sample weight and inversely proportional to some function of surface to volume ratio. If these functions are assumed to be linear, and if volume is equated to weight/density, the times required for effecting a given percentage weight loss would be directly proportional to the ratio, $\text{weight}^2/\text{surface area}$.

To test the applicability of this relation, it was used to calculate weight loss curves for hypothetical samples in the form of a centimeter cube from the weight loss data for each of the experimental samples. The results are presented graphically in FIG 55. The seven curves fall very nearly one upon the other, thus demonstrating that, for the range of sample sizes and shapes used, the correlation is adequate.

The expected and observed dependence of rate of weight loss on mass and area emphasizes the need for complete description of specimens,

including all dimensions. While total weight loss, assuming ultimate achievement of near-equilibrium conditions, should be independent of configuration for a given material, rigorous comparisons of weight loss rates are possible only for specimens having complete geometric identity.

Adequate scaling parameters for valid comparisons of various sizes and shapes of different materials have yet to be determined. Although a preliminary correlation has been established, it is reasonable to expect that diffusivities, evaporation rates and evaporation coefficients, surface roughness, and the orientation and size of various surfaces of anisotropic materials may be important and should be considered.

RESULTS OF SCREENING TESTS

Preliminary inspection of the total weight loss results of the screening tests showed good correlation with those obtained in the standard (continuous weighing) tests except for three materials (heat shrinkable tubing, plastic tubing, and polyurethane) for which the weight losses in the screening tests were appreciably smaller. To obtain additional information regarding these apparent discrepancies, both screening and standard tests were repeated; the results showed that these particular materials had undergone changes during storage (three to 18 months between the two types of tests) which markedly decreased the weight losses sustained during exposure to test conditions. Undoubtedly, some of the other materials underwent similar but less marked changes which are too small to be detected and, therefore, are reflected only in the scatter of the data. These results emphasize the importance of documenting the past history of all test specimens.

Inspection of the raw data also indicated that oxidation of some samples probably took place during tests at 150°C. Specifically, the results indicated that several materials gained weight at a significant rate (> 0.1 mg/day) during the latter portion of the tests. Although this phenomenon was masked by the loss in weight due to evaporation and/or thermal decomposition during the initial portion of the tests, it appears likely that oxidation began as soon as the samples reached the test temperature and continued throughout the remainder of the tests.

Calculations of oxygen availability, based on the measured pressures and leak rates for the vacuum ovens, indicated the presence of a

sufficient quantity to permit oxidation to take place at a much faster rate than that required by the measured gain in weight. This effect also doubtlessly contributed to the deviations of the screening test results from those obtained in the regular vacuum systems where the pressures were sufficiently low to preclude appreciable oxidation of the samples.

Another possible source of error in the screening test results arises from the simultaneous testing of numerous samples of different materials in a single oven. However, for the same widely accepted reasons that material evaporating from a given sample is not expected to return to that sample when the pressure in the test chamber is low, material evaporating from any given sample would not be expected to contaminate other samples appreciably.

Results of screening tests for 14 elastomers, 7 electrical insulating materials, and 6 miscellaneous materials tested at one or more temperatures are plotted against comparable values obtained by the standard test procedure in FIG 56. Statistical analysis showed the data to be compatible with a straight line with intercept equal to zero and slope equal to unity, or, in other words, to conform to the equation,

$$Y = X$$

where:

Y = weight loss in standard test, percent

X = weight loss in screening test, percent.

The standard error of values computed with this equation, 0.45 percent, does not greatly exceed the expected experimental variations inherent in the test method. The correlation coefficient, 0.98, indicates excellent agreement between results obtained in the two tests despite the cross contamination and other differences in test conditions. The close agreement obtained under these diverse conditions indicates that extreme high vacuum may not be required for preliminary compatibility testing of many materials. This finding is consistent with the results of other investigations; however, it should be noted that rates of weight loss for the various pressure levels were not considered in this portion of the study. Extensive work is required to form a more general conclusion as to the merits of soft vacuum or inert gas testing.

In a previous report, Riehl (Ref. 2) showed that some materials regain weight on standing in air after vacuum exposure. This was considered to be due to absorption of moisture and/or atmospheric gases. It was suggested that determination of weight-regain characteristics would be valuable in discerning between actual material loss and simple outgassing of the sample in vacuum. To obtain additional information on this subject, weights of 95 samples (representing approximately 25 materials tested at different temperatures) were determined immediately after completion of the screening tests and compared with the corresponding values determined after the samples had stood in air for several days and had been desiccated for 24 hours. Of the 95 samples, 80 either increased in weight or showed no change; 32 of the weight increases were equal to or greater than the percentage deviations corresponding to a weight change of 0.3 mg, this value being taken to represent the maximum difference which could reasonably be attributed to weighing errors. For the 15 samples which lost additional weight during this treatment, only five weight losses were equal to or greater than the deviations corresponding to a 0.3 mg weighing error. Taken together, these data indicate that for most materials the differences between total and permanent weight losses are small, the average and standard deviation for the 95 values obtained in this investigation being 0.03 and 0.11 percent of original weight, respectively. However, for other materials, such as the inorganic papers mentioned earlier in this report (Table 5), weight-regains may be much larger. Therefore, it appears desirable to determine routinely such values as an adjunct to the standard test procedure.

It appeared possible that elevated temperature tests would remove bound water that would be unaffected by room temperature tests; if this assumption is correct, it would be expected that the tendency to regain moisture would be a function of test temperature. A statistical analysis of the data was carried out to examine this possibility. The study yielded only low correlation coefficients, and thus failed to indicate any significant effect of test temperature on the tendency of different materials to regain moisture on subsequent exposure to the air. However, this result is based on extremely preliminary data and will be confirmed by further testing.

SUMMARY

The rate of evaporation of 54 solid materials in a vacuum environment was determined by both continuous and before-and-after weighing. Tests were made at room temperature, and up to 427°C, as feasible for the material.

Materials tested included seventeen elastomers, six plastics, seven reinforced plastics, eleven electrical insulations, and thirteen miscellaneous types. The latter included two lithium alloys, four inorganic papers, and two organic foams. The weight losses varied from 0.3 mg (limit of detection) up to 39 percent in 20 hours at 150°C.

Preliminary tests with samples of a given material (Buna-N) having various sizes and shapes indicated that the ratio, weight^2/area, was an adequate scaling parameter for correlating weight loss rates for this particular material. It is to be emphasized, however, that the current state of the art permits comparison of rates between materials in general only for specimens which are geometrically identical. Comparisons on other bases must be undertaken with extreme caution.

Because the standard continuous weighing test procedure is time consuming and utilizes equipment over extended periods, a screening procedure was investigated for preliminary testing of materials. Comparison of total weight loss results on 27 materials obtained by a screening procedure (weighing before and after exposure to 0.1 - 0.01 Torr in a vacuum oven) with those obtained by continuous weighing in the standard procedure ($< 10^{-5}$ Torr system) showed that high vacuum may not be required for preliminary testing of many materials. However, in some instances, the partial pressure of oxygen present in the screening test may result in weight gains for easily oxidizable materials.

Weight regains of test samples on re-exposure to air are important in differentiating between actual material losses and losses of moisture and other atmospheric constituents. For materials considered herein, these differences averaged 0.03 percent with a standard deviation of 0.11 percent.

