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#### STATISTICAL STUDY OF PRIMER SENSITIVITY DROP-TESTS

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### U. S. NAVAL ORDNANCE LABORATORY white oak, maryland

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#### STATISTICAL STUDY OF PRIMER SENSITIVITY DROP-TESTS

#### INTRODUCTION

1. Sensitivity is an important characteristic of initiating elements and one which is frequently determined during the development of primers and detonators. During the development work where sample size is limited and where high accuracy of results is not essential, sensitivity is determined by the up-and-down (Bruceton) technique. Interval size is chosen arbitrarily as dictated by the experience of the operator.

2. In the sensitivity testing of mechanically initiated components, arithmetic intervals are used. In those cases where the sensitivity pattern does not follow a normal distribution, it occasionally happens that calculations of low percentage firing heights give negative (impossible) values. In the sensitivity testing of electric initiators logarithmically spaced intervals have been used extensively. One advantage of this is the elimination of predicted negative firing heights.

3. Where accuracy of a higher degree than that necessary during the development work is required, such as in preliminary design and design proof tests, the rundown technique is used. Here again the experience of the operator dictates the interval size.

4. The arithmetic interval has long been used in mechanical primer and detonator testing, although there is no known statistical evidence of its superiority over the logarithmic interval. It was decided, therefore, that a study of sensitivity testing be made in order to increase the quantity and quality of information which might be obtained from the samples available for test.

A Contraction

5. Two types of primers were used in this study, percussion type and stab type. The percussion primer was the Mk 101 type containing an experimental priming mixture (NOL No. 17) of the following composition:

Basic lead styphnate	20%
Barium nitrate	35%
Tetracene	5%
Antimony sulfide	20%
RDX	20%

Two stab type primers were used in the study -- the Mk 102 Mod 0 and a Mk 120 type primer. Since the two types of primers exhibited somewhat different sensitivities, each

type will be discussed individually.

The Mk 101 Type Primer (Percussion)

Test Procedure

A group of Mk 101 primers containing #17 explosive mix 6. and supposedly manufactured under constant conditions was employed throughout the study. A series of four tests of the Bruceton or "up and down" type was first conducted. The Bruceton test, now used extensively at NOL. is fully described in reference 1. Each test consisted of 200 trials. Two of the tests were conducted at drop heights equally spaced at 1/4 inch and 1/2 inch intervals, respectively, on the arithmetic scale. The remaining two tests were run at drop heights approximately equally spaced at .05 and .10 intervals, respectively, on the logarithmic scale. In this way it was hoped that information could be obtained relative to the effect of: (a) arithmetic vs. logarithmic intervals, and (b) variation in interval size, on the accuracy of the results obtained. Furthermore. by breaking the 200 trial Bruceton tests down into smaller samples, it was hoped that information could be obtained on the effect of sample size on the precision of estimates obtained by the Bruceton method.

7. Following the running of the Bruceton tests described above, enough additional trials were conducted so as to obtain a complete rundown with a minimum of 100 trials at 1/4 inch intervals. The great majority of the trials already run in the Bruceton tests were incorporated into the rundown. The Bruceton tests thus comprised sub-samples of the large rundown sample of 1439 trials. Throughout the trials the selection of the primers was randomized so as to minimize the effect of a possible sequence of non-representative primers.

8. The data from the complete rundown were analyzed by the method of probits to be described below. This analysis produced estimates of the 1%, 50% and 99% firing points which were used as norms against which the Bruceton estimates could be compared. The probit analysis also produced tests of the "goodness-of-fit" of the experimental data to the theoretical normal distribution.

9. The validity of the Bruceton method of obtaining estimates is based on the assumption that the explosion percentages follow a cumulative normal distribution when plotted against height or whatever function of height is employed in equally spacing the intervals at which trials are conducted. Hence the comparison of the "goodness of fit" of the data as analyzed on both the arithmetic and

logarithmic scales was perhaps the most important aspect of the probit analysis.

10. The data of the various Bruceton tests and subtests was then analyzed using the method described in reference 1. Estimates of the various percentage points were obtained and the assumption of normality was further tested.

11. The statistical technique known as Probit Analysis is fully discussed in reference 2, in connection with the problems of biological assay. However, it is readily seen to be adaptable to the analysis of the results of sensitivity tests on explosives and in this connection it is further discussed in references 3 and 6. A brief description of the method follows.

12. A number of trials are first conducted at various heights which need not be equally spaced. The number of explosions at each height is recorded and the corresponding percentage is computed. These experimentally obtained percentages are then transformed to quantities called probits by consulting a table. The probits are then plotted against height or some function of the height on ordinary graph paper. These probits are ordinates of a certain normal distribution and are such that the points plotted on the graph referred to above would lie in a straight line if the explosion percentages were truly normally distributed. If the conditions of normality are reasonably well approximated by the experimental data the plotted points will exhibit a marked linear trend.

13. The next portion of the probit analysis consists of fitting a line, known as a regression line, to the points plotted on the graph. The method employed is an iterative one. A line which seems to best fit the data is first drawn by observation. If the points cluster very closely about this line, no further refinement may be necessary and the line thus drawn may be employed in the remainder of the analysis. However, if this is not the case, a betterfitting line can be obtained by an arithmetical procedure which involves weighting factors which depend upon both the number of trials conducted at each level and the di'tance of the level from the 50% point of the distribution. In determining the fitted line a point near the 50% point carries considerably more weight than one near an extreme. The weighting factors also increase with the number of trials. This arithmetical procedure can be carried through any number of cycles until what is for practical purposes the "best-fitting" line is obtained.

14. The criterion of best fit in the arithmetical procedure described above is the convergence, in the practical

sense, of two successive cycles of computation. In other words, when a line is obtained which is, for practical purposes, identical with the line obtained from the preceding cycle of computation, then the best fit is adjudged to have been attained.

