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SUPPLEMENT 3 ADDITIONAL DEMONSTRATION OF STATISTICAL BASIS FOR THE SQUARE-ROOT-SUM-OF-THE-SQUARES METHOD

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STUDY TO DEMONSTRATE THE SRSS COMBINED RESPONSE HAS GREATER THAN 84 PERCENT NONEXCEEDANCE PROBABILITY WHEN THE NEWMARK-KENNEDY ACCEPTANCE CRITERIA ARE SATISIFIED

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EXECUTIVE SUMMARY

The square-root-sum-of-the-squares (SRSS) method for combining peak dynamic responses has been justified on several bases, including:

1. Reliability Basis
2. Optimum Design Basis
3. Dynamic Margin Basis
4. Statistical Basis

This study is concerned with providing further demonstration of the adequacy of the SRSS method using the statistical basis. Although not treated in this study, one should keep in mind that the SRSS combination of peak responses might also be justified using other than the statistical basis.

The statistical basis for the SRSS method is that the SRSS combined peak response should have as great a nonexceedance probability as that required for the individual responses in the response combination. This might be called the risk-in equals risk-out principle. The SRSS method was founded (Reference 1) on this basis for certain stochastic processes. The Newmark-Kennedy Criteria (Reference 2) was developed to provide a means for judging whether the statistical basis had been met for the combination of peak responses from multiple transient dynamic loadings. The intent of the two Newmark-Kennedy criteria is to provide reasonable confidence that the SRSS combined response has an 84 percent nonexceedance probability (NEP) or greater when the individual responses being combined are defined at the 84 percent NEP level. Bases for these criteria have previously been presented. The intent of this report is to strengthen these bases.

A series of demonstration analyses using actual Mark II response combination cases from Reference 3 are presented. These analyses demonstrate that when the time phase Cumulative Distribution Function (CDF) for combined response satisfies Criterion 2 and the individual responses are conservatively defined (at approximately the 84th percentile, or 1.15 times the median, whichever is greater), the peak combined response (accounting for randomness of amplitude and time phasing) consistently exceeds the 84th percentile NEP. Results show this conclusion to be insensitive to the shape of the probability distribution

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function for amplitude of peak individual responses and remains valid over the entire range of potential amplitude dispersions.

A simple mathematical procedure based on several simplifying assumptions has been developed for approximating the general CDF directly from the time-phase CDF and a knowledge of the peak response amplitude dispersions. The general CDF curves obtained using this simple mathematical procedure are compared with those obtained using the more exact Monte Carlo techniques to demonstrate conclusively that this mathematical procedure does accurately predict the NEP associated with the SRSS combined response accounting for both random peak amplitude and time phasing. This simplified mathematical procedure proved that for any response combination in which the time-phase CDF satisfies Criterion 2, the 84 percent NEP peak combined response cannot exceed the SRSS combined response by more than 9 percent; and the likelihood of this level of exceedance is extremely low and requires the worst possible combination of each parameter involved.

The conclusion is that the Newmark-Kennedy Criterion 2 represents a conservative criterion for judging the acceptability of SRSS combination of responses when the individual responses being combined are conservatively defined (at the 84 percent NEP or 1.15 times their median, whichever is greater).

Previous studies using real Mark II response time histories have demonstrated that Criterion 1 is more conservative than Criterion 2. Thus, meeting Criterion 1 also provides good assurance of meeting the intent of the criteria for Mark II responses.

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1. INTRODUCTION

1.1 SUMMARY

The square-root-sum-of-the-squares (SRSS) method for combining peak dynamic responses* was first proposed by Rosenblueth (Reference 1) in 1951. A number of studies (see References 2 through 9) address the acceptability of combining multiple peak dynamic responses resulting from multiple independent dynamic transient load-time histories using the SRSS method. Appendix A presents a brief overview of the salient conclusions from these studies. Essentially, these studies have concluded that there are several bases for accepting the SRSS combination of peak dynamic responses, including:

a. Reliability Basis. The use of SRSS combination of peak responses in design does not significantly alter the reliability of structural components from that obtained through the use of absolute sum (AS) combination.