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FIGURE 1. 4D VACUUM SYSTEM

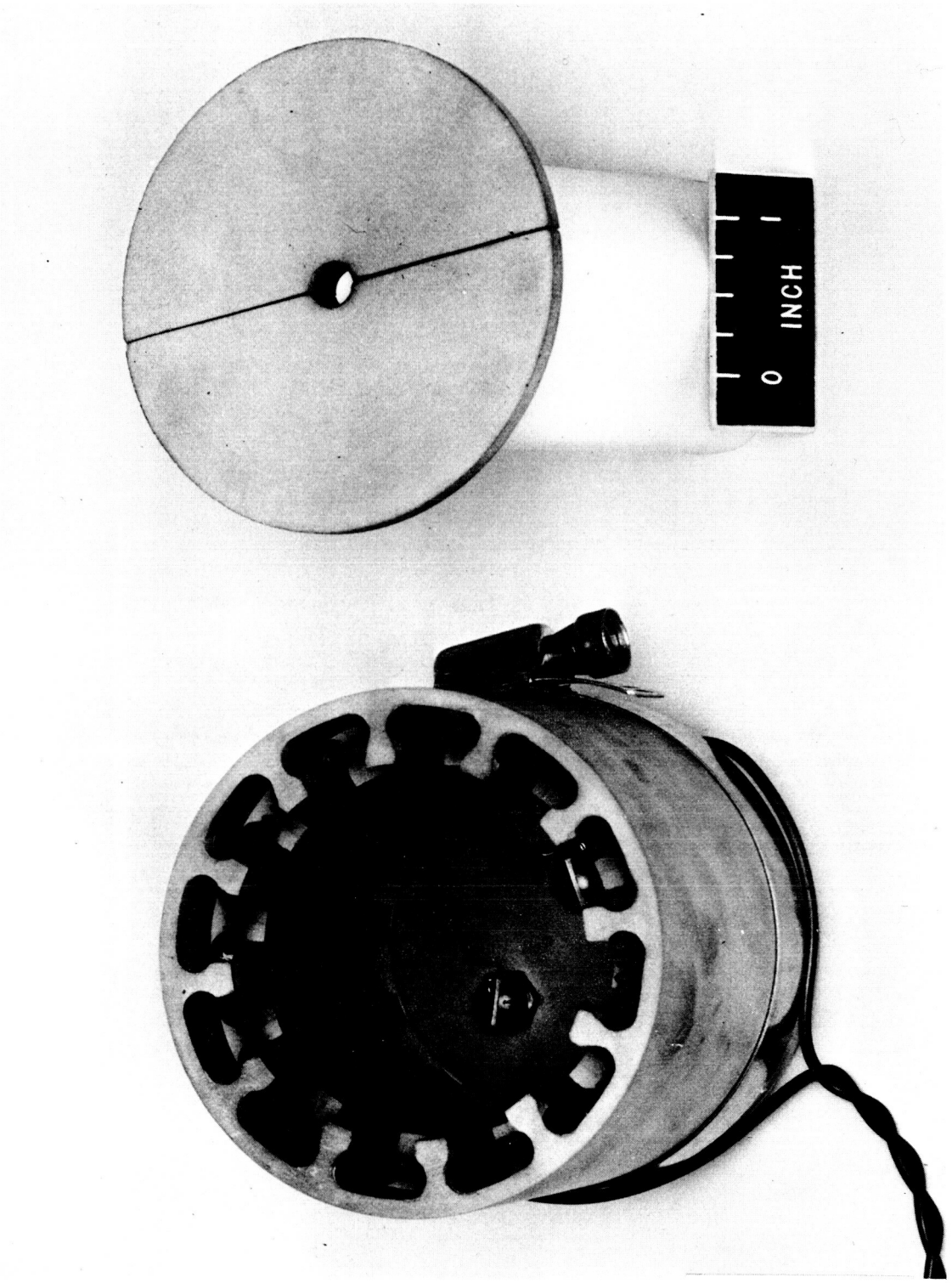

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FIGURE 2. CERAMIC OVEN FOR HEATING TEST SPECIMENS IN VACUUM

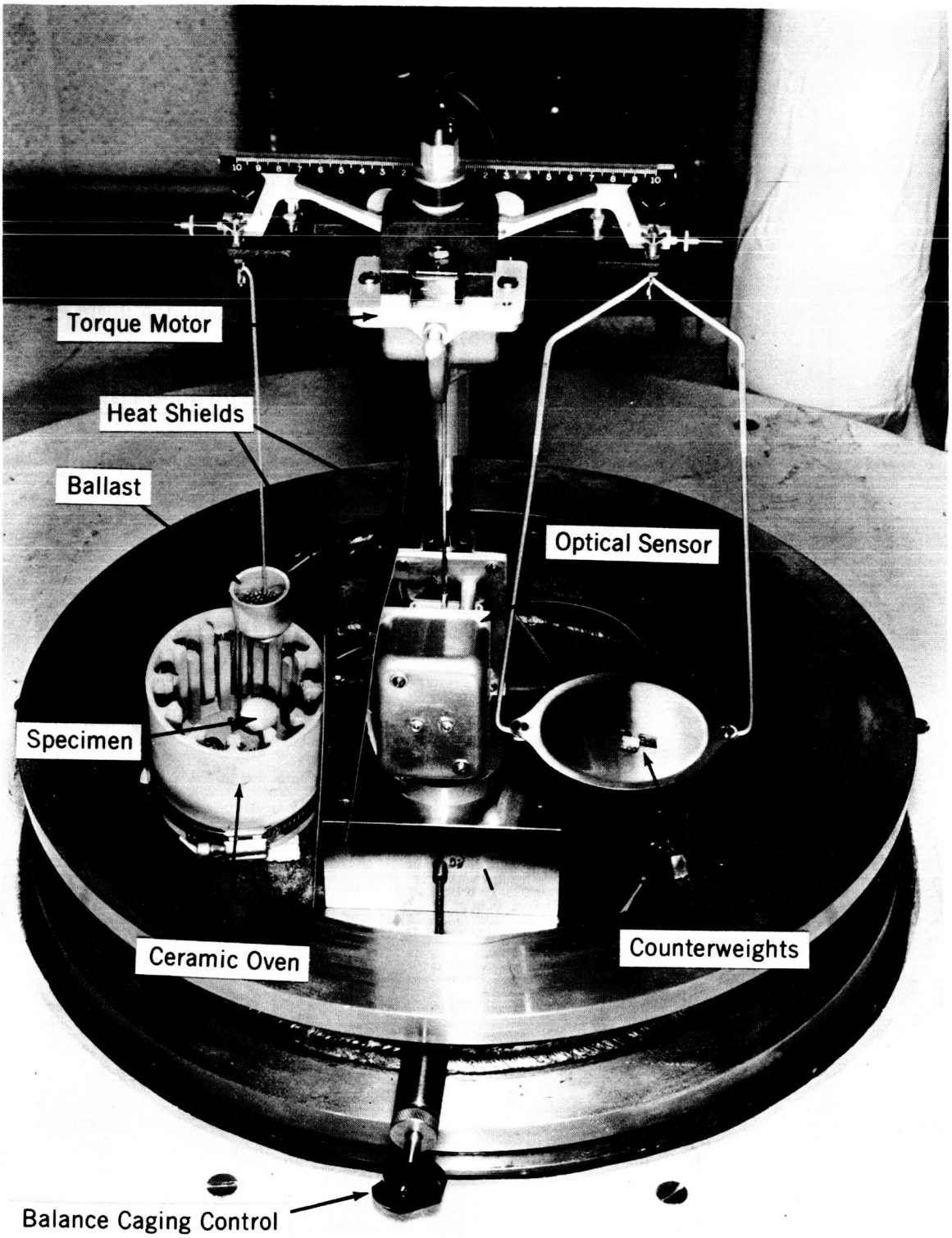

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FIGURE 3. CONTINUOUS RECORDING AUTOMATIC ELECTROBALANCE

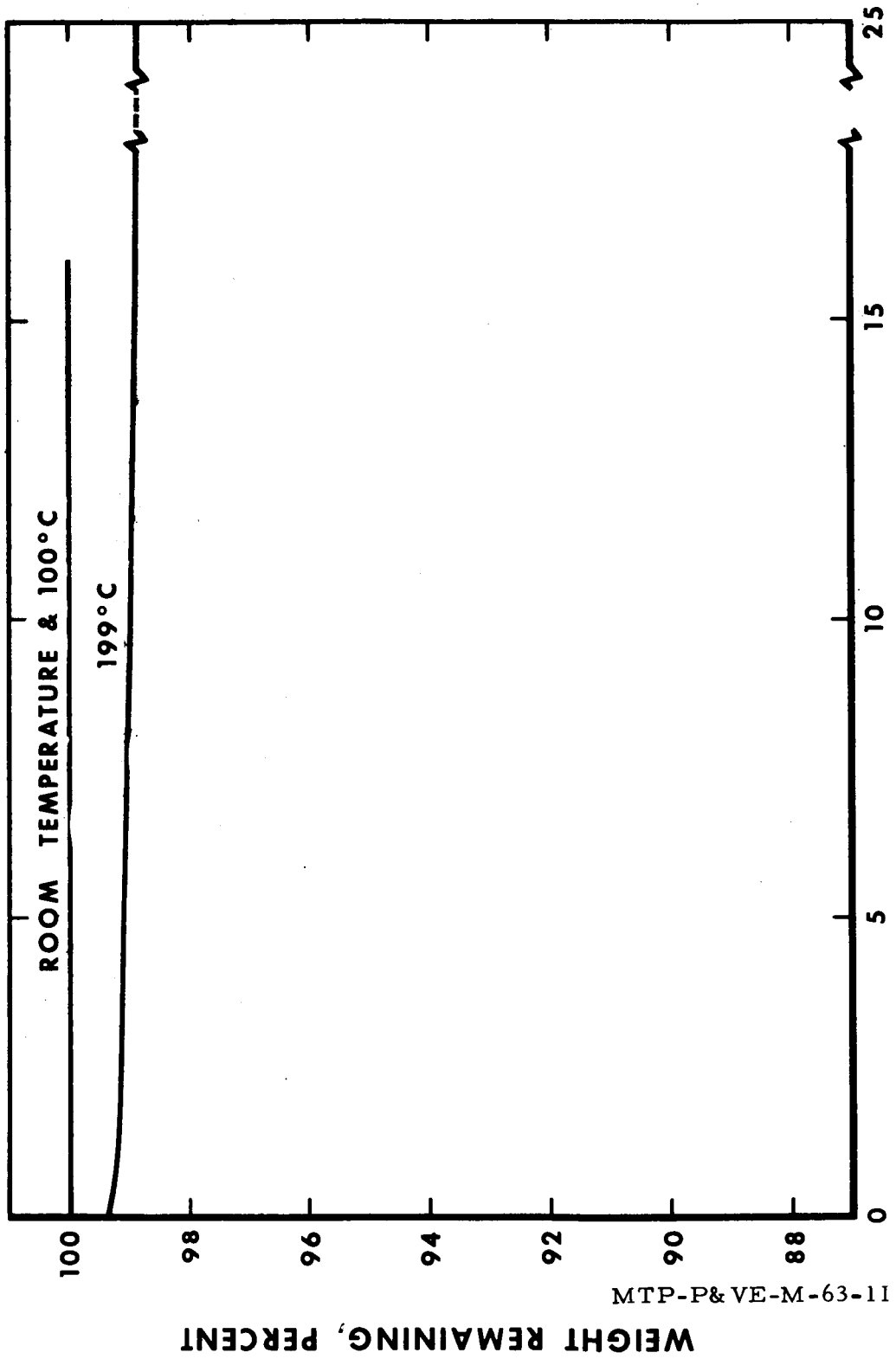


FIGURE 4. TIME WEIGHT HISTORY FOR KEL-F DURING EXPOSURE TO VACUUM

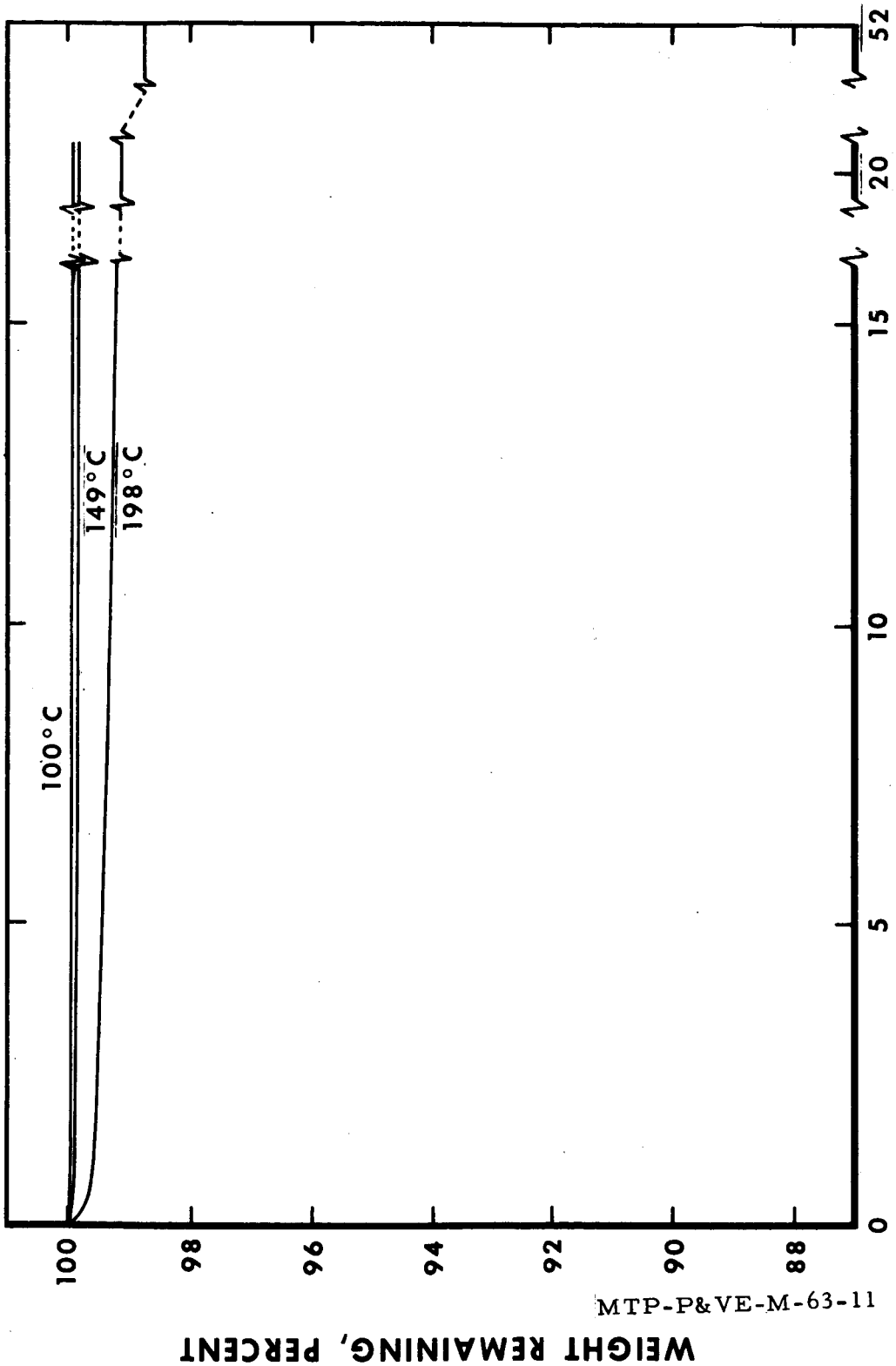


FIGURE 5. TIME WEIGHT HISTORY FOR VITON-B DURING EXPOSURE TO VACUUM

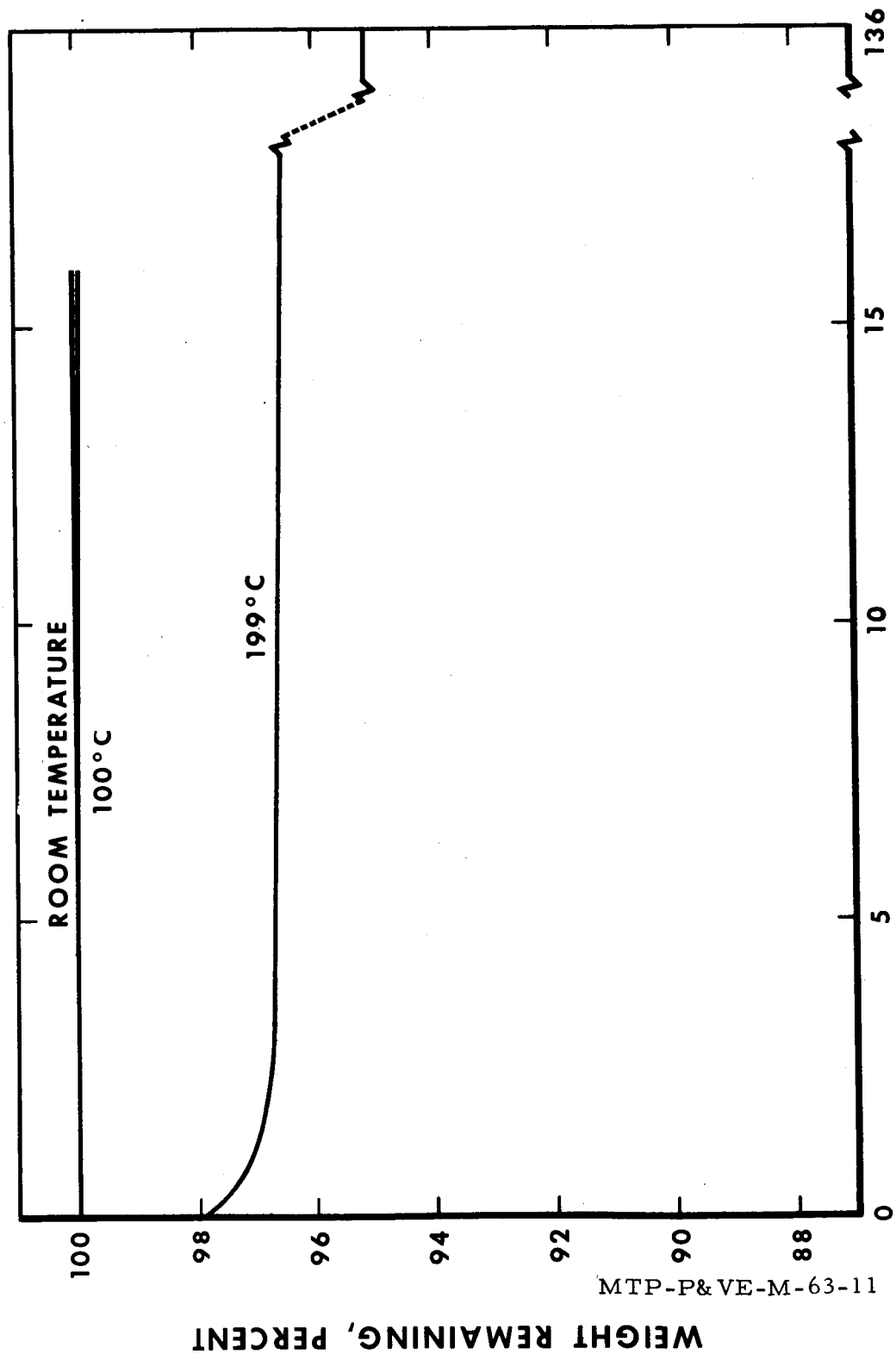


FIGURE 6. TIME WEIGHT FOR VITON-A DURING EXPOSURE TO VACUUM

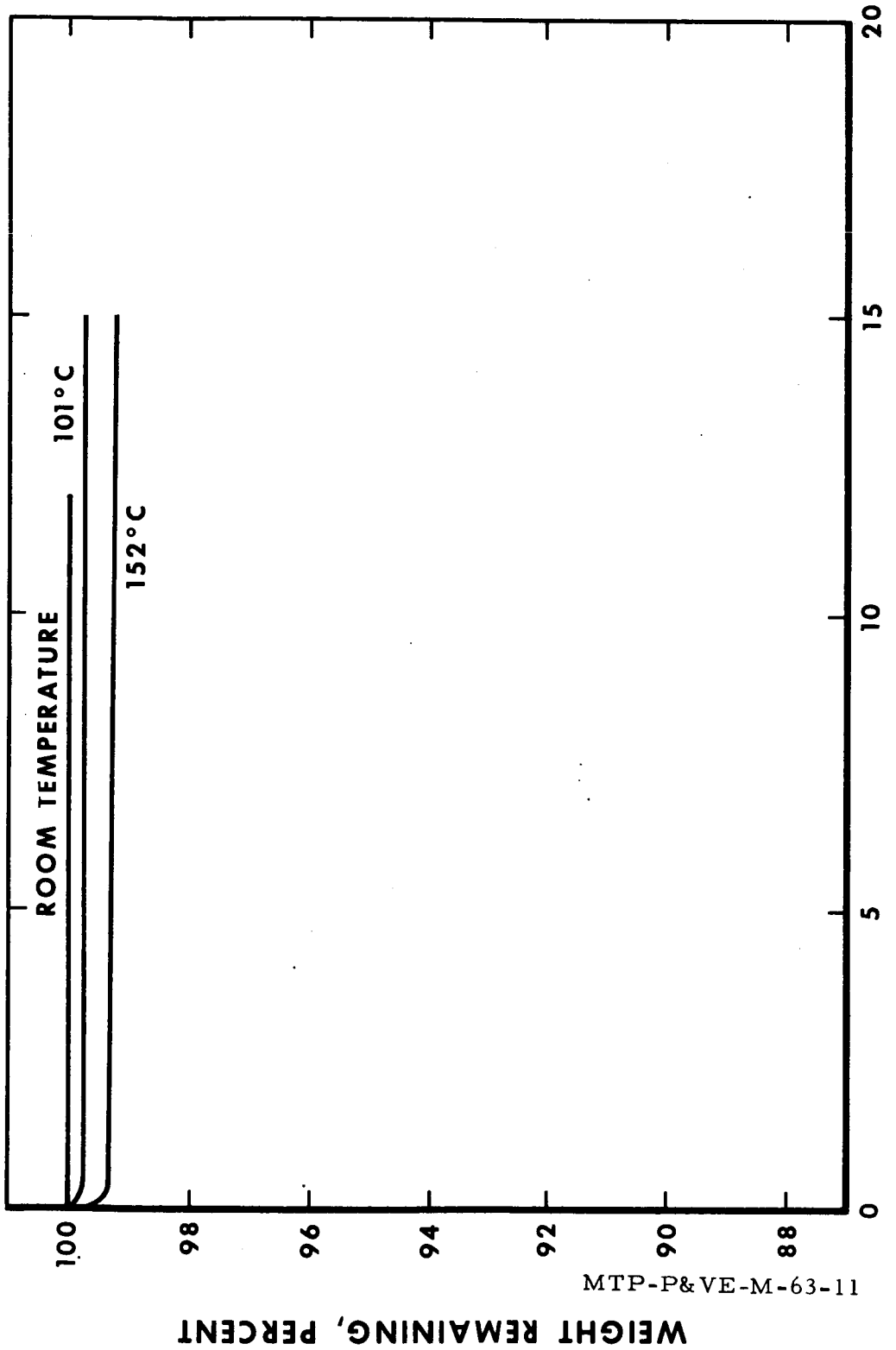


FIGURE 7. TIME WEIGHT HISTORY FOR POLYACRYLIC DURING EXPOSURE TO VACUUM

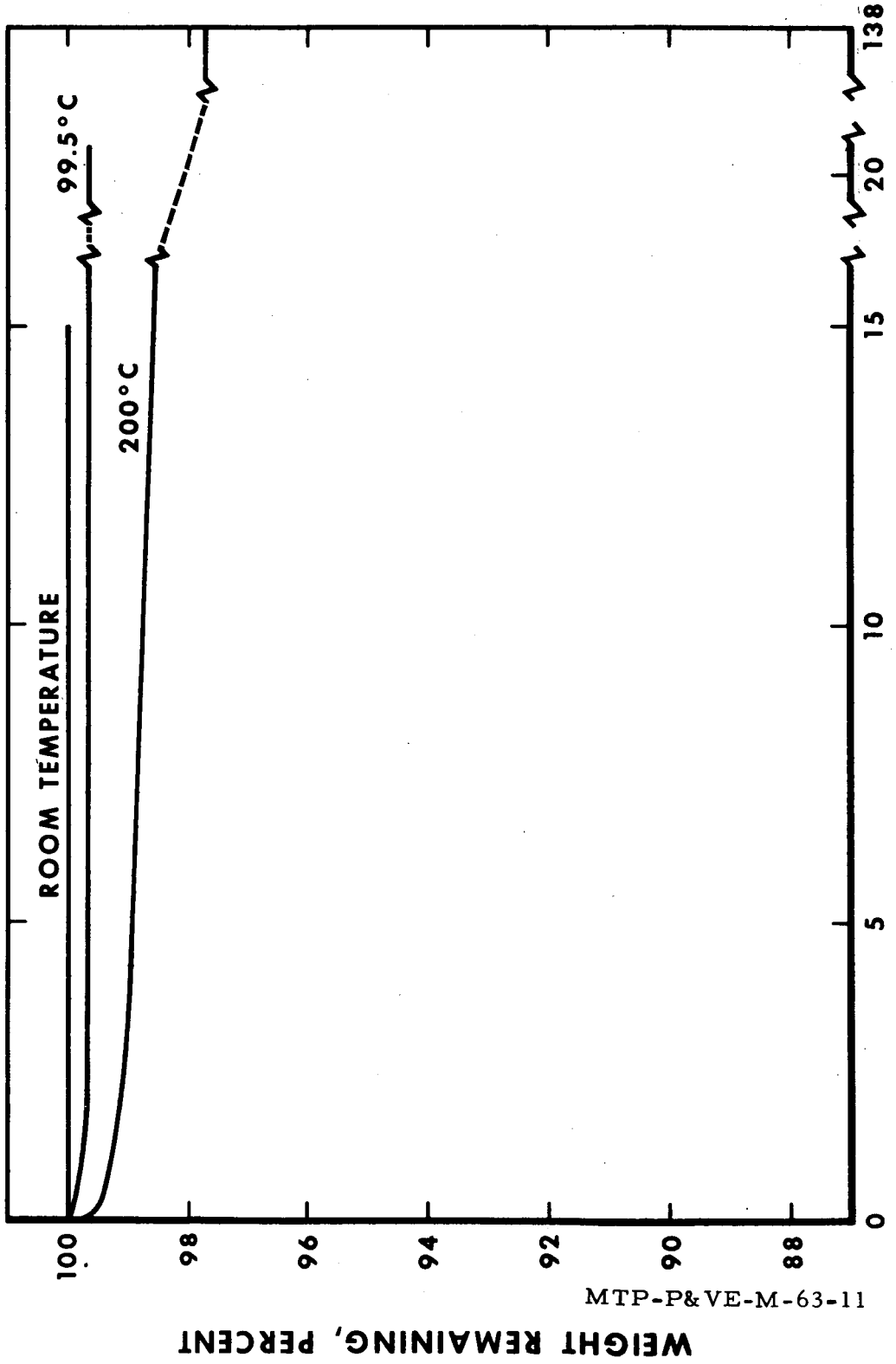


FIGURE 8. TIME WEIGHT HISTORY FOR FLUORINATED SILICONE DURING EXPOSURE TO VACUUM

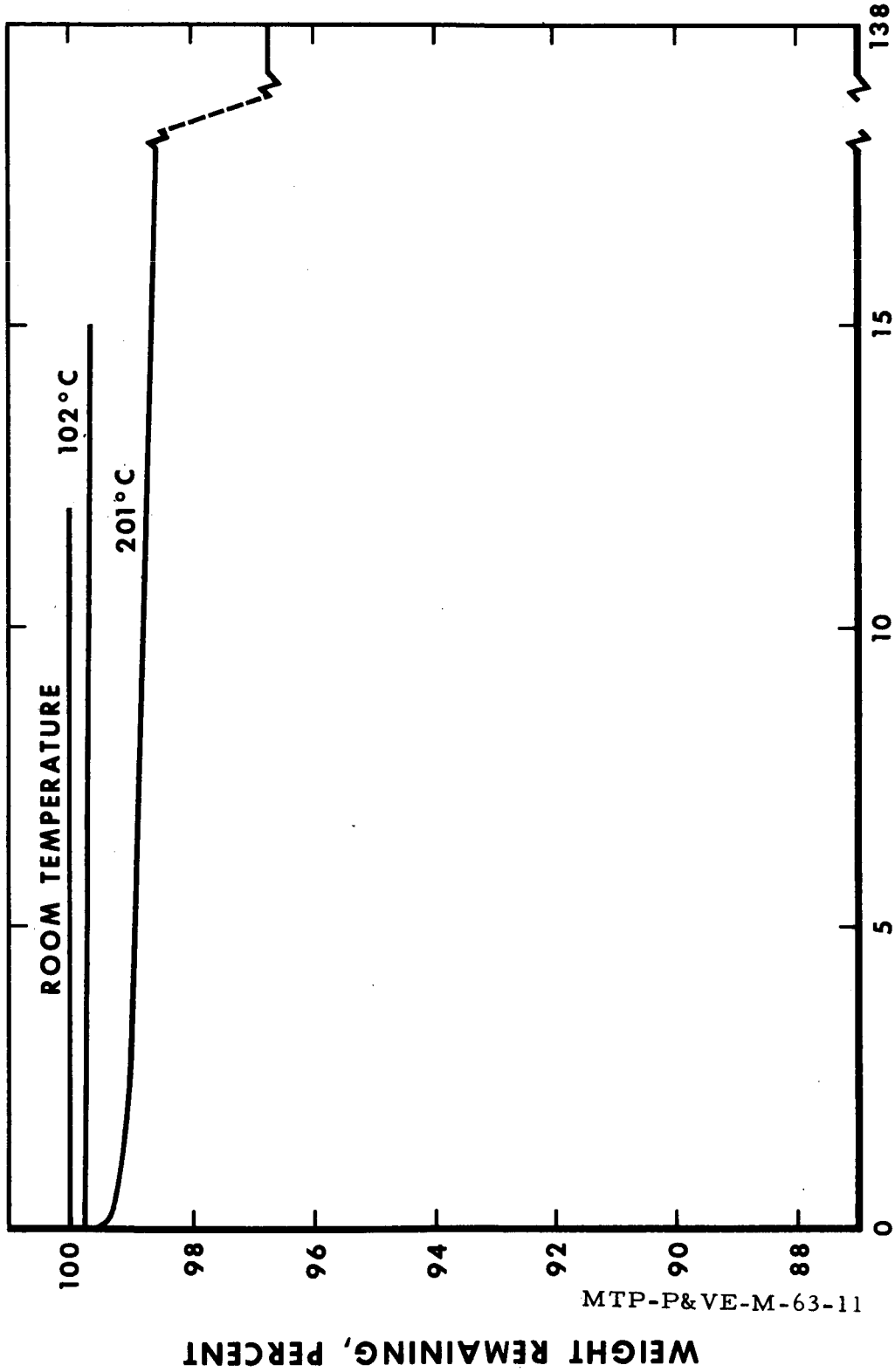


FIGURE 9. TIME WEIGHT HISTORY FOR SILICONE DURING EXPOSURE TO VACUUM

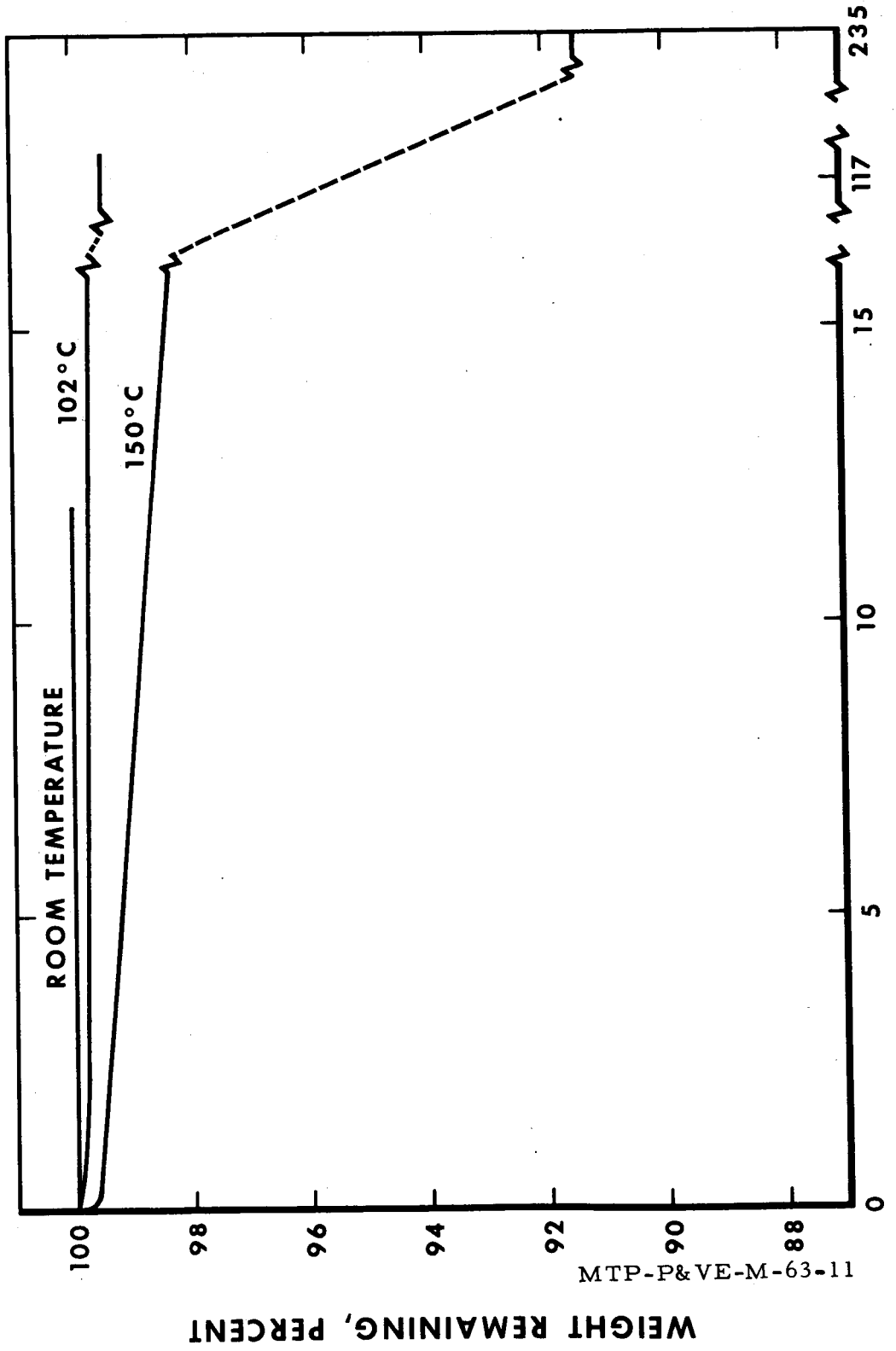


FIGURE 10. TIME WEIGHT HISTORY FOR HYPALON DURING EXPOSURE TO VACUUM