The fact that a regression line has been obtained 15. which is for practical purposes the best-fitting line for the data does not, however, necessarily imply that it is a good fit. The "goodness of fit" of the best-fitting line (or of any of the preceding lines) can be measured by the well-known % (chi-square) test. The test is thus a criterion of the validity of the assumption of normality in the distribution of the firing percentages. If by this standard the best fitting line shows a reasonably good fit, then its equation may be used to estimate the point at which any given percentage of the explosive units will fire. Confidence intervals for these estimates can also be computed. If, by the "2 criterion, it is impossible to obtain a reasonably good fit for the plotted points, then these confidence intervals must be increased by the application of a heterogeneity factor. In other words, if the normality assumption seems improbable, then a wider range of possible variation must be allowed for in the estimates obtained from the probit regression equation.

#### Results

16. The results of the complete rundown are shown in Cols. 1, 2 and 3 of Data Sheet 1. All of the trials conducted in the Bruceton tests were incorporated into this rundown except for a few levels at which only a very small number of trials were conducted. These could have only a negligible effect on the probit line, while at the same time they would increase the labor involved in the arithmetical process of fitting the line.

The calculations involved in the probit analysis of 17. the data are shown on Data Sheets 1, 2 and 3, and the graphical picture is presented by Figures 1 and 2. The probits corresponding to the empirical explosion percentages are shown in column 5 of Data Sheet 1 and these probits are plotted against height in Figure 1 and against log height in Figure 2. The solid line on each of these graphs is the line drawn by observation referred to in the preceding description of the probit analysis. The various cycles of arithmetical calculations involved in obtaining the best-fitting regression line are shown. The first cycle of computations involved in the fitting of a line to the empirical probits plotted in Figure 1 are shown in columns 6 through 10 of Data Sheet 1. The corresponding calculations for Figure 2 are shown in columns 11 through 16

of Data Sheet 1. The succeeding cycles of calculation are shown on Data Sheets 2 and 3. These calculations are described in detail in reference 2, pages 199-208.

18. The final adjusted lines are the dashed lines shown in Figures 1 and 2. The goodness of fit of the adjusted lines at each stage of the calculations is indicated by the following values, which can be readily obtained from the computations involved in the fitting of the line with only slight additional labor.

	Height	Log Height
lst Cycle	8.232	10.410
2nd Cycle	8.065	8.811
3rd Cycle	8.405	8.787

The subscript 11 on each of these  $\chi^{2_1}$ s indicates that it has 11 degrees of freedom. The average value of such a  $\chi^2$ function is 11. Hence any value less than 11 indicates a reasonably good fit and supports the hypothesis of normality. Conversely, a value considerably in excess of 11 would cast doubt on the normality hypothesis.

19. By this criterion the fit is a good one for both height and log height, with the former enjoying a very slight advantage. It will be noted that in the case of height the % value for the final line is slightly higher than for the preceding lines. This is due to the fact, alluded to in reference 2, page 54, that the process of obtaining the best-fitting line in the sense of convergence is not precisely equivalent to minimizing the % value though the final % value will usually not differ by much from the minimum.

20. These figures would tend to the conclusion that good results can be obtained in Bruceton tests run at both arithmetically and logarithmically spaced intervals. The superiority enjoyed by the former seems too slight to enforce the conclusion that it is definitely better. Hence factors other than theoretical normality will influence the choice of intervals, and this matter will be discussed in a later portion of this report.

21. Attention will next be focused on the equation of the regression line which will be used to estimate the various percentage points. By the  $\chi^2$  criterion the line which best represents the experimental data is that which expresses the functional relationship between probit and height and whose equation is:

1. Y = -.532 + 2.182Xor 2.  $X = \frac{Y + .532}{2.182}$ 

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If the probit corresponding to any given percentage is substituted for Y in equation 2, then the Height X corresponding to that percentage can be readily obtained. In this way the following estimates were obtained:

1%	Height:	1.47	inches
50%	Height:	2.54	inches
99%	Height:	3.60	inches

22. These would appear to be the best estimates of the given percentage points. However, since log height also appears to be a reasonably good normalizing function it seems pertinent to record the corresponding percentage heights as estimated from the best regression equation connecting probit with log height. This equation is:

$$x^{1} = \underline{x + .096}$$
  
12.782

23. The various percentage heights are obtained in the same way as previously except that  $X^{\perp}$  is now a logarithm and must be transformed back to the original units of height. In this way the following estimates are obtained.

1% Height:	1.65	inches
0%_Height:	2.51	inches
9% Height:	3.81	inches

It will be noted that the estimates of the 50% height as obtained by the arithmetic and logarithmic scales differ only slightly, whereas in the case of estimates of the extreme points the agreement is not so good.

24. A question may arise as to the reason for as large a discrepancy as was shown in the estimation of the extreme point by the two scales when both were adjudged by the  $\chi^2$  criterion to give reasonably good fits to the normal regression line.

25. The answer to this question lies partly in the fact that the  $\mathcal{X}^2$  criterion expresses the <u>average</u> goodness of fit over the entire regression line, with values at the extreme points of the line contributing but little to the computed  $\mathcal{X}^2$  value. Therefore, the major, central portion, of both regression lines may fit the experimental data well and the  $\mathcal{X}^2$  values may be comparable, but the extremes of at least one of the lines must deviate since both assumptions of normality, i.e., with height or log height, cannot be correct. It should be noted also that the nature of the logarithmic function is such that it will always give higher estimates of the extreme points (both the 1% and 99% points) no matter which assumption of normality is correct. For when the sensitivity is normal with regard to height the logarithmic plot will have its extremes bend

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upward away from the regression line, and when the sensitivity is normal with respect to log height, the experimental values of the extremes plotted on the height basis will bend downward away from the regression line. In either case the extremes (both high and low) will be higher on the log height basis.

26. The statistics given above are estimates of the precise points at which given percentages of the primers under consideration may be expected to fire. However, like all statistical estimates of this kind, they may be expected to vary from sample to sample. Hence they should be surrounded by certain ranges of variation known as confidence intervals. These are obtained by computing the standard deviation of the estimate in question and multiplying it by an appropriate factor depending upon the probability level at which one wishes to fix the confidence range.