b. Optimum Design Basis. The case has been presented that the optimum balance between strength and ductility, and between stiffness under dynamic inertial effects and flexibility to withstand thermal and displacement effects is better achieved through the use of SRSS combination of dynamic response rather than AS combination.

c. Dynamic Margin Basis. Results show that the ratio between the dynamic versus static margin to failure is generally sufficient, such that there is a greater dynamic margin against failure for structures designed for SRSS combined dynamic responses than the static margin.

d. Statistical Basis. The statistical basis for the SRSS method is that the SRSS combined peak response should have at least as great a non-exceedance probability as the individual responses being combined. This might be called the "risk-in equals the risk-out principle."

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*In this report the words "peak response" are used to represent the maximum peak response.

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Each of these four bases represents a valid method of justifying SRSS combination of peak dynamic responses. The greatest amount of effort has been concentrated upon further clarification of the Statistical Bases. The Newmark-Kennedy Criteria presented in August 1978 (see Appendix B or Reference 2) for judging the applicability of the SRSS method of response combination is founded on this Statistical Basis. The bases of the Newmark-Kennedy Criteria was previously presented in Reference 2. This report further demonstrates that the Newmark-Kennedy Criteria achieved the goal of maintaining "risk-in equals risk-out," i.e., the Statistical Basis. The reader should not become overwhelmed by the mathematical "niceties" of the Statistical Basis and remember that the SRSS combination of peak responses might also be justified on other bases when the Newmark-Kennedy Criteria are not met.

1.2 PROBLEM AS ADDRESSED IN THIS REPORT

The intent of the Newmark-Kennedy Criteria for SRSS combination of transient responses is to provide reasonable confidence that a nonexceedance probability of approximately 84 percent is achieved for the peak combined response. Two criteria are presented. In either criterion, the individual responses must be specified at approximately the 84th percentile or greater. Satisfying either criterion should be sufficient to provide a reasonable confidence that the SRSS combined response level achieves a nonexceedance probability of approximately 84 percent. For the limited case of independent stochastic input forcing functions with certain characteristics, a heuristic proof exists that the SRSS combined response has the same nonexceedance probability as the individual responses being combined. Results have shown that earthquake acceleration time histories can be approximated as stochastic input forcing functions. However, no absolute mathematical proof exists for ensuring that satisfying either Criterion 1 or 2 for dynamic responses in general provides a reasonable confidence of achieving a nonexceedance probability of 84 percent for the peak combined response. These criteria are based on the judgement of the authors, on an approximate mathematica derivation for Criterion 2 and on the authors' extrapolation of the limited proof that does exist in the field of earthquake engineering.

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A possible deficiency was noted in the criteria as originally written (Appendix B). Specifically, if a case were postulated where the individual responses have very little variance on peak amplitude, i.e., an amplitude coefficient of variation less than about 0.2, the criteria as originally stated may not assure that the SRSS combined response exceeds the 84th percentile nonexceedance probability even when the individual responses have achieved this nonexceedance probability. Seldom will real transient response data actually have such a low coefficient of variation. Nevertheless, when applying the criteria to the design of the Black Fox Station (Reference 5), the last sentence of the criteria preamble was revised to read:

> "This goal is achieved by compliance with any one of the following criteria, or any alternative method that meets the intent stated above, provided the intensity of loads or accelerations for each input are conservatively represented at the approximate level of the 84th percentile, or 1.2 times the median level, whichever is greater." Underscoring indicates change of language.

This recommendation was recognized as probably being more conservative than necessary and that further studies would justify a factor times the median response (F value) between 1.05 and 1.2.

Most of the 291 response combination cases presented in Reference 3 were further studied in Reference 4. This study showed that 235 cases considered (composed of various combinations of 105 individual independent response time histories) satisfied Criterion 1. All these 235 cases also met Criterion 2. However, some additional cases met Criterion 2 without meeting Criterion 1. Since Criterion 1 is more simple than Criterion 2, it was intended to be more stringent than Criterion 2. The intent was to have an easy-to-use criterion which would provide a high confidence that the more mathematical criterion (Criterion 2) would automatically meet. The results of the studies in Reference 4 clearly demonstrate that this intent was achieved.