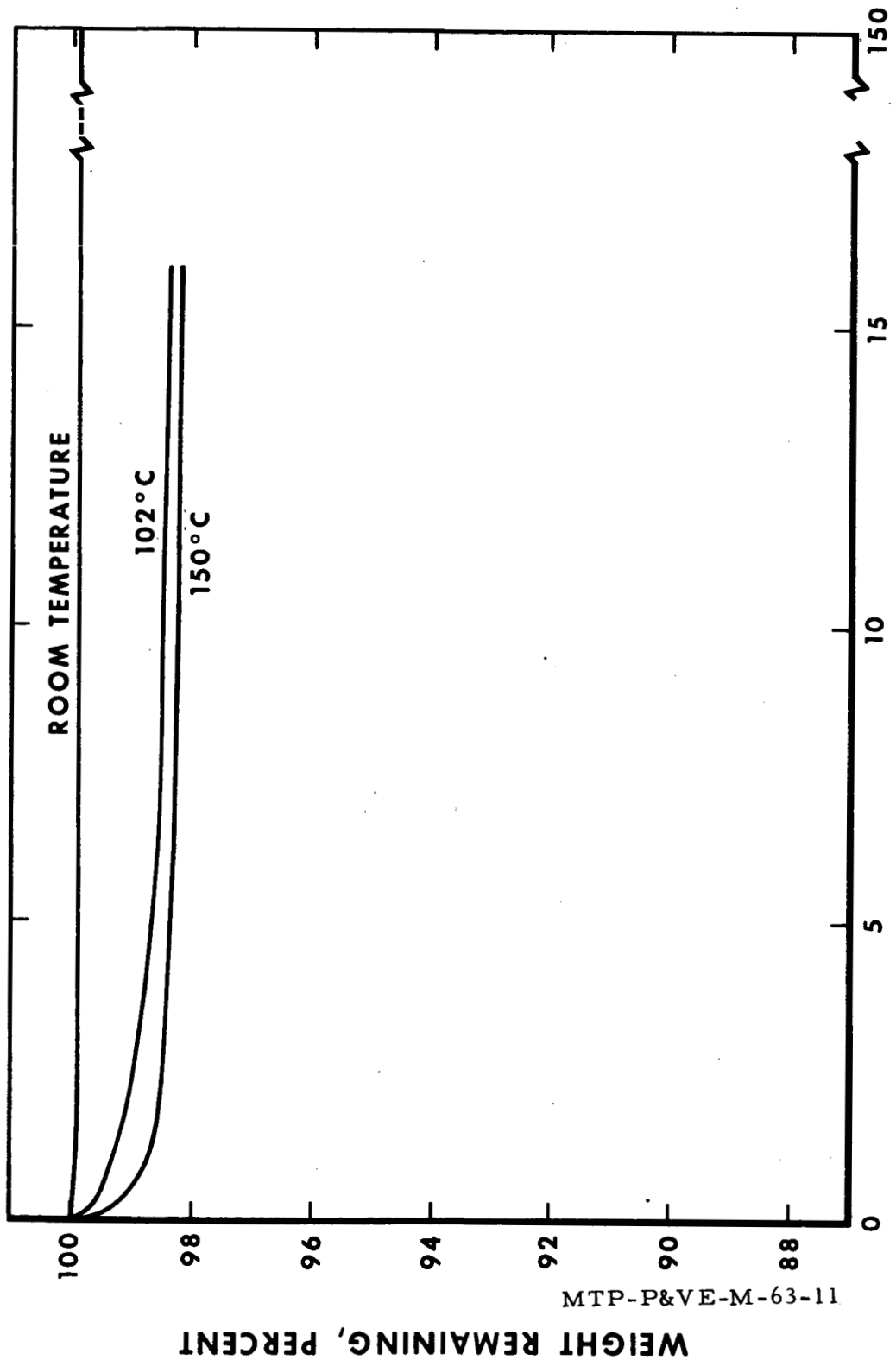


FIGURE 11. TIME WEIGHT HISTORY FOR NEOPRENE DURING EXPOSURE TO VACUUM

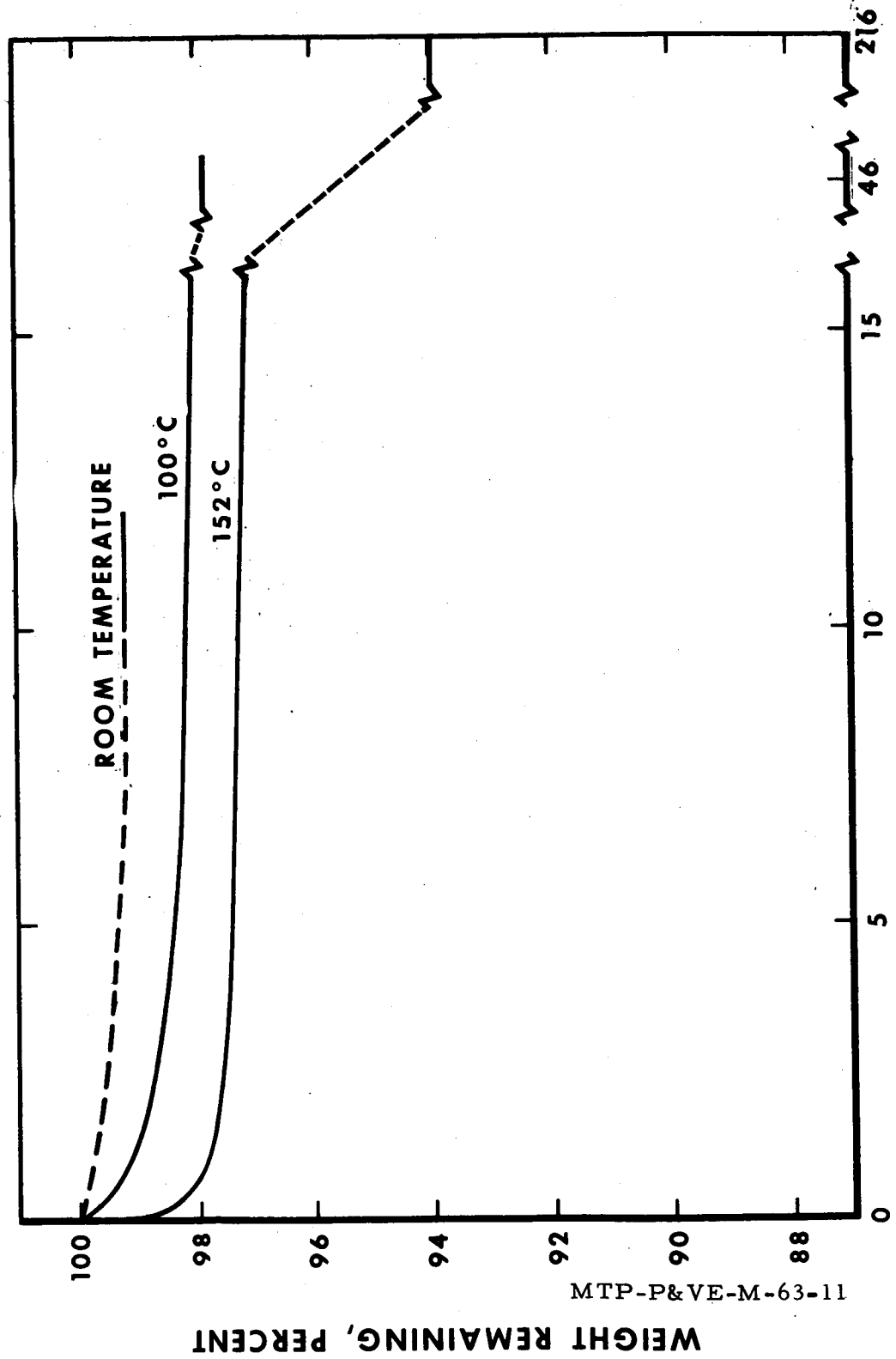


FIGURE 12. TIME WEIGHT HISTORY FOR POLYURETHANE DURING EXPOSURE TO VACUUM

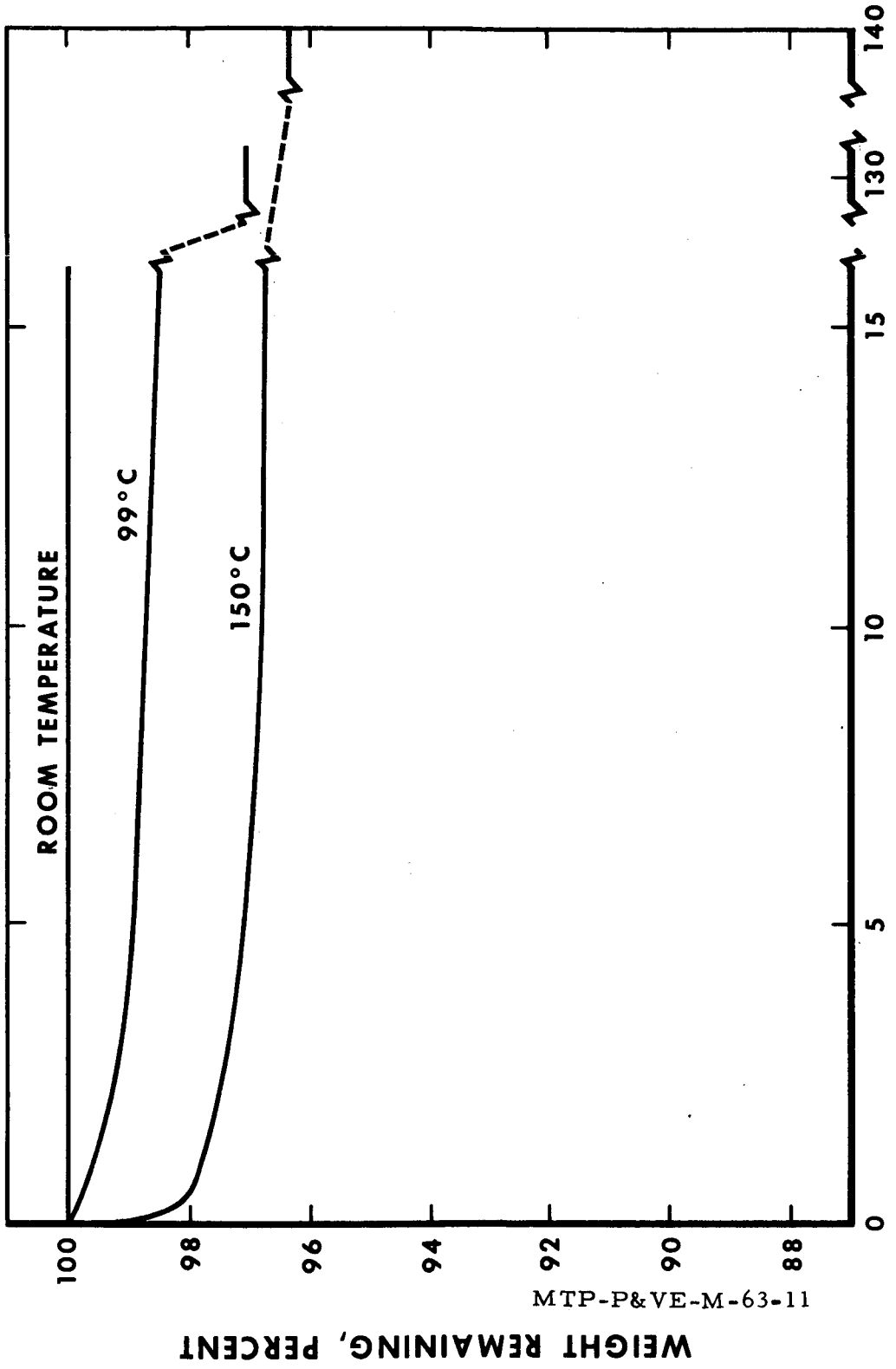


FIGURE 13. TIME WEIGHT HISTORY FOR BUTYL DURING EXPOSURE TO VACUUM

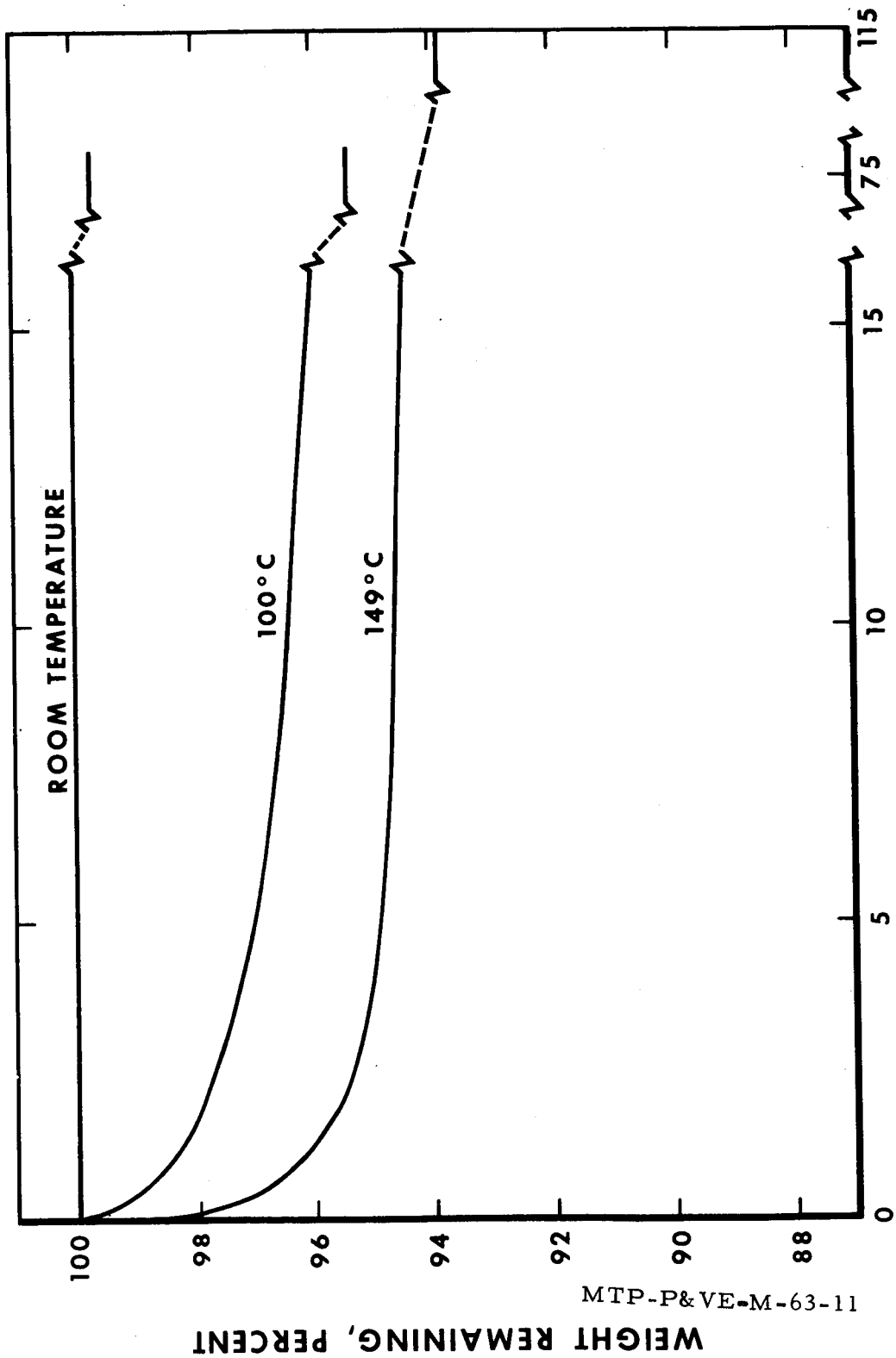


FIGURE 14. TIME WEIGHT HISTORY FOR STYRENE-BUTADIENE DURING EXPOSURE TO VACUUM

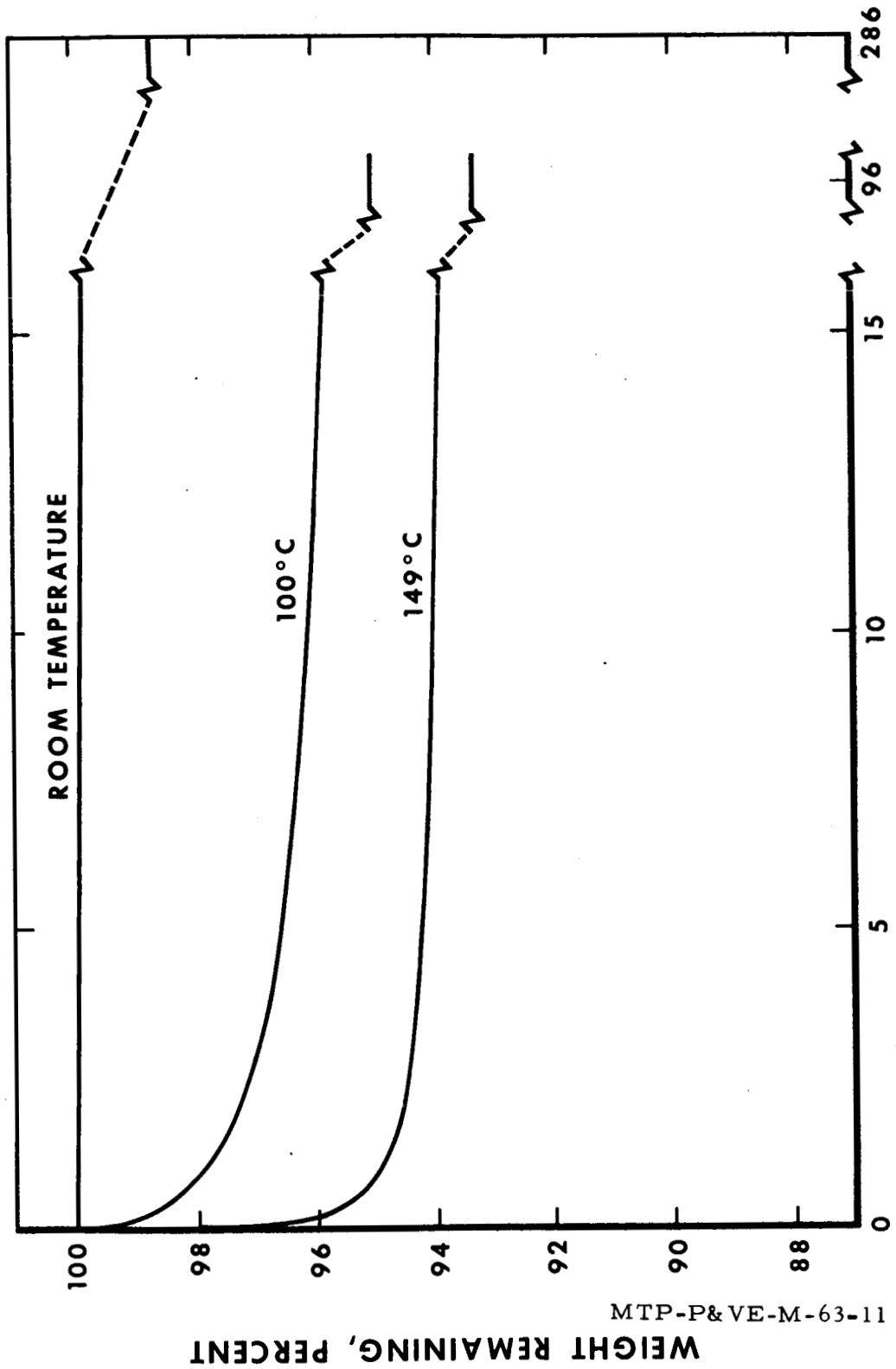


FIGURE 15. TIME WEIGHT HISTORY FOR NATURAL RUBBER DURING EXPOSURE TO VACUUM

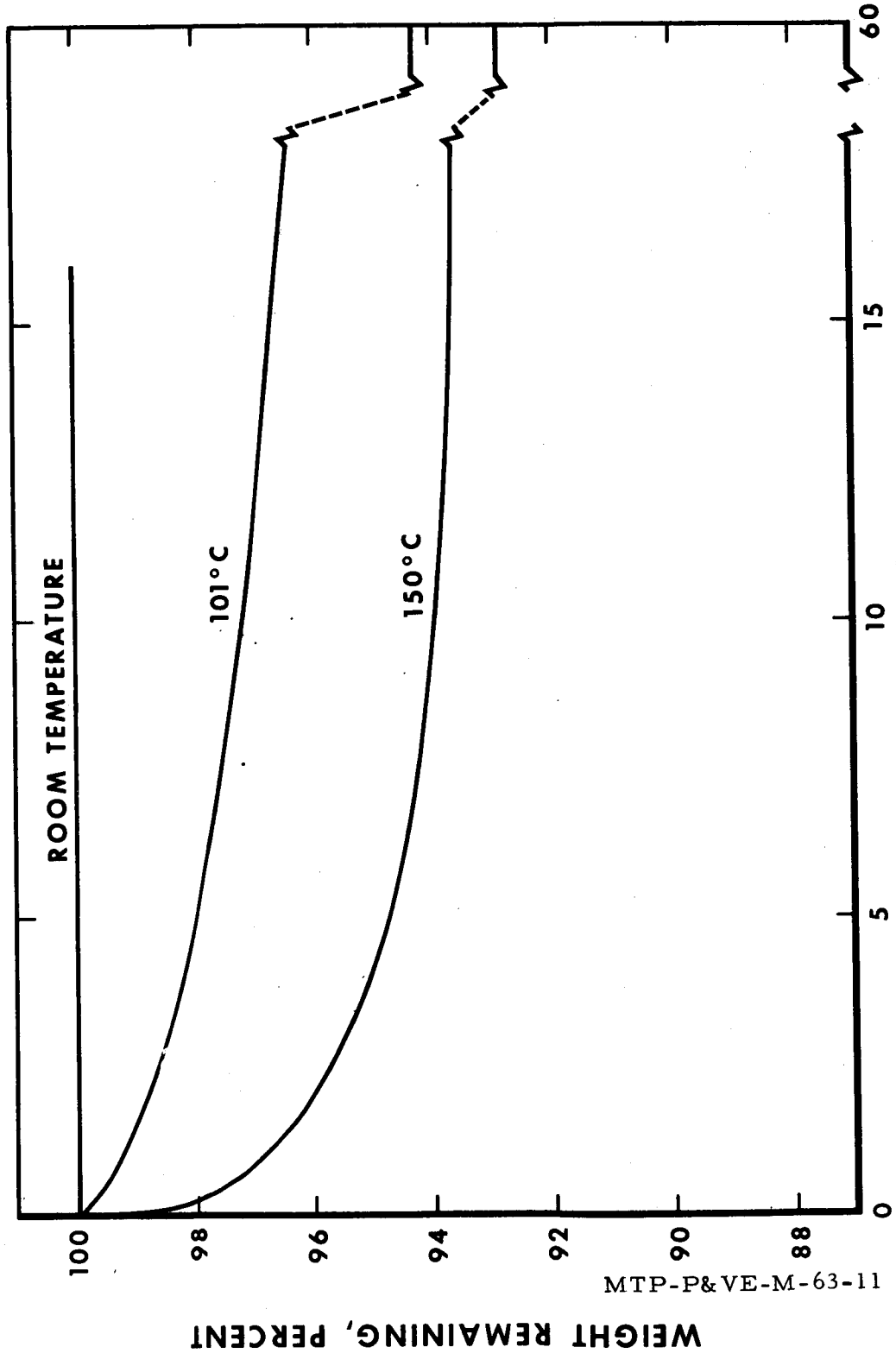


FIGURE 16. TIME WEIGHT HISTORY FOR BUNA-N (M-P&VE-MR) DURING EXPOSURE TO VACUUM

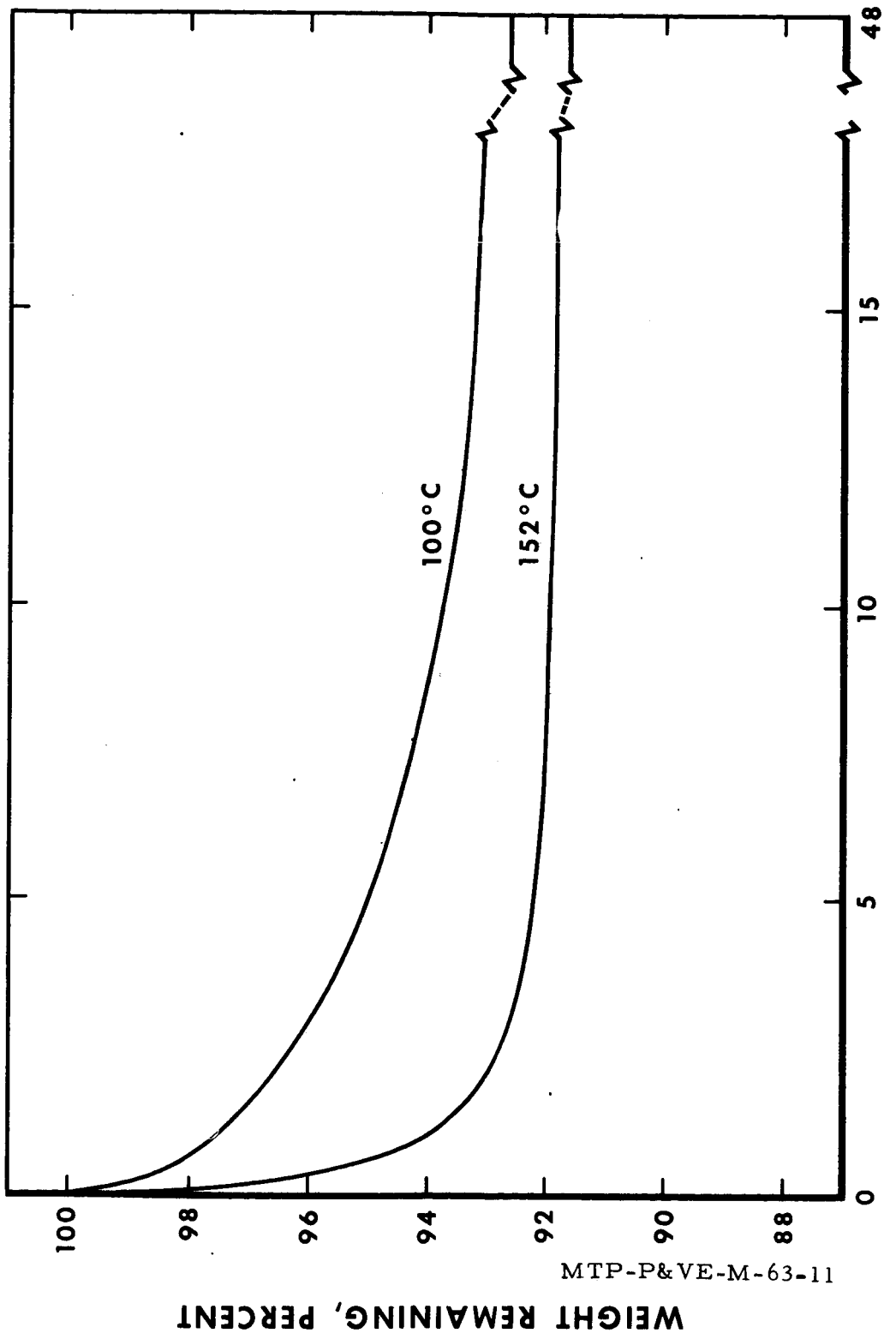


FIGURE 17. TIME WEIGHT HISTORY FOR NEOPRENE, 5 PPH ANTIOX 4010 DURING EXPOSURE TO VACUUM

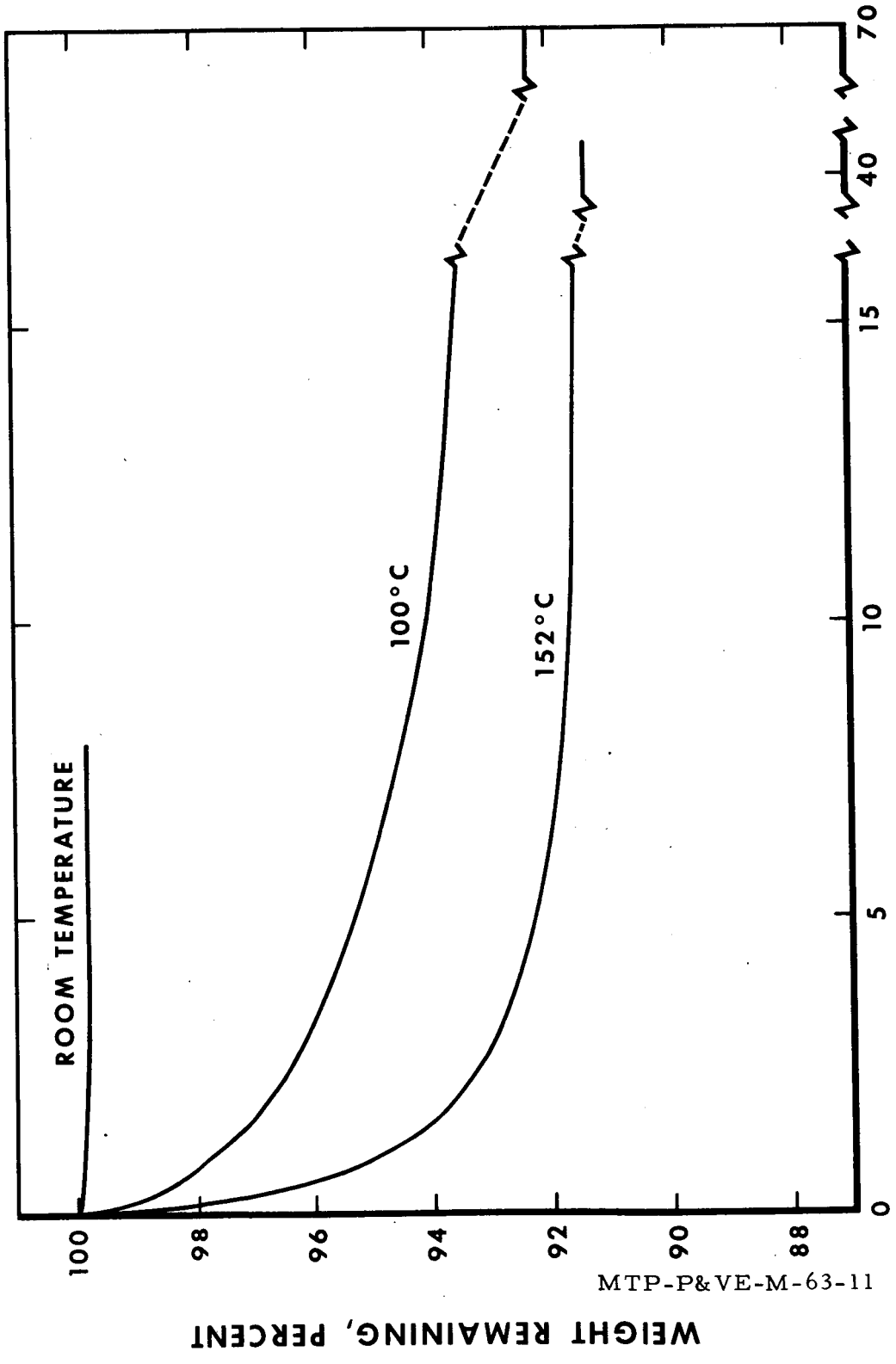


FIGURE 18. TIME WEIGHT HISTORY FOR NEOPRENE WRT DURING EXPOSURE TO VACUUM

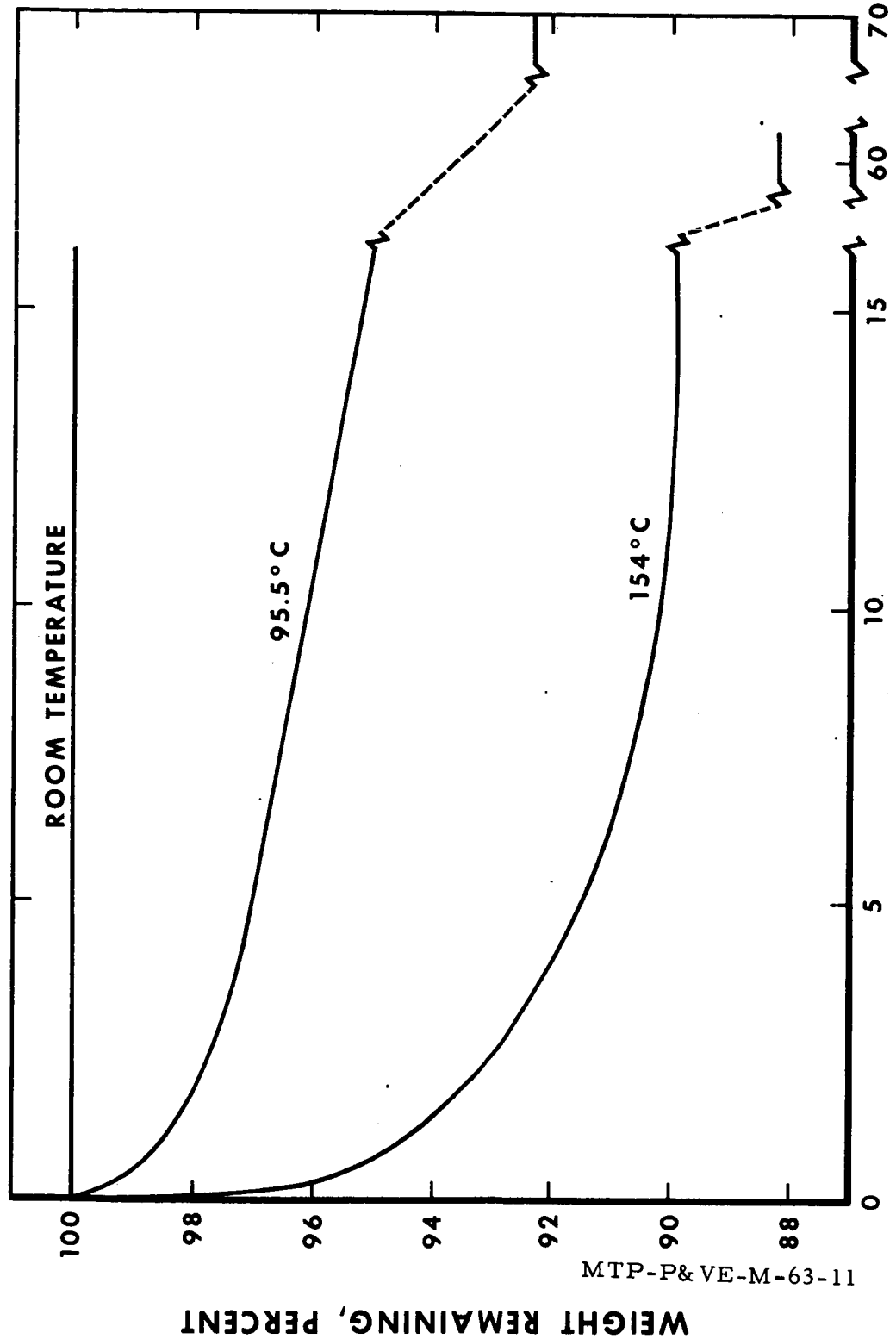


FIGURE 19. TIME WEIGHT HISTORY FOR BUNA-N (PARKER-HANNIFIN) DURING EXPOSURE TO VACUUM

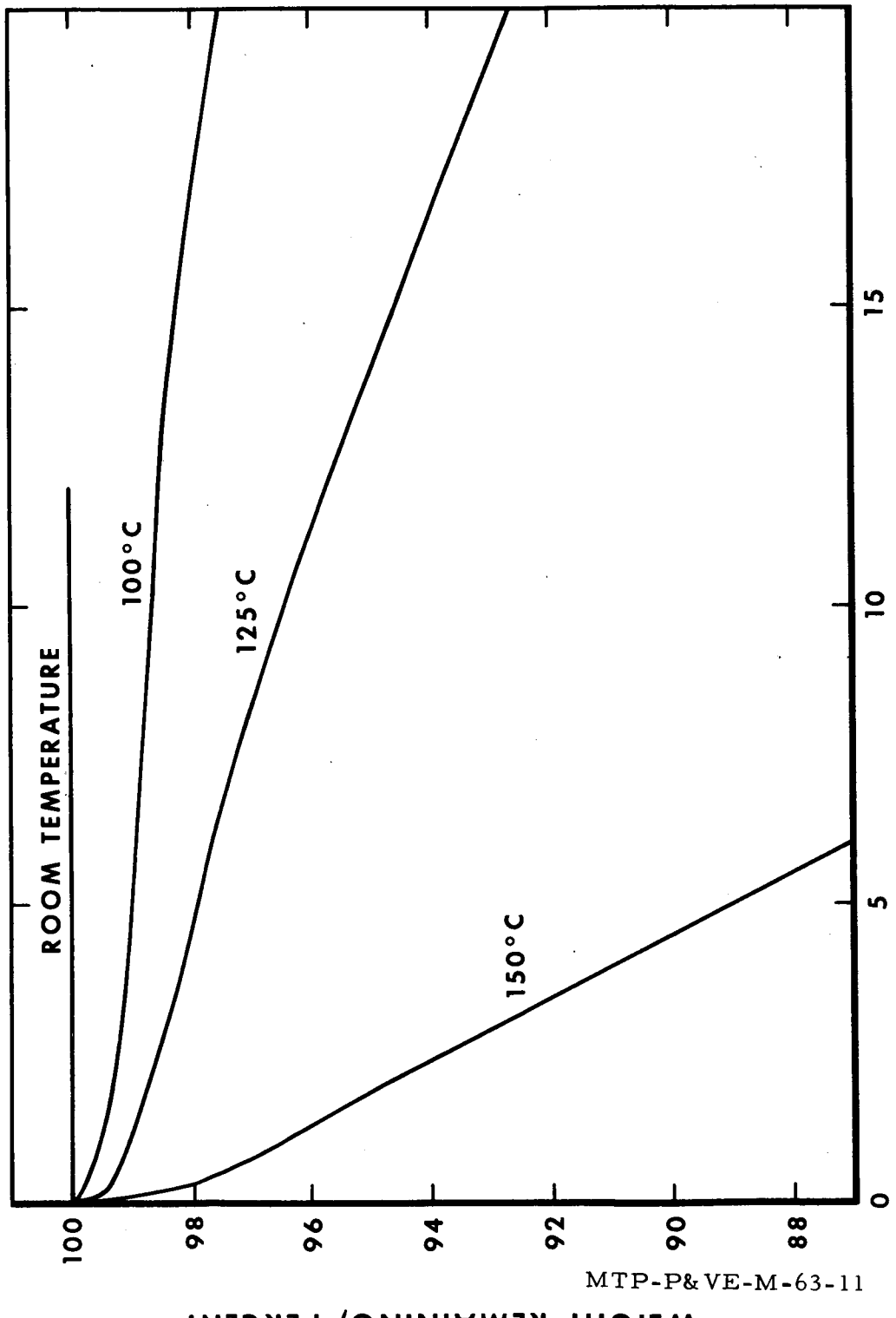
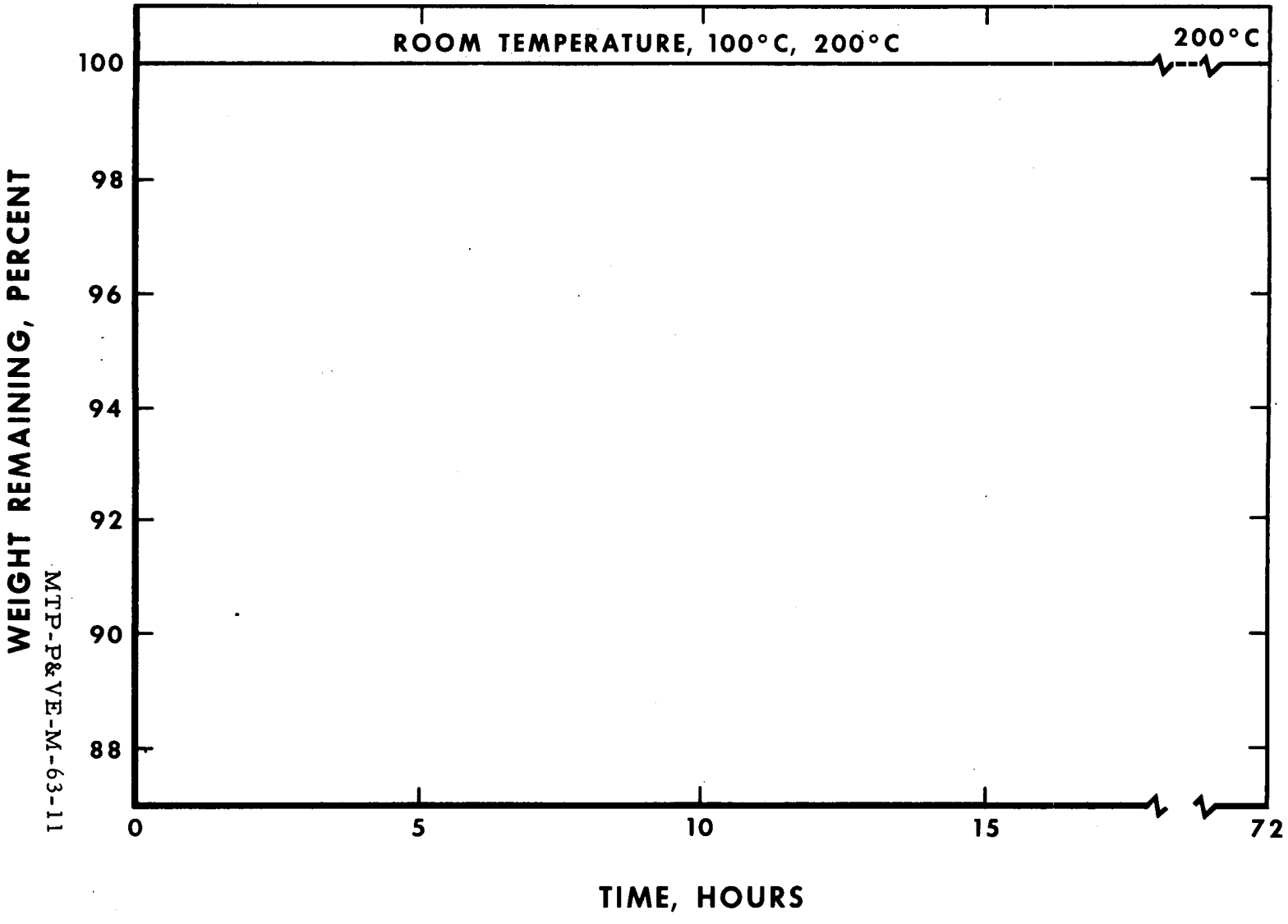