27. For the estimates obtained from the probit-height regression line which, as noted above, appear to be the "best" estimates obtainable from the data, the respective 99% confidence intervals are:

> 1% Height: 1.32 - 1.62 50% Height: 2.49 - 2.59 99% Height: 3.46 - 3.74

28. The data obtained in the Bruceton tests were analyzed in the usual manner as described in reference 1. Estimates of X (50% PT.) and  $\sigma$  (std. dev.) were first obtained from each of the four Brucetons consisting of 200 trials each. These tests were then broken down into groups of 100 and finally into groups of 50 and estimates of X and  $\sigma$ again computed, so that 28 sets of estimates were obtained in all. These are tabulated below together with corresponding estimates of the 1% and 9% points. Since they are relatively familiar, details of the calculations are not included in this report.

1/4 Inch Intervals

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No.	Trials	<b>X</b>	6	1% Pt.	99% Pt.
	200	2.55	•32	1.81	3.29
	100	2.54	•33	1.77	3.31
	50	2.54	•33	1.77	3.31
	50	2.54	•33	1.77	3.31
	100	2.50	• 32	1.82	3.30
	50	2.20	•24	2.02	5°14
	50	2.73	• 37	1°05	3.44

#### 1/2 Inch Intervals

No. Trials	Ť	5	1% Pt.	99% Pt.
200	2.60	.42	1.62	3.58
100	2.64	.48	1.52	3.76
50	2.71	.66	1.17	<b>4.2</b> 5
50	2.57	.27	1.94	3.20
100	2.57	•34	1.78	3.36
50	2.63	•30	1.93	3.33
50	2.51	• 35	1.70	3.32

In the tabulation of the results obtained using logarithmically spaced intervals,  $\sigma$  will be given in logarithm units since it has significance only when thus expressed.

#### .05 Logarithm Intervals

No. Trials	X	6 (log.)	1% Pt.	99% Pt.
200	2.50	.087	1.57	3.97
100	2,50	.078	1,65	3.79
50	2.53	.090	1.56	4.09
50	2.47	-,068	1.72	3.56
100	2.47	.096	1.48	4.12
50 ·	2.43	.127	1.23	4.80
50	2.48	.061	1.79	3.44

#### .10 Logarithm Intervals

No. Trials	X	σ(log.)	1% Pt.	99% Pt
200	2.45	.084	1.57	3.85
100	2,42	.104	1.39	4.23
50	2.39	.099	1.41	4.06
50	2.45	107	1.38	4.36
100	2.49	.063	1.77	3.49
50	2.43	.062	1.71	3.47
50	2.55	.057	1.88	3.46

29. A graphical picture of the distribution of these estimates and their degree of conformity with the corresponding estimates obtained by the probit analysis of the entire data on the arithmetic scale is presented in Figures 3, 4 and 5. On these graphs drop-heights are measured along the vertical axis and estimates obtained from the various tests are represented by horizontal lines drawn at the appropriate height. The solid line drawn across the entire length of the graph represents the probit estimate of the percentage point in question and the two broken lines which bracket it indicate its confidence interval. The

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shorter horizontal lines represent Bruceton estimates involving various numbers of trials as indicated by the legend at the bottom of the graph. Each graph has been divided into four sections by vertical lines, each section containing the estimates obtained from tests conducted with a given interval size as specified on the 200-trial line in each case. The shorter lines in each section represent estimates obtained through the subtests into which the 200-trial tests were broken as described previously.

30. A glance at the graphs shows that the Bruceton estimates are subject to a considerable dispersion and that many of them fall outside the 99% confidence ranges for the probit estimates. As would be expected, this variation is much less marked in the case of the 50% point than for the extremes. Focusing attention on Figure 3, there seems to be a definite tendency for estimates of the 50% point obtained using arithmetic intervals to be above the "true" value and for those obtained using logarithmic intervals to be below it. It may also be noted that on the basis of the number of estimates of the 50% point falling within the probit range, the 1/4-inch interval was considerably superior to any of the others. It should perhaps be noted that had a similar comparison been made using the logari'nmic probit confidence range, the .05-log interval would have placed the most estimates within that range, with the 1/4-inch interval close behind.

31. The results of the above comparison seem to be in accord with theoretical considerations which indicate that small interval sizes (about .5) are best for estimating the 50% point.

32. Perhaps the most striking fact indicated by the graphs is that whereas the 1/4-inch interval made the best showing for the 50% point, placing all seven estimates within the confidence range, it fared worse than any of the other interval sizes in estimation of the 1% and 99% points, failing to place a single estimate within the confidence intervals. Since estimates of extreme percentage points are obtained by adding or subtracting certain multiples of the standard deviation,  $\sigma$ , to the mean or 50% point, X, this can only mean that this interval size, while excellent for estimating X, was very poor for estimating  $\sigma$ . This is again in accord with theoretical considerations, which indicate that small interval sizes are inefficient for estimate ing  $\sigma$ .

33. The practical fact which must therefore be faced in sensitivity testing is that  $\overline{X}$  and  $\mathcal{O}$  cannot be estimated with optimum accuracy by a single test. In recognition of

this fact the Bruceton test is classified under two separate headings in reference 4. They are referred to as the Up and Down-Small Interval Size and the Up and Down-Large Interval Size. The former is recommended for estimation of only the 50% point, whereas the latter is recommended for the simultaneous estimation of more than one of the 10%, 50% and 90% points.

34. It seems fairly evident, however, that an even better procedure for the estimation of the 50% point and one or more extreme points would be to resort to two tests, one to estimate  $\overline{X}$  and the other to estimate  $\mathcal{T}$ . This alternative is, of course, limited by the amount of experimental material one can afford to expend, but it would seem to merit serious consideration wherever the availability of expendable material permits.

35. For the data under present consideration the estimate of  $\sigma$  from the arithmetic probit analysis is .46 inches. Reference to the Bruceton estimates tabulated above shows that the estimates obtained in the 1/4 inch tests are uniformly too low. Unfortunately the 1/2 inch tests showed a distressing randomness in the estimation of o but two rather good estimates were obtained, i.e., .42 for the en-tire 200-trial sequence and .48 for one of its 100-trial subsequence. In the case of the logarithmic Bruceton tests the best estimates of o (as compared with the log probit estimates) were those obtained from 200 and 100trial tests. There seem to be experimental indications that more trials are necessary for the accurate estimation of of than for X. This would mean that if, as recommended above, a prescribed number of trials are to be divided into two sets, one using small interval sizes to estimate X. and the other using larger interval sizes to estimate  $\mathcal{O}_{2}$ a greater proportion of the trials should be included in the latter test than in the former. The optimum ratio for this proportion would seem to merit further study.