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The only significant issues that need more study are:

a. Demonstrate that meeting Criterion 2 does provide high confidence that approximately the SRSS combined response achieves a nonexceedance probability of approximately 84 percent or greater. Demonstrations have proved that meeting Criterion 1 does provide high confidence that Criterion 2 would also be met. Therefore, the demonstration bolsters the confidence in both Criterions 1 and 2.

b. Specify more accurately the level of conservatism for individual responses being combined, i.e., in the requirement that the individual responses be specified at approximately the 84th percentile or at F times the median level, the value of F needs to be determined.

1.3 REPORT CONTENT

Section 2 presents a series of demonstration analyses using actual Mark II response combination cases from Reference 3 and the Monte Carlo technique. These analyses demonstrate that when the time phase Cumulative Distribution Function (CDF) of combined response satisfies Criterion 2, and the individual responses (or inputs) are conservatively defined (at approximately the 84th percentile or F time the median, whichever is greater), the NEP of the peak combined response (accounting for randomness of amplitude and time phasing) will exceed approximately the 84th percentile. Also presented in Section 2 is a series of analyses that were performed to better define the factor F by which the median level of peak individual responses should be multiplied to provide a sufficiently conservatively defined individual response for cases where there is very little dispersion.

Section 3 presents a mathematical formulation which can be used to derive an approximate CDF curve for combined response accounting for both randomness of individual peak response amplitudes as well as randomness of time phasing, when the time-phase only CDF curve for combined response and the ratio of the 84th percentile to 50th percentile peak individual responses are defined.

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This simplified closed form mathematical procedure is used to prove that approximately the SRSS combined response will always have an 84th percentile nonexceedance probability or greater whenever Criterion 2 is satisfied by the time phase only CDF, if the individual responses are conservatively defined in accordance with the preamble of the Newmark-Kennedy Criteria.

Section 4 summarizes all of the significant conclusions of this report. Appendix A presents the background for the SRSS combination of peak dynamic responses. Appendix B presents the Newmark-Kennedy Criterion as originally written in August 1978. Appendix C presents the results of several additional studies that were performed to verify assumptions and procedures used in the studies presented in Section 2.

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2. EVALUATION OF SELECT MARK II LOAD COMBINATION CASES

2.1 INTRODUCTION

Studies presented in Reference 3 investigated the combined response for 291 actual Mark II plant response combinations. In Reference 3 the amplitude of individual responses was treated as being known and the relative time phasing of responses was treated as random. Based upon an assumed probability density function (PDF) for time phasing, a CDF of peak combined response was generated for each of the 291 response combinations. These CDF curves are conditional upon the assumption that the individual response amplitudes are known and only random time phasing defined by its PDF curve exists. Criterion 2 of the Newmark-Kennedy criteria uses these time phasing only CDF curves and requires that the following criteria be met:

a. There is estimated to be less than approximately a 50 percent conditional probability that the actual peak combined response from these conservatively defined loadings exceeds approximately the SRSS calculated peak response, and

b. There is estimated to be less than approximately a 15 percent conditional probability that the actual peak combined response exceeds approximately 1.2 times the SRSS calculated peak response.

The amplitude of response is also a random variable for each individual response time history. A more general CDF curve can be generated assuming random amplitudes and random time phasing. When Criterion 2 (based on time phase only CDF curves) is met, then it can be shown with reasonable confidence that these more general CDF curves will show approximately 84 percent or greater nonexceedance probability for the SRSS combined responses (see Figure 2.1). As shown, the notation $SRSS_{84}$ refers to the SRSS combined response using individual response amplitudes defined at the 84 percentile nonexceedance probability.

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All 291 response cases studied in Reference 4 meet Criterion 2 as defined by the solid line (time phase only) in Figure 2.1. For a few of the more critical cases (those which come closest to failing Criterion 2), CDF curves can be generated for random time phasing and random amplitude using varying assumptions on the PDF for amplitude. Showing that the $SRSS_{84}$ combined response amplitude exceeds the 84th percentile on such curves demonstrates that the intent of the Newmark-Kennedy Criteria is met when Criterion 2 has been met.