FIGURE 20. TIME WEIGHT HISTORY FOR THIOKOL DURING EXPOSURE TO VACUUM



MTP-P&VE-M-63-11

FIGURE 21. TIME WEIGHT HISTORY FOR TEFLON-TFE DURING EXPOSURE TO VACUUM

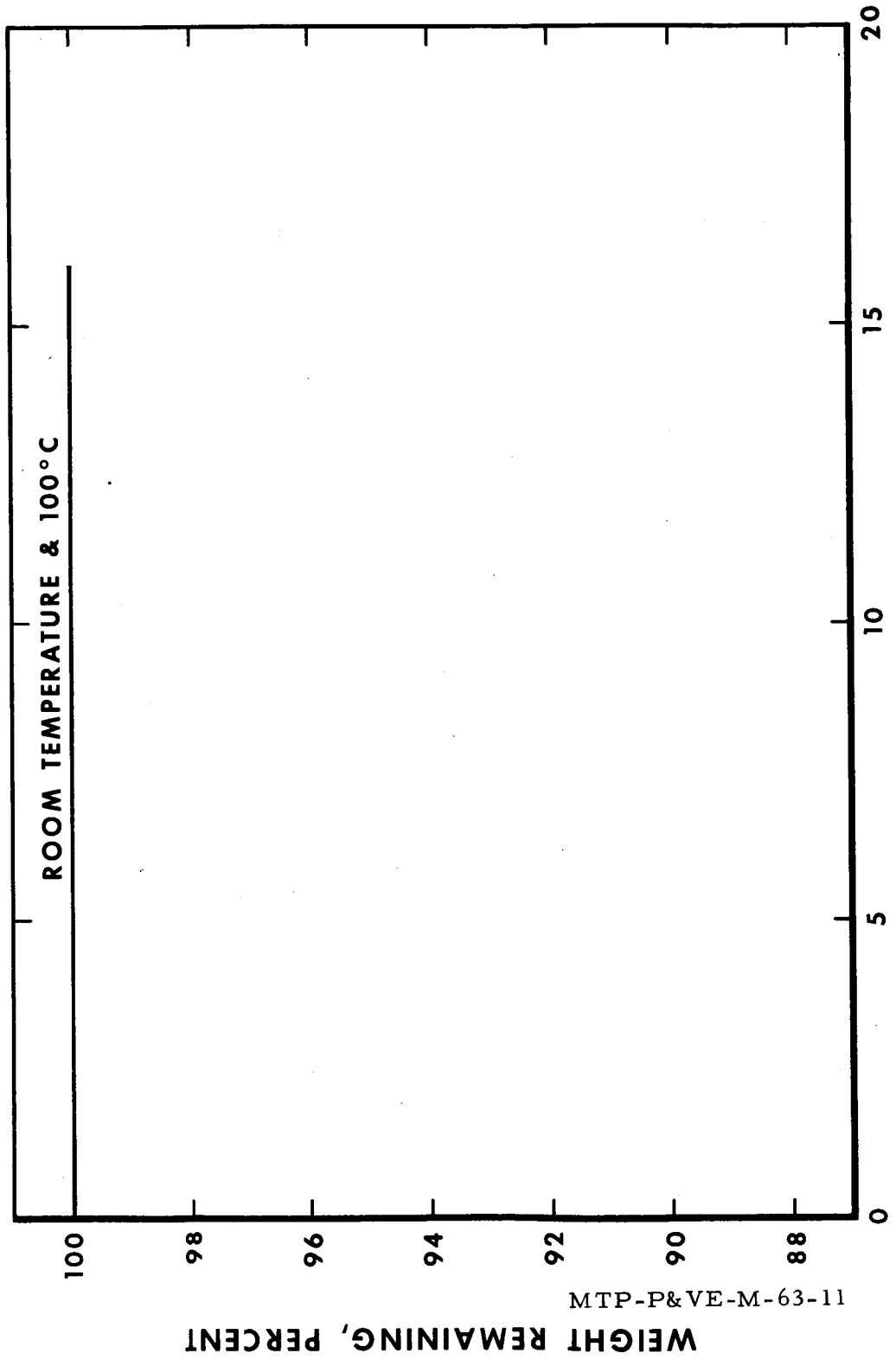


FIGURE 22. TIME WEIGHT HISTORY FOR MYLAR DURING EXPOSURE TO VACUUM

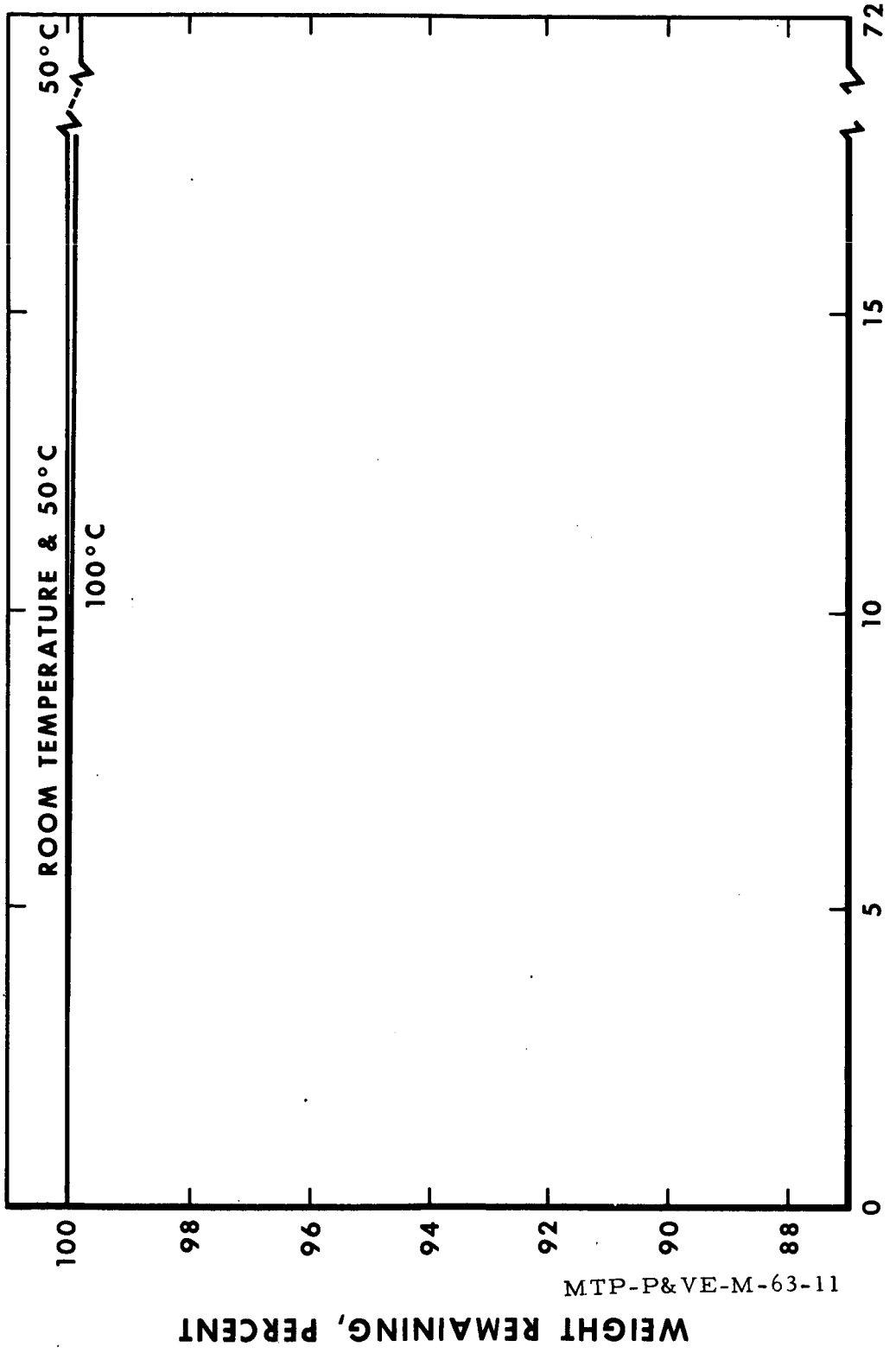


FIGURE 23. TIME WEIGHT HISTORY FOR POLYETHYLENE DURING EXPOSURE TO VACUUM

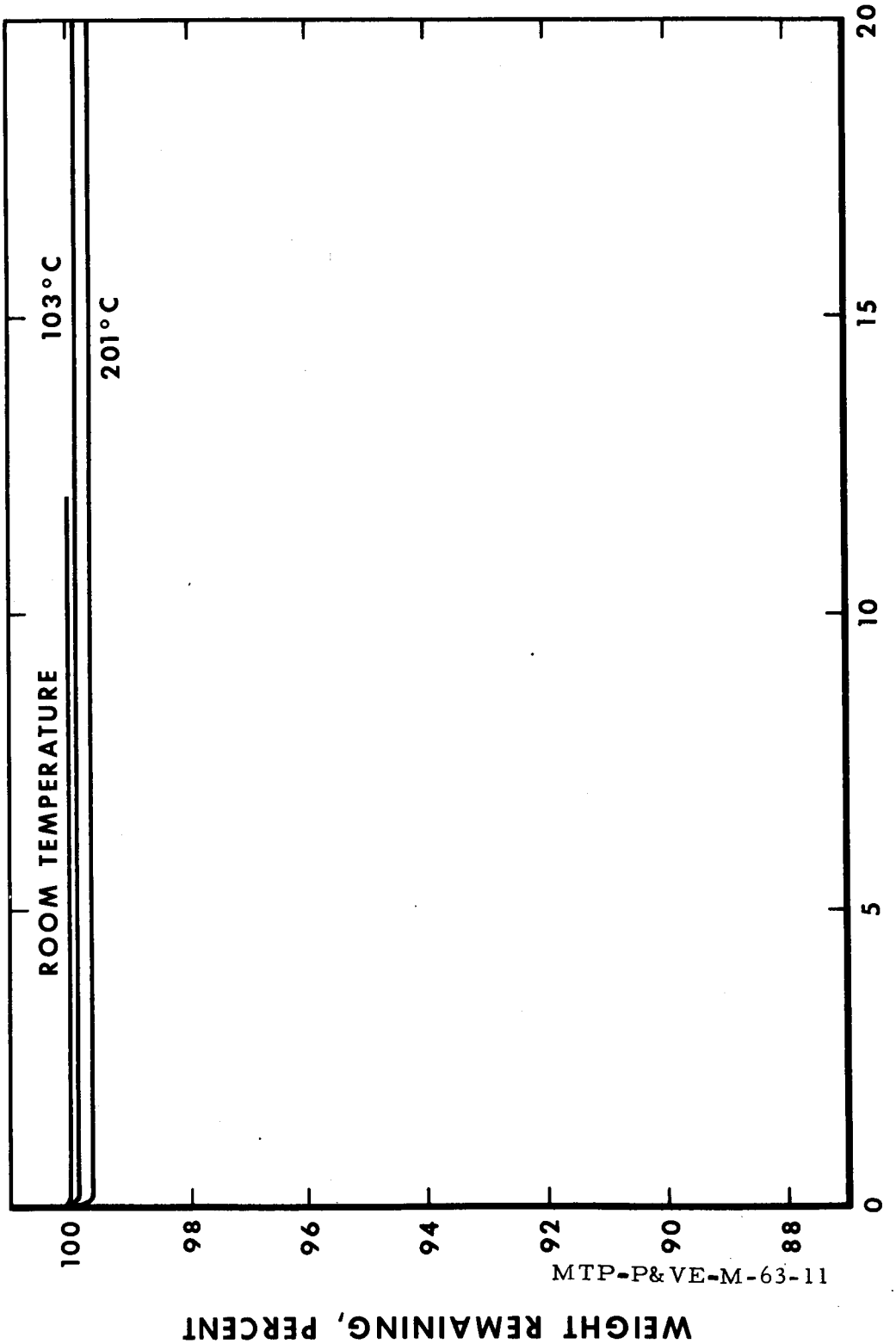


FIGURE 24. TIME WEIGHT HISTORY FOR POLYIMIDE TAPE-M DURING EXPOSURE TO VACUUM

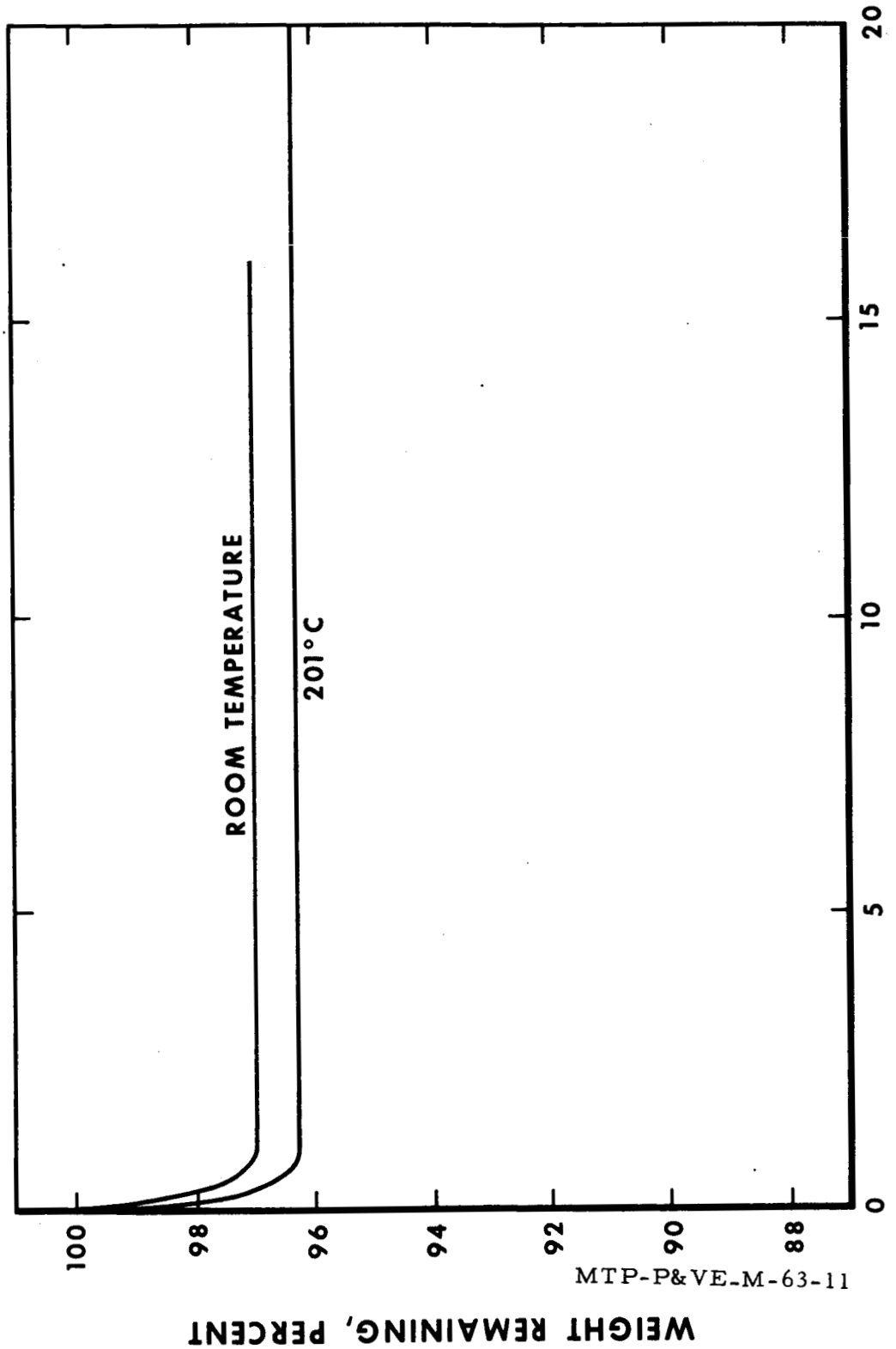


FIGURE 25. TIME WEIGHT HISTORY FOR POLYAMIDE FILM-HT-1 DURING EXPOSURE TO VACUUM

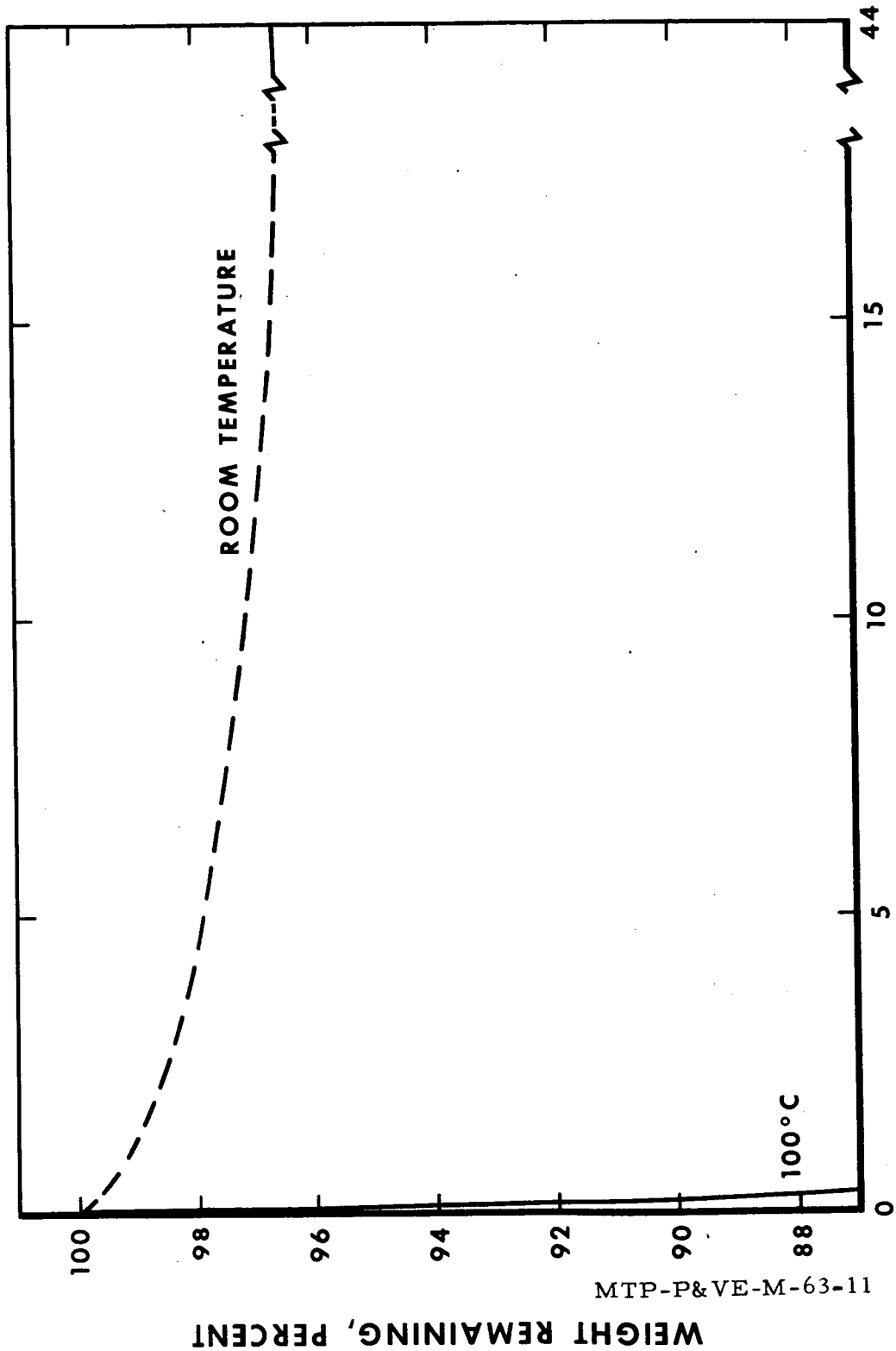


FIGURE 26. TIME WEIGHT HISTORY FOR POLYVINYL CHLORIDE DURING EXPOSURE TO VACUUM

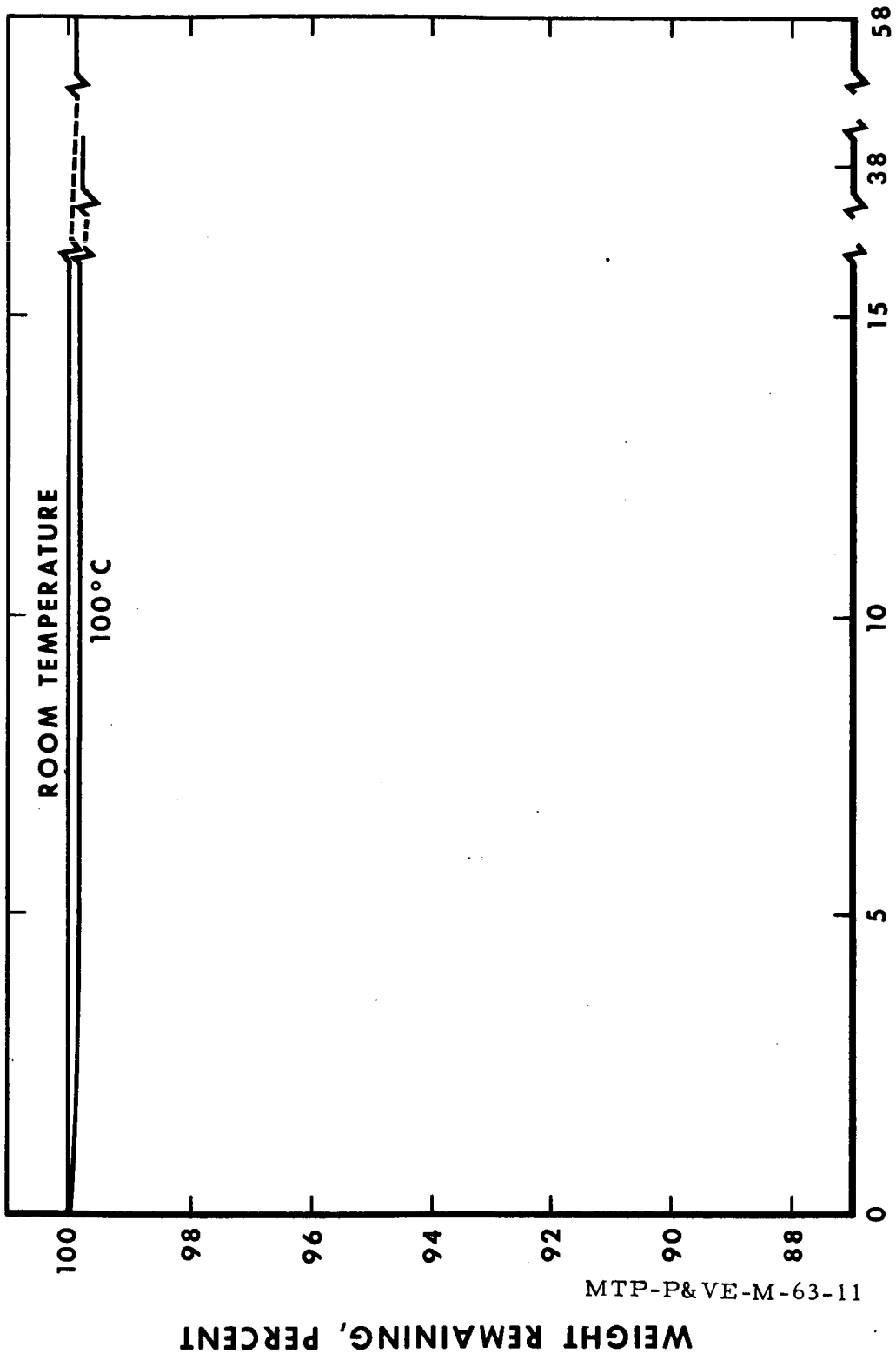


FIGURE 27. TIME WEIGHT HISTORY FOR HETRON 31 DURING EXPOSURE TO VACUUM

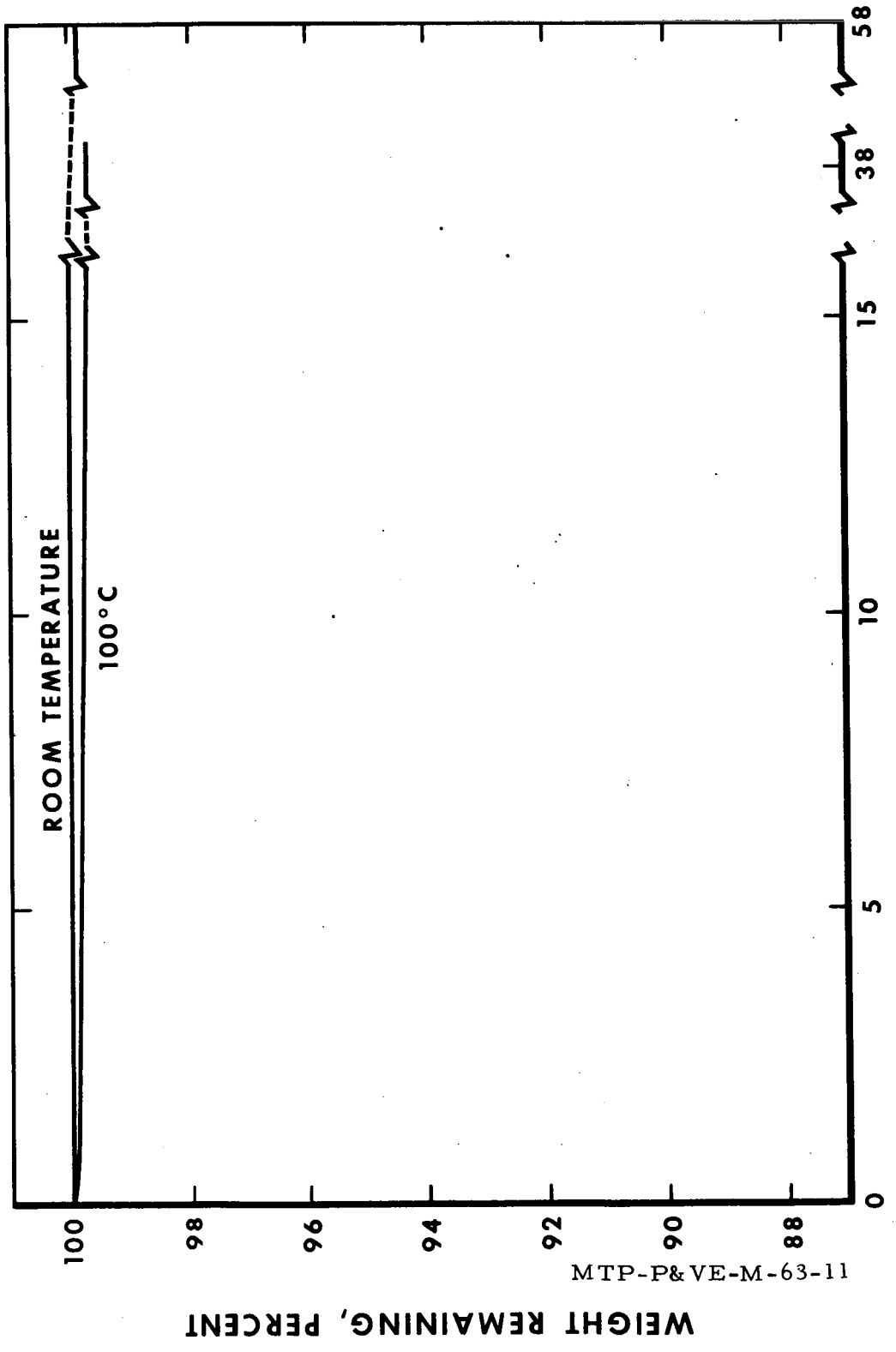


FIGURE 28. TIME WEIGHT HISTORY FOR HETRON 92 DURING EXPOSURE TO VACUUM

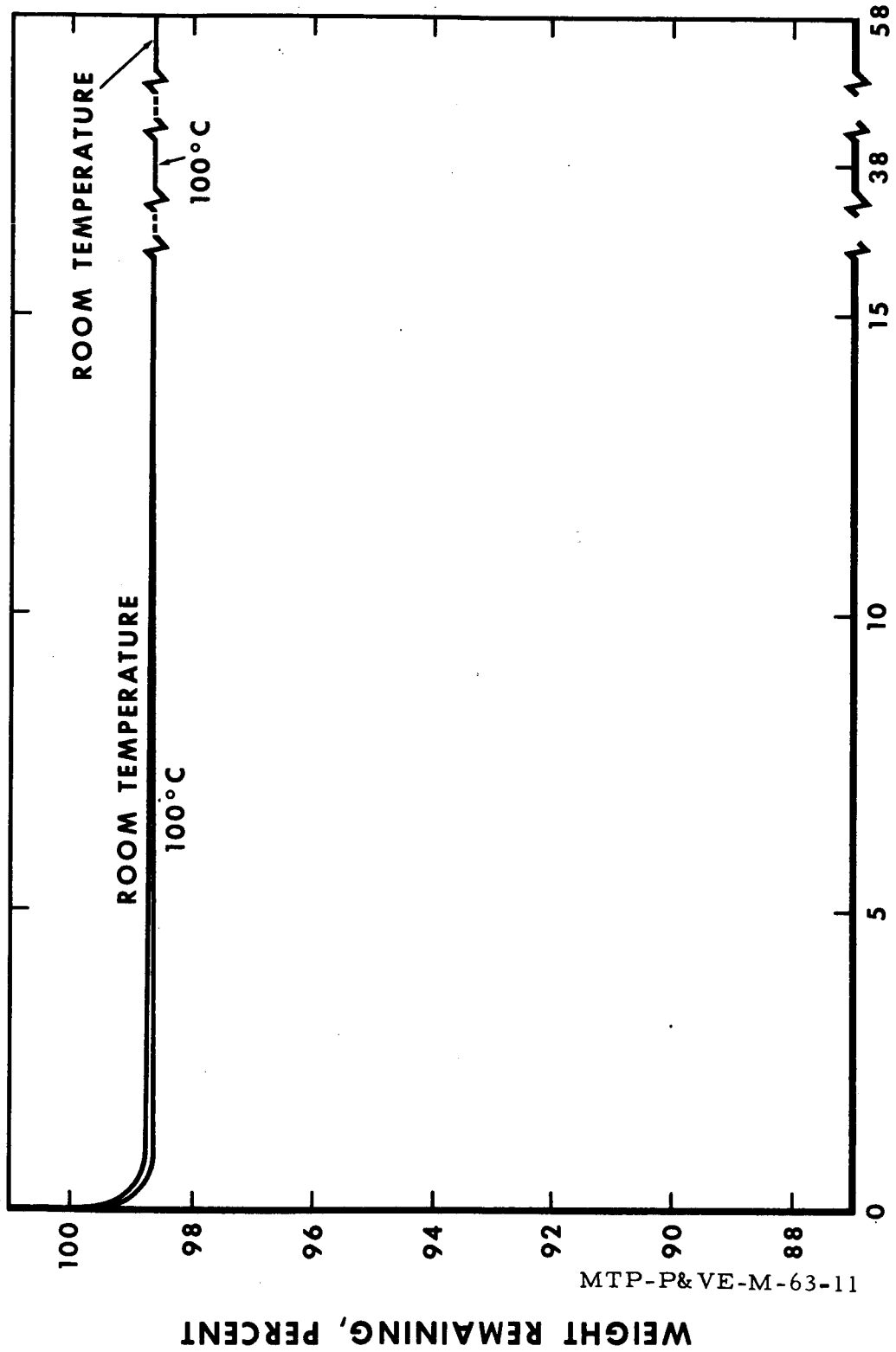


FIGURE 29. TIME WEIGHT HISTORY FOR VIBRIN 135 DURING EXPOSURE TO VACUUM

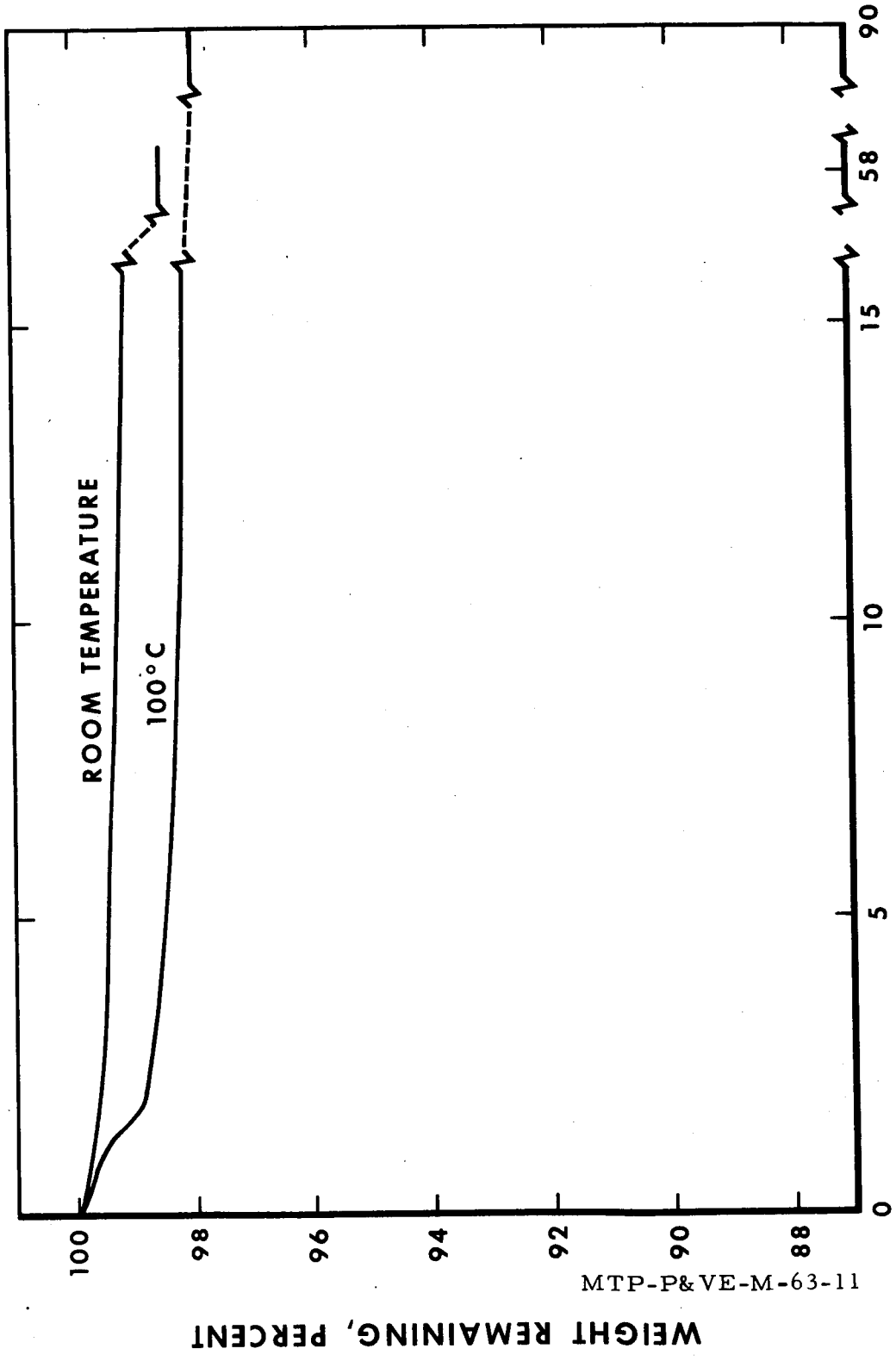


FIGURE 30. TIME WEIGHT HISTORY FOR CONOLON 506A DURING EXPOSURE TO VACUUM

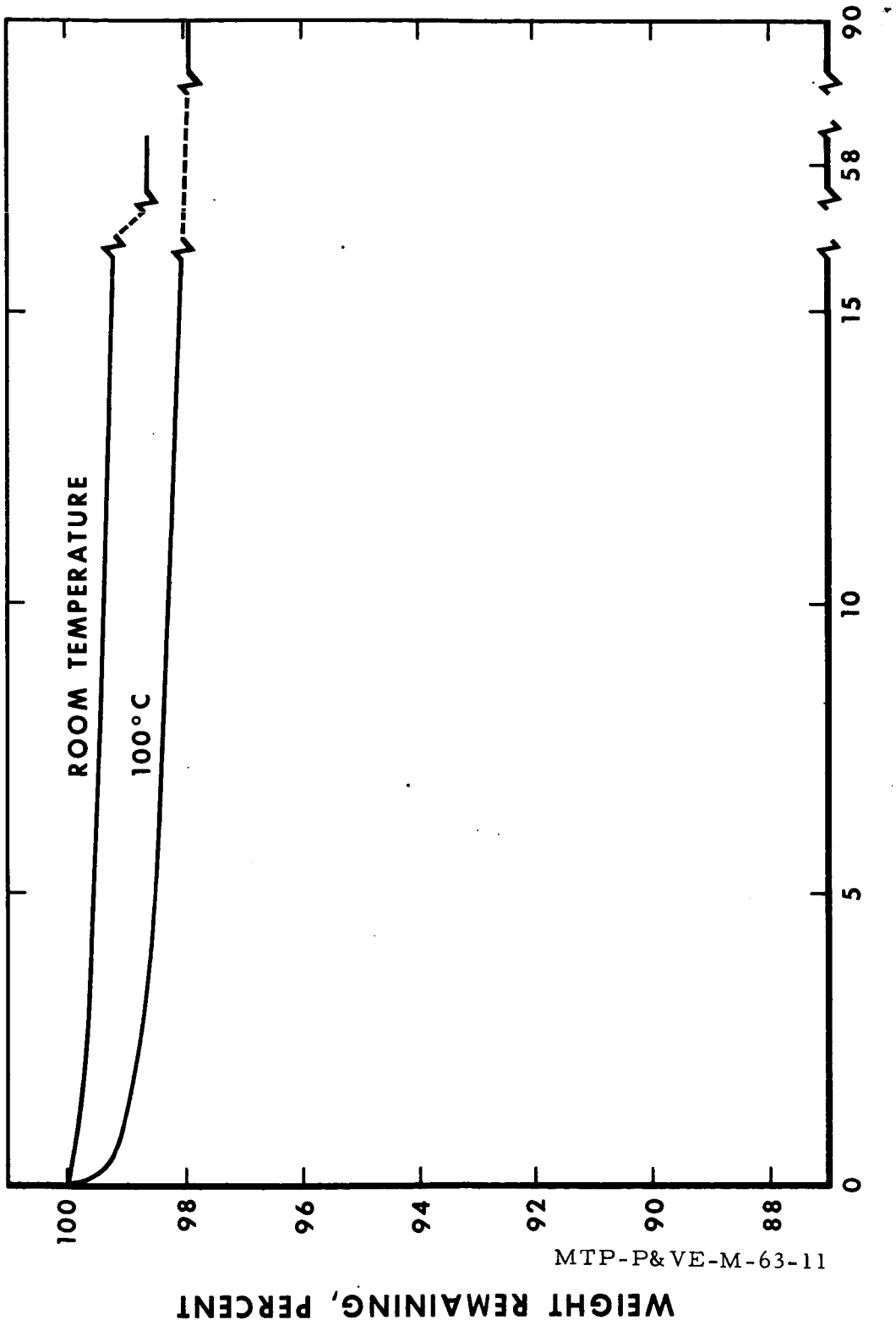


FIGURE 31. TIME WEIGHT HISTORY FOR CONOLON 506 (REINFORCED PLASTIC) DURING EXPOSURE TO VACUUM

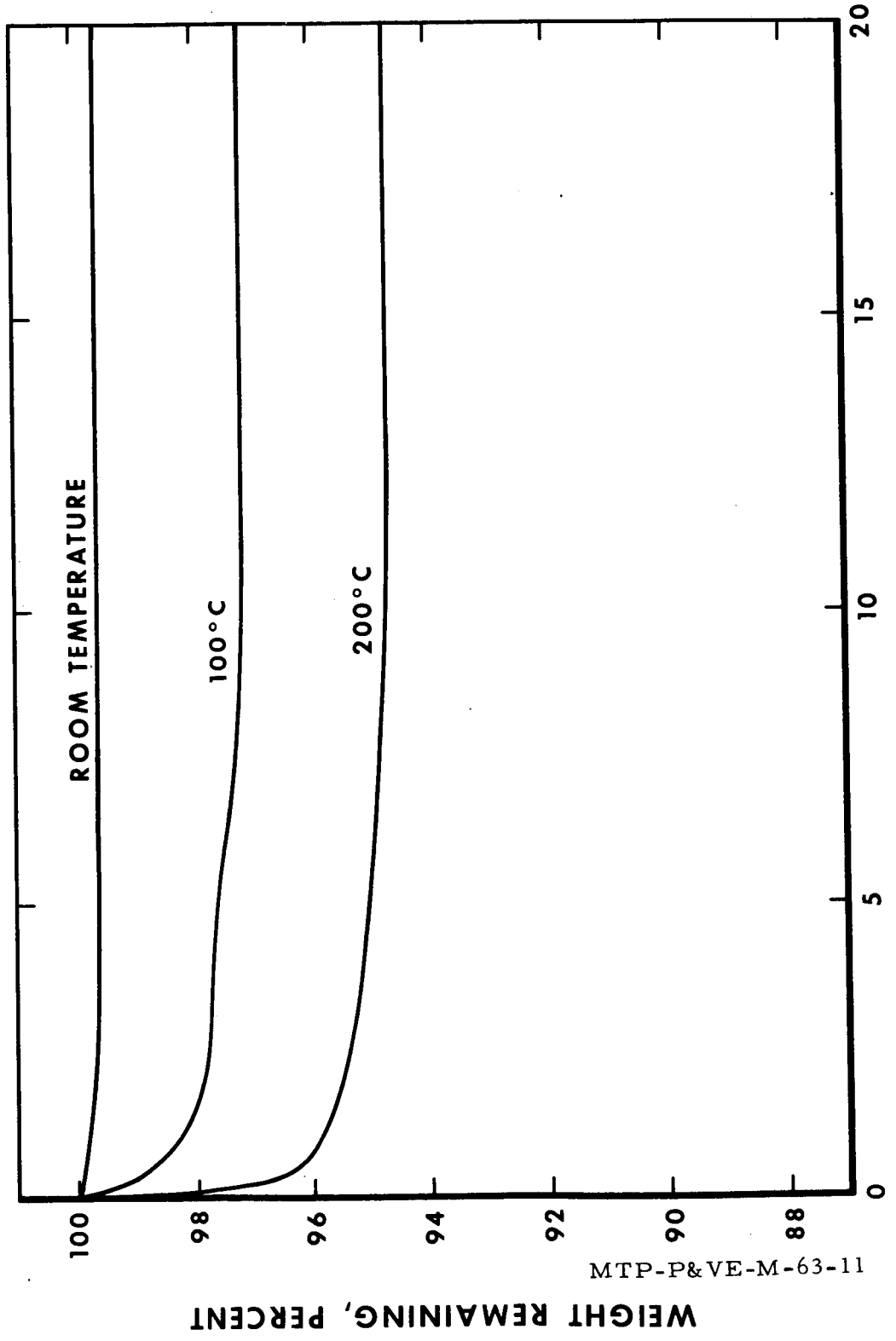


FIGURE 32. TIME WEIGHT HISTORY FOR CONOLON 506 (FIBERGLASS LAMINATE) DURING EXPOSURE TO VACUUM

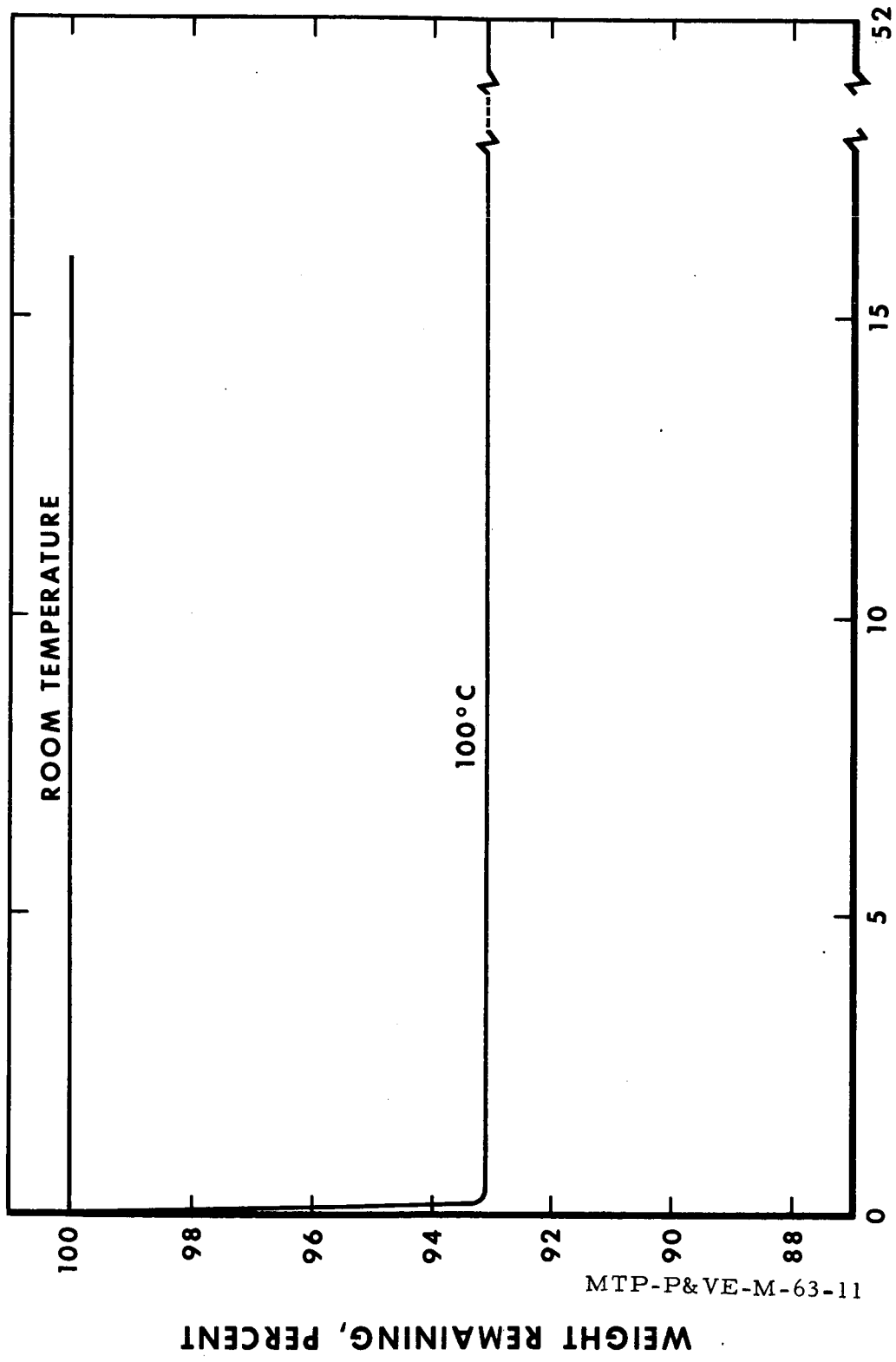


FIGURE 33. TIME WEIGHT HISTORY FOR MOBALOY AH-81 DURING EXPOSURE TO VACUUM

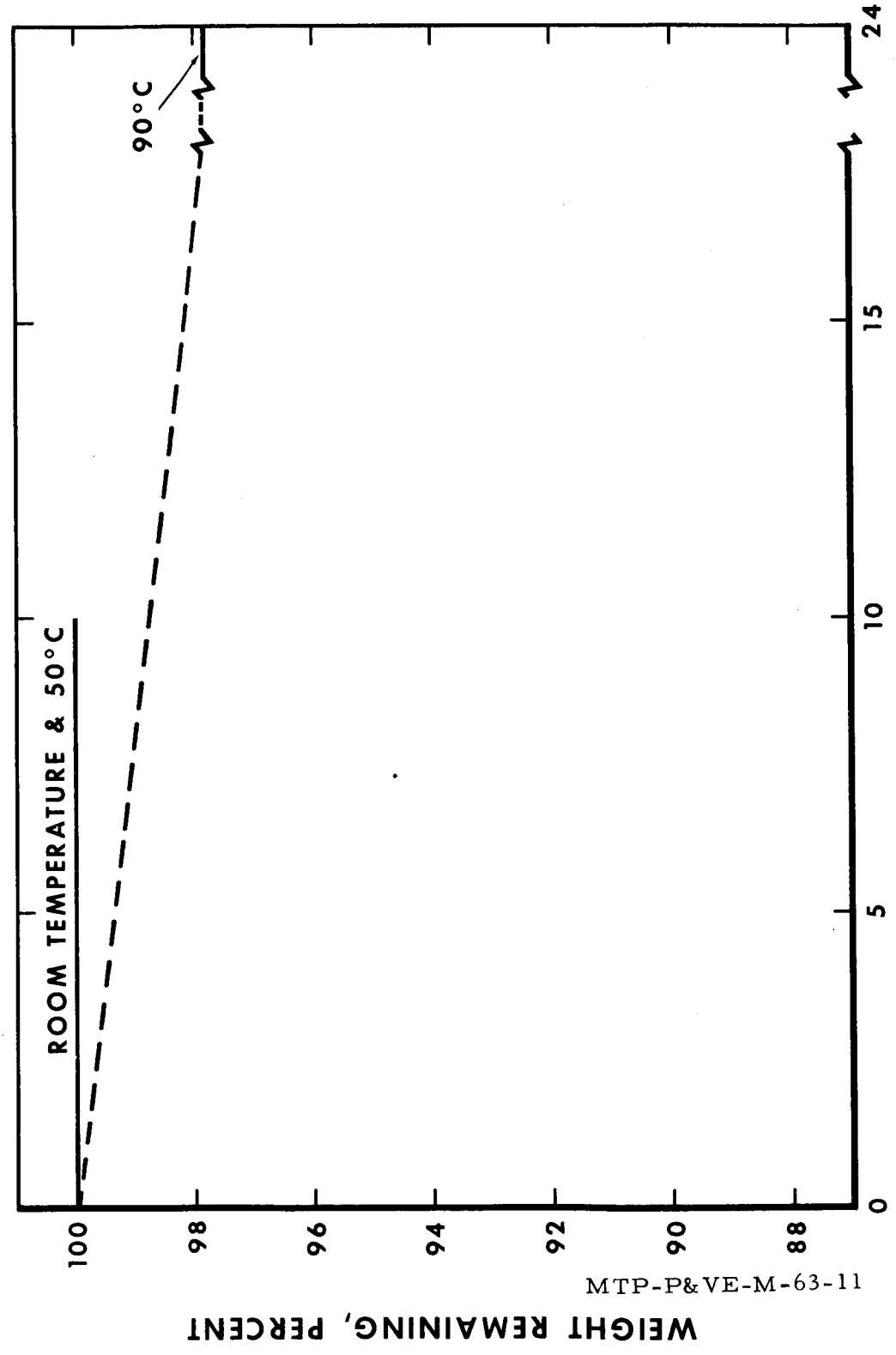


FIGURE 34. TIME WEIGHT HISTORY FOR POLYESTER TAPE, MS-6856, DURING EXPOSURE TO VACUUM

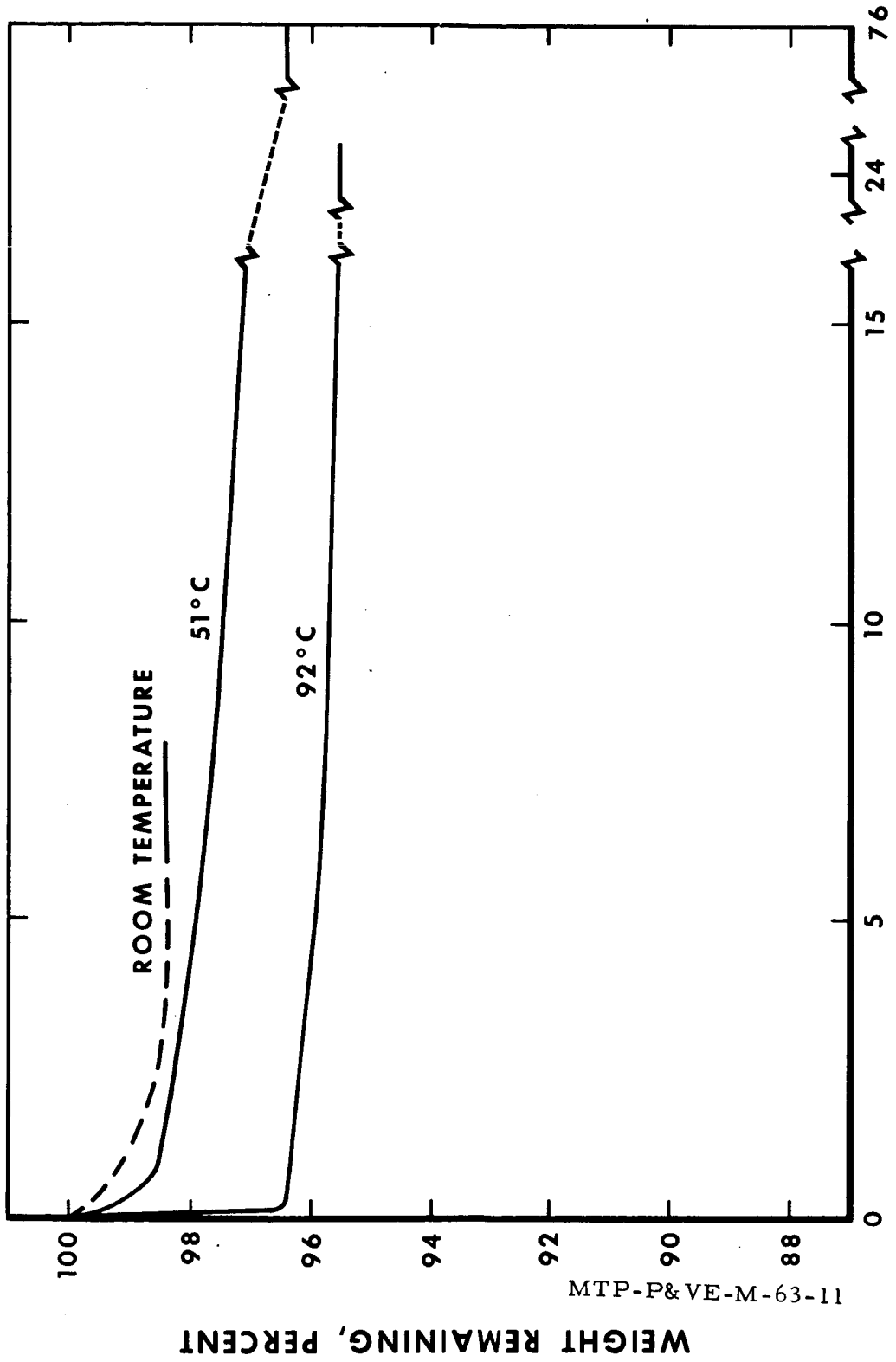


FIGURE 35. TIME WEIGHT HISTORY FOR ACETATE CLOTH TAPE, MS-6768, DURING EXPOSURE TO VACUUM

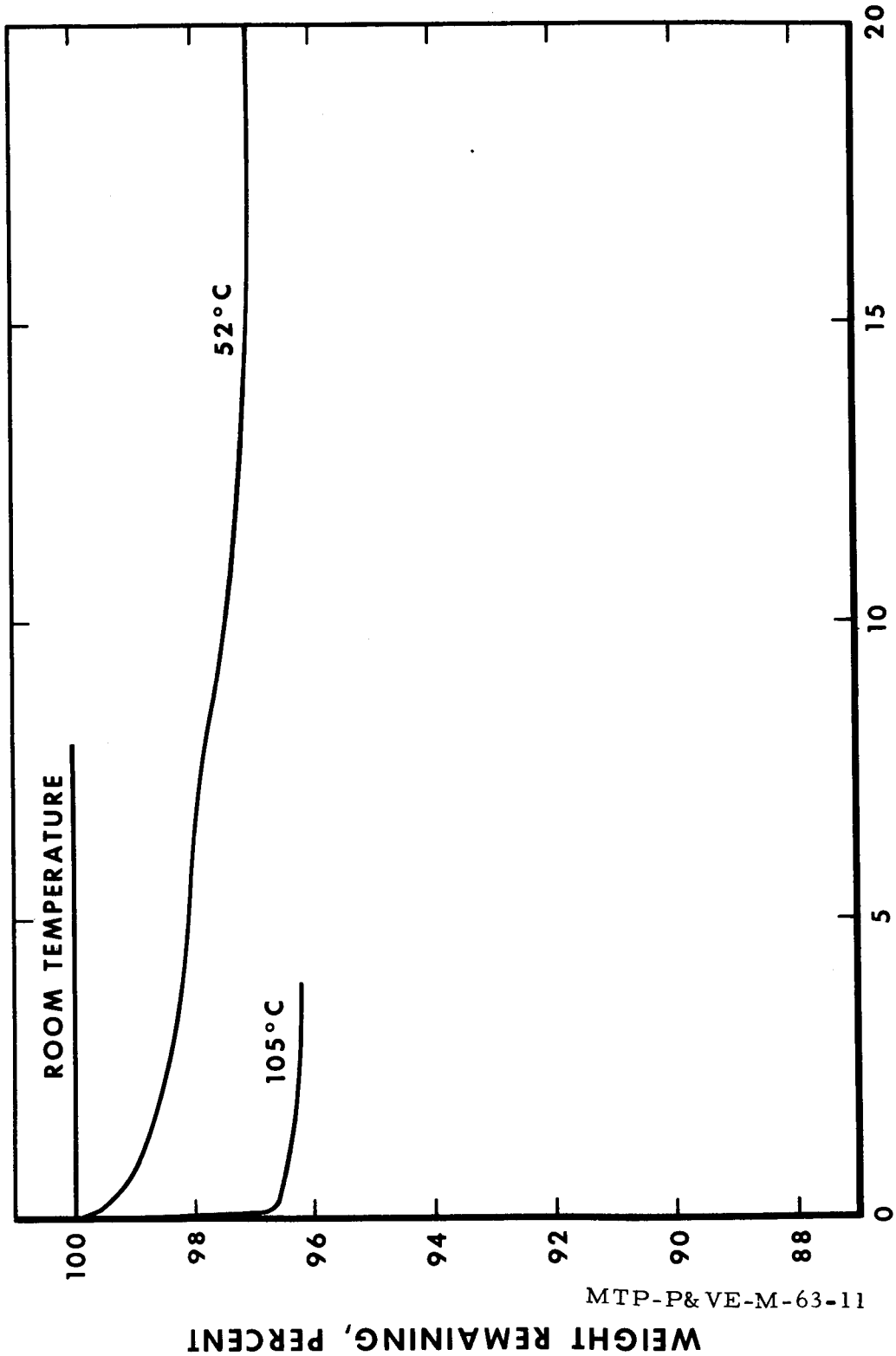


FIGURE 36. TIME WEIGHT HISTORY FOR FIBERGLASS TAPE, MS-6771, DURING EXPOSURE TO VACUUM

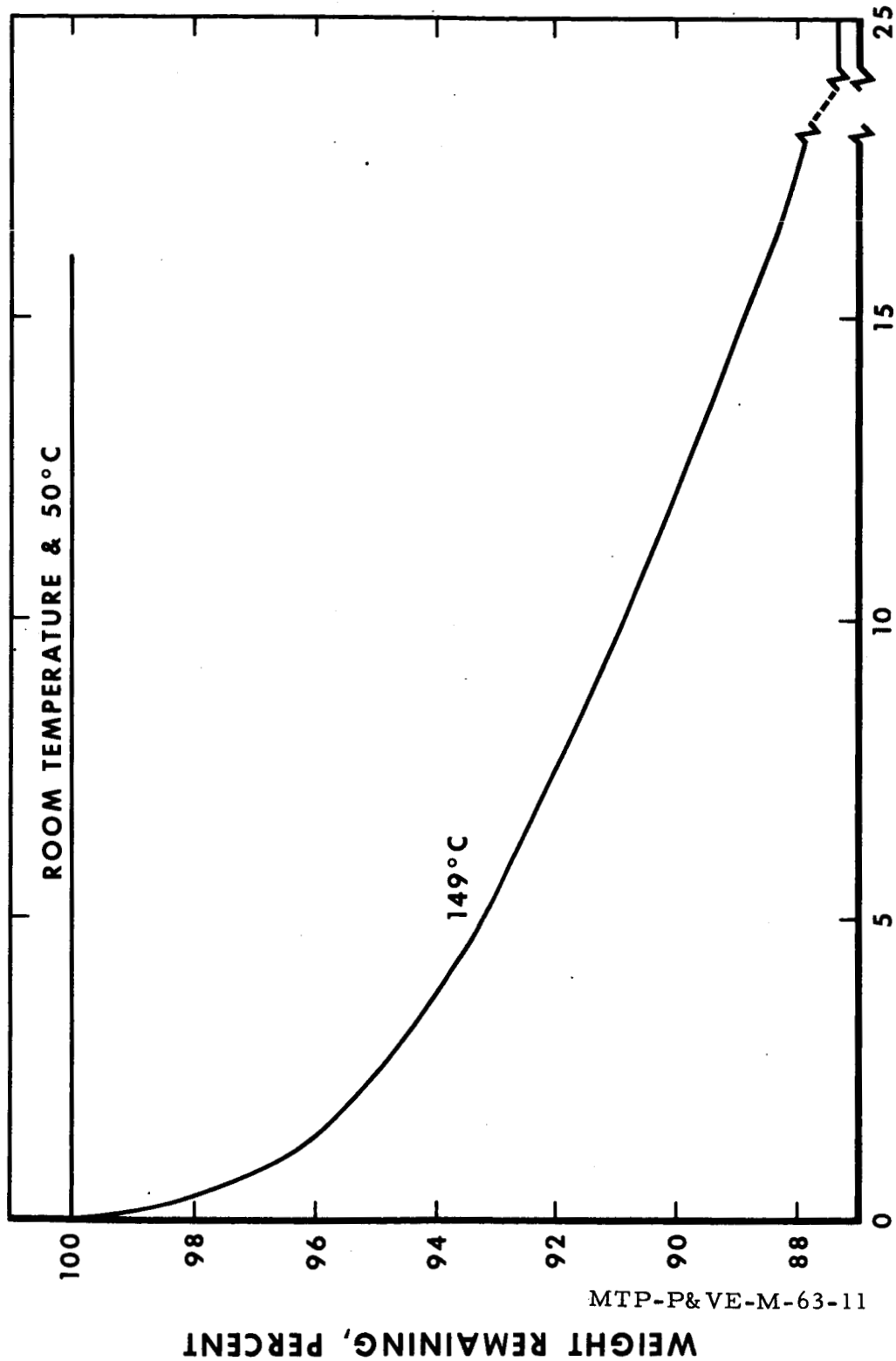


FIGURE 37. TIME WEIGHT HISTORY FOR IRRADIATED POLYOLEFIN TUBING, MS-7308, BLACK, DURING EXPOSURE TO VACUUM

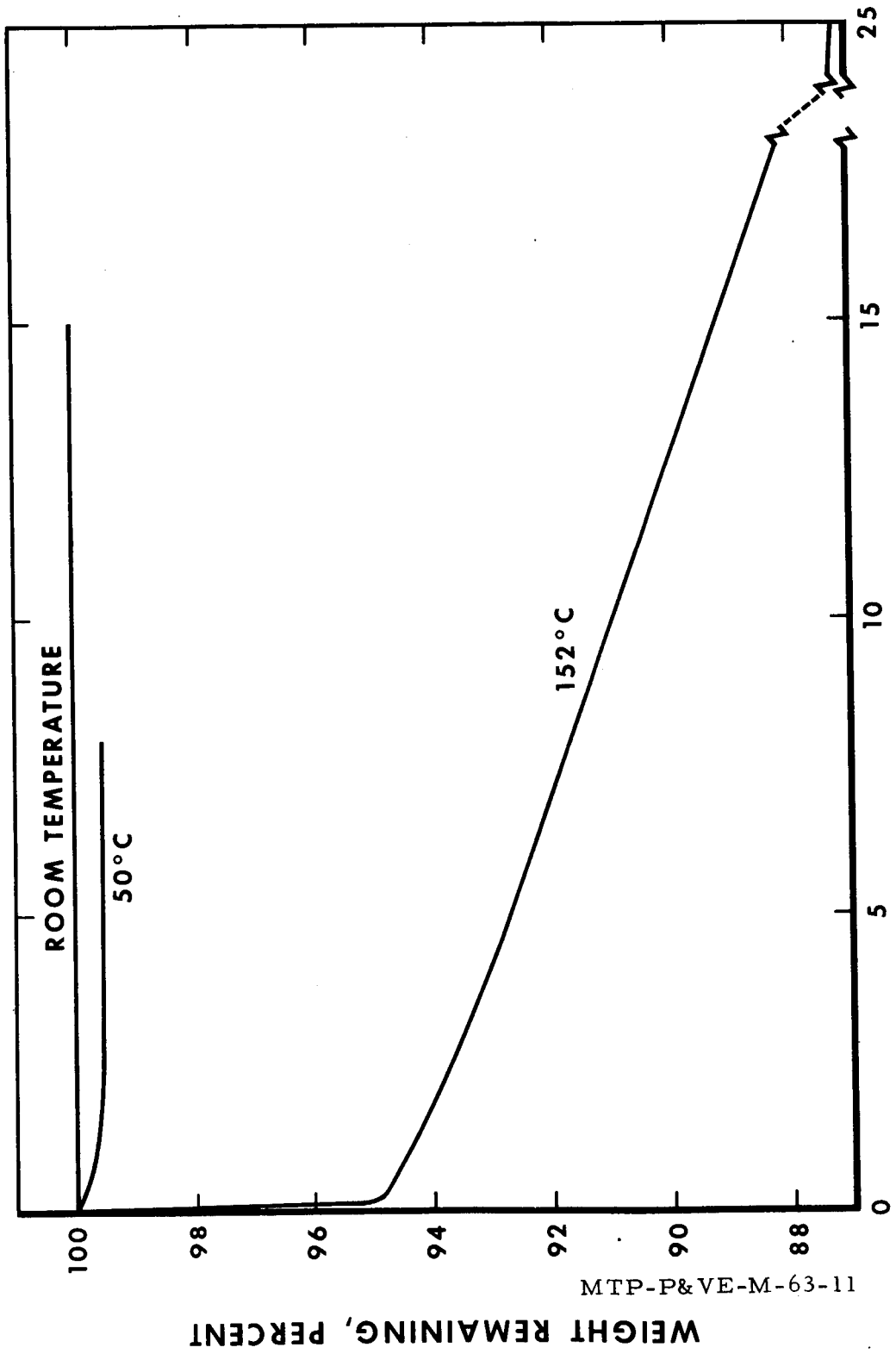


FIGURE 38. TIME WEIGHT HISTORY FOR IRRADIATED POLYOLEFIN TUBING, MS-7308, GREEN DURING EXPOSURE TO VACUUM

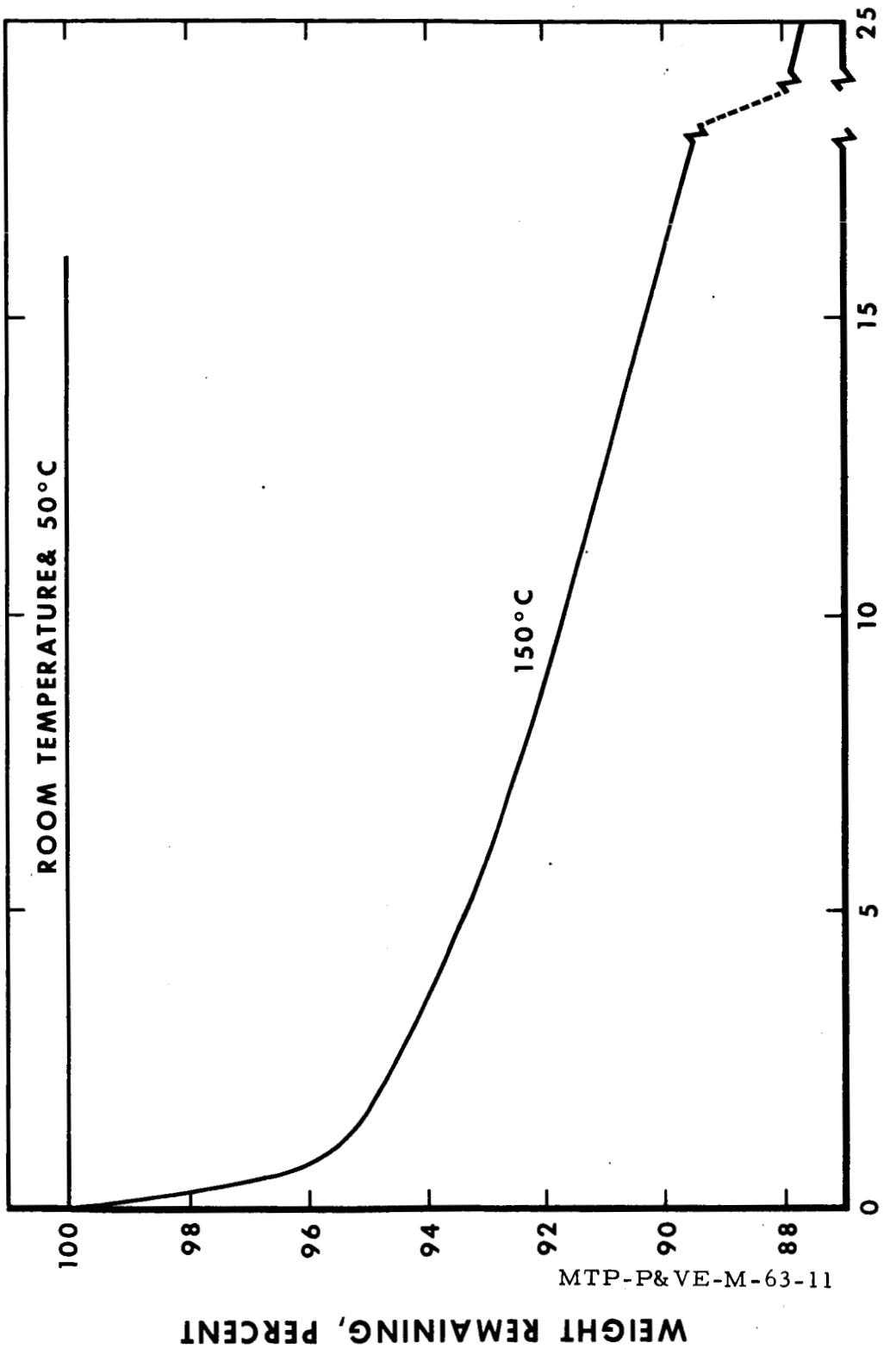


FIGURE 39. TIME WEIGHT HISTORY FOR IRRADIATED POLYOLEFIN TUBING, MS-7308, GRAY, DURING EXPOSURE TO VACUUM

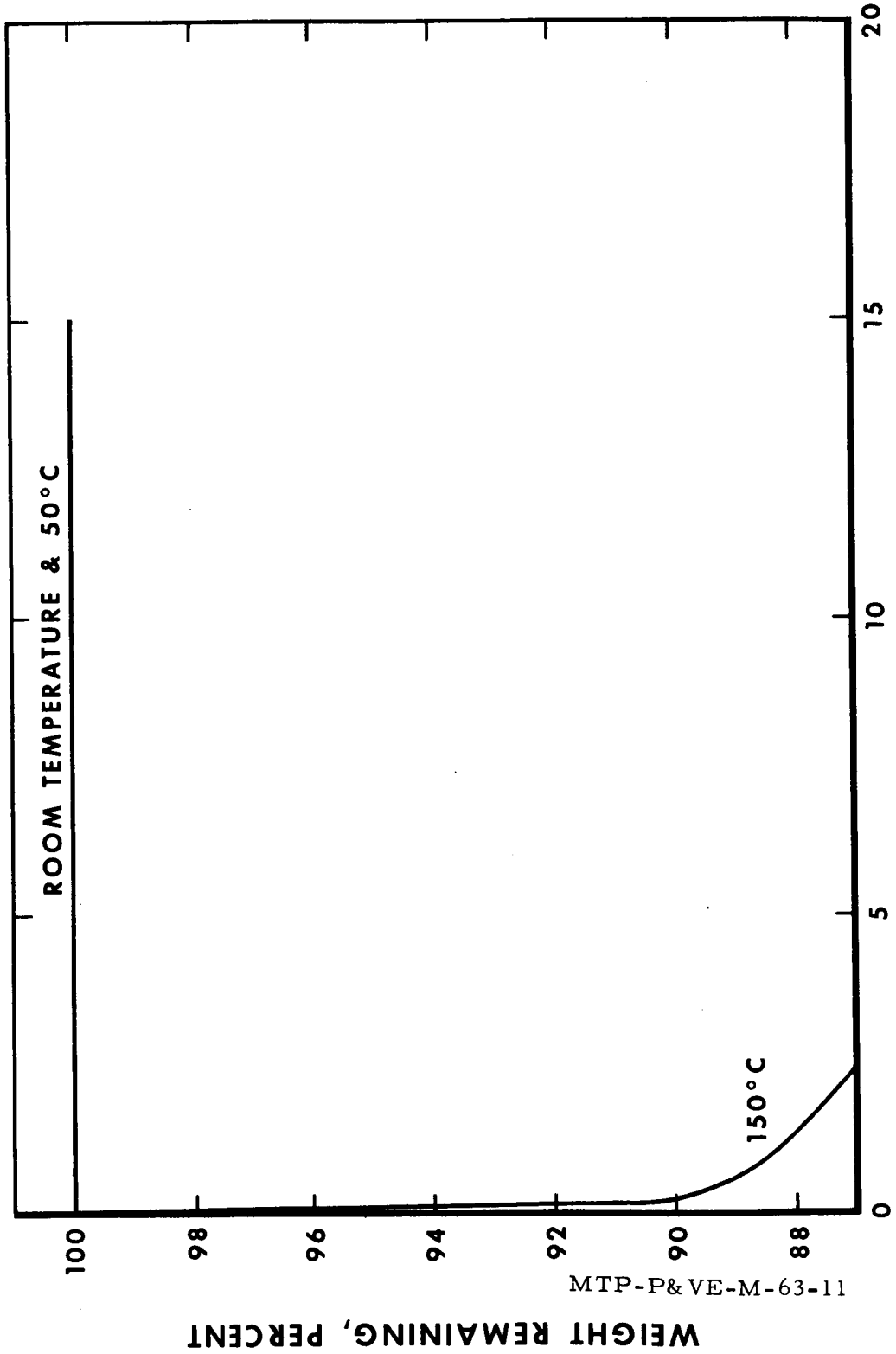


FIGURE 40. TIME WEIGHT HISTORY FOR IRRADIATED POLYOLEFIN TUBING, MS-7247, WHITE, DURING EXPOSURE TO VACUUM

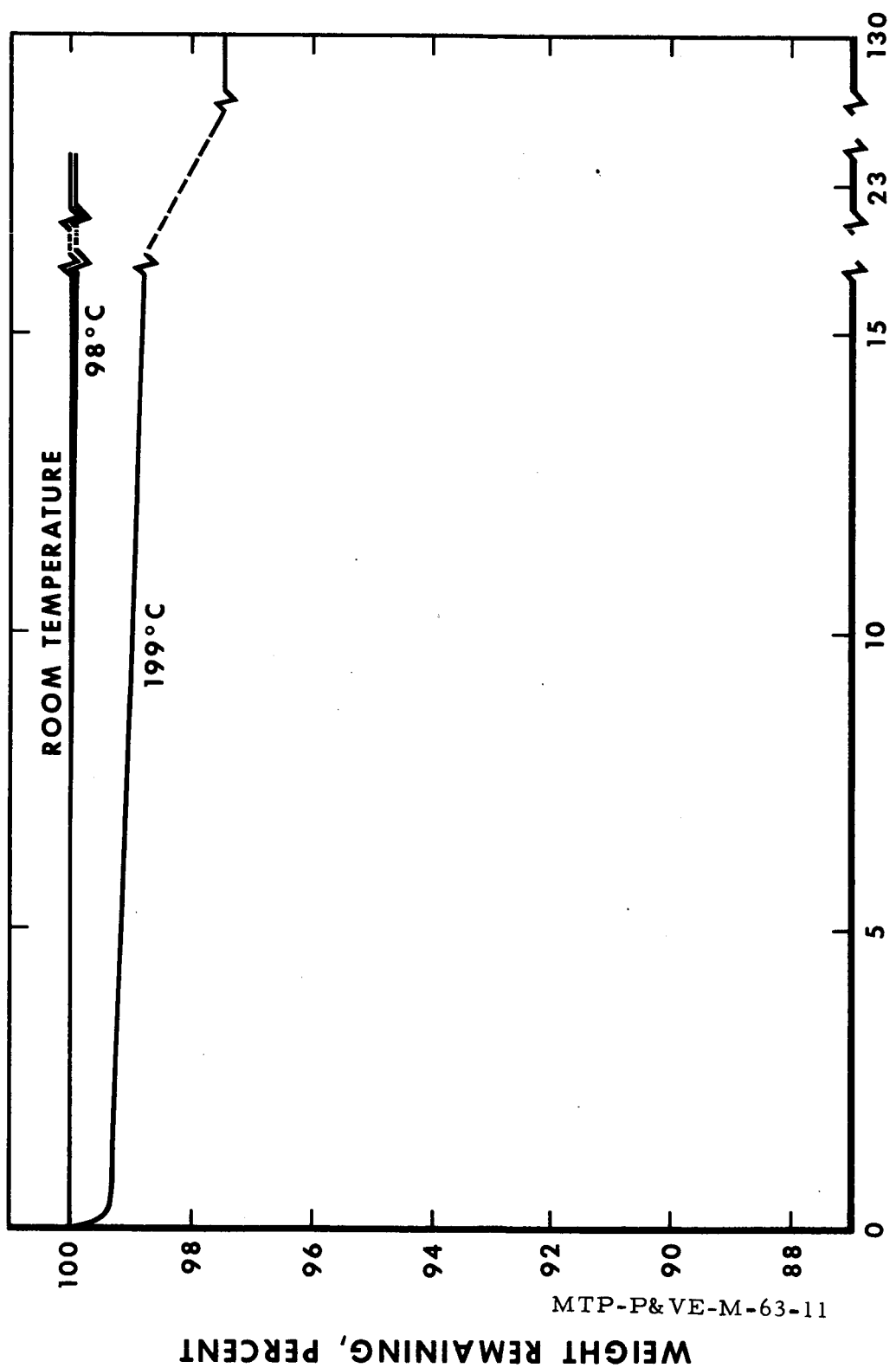


FIGURE 41. TIME WEIGHT HISTORY FOR COPPER CLAD GLASS EPOXY DURING EXPOSURE TO VACUUM

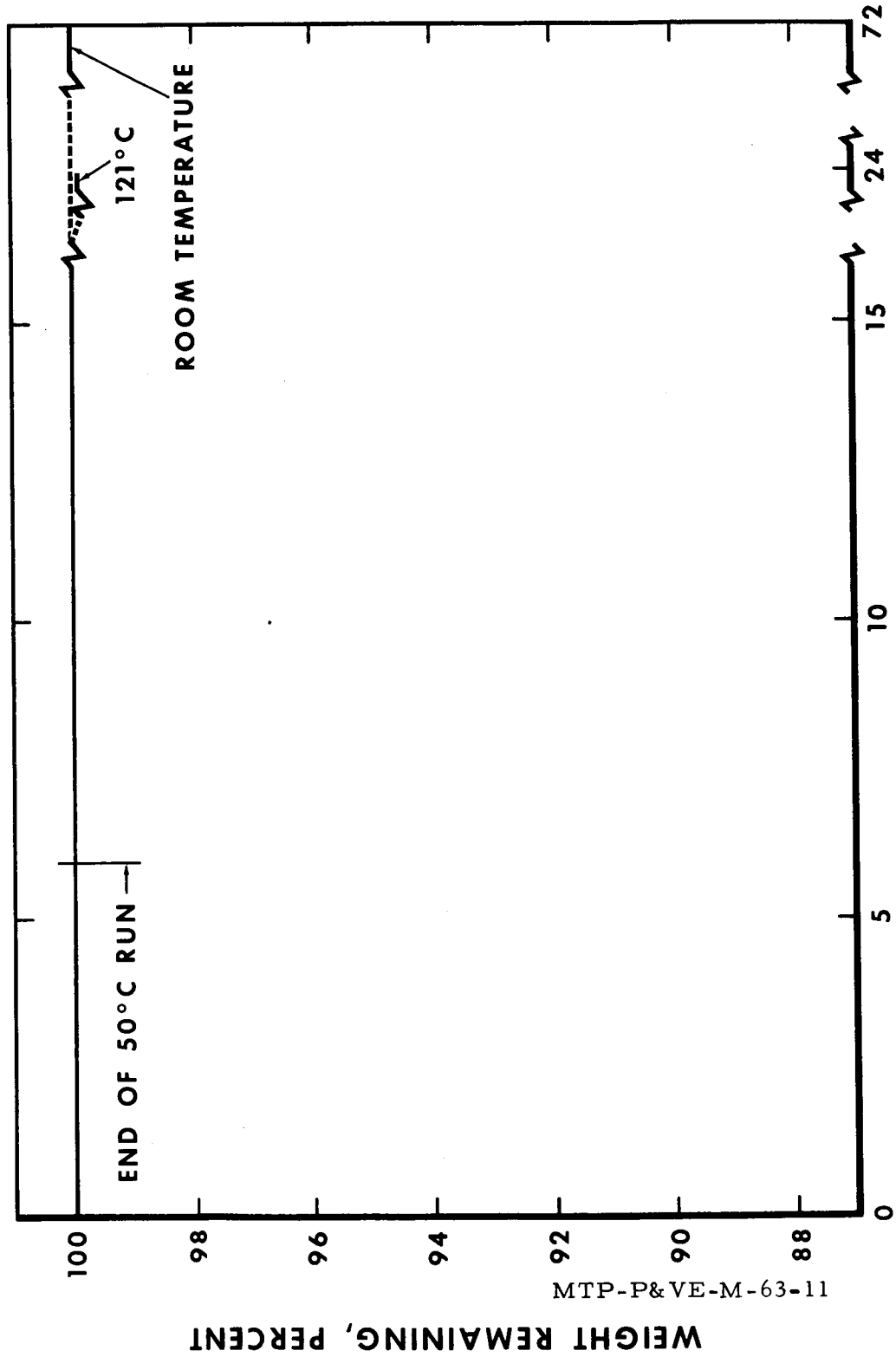


FIGURE 42. TIME WEIGHT HISTORY FOR EPOXY IMPREGNATING COMPOUND DURING EXPOSURE TO VACUUM

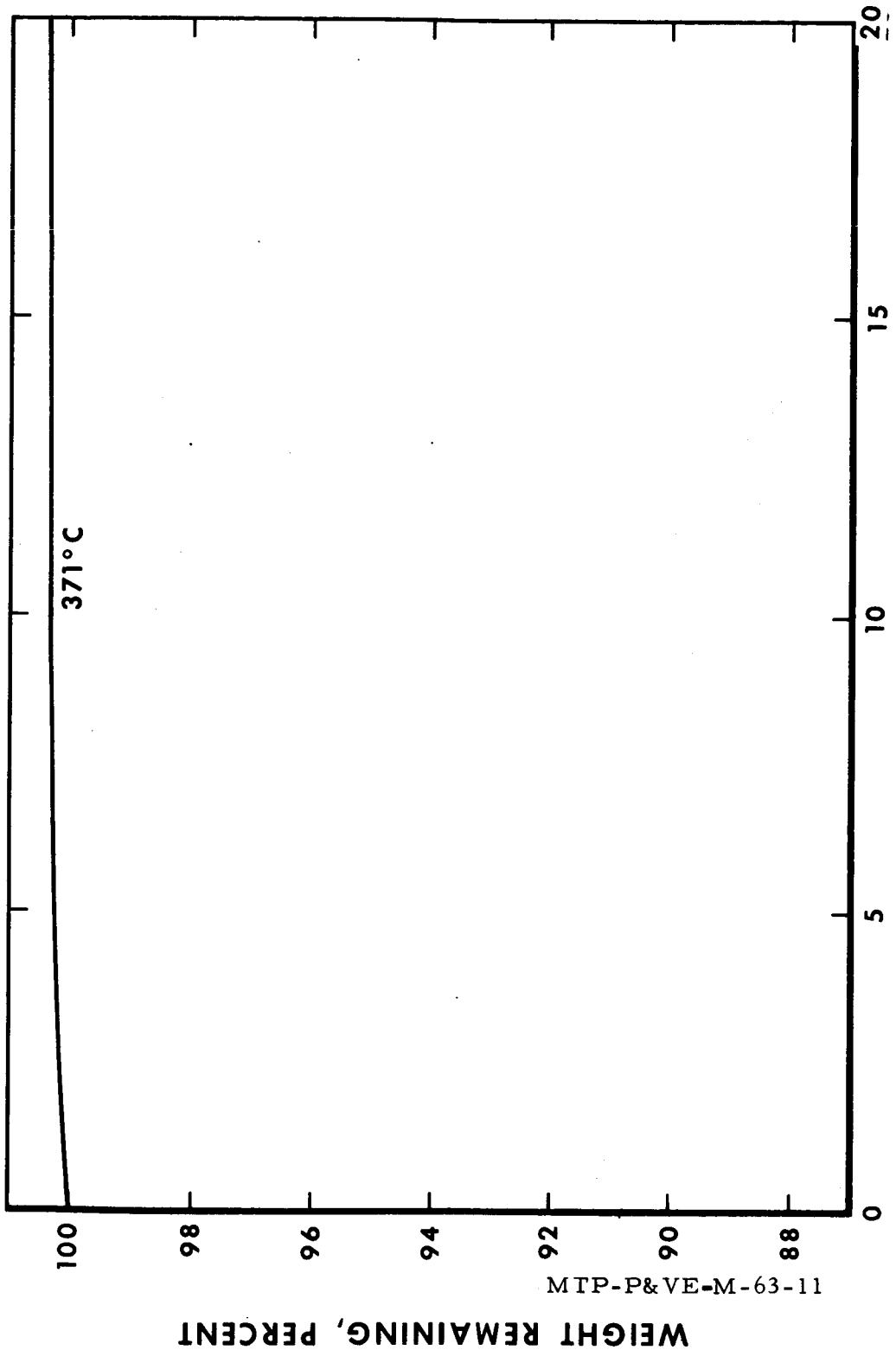


FIGURE 43. TIME WEIGHT HISTORY FOR LITHIUM ALLOY LA-141 DURING EXPOSURE TO VACUUM

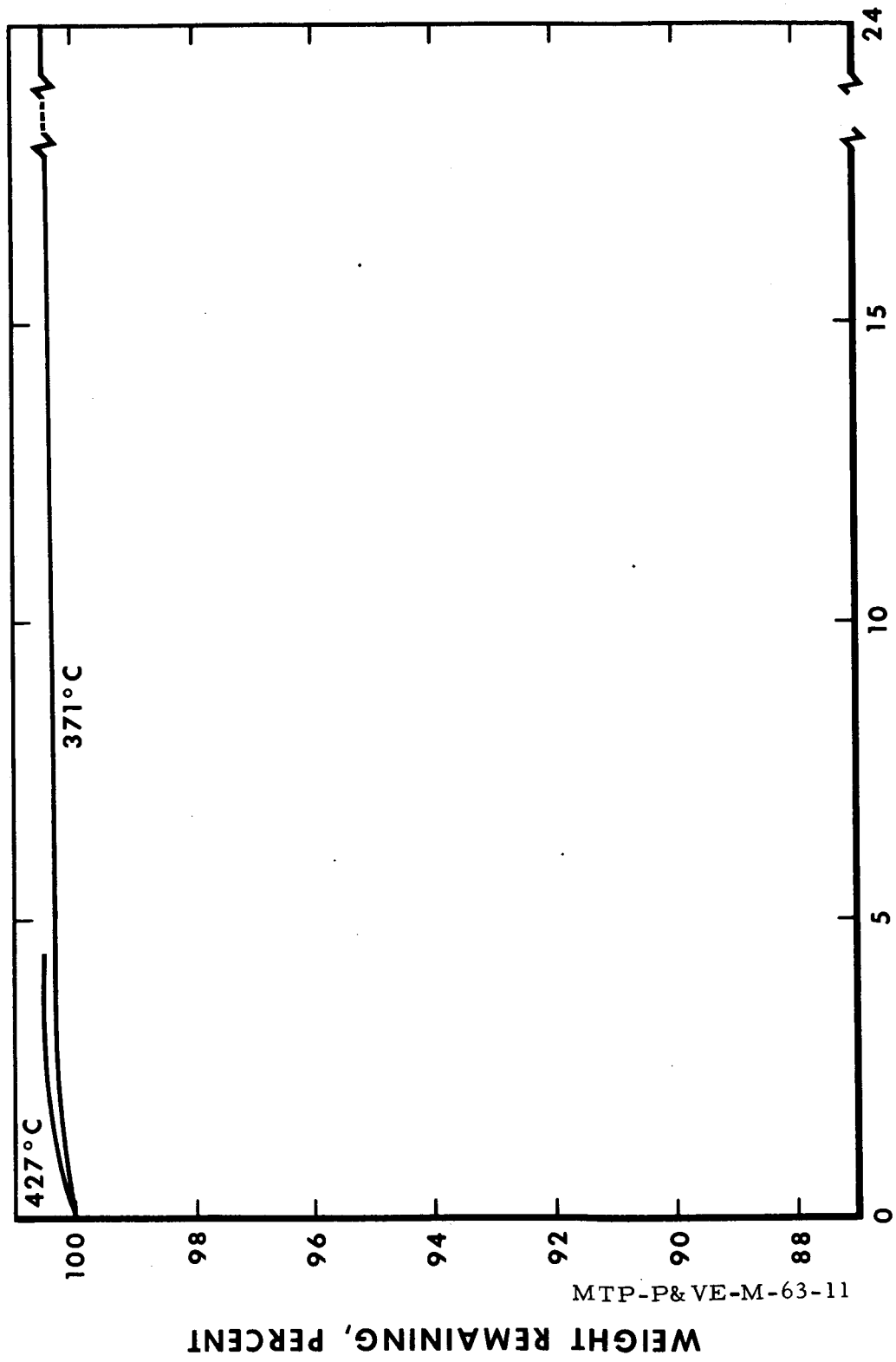


FIGURE 44. TIME WEIGHT HISTORY FOR LITHIUM ALLOY LA-91 DURING EXPOSURE TO VACUUM

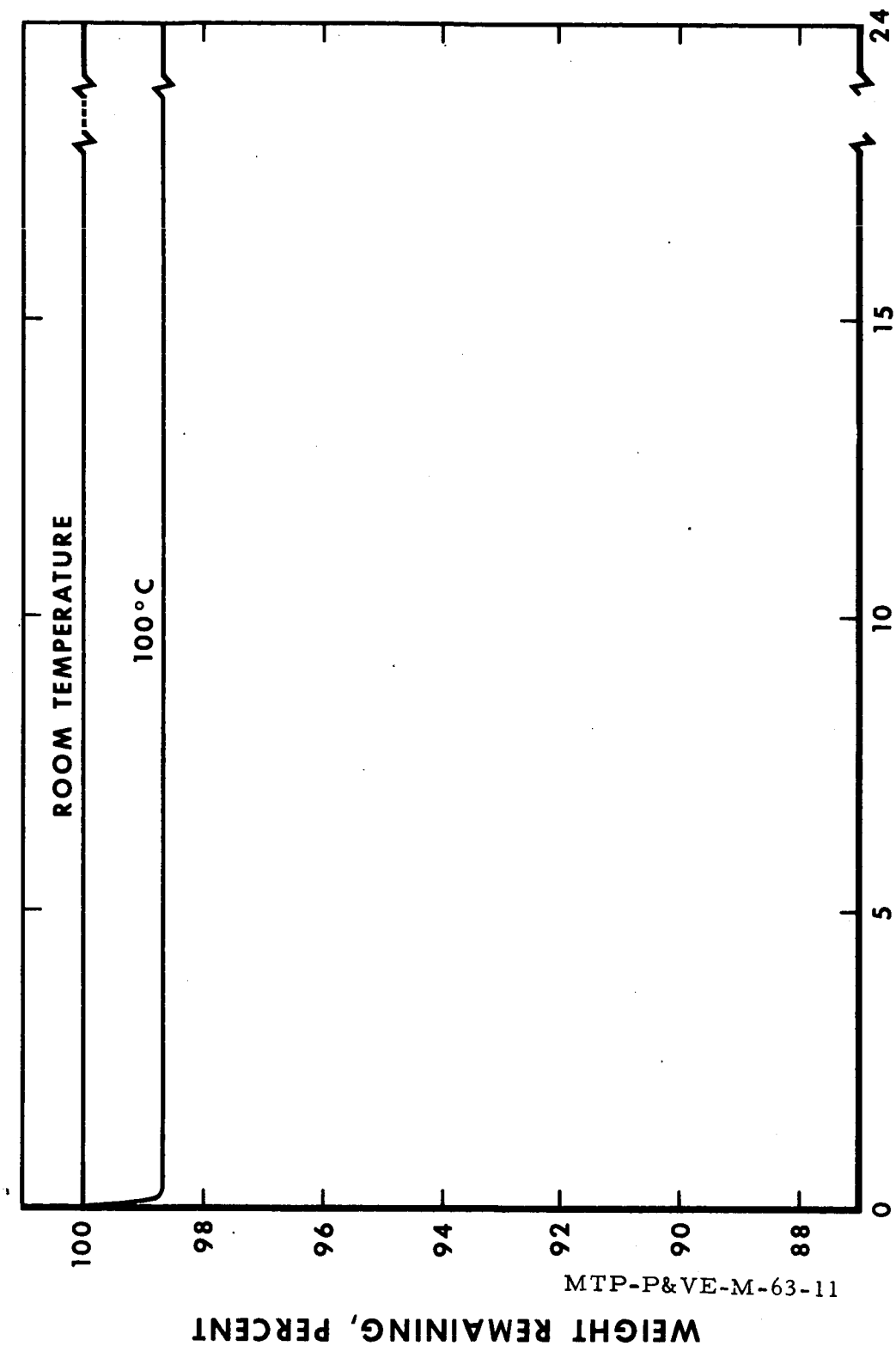


FIGURE 45. TIME WEIGHT HISTORY FOR UNIFOAM THERMAL INSULATION DURING EXPOSURE TO VACUUM

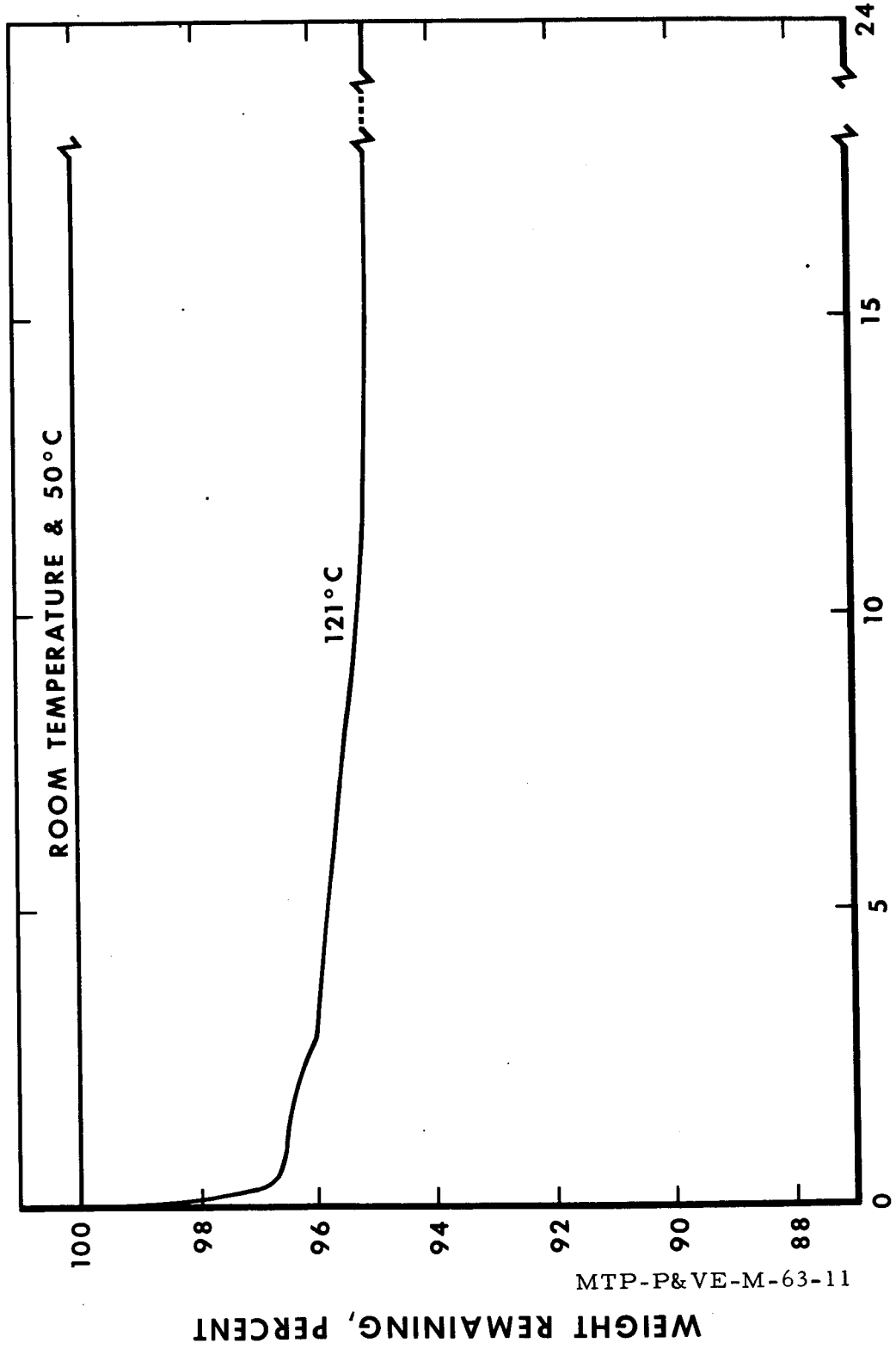


FIGURE 46. TIME WEIGHT HISTORY FOR URETHANE FOAM DURING EXPOSURE TO VACUUM

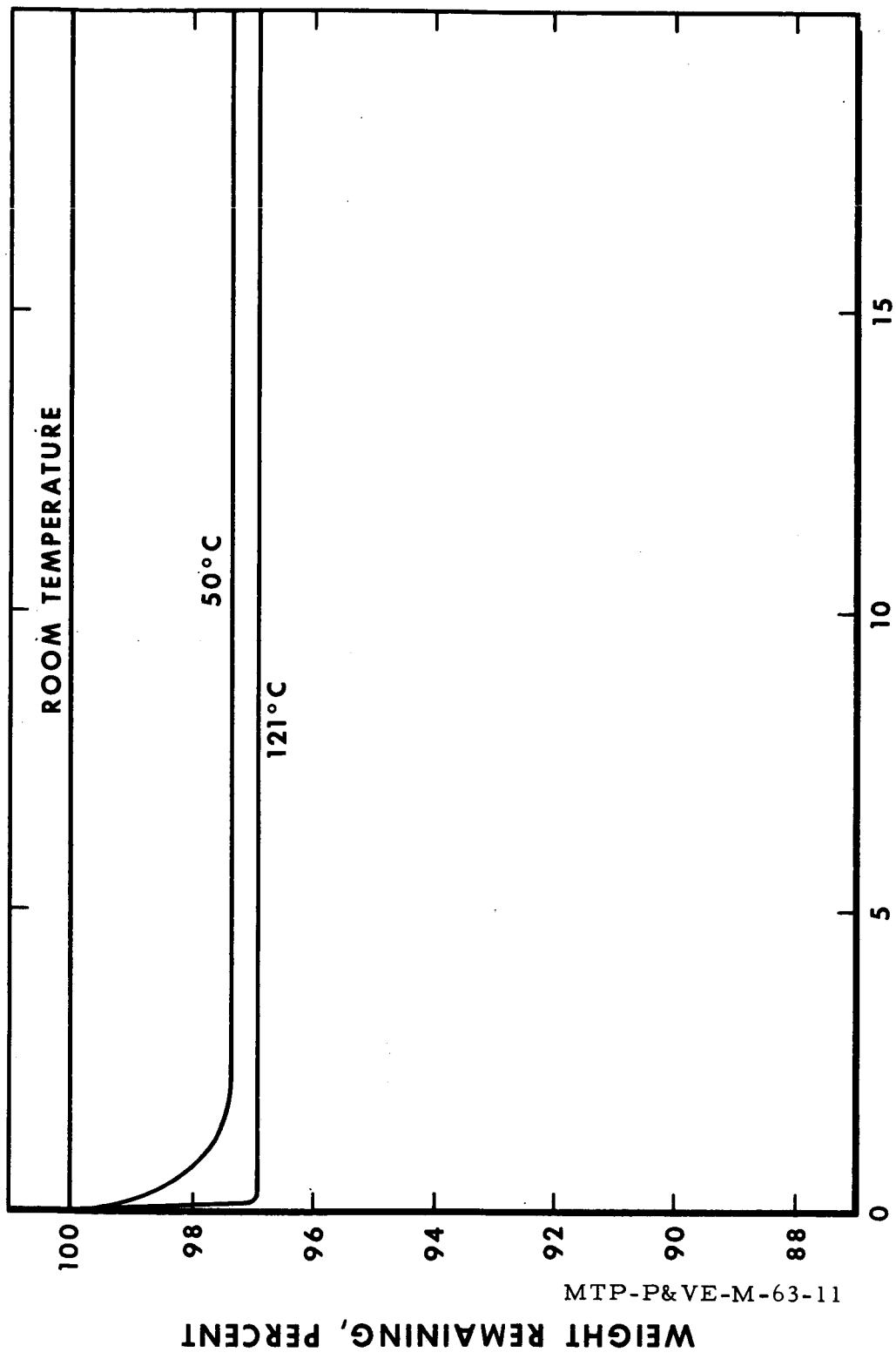


FIGURE 47. TIME WEIGHT HISTORY FOR CONDUCTIVE GASKET DURING EXPOSURE TO VACUUM

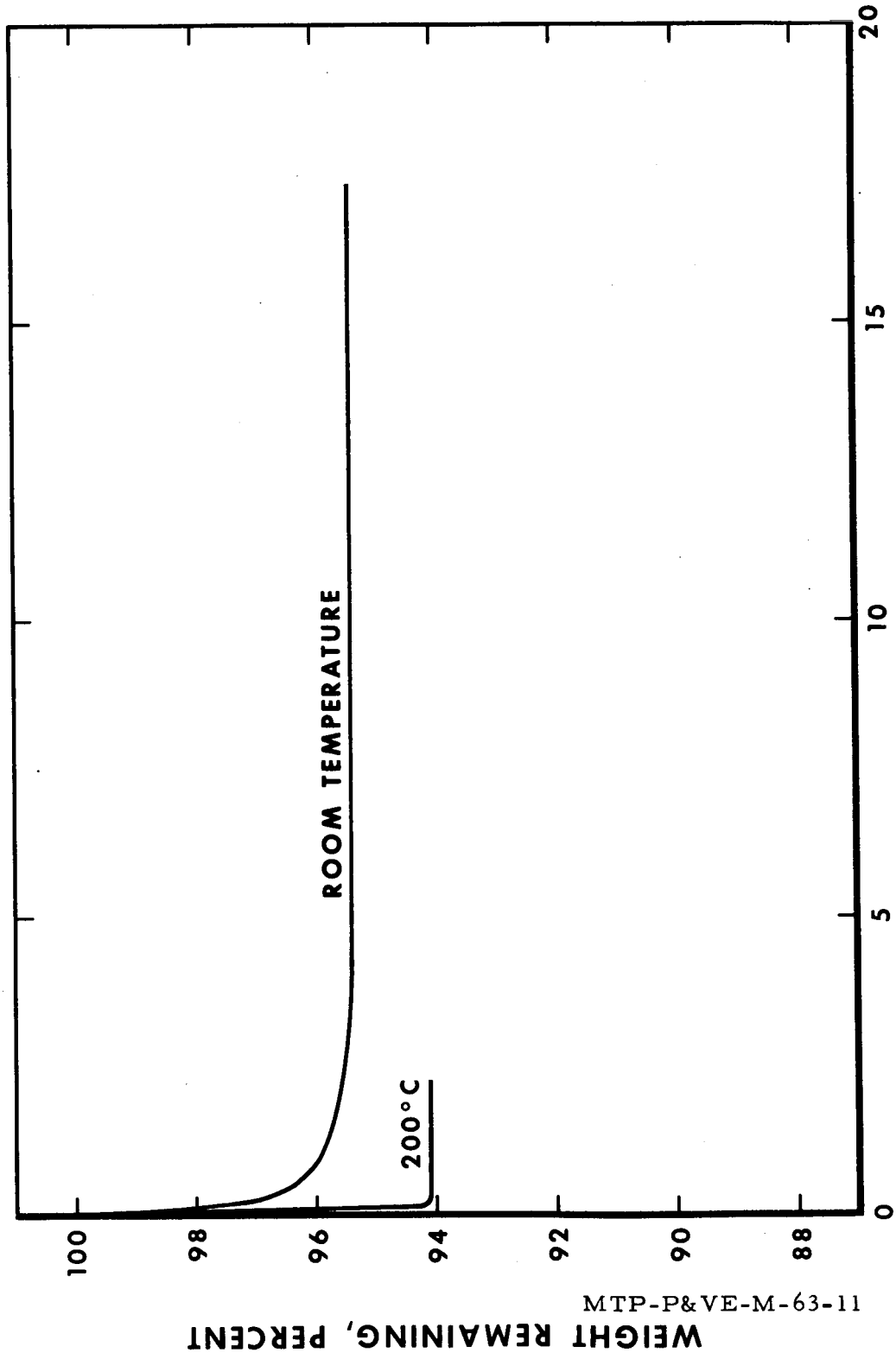


FIGURE 48. TIME WEIGHT HISTORY FOR CRYSTAL MK PAPER DURING EXPOSURE TO VACUUM

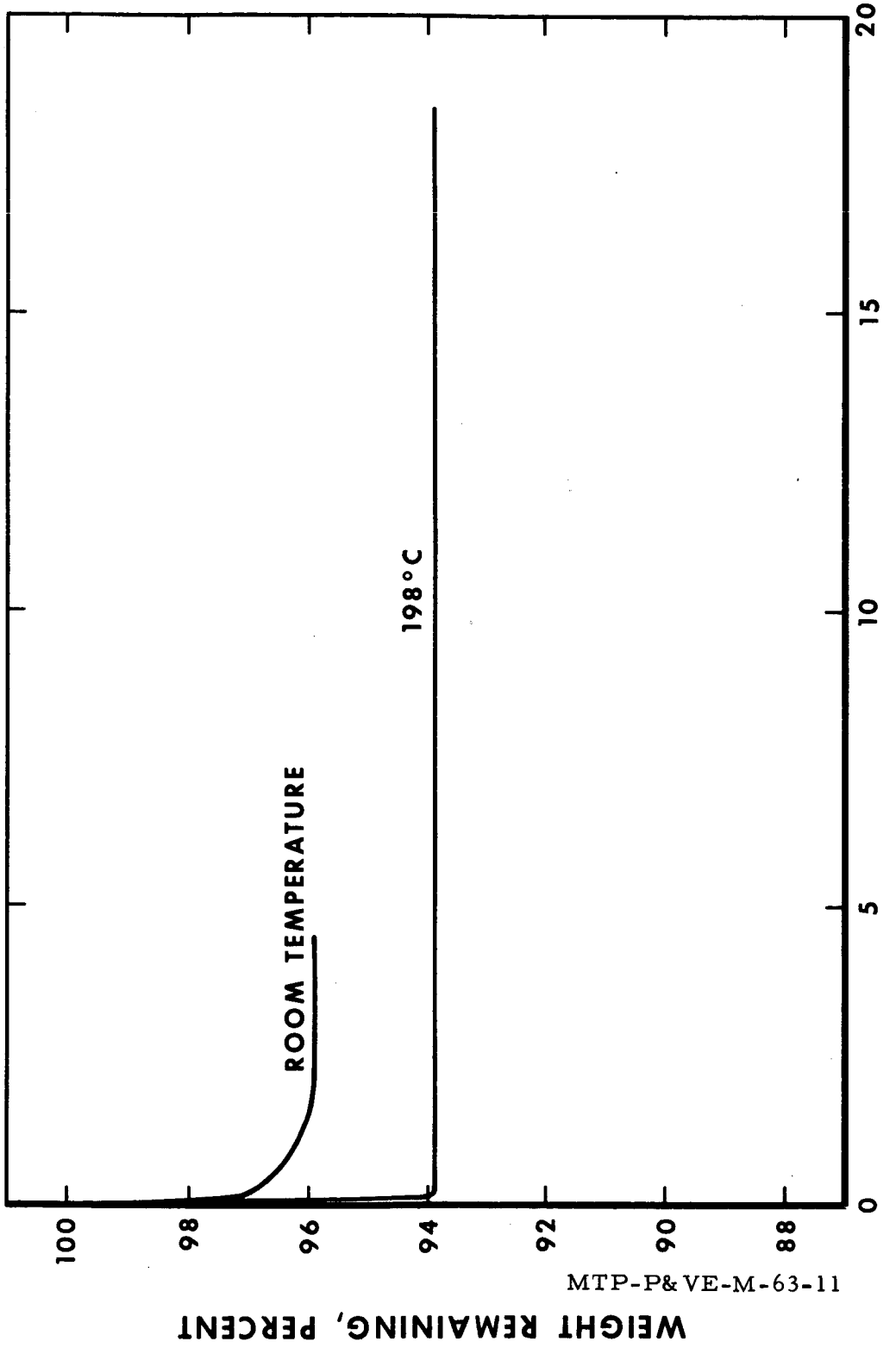


FIGURE 49. TIME WEIGHT HISTORY FOR CRYSTAL M PAPER DURING EXPOSURE TO VACUUM