36. Taken as a whole the picture of the Bruceton estimates is not a particularly happy one. Figures 4 and 5 show an alarming spread among the estimates of extreme percentage points. Large sample size seems to give no guarantee of success. Of the 200 trial tests only one of the four estimates fell within the probit confidence interval for the 99% point and two of the four for the 1% point. The use of many of the estimates to specify extreme percentage firing points would have proved highly misleading. It might be mentioned, however, that if the confidence intervals of the log probit analysis had been used, each of the 200trial log Bruceton estimates would have fallen within the required limits for both the 1% and 99% points, although

most of the estimates obtained from a lesser number of trials would have fallen outside the confidence interval.

37. If one looks for a pattern in the dispersion of the Bruceton estimates it is seen from the graphs that for arithmetic intervals the estimates tend to be too low in the case of the 99% point and too high in the case of the 1% point. This state of affairs is undoubtedly due to a consistent underestimation of  $\sigma$ . In the case of the logarithmically spaced tests the estimates tend to be high at both extremes when compared with the arithmetic estimates. This state of affairs would rather be expected, as previously noted, and would not have prevailed if the logarithmic probit confidence interval had been employed on the graph.

38. It should, of course, be noted that confidence intervals can be computed for the Bruceton estimates as well as for the probit estimates and that, if these were included on the graphs, the confidence intervals surrounding some of the Bruceton estimates which lie outside the probit range would overlap that range.

39. This leads to the point that no estimate of any percentage point should be given without also specifying either a confidence interval or the standard deviation of the estimate from which a confidence interval can be computed. Without this additional information the person to whom the estimate is furnished has no idea of how much reliance may be placed upon it. The calculations involved in computing the confidence intervals for the Bruceton estimates are described in reference 1, pgs. 20-22, and in reference 3, pg. 97. As an illustration, the estimates with their corresponding 99% confidence intervals obtained from the 200-trial 1/2 in. Bruceton test conducted as part of the present study are as follows:

1%	point	1.62	٠	•37
50%	point	2.60	*	<b>.</b> 11
99%	point	3.58		•37

Note that although the estimate of the 50% point is considerably above the probit estimate of 2.53, its confidence interval includes that value, extending from 2.49 to 2.71.

40. It has been shown theoretically that the reliability of the Bruceton method decreases rather rapidly with the distance of the point estimated from the 50% point. For example, it has been shown (reference 4, page 91) that the method is only about half as accurate for estimating the 10% point as for estimating the 25% point. In this connection it should be noted that in reference 4 the Bruceton

method is not recommended under any conditions for estimating points outside the 10%-90% range. For precise estimates of more extreme points other methods should be resorted to.

41. The question of arithmetic vs. logarithm intervals was further investigated by application of the 2 test to the separate 200-trial Bruceton tests as suggested in reference 1, pages 29-33. The calculations are shown on Data Sheet 4 and the results are as follows:

Interval	Chi-Square Value	Probability Level
1/4 inch	$x_{2}^{2} = 1.40$	.50
1/2 inch	$\chi_{1}^{2} = .68$	•43
.05 (log)	<sup>-</sup> لائے = 2.86	.42
.10 (log)	$\chi_{i}^{2} = .95$	•34

42. The subscript on each of these  $\lambda^{2}$ 's represents its number of degrees of freedom, and since this number varies the  $\chi^2$  values cannot be compared directly. For this reason the probability of obtaining a larger  $\chi^2$  value has been given in each case. Since high probability indicates good fit, the evidence again points, as in the case of the  $\chi^2$  analysis of the entire set of data, to the fact that arithmetically spaced intervals are at least as good as, if not somewhat better than, logarithmic intervals for the Bruceton test.

43. It might be well to point out that, entirely aside from theoretical considerations of normality, logarithmic intervals suffer a practical limitation which restricts their usefulness. To elucidate this point let it be recalled that in calculating the mean for a set of Bruceton data the test heights are coded to the integers 0, 1, ... etc. Thus if the testing heights are denoted by  $X_i$ , the lowest testing height by  $X_c$ , and the interval size by d, then the coded heights,  $h_i$ , are given by:

$$h_1 = \frac{X_1 - X_0}{\alpha}$$

so that h = 0,  $h_1 = 1$ , etc. A weighted mean,  $\ddot{H}_1$  is then computed and X is obtained, using the relationship

 $\ddot{\mathbf{X}} = \mathbf{X}_0 + \mathbf{d} \mathbf{\bar{h}}$ 

It is from this coding that the simplicity of the Bruceton analysis is derived and for arithmetically spaced intervals it is beyond criticism. In the case of logarithmic

intervals the situation is complicated by the fact that in attempting to space the intervals equally on a logarithmic scale one is limited by the accuracy with which the drop testing device is calibrated. This means that, having chosen a certain logarithmic interval which one wishes to use in spacing the testing heights, one is forcel in each case to choose the calibrated testing height which is nearest to the correct height and consequently the testing heights are not really equally spaced. The mathratical consequence of this is that the coded heights, 0, 1, 2, do not correspond to the actual heights and an additional error is therefore introduced into the Bruceton calculations. For example, in the 200-trial Bruceton test at. logarithmic intervals of .05, the lowest actual testing height was 1.80 inches and the highest was 3.55 inches. This actual logarithm of these heights is to three decimal places, .255 and .550. Using these values we have:

$$h_6 = \frac{.550 - .255}{.05} = 5.9$$

whereas the integral value,  $h_6 = 6$ , was actually used in the Bruceton calculations. The error introduced in this way could have been avoided by using the actual testing heights in calculating m and  $\sigma$ , but in so doing one of the principal virtues of the Bruceton analysis, namely simplicity of calculation, would have been lost. It should of course be emphasized that the limitation just described is not intrinsic to the logarithmic method itself but, rather, that it arises in connection with its use with a particular drop-testing apparatus.