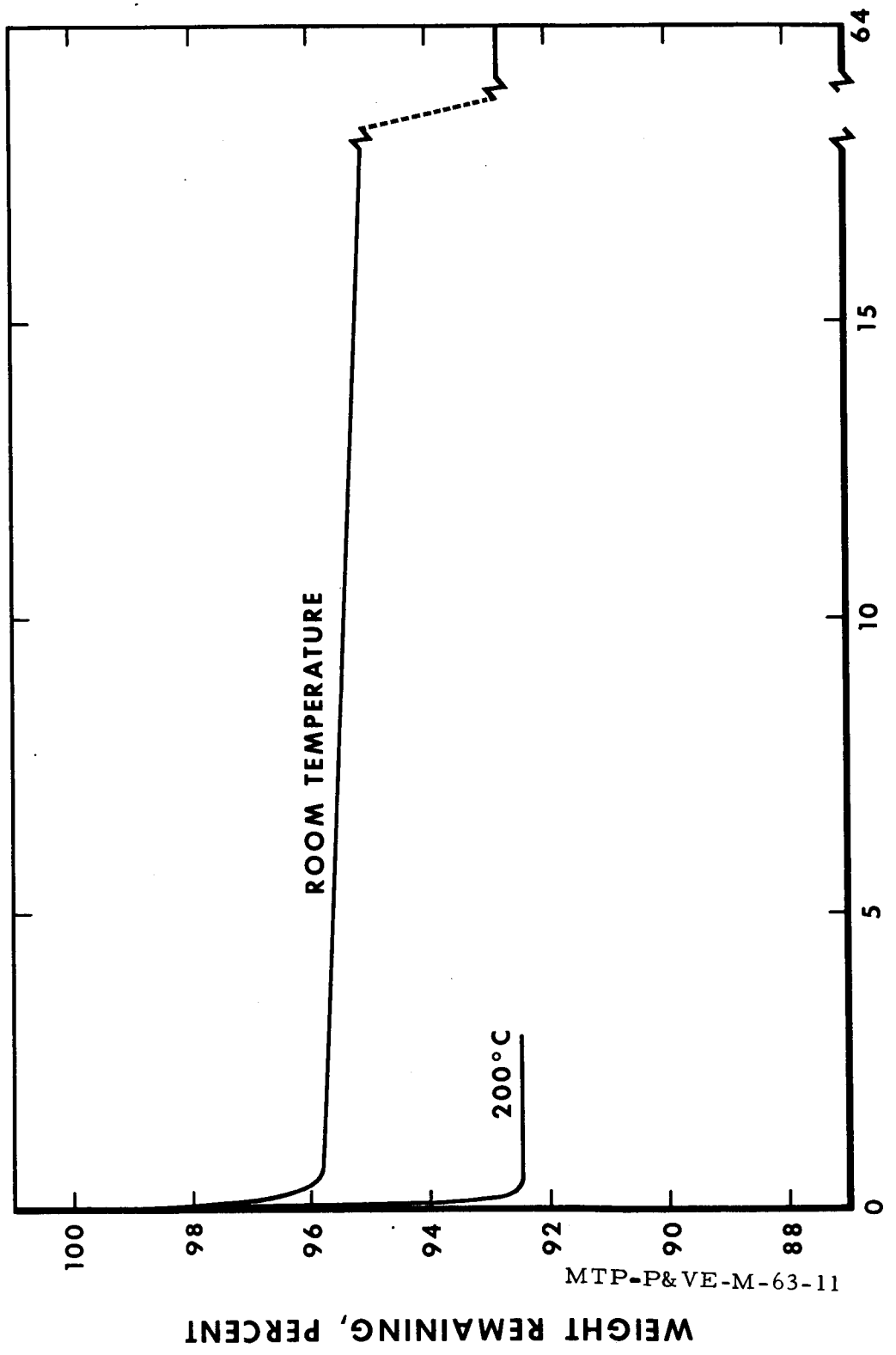


FIGURE 50. TIME WEIGHT HISTORY FOR CRYSTAL MG PAPER DURING EXPOSURE TO VACUUM

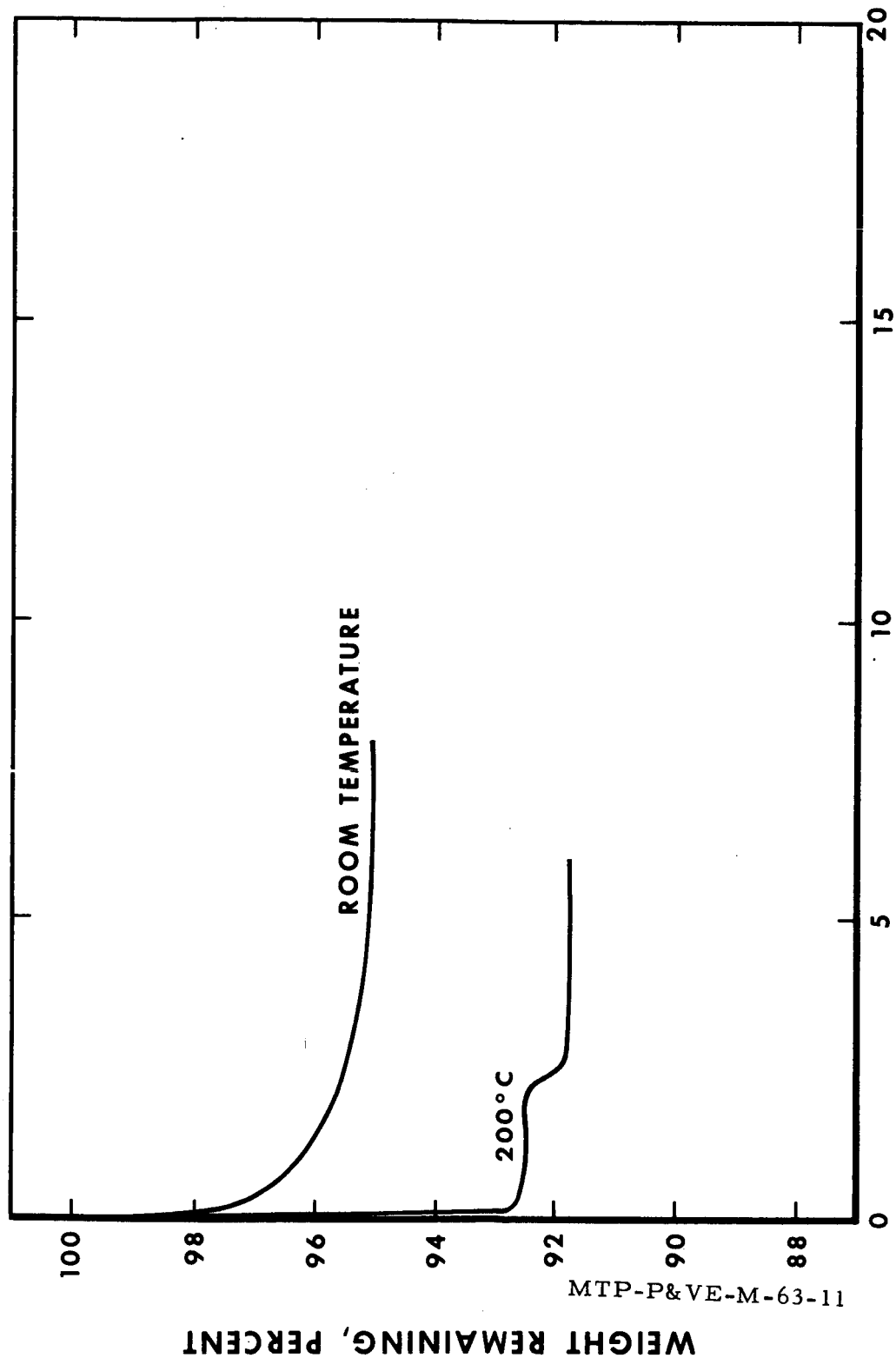


FIGURE 51. TIME WEIGHT HISTORY FOR CRYSTAL MP PAPER DURING EXPOSURE TO VACUUM

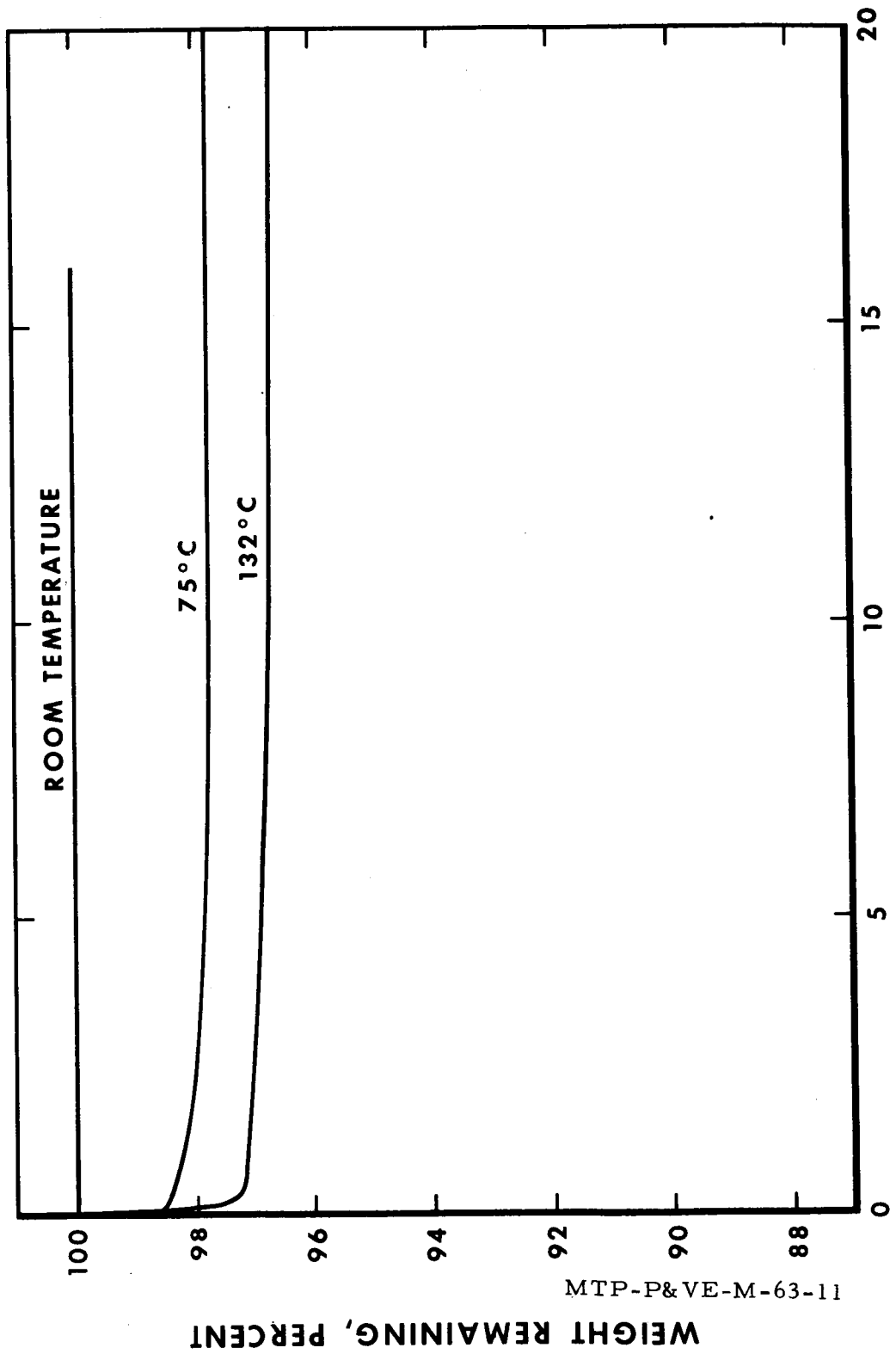


FIGURE 52. TIME WEIGHT HISTORY FOR DACRON LACING TAPE DURING EXPOSURE TO VACUUM

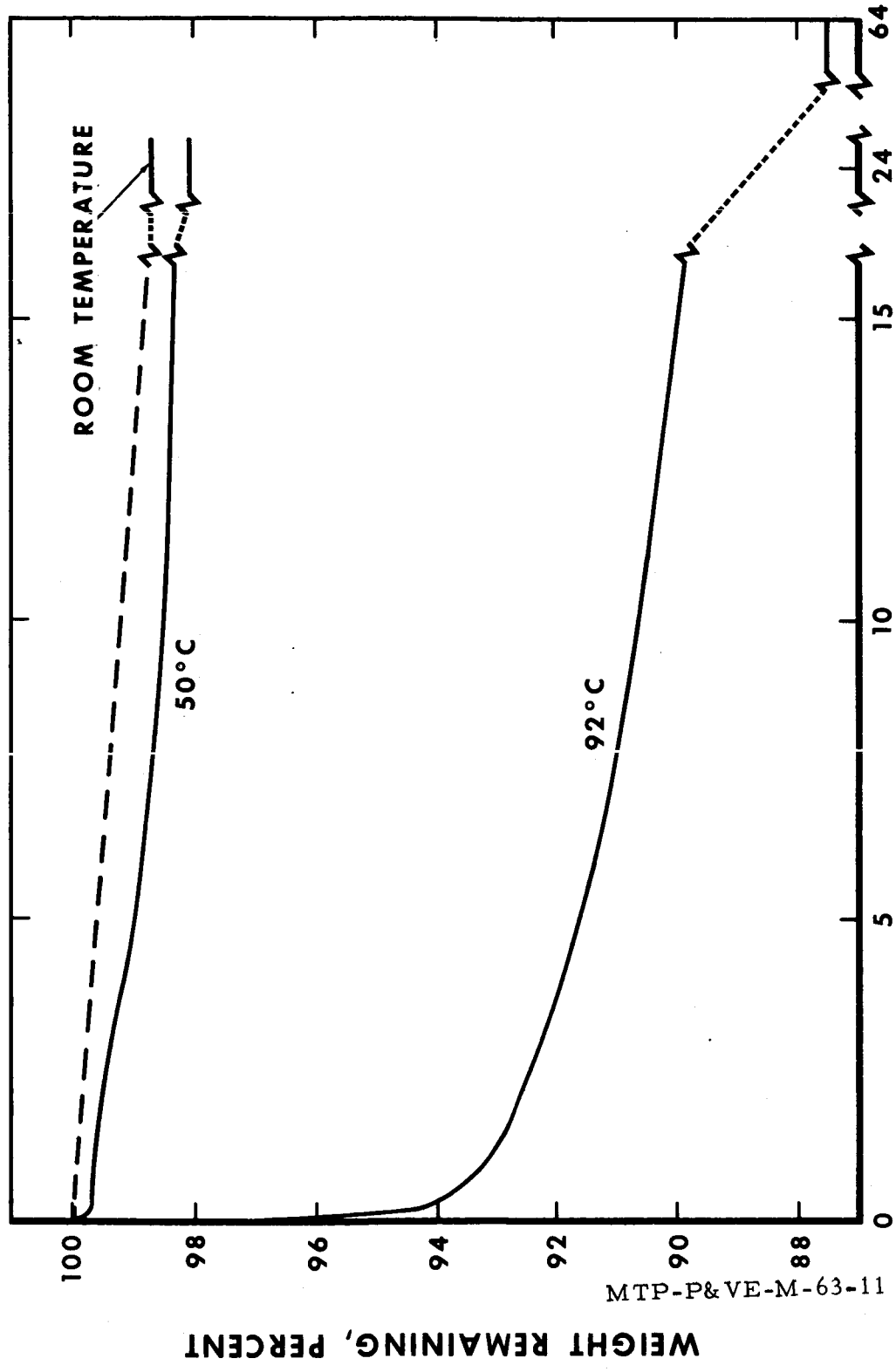


FIGURE 53. TIME WEIGHT HISTORY FOR NYLON TYING CORD DURING EXPOSURE TO VACUUM

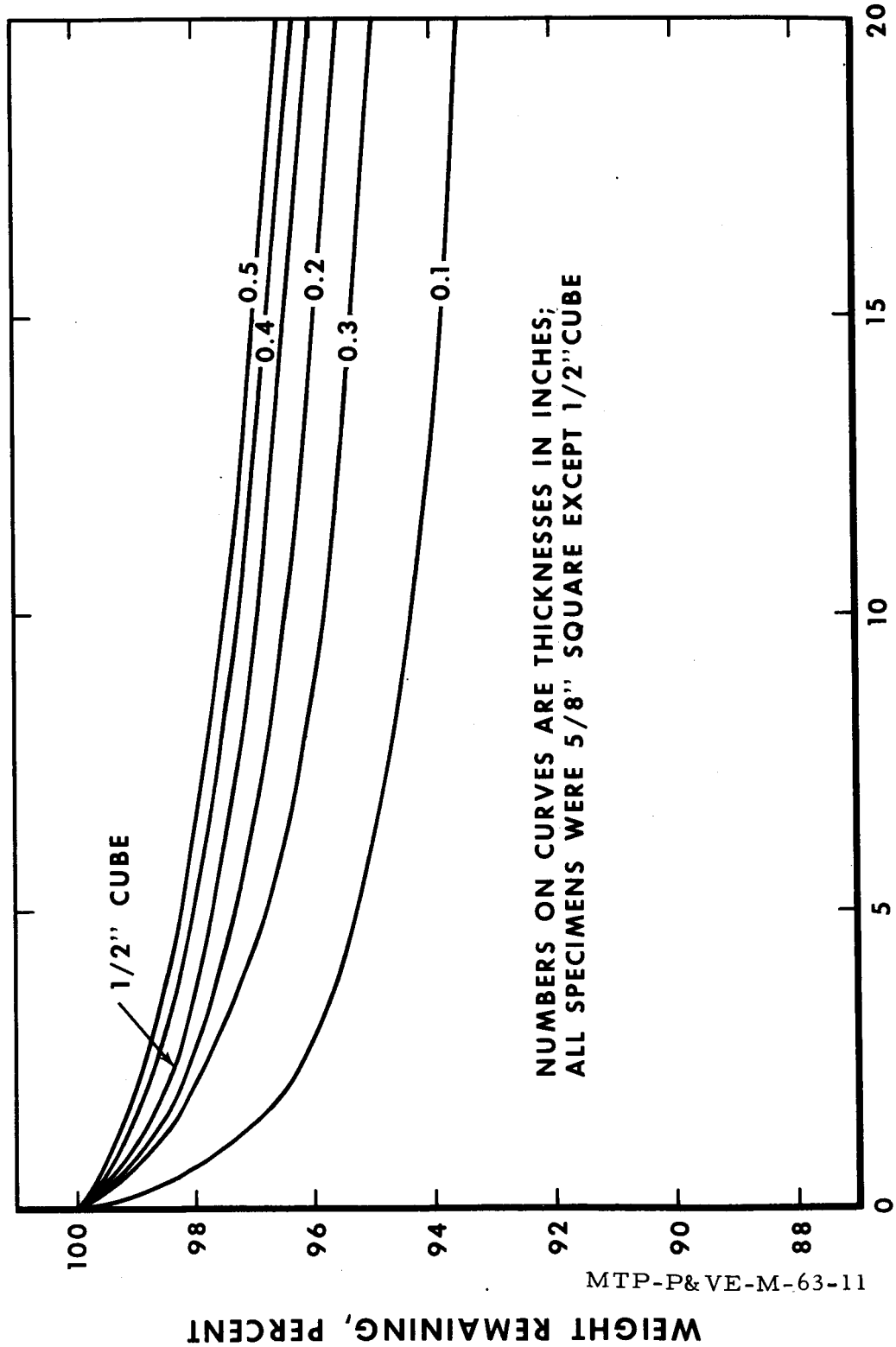


FIGURE 54. TIME WEIGHT HISTORIES FOR DIFFERENT CONFIGURATIONS OF BUNA-N DURING EXPOSURE TO VACUUM

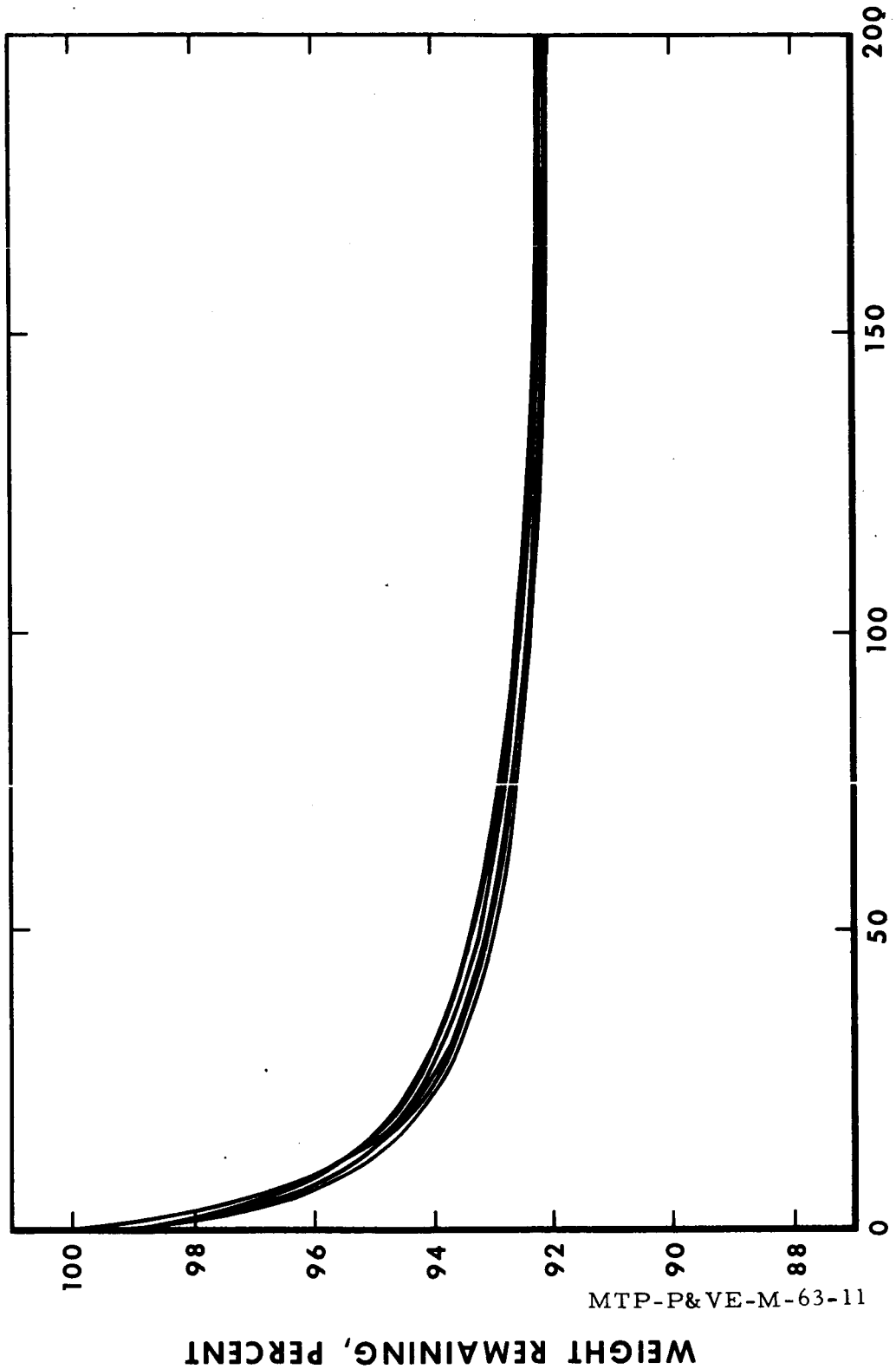


FIGURE 55. PREDICTED TIME-WEIGHT HISTORIES FOR HYPOTHETICAL CENTIMETER CUBE OF BUNA-N BASED RESULTS GIVEN IN FIGURE 54

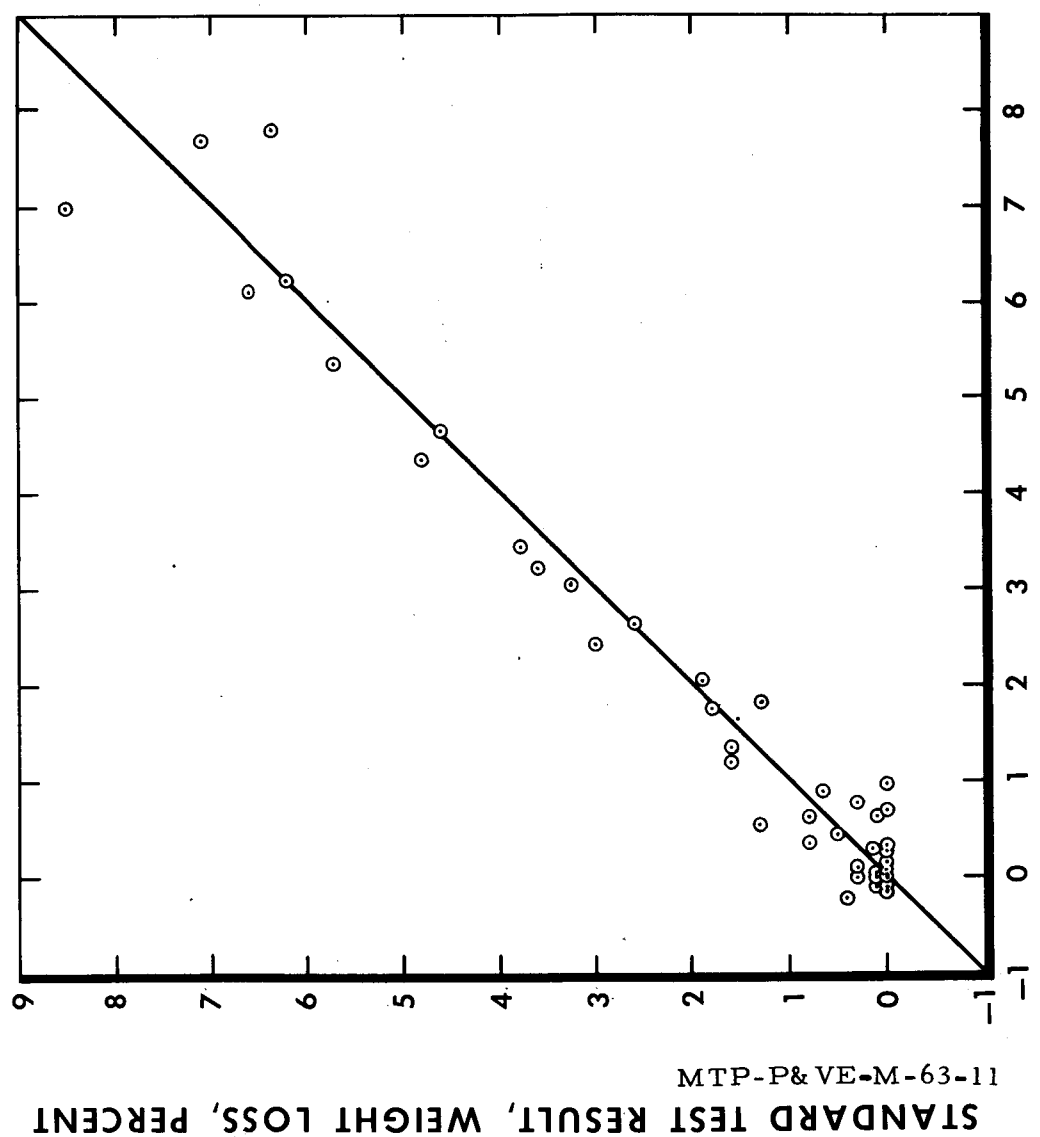


FIGURE 56. COMPARISON OF RESULTS FROM STANDARD AND SCREENING TESTS

Table 1. Elastomers

Material	Sample Dimensions, Cm	Surface Area, Cm^2	Temperature, °C Programmed	Temperature, °C Actual	Initial Weight, g	Weight Loss Total, g	Weight Loss Total, %	Figure No.	Change in Physical Appearance
Kel-F	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.8933	0.0000	0.0	4	None
RA-27060	1.588 Dia. X 0.178	4.85	100	100	0.9053	0.0000	0.0	4	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	200	199	0.9063	0.0103	1.1	4	Turned black
Viton-B	1.588 Dia. x 0.254	5.17	100	100	1.1162	0.0007	0.1	5	None
a-495-VB	1.588 Dia. x 0.254	5.17	150	149	1.1005	0.0020	0.2	5	None
M-P&VE-MR	1.588 Dia. x 0.254	5.17	200	198	1.1125	0.0135	1.2	5	None
Viton-A	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.7644	0.0000	0.0	6	None
RA-26360	1.588 Dia. x 0.178	4.85	100	100	0.7375	0.0005	0.1	6	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	200	199	0.7395	0.0361	4.9	6	Turned black
Polyacrylic	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4849	0.0000	0.0	7	None
RA-32460	1.588 Dia. x 0.178	4.85	100	101	0.4758	0.0015	0.3	7	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	152	0.4904	0.0040	0.8	7	None
Fluorinated Silicone	1.588 Dia. x 0.229	5.05	R.T.	R.T.	0.5469	0.0000	0.0	8	None
RA-27760	1.588 Dia. x 0.229	5.05	100	100	0.5251	0.0018	0.3	8	None
M-P&VE-MR	1.588 Dia. x 0.229	5.05	200	200	0.5165	0.0120	2.3	8	None
Silicone	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4573	0.0000	0.0	9	None
RA-28560	1.588 Dia. x 0.178	4.85	100	102	0.4556	0.0016	0.4	9	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	200	201	0.4575	0.0149	3.3	9	None
Hypalon	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.5196	0.0000	0.0	10	None
RA-32860	1.588 Dia. x 0.178	4.85	100	102	0.5393	0.0027	0.5	10	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	150	0.5301	0.0449	8.5	10	Cracked at surface
Neoprene	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.5634	0.0003	0.1	11	None
RA-24160	1.588 Dia. x 0.178	4.85	100	102	0.5542	0.0090	1.6	11	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	150	0.5463	0.0097	1.8	11	None
Polyurethane	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4916	0.0041	0.8	12	None
RA-33260	1.588 Dia. x 0.178	4.85	100	100	0.5112	0.0110	2.2	12	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	152	0.5156	0.0311	6.0	12	None
Butyl	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4491	0.0000	0.0	13	None
RA-25660	1.588 Dia. x 0.178	4.85	100	99	0.4475	0.0132	3.0	13	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	150	0.4506	0.0162	3.6	13	None
Styrene-Butadiene	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4659	0.0014	0.3	14	None
RA-35260	1.588 Dia. x 0.178	4.85	100	100	0.4774	0.0220	4.6	14	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	149	0.4675	0.0288	6.2	14	None
Natural Rubber	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4192	0.0053	1.3	15	None
RA-33860	1.588 Dia. x 0.178	4.85	100	100	0.4353	0.0209	4.8	15	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	149	0.4880	0.0270	6.6	15	None
Buna-N	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.4177	0.0002	0.0	16	None
RA-30760	1.588 Dia. x 0.178	4.85	100	101	0.4219	0.0240	5.7	16	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	150	150	0.4197	0.0297	7.1	16	None
Neoprene, 5PPH Antiox 4010									
Compound 2277	1.588 Dia. x 0.178	4.85	100	100	0.4426	0.0321	7.3	17	None
Precision Rubber Products	1.588 Dia. x 0.178	4.85	150	152	0.5621	0.0455	8.3	17	None
Neoprene WRT	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.6520	0.0015	0.2	18	None
Compound 3046-70	1.588 Dia. x 0.178	4.85	100	100	0.6520	0.0486	7.5	18	None
Plastics & Rubber Products	1.588 Dia. x 0.178	4.85	150	152	0.6495	0.0555	8.5	18	None
Buna-N	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.5353	0.0000	0.0	19	None
Compound 66-581	1.588 Dia. x 0.178	4.85	100	96	0.4977	0.0371	7.4	19	None
Parker-Hannifin	1.588 Dia. x 0.178	4.85	150	154	0.5035	0.0591	11.7	19	None
Thiokol	1.588 Dia. x 0.178	4.85	R.T.	R.T.	0.5403	0.0000	0.0	20	None
RA-31860	1.588 Dia. x 0.178	4.85	100	100	0.5500	0.0842	15.3	20	None
M-P&VE-MR	1.588 Dia. x 0.178	4.85	125	125	0.5490	0.1504	27.3	20	Cracked at surface
	1.588 Dia. x 0.178	4.85	150	150	0.5545	0.2161	39.0	20	Cracked at surface

Table 2. Plastics

Material	Sample Dimensions, Cm	Surface Area, Cm^2	Temperature, °C Programmed	Temperature, °C Actual	Initial Weight, g	Weight Loss Total, g	Weight Loss Total, %	Figure No.	Change in Physical Appearance
Teflon-TFE DuPont	3.015 x 1.905 x 0.076	12.2	R.T.	R.T.	0.9887	0.0000	0.0	21	None
	3.015 x 1.905 x 0.076	12.2	100	100	0.9865	0.0000	0.0	21	None
	3.015 x 1.905 x 0.076	12.2	200	200	0.9500	0 0000	0.0	21	None
Mylar DuPont	2.5 x 5.0 x 0.0025	25.0	R.T.	R.T.	0.0397	0.0000	0.0	22	None
	2.5 x 5.0 x 0.0025	25.0	100	100	0.0397	0.0000	0.0	22	None
	2.5 x 5.0 x 0.0025	25.0	200	-	-	-	-	22	*
Polyethylene Source Unknown	1.588 Dia. x 0.409	5.87	R.T.	R.T.	0.6700	0.0000	0.0	23	None
	1.588 Dia. x 0.409	5.87	50	50	0.6750	0.0013	0.2	23	None
	1.588 Dia. x 0.409	5.87	100	100	0.6705	0.0005	0.1	23	Sample melted
Polyimide Tape M DuPont	45.72 x 1.27 x 0.0051	116	R.T.	R.T.	0.4135	0.0000	0.0	24	None
	45.72 x 1.27 x 0.0051	116	100	103	0.4135	0.0005	0.1	24	None
	45.72 x 1.27 x 0.0051	116	200	201	0.4125	0.0015	0.4	24	None
Polyamide Film HT-1 DuPont	5.080 x 2.032 x 0.0087	20.6	R.T.	R.T.	0.0595	0.0018	3.0	25	None
	5.080 x 2.032 x 0.0087	20.6	200	201	0.0599	0.0022	3.7	25	None
Polyvinyl Chloride (PVC) Film M-P&VE-MR	2.540 x 1.270 x 0.023	6.45	R.T.	R.T.	0.0880	0.0030	3.4	26	None
	2.540 x 1.270 x 0.023	6.45	100	100	0.0870	0.0262	30.1	26	Became hard and began to decompose

* Test was started at 200°C but sample melted with no apparent decomposition.

Table 3. Reinforced or Laminated Plastics

Material	Sample Dimensions, Cm	Surface Area, Cm^2	Temperature, °C Programmed	Temperature, °C Actual	Initial Weight, g	Weight Loss Total, g	Weight Loss Total, %	Figure No.	Change in Physical Appearance
Reinforced Plastic, Polyester									
Resin; Hetron 31	2.54 x 2.54 x 0.318	16.1	R.T.	R.T.	3.6836	0.0038	0.1	27	None
Narmco Industries	2.54 x 2.54 x 0.318	16.1	100	100	3.7476	0.0076	0.2	27	None
Reinforced Plastic, Polyester									
Resin; Hetron 92	2.54 x 2.54 x 0.318	16.1	R.T.	R.T.	3.8764	0.0057	0.1	28	None
Narmco Industries	2.54 x 2.54 x 0.318	16.1	100	100	4.0092	0.0109	0.3	28	None
Reinforced Plastic, Polyester									
Resin; Vibrin 135	2.54 x 2.54 x 0.318	16.1	R.T.	R.T.	3.4273	0.0462	1.3	29	None
Narmco Industries	2.54 x 2.54 x 0.318	16.1	100	100	3.5336	0.0475	1.3	29	None
Reinforced Plastic, Phenolic									