44. Before concluding the discussion of arithmetic vs. logarithmic drop heights one more point which has been raised in that connection will be considered. This is that in using arithmetic heights a negative drop height is occasionally estimated to correspond to a low explosion percentage.

45. It is of course evident at the outset that whenever the normal function is used to predict the height corresponding to a given explosion percentage this height will be negative if the given percentage is small enough. This is a consequence of the fact that the cumulative normal curve or ogive is, at its lower tail, asymptotic to the horizontal axis, lying entirely above it, and therefore the extreme portions of this section of the curve would predict positive explosion percentages for zero height or for any negative height. As a matter of fact the same difficulty is mat at the other end of the distribution where the curve is asymptotic to a line parallel to the horizontal axis and one unit above it. Here a positive percentage of misfires will be predicted for any drop height however large. All of this simply means that

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whereas the normal curve may be an excellent approximation to the true explosion curve over the central portion of its range, corresponding roughly to m=3, it cannot be used outside that range and this will cause no difficulty in most practical situations.

46. If one uses a logarithmic scale the difficulties encountered at the lower end of the distribution seem to be avoided since a height predicted from the fitted normal curve will always be expressed in logarithmic units and hence the corresponding arithmetic height must always be positive. The difficulties at the other end of the range remain.

47. The device of using the logarithmic scale simply to avoid the occasional estimation of a negative drop height seems, however, to be an artificial mode of escape and its choice on this ground alone seems hardly justified. The main consideration would seem to be the choice of a function, whether height, log height, or possibly some other one, which best approximates the normal distribution. Having chosen the function which best meets this criterion, an occasional encounter with a negative height should be looked upon simply as a consequence of the use of the normal distribution and should cause no undue alarm.

48. It might be noted at this point that since the logarithmic scale has been by no means proved not to be the true distribution, its use in certain situations for estimating percentage firing points at the upper extreme merits consideration in view of the previously noted tendency for logarithmic estimates to be higher than the arithmetic ones. For this reason a logarithmic estimate of a high percentage point might be said to be somewhat safer than an arithmetic one since the probability of underestimation is smaller. For the same reason an arithmetic estimate might be regarded as safer at the lower extreme since at that end of the range overestimation of a percentage firing point is to be avoided for reasons of safety.

> The Mk 120 Type Primer and the Primer Mk 102 (Stab Initiated Primers)

Test Procedure

49. The statistical procedure used in the study of sensitivity tests of the Mk 120 type primer was identical with that used in the case of the Mk 101. The results obtained from these tests will be detailed and interpreted below.

#### Results

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50. Since only 800 primers were available for testing purposes, the scope of the testing program was necessarily reduced as compared with the Mk 101 primer, but the same scheme was followed. In this case only two Bruceton tests were conducted, each consisting of 200 trials and at intervals of 1/2 inch and .04 (log) respectively. After the completion of these two Bruceton tests the remainder of the primers was expended at various levels in order to obtain as complete a rundown as possible. As will be seen from column 4 of Data Sheet 5, a 100% experimental point was reached with 40 trials at 8.50 inches, but the lowest empirical percentage obtained was 2% in 50 trials at 1.50 inches.

51. The probit analysis of the entire set of data did not produce results which were nearly as reassuring as far as the criterion of normality was concerned, as was the case with the Mk 101 primer. The plotted probits are shown for height on Figure 6 and for log height on Figure 7. In both cases, although a general linear trend is evidenced, there is also considerable scatter.

52. The probit analysis was carried through two cycles in both cases. The graphs show the original line fitted by observation and the two adjusted lines. The line produced by the second cycle in the case of log height was practically indistinguishable from the previous line and hence has not been shown on the graph.

53. The calculations involved in the probit analysis are shown on Data Sheets 5 and 6. The 22 values for both stages of the adjusted line are shown below:

		Arithmetic	Logarithmic	
lst	cycle	$\chi^2_{14} = 32.163$	$\chi^2_{14} = 34.290$	
2nd	cycle	$\chi_{14}^2 = 26.747$	$\chi_{I4}^2 = 31.209$	

54. These values are well above the expected chance levels and hence the hypothesis of normality is definitely under suspicion in both cases. As in the case of the Mk 101 type primer, some superiority for the arithmetic scale was indicated.

55. In some cases a large  $\chi^2$  value may be misleading in view of the fact that it contains unusually large contributions from the ends of the range where the probabilities are very high or very low, and in such a case the

fit may be actually better than the  $\varkappa^2$  value would indicate. In these cases a more accurate picture may sometimes be obtained by grouping several levels together at each end of the range. This was carried out for the arithmetic scale, the calculations being shown on Data Sheet 7, and a slight improvement was shown. However, the value  $\varkappa^2 = 15.21$  is still a rather improbable one under the hypothesis of normality and this hypothesis, while not to be rejected, is Certainly not strongly supported.

56. In the probit analysis, departures from normality as indicated by a large  $\lambda^2$  value are allowed for by applying a heterogeneity factor to the variances of the estimates. This factor has the effect of increasing the size of the confidence interval for each estimate. In other words, the net effect of considerable departures from normality is to decrease the precision with which estimates of the various percentage firing points can be specified. The use of the heterogeneity factor will be illustrated presently.

57. The equation of the fitted probit regression line as obtained from the second cycle of calculations on the arithmetic scale is

#### $\underline{Y} = 2.34 + .59X$

where, as before, X represents the drop height and Y the corresponding probit. Using this equation the following heights were estimated:

1% Height : .56 inches 50% Height : 4.51 inches 99% Height : 8.46 inches

The variances of the three estimates listed above are .0838, .0084, and .0765, respectively. However, because of poor fit these quantities must be corrected by the heterogeneity factor as stated above. This factor is obtained by dividing the  $\chi^2$  value obtained by its number of degrees of freedom. Using the  $\chi^2$  value which was obtained by grouping several levels together we have:

 $\frac{\chi_{0}^{2}}{9} = \frac{15.21}{9} = 1.69$ 

If the variances listed above are multiplied by the factor they become .1416, .0142, and .1293, respectively. The respective standard errors are obtained by extracting the square roots of these numbers, and these standard errors are then multiplied by a factor obtained from a table of

Student's "t" to obtain the following confidence intervals:

> 1% Height : 0 - 1.80 50% Height : 4.12 - 4.90 99% Height : 7.29 - 9.63

58. The confidence interval for the 1% height actually includes negative heights but only the positive portion of the range has been tabulated.