Resin; Conolon 506A	2.54 x 2.54 x 0.318	16.1	R.T.	R.T.	3.9738	0.0595	1.5	30	None
Narmco Industries	2.54 x 2.54 x 0.318	16.1	100	100	3.9563	0.0820	2.1	30	None
Reinforced Plastic, Phenolic									
Resin; Conolon 506	2.54 x 2.54 x 0.318	16.1	R.T.	R.T.	3.9339	0.0551	1.4	31	None
Narmco Industries	2.54 x 2.54 x 0.318	16.1	100	100	3.9455	0.0830	2.1	31	None
Fiberglass Laminate	1.59 Dia. x 0.042	4.1	R.T.	R.T.	0.0903	0.0004	0.4	32	None
Phenolic Resin; Conolon 506	1.59 Dia. x 0.042	4.1	100	100	0.0865	0.0025	2.9	32	Slight darkening
Narmco Industries	1.59 Dia. x 0.042	4.1	200	200	0.0903	0.0043	5.3	32	Turned dark brown
Mobaloy AH-81	1.59 Dia. x 0.048	4.1	R.T.	R.T.	0.1084	0.0000	0.0	33	None
Cordo Molding Products	1.59 Dia. x 0.048	4.1	100	100	0.1030	0.0070	6.8	33	None

Table 4. Electrical Insulation

Material	Sample Dimensions, Cm	Surface Area, Cm^2	Temperature, °C Programmed	Temperature, °C Actual	Initial Weight, g	Weight Loss Total, g	Weight Loss Total, %	Figure No.	Change in Physical Appearance
Wire, Insulated, MS-7534, Primary Insulation, Type KT-FEP, Teflon with ML Overlay Polyamide-Imide MIL-W-16878. duPont	0.10 Dia. x 2.38	0.70	R.T.	R.T.	0.0990*	-0.0003			None
	0.10 Dia. x 2.38	0.70	50	50	0.0991*	0.0000			None
	0.10 Dia. x 2.38	0.70	150	149	0.0991*	0.0000			None
Wire, Magnet MH-7081 HiTemp Wire & Cable	0.0076 Dia. x 152.4	3.65	R.T.	R.T.	0.0460*	-0.0005			None
	0.0076 Dia. x 152.4	3.65	75	75	0.0439*	0.0000			None
	0.0076 Dia. x 152.4	3.65	150	155	0.0439*	0.0000			None
Wire, Magnet MH-7332 HiTemp Wire & Cable	0.076 Dia. x 11.0	2.6	R.T.	R.T.	0.4024*	0.0025			None
	0.076 Dia. x 23.8	5.7	100	100	0.8829*	0.0007			None
	0.076 Dia. x 61.0	14.6	250	240	2.2578*	0.0015			None
Wire, Magnet MH-7021 Phelps-Dodge Copper Products	0.046 Dia. x 38.1	5.5	R.T.	R.T.	0.4502*	0.0010			None
	0.046 Dia. x 91.5	13.1	50	50	1.0843*	0.0005			None
	0.046 Dia. x 91.5	13.1	130	125	1.0781*	0.0010			None
Tape, Polyester, Pressure Sensitive MS-6856 3M #56	0.635 Wide x 20.7	13.2**	R.T.	R.T.	0.0915	0.0000	0.0	34	None
	0.635 Wide x 20.7	13.2**	50	50	0.0915	0.0000	0.0	34	None
	0.635 Wide x 7.6	4.8**	94	90	0.0323	0.0007	2.2	34	None
Tape, Thermosetting Electrical MS-6768, Acetate Cloth 3M #28	1.27 Wide x 4.0	5.2**	R.T.	R.T.	0.0915	0.0015	1.6	35	None
	1.27 Wide x 4.0	5.2**	50	51	0.0947	0.0034	3.6	35	None
	1.27 Wide x 7.6	9.7**	94	92	0.1674	0.0075	4.5	35	None
Tape, Thermosetting Electrical MS-6771, Fiberglass, Pressure Sensitive 3M #27	0.635 Wide x 6.6	4.2**	R.T.	R.T.	0.0937	-0.0016	-1.7	36	None
	0.635 Wide x 6.6	4.2**	50	52	0.0951	0.0028	3.0	36	None
	0.635 Wide x 7.6	4.8**	100	105	0.1097	0.0042	3.8	36	Slight discoloration
Tubing, Heat Shrinkable Irradiated Polyalefin, MS-7308 Rayclad Corporation (Black)	1.30 OD x 1.25 ID x 0.5	4.0	R.T.	R.T.	0.0951	-0.0004	-0.4	37	None
	1.30 OD x 1.25 ID x 0.5	4.0	50	50	0.0954	0.0000	0.0	37	None
	1.30 OD x 1.25 ID x 0.5	4.0	150	151	0.0954	0.0118	12.4	37	50% shrinkage
Tubing, Heat Shrinkable Irradiated Polylefin MS-7308 Rayclad Corporation (Green)	0.55 OD x 0.50 ID x 0.9	3.0	R.T.	R.T.	0.0576	0.0000	0.0	38	None
	0.55 OD x 0.50 ID x 0.9	3.0	50	50	0.0577	0.0003	0.5	38	None
	0.55 OD x 0.50 ID x 0.9	3.0	150	152	0.0574	0.0074	12.9	38	40% shrinkage, turned black
Tubing, Heat Shrinkable Irradiated Polyolefin MS-7308 Rayclad Corporation (Gray)	0.7 OD x 0.65 ID x 0.9	3.8	R.T.	R.T.	0.0882	-0.0003	-0.3	39	None
	0.7 OD x 0.65 ID x 0.9	3.8	50	50	0.0883	0.0000	0.0	39	None
	0.7 OD x 0.65 ID x 0.9	3.8	150	151	0.0879	0.0108	12.3	39	50% shrinkage, turned black
Tubing, Heat Shrinkable and Flexible Irradiated Polyolefin MS-7247 Rayclad Corporation (White)	0.3 OD x 0.25 ID x 3.5	6.0	R.T.	R.T.	0.0972	0.0000	0.0	40	None
	0.3 OD x 0.25 ID x 3.5	6.0	50	50	0.0976	0.0000	0.0	40	None
	0.3 OD x 0.25 ID x 3.5	6.0	150	150	0.0975	0.0160	16.4	40	3% Shrinkage, turned black

* Weights include wire.
** All tapes were adhered to aluminum foil during vacuum tests. Surface areas given are areas of non-adhesive side.

NOTE: Negative weight loss indicates gain.

Table 5. Miscellaneous

Material	Sample Dimensions, Cm	Surface Area, Cm^2	Temperature, °C Programmed	Temperature, °C Actual	Initial Weight, g	Weight Loss Total, g	Weight Loss Total, %	Figure No.	Change in Physical Appearance
Epoxy, Glass, Copper Clad	1.59 x 1.59 x 0.32	7.1	R.T.	R.T.	1.6893	0.0000	0.0	41	None
MH-6474	1.59 x 1.59 x 0.32	7.1	100	98	1.6612	0.0015	0.1	41	None
Minneapolis Honeywell	1.59 x 1.59 x 0.32	7.1	200	199	1.7055	0.0432	2.5	41	Slight delamination
Epoxy Impregnating Compound	1.59 x 1.59 x 0.32	7.1	R.T.	R.T.	0.9274	0.0000	0.0	42	None
MH-6293H	1.59 x 1.59 x 0.32	7.1	50	50	0.9470	0.0000	0.0	42	None
Minneapolis Honeywell	1.59 x 1.59 x 0.32	7.1	120	121	0.9276	0.0012	0.1	42	None
Metal Alloy, Li-Mg-Al									
LA 141	2.54 x 2.76 x 0.159	15.7	371	371	2.0013	-0.0085	-0.4	43	None
M-P&VE-MM								43	
Metal Alloy, Li-Mg-Al									
LA 91	2.54 x 0.159 x 2.65 x 2.48	15.2	371	371	1.2531	-0.0064	-0.5	44	None
M-P&VE-MM	2.54 x 0.159 x 2.65 x 2.48	14.2	427	427	1.1072	-0.0062	-0.6	44	None
Unifoam Thermal Insulation	1.59 Dia. x 0.635	7.1	R.T	R.T	0.0392	0.0000	0.0	45	None
Wm. T. Burnett, Inc.	1.59 Dia. x 0.635	7.1	100	100	0.0392	0.0005	1.3	45	None
Urethane Foam	1.59 Dia. x 0.32	5.6	R.T.	R.T.	0.1168	0.0008	0.7	46	None
MH-7212A	1.59 Dia. x 0.32	5.6	50	50	0.1186	0.0000	0.0	46	None
Nopco Chemical	1.59 Dia. x 0.32	5.6	120	122	0.1181	0.0058	4.9	46	None
Gasket, Conductive	1.47 Dia. x 0.04	3.4	R.T.	R.T.	0.0985	-0.0009	-0.9	47	None
MS-6085	1.47 Dia. x 0.04	3.4	50	51	0.0984	0.0026	2.6	47	None
Connecticut Hard Rubber	1.59 Dia. x 0.04	4.1	120	122	0.1161	0.0036	3.1	47	None
Paper, Inorganic									
Crystal MK	0.64 x 0.0025 x 3.97 x 2.54	5.0	R.T.	R.T.	0.0990	0.0045*	4.5	48	None
3M	0.64 x 0.0025 x 3.97 x 2.54	3.3	200	201	0.0728	0.0043*	5.9	48	None
Paper, Inorganic									
Crystal M	6.86 x 0.89 x 0.0025	12.1	R.T.	R.T.	0.0982	0.0040*	4.1	49	None
3M	6.86 x 0.89 x 0.0025	12.1	200	198	0.0977	0.0060*	6.1	49	None
Paper, Inorganic									
Crystal MG	5.08 x 1.27 x 0.0025	12.9	R.T.	R.T.	0.0783	0.0056*	7.2	50	None
3M	5.08 x 1.27 x 0.0025	12.9	200	200	0.0784	0.0059*	7.5	50	None
Paper, Inorganic									
Crystal MP	4.76 x 1.27 x 0.0025	12.1	R.T.	R.T.	0.0972	0.0048*	4.9	51	None
3M	4.76 x 1.27 x 0.0025	12.1	200	200	0.0993	0.0082*	8.2	51	None
Lacing Tape, Dacron	81 Long x 0.2 Wide	**	R.T.	R.T.	0.5370	0.0006	0.1	52	None
MH-7335	91.4 Long x 0.2 Wide	**	75	75	0.6106	0.0140	2.3	52	None
Western Fishing Line	91.4 Long x 0.2 Wide	**	130	132	0.6035	0.0201	3.3	52	None
Tying Cord, Nylon, Style 18	16.5 Long x 0.24 Wide	**	R.T.	R.T.	0.0977	0.0013	1.3	53	None
MIL-T-713, Type P, 22-32 % Wax	16.5 Long x 0.24 Wide	**	50	52	0.0971	0.0019	2.0	53	None
Textile Thread Company	61 Long x 0.24 Wide	**	90	92	0.3568	0.0443	12.4	53	None

* Samples rapidly returned to nearly original weight upon exposure to atmosphere
** Non-rigid structure precluded definition of surface area.

NOTE: Negative weight loss indicates gain.

REFERENCES

1. Caruso, S. V., and Looney, W. C., A Study of the Outgassing and Evaporation Products of Some Materials Upon Exposure to Reduced Pressure, Marshall Space Flight Center, MTP-P&VE-M-62-7, April 2, 1962.

2. Riehl, W. A., Considerations on the Evaporation of Materials in Vacuum, Chemical Engineering Progress Symposium Series, No. 40, Vol. 59, 1963, pp. 103-117.

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VACUUM COMPATIBILITY OF ENGINEERING MATERIALS (SOLIDS)

By

J. B. Gayle, S. V. Caruso, and C. T. Egger

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