59. The first and most obvious remark to be made about these confidence intervals is that they are very wide. This becomes even more evident if they are compared with the corresponding intervals obtained in the tests of the Mk 101 type primer and listed on page 6 of this report. The upshot of this is that the experimental material used in the study of the Mk 120 type primer behaved in such a way that it is impossible to confine estimates of its percentage firing points to reasonably small confidence intervals even through the use of the relatively elaborate probit analysis.

60. The results of the various Bruceton tests and subtests are tabulated below:

#### - 1/2 inch intervals

No. trials	Ż	σ	1% Pt.	99% Pt.
200 100 50 50 100 50	4.86 4.60 4.42 4.79 5.12 5.10 5.12	1.51 .47 .95 1.76 1.16 .73 1.59	1.35 1.18 2.21 .70 2.42 3.40 1.42	8.37 8.02 6.63 8.88 7.82 6.80 8.82
	.04 (1	og) inter	vals	
No. trials	ĩ	$\sigma$ (log)	1% Pt.	99% Pt.
200 100 50 50 100 50 50	4.48 4.81 5.18 4.52 4.16 4.06 4.30	.220 .189 .098 .237 .165 .113 .205	1.38 1.75 3.06 1.27 1.72 2.22 1.43	14.55 13.24 8.75 16.07 10.07 7.45 12.88

61. As would be expected from experimental material of this kind, an extremely wide range of variation was exhibited. For instance, it will be noted that estimates of the 1% point as obtained from the 1/2 in. Bruceton tests vary from .70 inches to 3.40 inches, whereas estimates of the 99% pt. as obtained from the .04 log test vary from 7.45 to 14.55 inches. Needless to say, little reliance could be placed on any single Bruceton estimate obtained for primers of this sort.

62. The confidence ranges of the probit estimates were so wide and the variation of the Bruceton estimates so extreme that there seemed little point in illustrating that variation graphically as was done with the test results of the 101 primer. If the same scale was used as in the previous graphs even the confidence intervals of 1% and 99% probit estimates could not be contained on a single sheet and to compress the scale would only be misleading.

63. The  $\chi^2$  tests for the two individual 200-trial Brucetons were run as was done in the case of the Mk 101. The calculations are shown on Data Sheet 8 and the results are shown below:

Interval	Chi-square value	Probability Level
1/2 inch	XZ = 4.96	.43
.04 (log)	78 = 13.50	.10

64. The value obtained for the arithmetic intervals seems to contradict the poor fit indicated by the probit analysis of the entire rundown. However, since this value is derived from one-fourth of the total number of trials and concentrated in the neighborhood of the 50% point, it is not adjudged to be as reliable an indicator of the true situation as the probit? value. Comparison of the two %2 values listed above again indicates superiority for arithmetically spaced intervals for the Bruceton test.

65. Before concluding the remarks on the Mk 120 type primer the results of a set of calculations carried out prior to the initiation of the present study should perhaps be mentioned. There was available for analysis a set of data obtained from a rundown test of Mk 102 primers which had been conducted in September 1944. The priming mixture contained in the primers was mercury fulminate Pom Pom No. 74. The rundown was complete, consisting of 100 trials at each of 16 levels spaced 1/4 inch apart.

66. The data were analyzed by the probit method. The probit curves are shown on Figures & and 9 and the calculations on Data Sheets 9, 10 and 11. A glance at the explosion percentages shown in Column 3 of Data Sheet 9 shows a curious slowness of tailing off at the upper end of the range. Nearly half of the total range of test heights is included in the 90%-100% explosion percentage interval. This factor undoubtedly affected the statistical results, as will be seen.

67. The  $\chi^2$  values obtained after a single cycle of calculations were as follows:

Height Log Height  $\gamma_{13}^2 = 35.347$   $\gamma_{13}^2 = 14.951$ 

68. The calculations for height were carried through a second cycle but the fit was even poorer, a possibility previously alluded to. A third X<sup>2</sup> value for height was calculated by grouping extreme intervals but no improvement in fit was noted.

69. Thus the two  $\chi^2$  values shown above seem to contradict the evidence obtained in the main body of this study in that the logarithmic scale seems to be definitely superior to the arithmetic as far as goodness-of-fit to the normal distribution is concerned. However, a study of the graphs strongly indicates that the poor fit indicated for height is in the main caused by the last few points at the top of the probit graph; that is, the points corresponding to the probits determined by the unusually long tail of the distribution. Use of the logarithmic scale brings about a contraction of the horizontal height scale at its upper end, thus bringing the points plotted at the tail closer to the line determined by the remaining points.

70. The result obtained in this case is therefore not thought to contradict the conclusions previously stated concerning the relative value of arithmetic vs. logarithmic intervals for the testing of primers in general. In this case the unusually long tail at the upper end of the distribution was thought to reflect inferior quality in the primers under test. Logarithmic tests would therefore seem to merit serious consideration whenever material of this kind is under test.

#### Conclusions

71. The following general conclusions appear applicable

to the tests which have been described and discussed in this report:

a. The probit analysis should replace the Bruceton whenever the exact specification of extreme percentage points is required. Attention is again invited to references 3 and 6 in this connection.

b. Whenever possible, when using the Bruceton method, separate tests using different interval sizes should be used to estimate and

c. In any case, Bruceton tests should not be used to estimate points outside the 10%-90% range.

d. No marked superiority for either arithmetic or logarithmic intervals has been disclosed. Either may be used as seems appropriate.

e. Appropriate confidence intervals should be computed and furnished with all estimates.

72. Some qualification should be applied to the above conclusions, however, in those cases where primers exhibit the erratic performance noted for the Mk 102 and Mk 120 type described above. The use of the Bruceton test in evaluating primers which show erratic behavior would seem to be open to serious question. The probit analysis with appropriately stated confidence intervals would seem to be a reasonable alternative.

#### Suggestions for Further Study

73. In view of the seeming unreliability of the Mk 120 and Mk 102 types of primers tested in the course of this study, further tests along the lines suggested in this report using a large group of Mk 102 and Mk 120 types of primers manufactured under carefully supervised conditions to insure uniformity would be of value. ł.

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74. Experimental testing of other "staircase" methods discussed in reference 4 would throw further light on tests for small samples that might be used to supplant the Bruceton. In most cases the alternative methods are considerably more complex in both testing procedure and subsequent analysis than is the case with the Bruceton and they are less flexible, allowing the estimation of only one percentage point for each test. Whether these disadvantages are offset by greater accuracy would be worth investigation.

75. Finally, in an attempt to diagnose the cause of spparent inconsistencies of primer firing under drop-test conditions, a critical review of the entire drop-test procedure would seem to be in order. A step in that di-rection has been made in reference 7, in which the problems connected with the transfer of energy from ball to primer through the medium of the firing pin are discussed from a theoretical point of view. It is pointed out in this connection that the maintenance of stable conditions with regard to this transfer of energy in the course of the test would require that the trials during a drop test be conducted from a constant height while the weights of both the ball and the firing pin were varied from trial to trial. Whether an even greater improvement could be effected by abandonment of drop-testing methods entirely in favor of testing devices of the pendulum type or timing devices in which the time interval between impulse and explosion is measured would seem to be a subject for fruitful research in the future.

#### Appendix A

#### Note on Computation of Confidence Intervals

In computing the confidence interval for a given estimate the standard deviation of the estimate is multiplied by a factor which depends upon the desired probability level. In this connection it is to be noted that these factors are not the same as those which are used in obtaining the estimates themselves, which are listed in reference 1, page 19. For example, the factor used to determine the estimates of the 99% firing point is 2.326, whereas the factor to be used in determining the 99% confidence interval of that estimate is 2.58. The correct factors to be used in computing confidence intervals at any probability level can be read from any table of normal area; and ord-inates and is found in the column headed "t" opposite the entry in the column headed " , which is half of the desired probability. For example, to determine the correct factor for a 95% confidence interval, the value 1.96 is located in the column headed "t" opposite the value .47500 (half of .98) in the column headed " 11 \_ 3ł

The values used for estimating any percentage firing point may be obtained from the same table, though the values listed in reference 1 are adequate for most purposes. To obtain these values from a table of normal areas, .50 is subtracted from the required percentage, expressed as decimal, the result is located in the " " column and the correct factor appears opposite it in the "t" column. Thus the value 2.326 used to estimate the 99% point is found by interpolating between the values 2.32 and 2.33 which appear in the "t" column coposite the values .48963 and .49010 respectively in the " column.

In the probit analysis where a heterogeneity factor is applicable a table of "student's t" must be used instead of the table of normal areas and ordinates. See reference 2, page 60.

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FIG. I PROBIT VS HEIGHT - MK IOI TYPE PRIMER

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FIG. 2 PROBIT VS LOG HEIGHT - MK IOI TYPE PRIMER

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# FIG. 3 PROBIT AND BRUCETON ESTIMATES OF 50% POINT MK 101 TYPE PRIMER

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FIG. 5 PROBIT AND BRUCETON EST:MATES OF 1% POINT MK 10! TYPE PRIMER

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FIG. 6 PROBIT VS HEIGHT-MK 120 TYPE PRIMER

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49.464	.51	100	91	6.4	30.2	6.34	15.402	191.468
21.448	• 50	.56	93	5.3	18.\$	6.46	9.400	121.448
61.205	•48	100	83	6.0	43.9	5-95	21.072	261,205
38.006	•45	44	73	5.6	24.6	5.61	11.070	138.006
20.712	- 44	100	70	5.5	56.1	5.52	25.564	320.712
73.176	.40	312	47	5.0	178.7	4.92	79.480	977.604
56.660	- 35	100	34	4-4	55.8	4.60	19,530	256.680
77.190	.30	127	ц	3.7	42.7	3.78	12.810	161.406
05.312	•24	100	3	3.0	13.1	3.13	3.144	41.003
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Probit Analysis - Mk 101 - 3rd Cycle

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		•		X	= 2.5593	<b>ÿ</b> =	5.0516				
·			345 <u>336</u> 8 b = 1 =	31111 6.61325 6.68185 9.93140 2.1818 5.0516+	<i>С</i> : 2.1818(х.	Sanity 6841.5010 <u>6645.2909</u> 196.2101 = .46 -2.5593)	2 1 1 2 1	2 3553.231 3116.740 436.491 428.085 - 8.405			

I = -.532+2.182X X = Y+.532

- <u>1+-532</u>

50% pt: 2.54 in.0m = .020(2.49-2.59)99% pt: 3.60 in.099 = .05499% C.I. (3.46-3.74)12 pt: 1.47 in.01 = .057(1.32-1.62)

inalysis - Lik 101 - 3rd Cycle

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11010379		3ra Cycle						Data	Sheet 3
8	9 Height	10 Log Height	11	12	13	14	15	16	17
<b>IBRY</b>	Y	Χ'	n	P	T	1197	y	nut t	181 <b>y</b>
6.792 28.840 80.080 49.464 21.448 61.205 36.006 20.712 73.176 56.630 77.190 65.312 17.632 96.537	8.2 7.1 6.3 6.3 6.5 5.5 4.4 3.3 2.7	.60 .57 .54 .51 .50 .48 .45 .45 .44 .40 .35 .30 .24 .18	100 100 100 56 100 44 100 312 100 127 100	100 99 99 93 83 73 70 47 41 30	7.6 7.2 6.8 6.4 6.3 6.0 5.7 5.5 5.0 4.4 3.0 2.2	4.0 9.2 18.0 30.2 18.8 43.9 23.4 58.1 198.7 55.8 42.7 13.1 2.5 18.4	7.94 7.31 7.13 6.34 6.46 5.95 5.61 5.52 4.92 4.60 3.78 3.13 1.88	2.400 5.244 9.720 15.402 9.400 21.072 10.530 25.564 79.480 19.530 12.810 3.144 0.450 214.745	31.760 67.252 128.340 191.468 121.448 261.205 131.274 320.712 977.604 256.680 161.406 41.003 41.003 4.700 2594.852
2 53.231 16:740 36.491 28.086 3.405				9 8 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	<b>x</b> = <b>Snax</b> <b>1.640</b> <b>8.958</b> <b>2.652</b> <b>2.7818</b> <b>5.1984</b> <b>5.1984</b> <b>5.1984</b> <b>5.1984</b> <b>5.1984</b> <b>5.295</b> <b>2.782</b>	4142 2 18 1 23 1 15 412.78 12.782	<b>3</b> <b>3</b> <b>3</b> <b>3</b> <b>3</b> <b>3</b> <b>4</b> <b>2</b> <b>3</b> <b>4</b> <b>5</b> <b>5</b> <b>5</b> <b>5</b> <b>5</b> <b>5</b> <b>5</b> <b>5</b>	= 5.1984	Somy 14456.089 14008.926 1447.163 1438.376 - 3.787
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Sheet 4	10 ( <u>n1-n1</u> ) <sup>2</sup> <u>n1</u> 1	= 역학 25 25 25 25 2 2 2 2 2 2 2 2	= 9,8,9,년,1,2,8, 1,1,1,8, 1,1,1,8, 1,1,1,1,1,1,1,1,1,	86. 다 다 일 88. 다 다 일 64. 파 년	<b>૪ં ઠં કે સં</b> શ્વે હું કું
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	ю <u>7</u>	2.245 6.143 6.143 747 2.245 747 747 747 747 747 747	1.000 14.682 14.147 5.735 5.735 14.147 5.735 5.735	1.000 12.158 3.679 3.679	1.000 5.897 5.024 72.671
<b>e</b> ‡a	bets) 7 q1/p1	11-294 1-294 1-294 1-294	6.353 .931 .110 .140	12.15g 1.169 .200	5.897 .852 .110
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1/4 inc	<sup>с</sup> म	2.20 2.25 3.00 3.00 10g	-255 -301 -302 -395 -395 -395 -447 -447 -447 -198 -1/2 1nd	1.50 2.00 3.00 3.00	202 202 802 80
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lat Cycle 9	10	11	12	13	14	15	16
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$\begin{array}{r} 21.250\\ 12.000\\ 57.750\\ 109.200\\ 132.000\\ 132.000\\ 142.650\\ 285.500\\ 118.300\\ 142.650\\ 95.770\\ 125.600\\ 43.320\\ 101.500\\ 50.500\\ 30.200\\ 15.600\\ 1531.390\end{array}$	19.425 6.315 54.131 101.640 133.760 194.300 253.884 137.280 152.60 111.146 152.290 51.642 133.110 82.820 48.169 31.616 1693.635	.93 .90 .58 .51 .77 .70 .65 .62 .65 .60 .55 .40 .30 .12	566655555544445552°	8.3 3.5.0 25.5 57.0 31.1 4.3 127.9 15.6 6 1.4 3.4 3.1 27.9 15.6 1.6 3.4	7.17 6.01 6.05 6.05 9.4.92 4.67 5.4 4.4.5 4.4.5 5.05 5.79 4.52 4.67 5.4 4.55 4.4.55 4.4.55 5.55 5.55 5.55	7.719 3.420 13.255 17.520 19.656 26.045 40.390 17.160 20.605 14.942 15.066 6.756 15.066 6.040 1.950 1.950 230.048	59.511 22.838 102.831 133.760 152.460 203.805 283.854 137.280 152.160 112.547 152.290 53.118 128.340 64.326 19.470 6.224 1784.847
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Probit Analysis of Ma 2nd Gyolo

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obit Analysis of Mr 120 Data 2nd Cycle

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2<sup>2</sup> Tests of Mk 120 Data

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8.00	7.06	98.0	16	14	15.7)			.90
7.90	6.76	96.1	50	19	48.0)	1.3		.88
6.90	6.18	88.1	50	43	44.0)		.21	.81
6.00	5.88	81.1	50	43	40.6	2.4	.75	.78
5.50	5.58	71.9	63	50	45.3	4.7	1.74	.74
5.00	5.29	61.4	96	46	48.9	12.9	7.31	.70
1.55	5.02	50.8	ii ii	25	20.8	4.2	1.72	
4.50	5.00	50.0	50	ž	25.0	Å.Ö	1.28	.65
4.15	4.79	41.7	38	14	15.8	1.8	35	.62
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3.80	6.5E	33.7	19	6	6.4	.4	OL.	.58
3.50	4.40	27.1	50	17	13.7	3.3	1.09	54
2.50	3:82	11.9	50		6.0)	<i></i>	n	10
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1.50	3.22	3.8	50	î	1.9)	• •		.18
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 $\chi_{g}^{2} = 15.21$ 

Data Sheet 7

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of Mk 120 Data

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.75	.78	5.82	79.4	50	43	39.7	3.3
1.74	.74	5.59	72.2	63	50	45.5	4.5
7.31	.70	5.37	É4.4	96	46	61.8	15.8
1.72	.66	5.15	56.0	11	25	23.0	2.0
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.71	.60	4.8]	42.5	50	22	21.2	0.8
. ÓL	.58	1.70	38.2	19	6	7.3	1.3
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50 70 51 32 15 .03 .22 .40 .60 .78	.187 .242 .305 .374 .440 .512 .587 .655 .782 .782	-61.3 .758 .695 .625 .560 .488 .415 .274 .218	4.348 3.132 2.279 1.674 1.275 .953 .704 .527 .377 .279	1.000 4.348 13.618 31.035 51.035 51.035 53.028 53.028 53.384 8.816 2.460	·3 1.4 4.3 9.7 16.3 20.7 19.7 13.9 7.5 2.8 .8 .8	1.27 .68 .11 2.28 .67 .53 .69 5.96 .72 .23 .36 $P = .10$		
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Probit Analysis of Mk 10

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Probit Analysis of Mr 102 Data

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Data Sheet 9

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Frobit Analysis of Mk 102 Data

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Data Sheet 10

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X<sup>2</sup> Tests of 11k 102 Data

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