2.2 FORMULATION

Figure 2.2 schematically illustrates two response time histories which overlap in time and then must be combined to obtain a peak combined response. The relative time lag between the time histories, t, is assumed to be random with a specified probability density function (PDF) for possible values of this time lag. Furthermore, each individual response time history is assumed to be specified in terms of a random amplitude scale factor, ${}^{F}R_{i}$ and a deterministic time history ${}^{A}i_{(t)}$. Thus:

$$ {}^{R}i_{(t)} = {}^{F}R_{i} \cdot {}^{A}i_{(t)} \tag{2.1} $$

The random amplitude scale factor is defined by a specified amplitude PDF.

In the studies conducted in Reference 3, only randomness of time phasing was considered, which is equivalent to assuming that amplitude scale factors ${}^{F}R_{i}$ are deterministically set to unity. The resultant CDF curve on peak combined response is defined as a time phase only CDF curve. To generate a time phase CDF curve, the PDF on relative time phasing must be assumed. The impact of variations in the PDF selected was parametrically studied in Reference 3. The conclusion was that within reasonable bounds, the shape and duration of the PDF on relative time phasing did not have a major effect on the resultant CDF curve for peak combined response. Thus, in the majority of the Reference 4 studies the following assumptions were made:

a. The start time on each of the shorter time histories was assumed to lag behind that of the longest time history.

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b. The shorter time histories were assumed to start prior to completion of the longest time history.

c. Within these bounds the PDF on time lag for each of the shorter time histories was assumed to be uniform and each time lag was independent of any others in the combination.

These assumptions (see Figure 2.2) allow a consistent approach to be used for all cases and assure that the two time histories do occur concurrently. For consistency, this study will continue to make those same assumptions on relative time phasing.

This study investigates the effect of randomness in the amplitude scale factors, F_{R_i}, on the resultant CDF curve for peak combined response. In this study, each of the individual response amplitude scale factors are assumed independent from the others. In all cases, a unity scale factor was set to correspond to an 84 percent nonexceedance probability (NEP). Thus, the unscaled amplitude time histories, $A_{i(t)}$, used in the time phase only CDF studies correspond to the 84 percent NEP. This is consistent with the preamble of the criteria, which require the individual responses to be specified at about the 84 percent NEP or greater.

Two different shaped PDF curves for the amplitude scale factors were considered: lognormal, and bounded uniform (see Figure 2-2). These two shapes were chosen because they differ significantly from each other, and bound many other possible shapes. With the 84 percent NEP amplitude scale factor defined as unity, then the entire shape of each of these PDF curves can be defined in terms of an amplitude dispersion factor, δ, given by:

$$\delta = \frac{F_{R_{84}}}{F_{R_{50}}} = \frac{1}{F_{R_{50}}} \tag{2.2}$$

where $F_{R_{84}}$ and $F_{R_{50}}$ represent the 84 percent and 50 percent NEP, respectively, for the amplitude scale factor.

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For the lognormal distribution:

$$F_{R_{NEP}} = F_{R_{50}} \cdot \exp(f \cdot \beta) = \frac{\exp(F \cdot \beta)}{\delta} \tag{2.3}$$

in which $F_{R_{NEP}}$ represents the amplitude scale factor for a given NEP, β represents the logarithmic standard deviation, and f represents the standardized Gaussian random variable corresponding to the given NEP. Using Equations 2.2 and 2.3, and noting that $F_{R_{84}}$ corresponds to f = 1, one obtains

$$\delta = \exp(\beta) \tag{2.4}$$

so the dispersion factor, δ, defined by Equation 2.2 can be directly converted into a logarithmic standard deviation, β, to be used in Equation 2.3.

Similarly, for the bounded uniform distribution with lower bound F_{R_L} and upper bound F_{R_u}:

$$F_{R_{NEP}} = F_{R_L} + \frac{(NEP)}{100} \left[F_{R_U} - F_{R_L} \right] \tag{2.5}$$

Given, that $F_{R_{84}} = 1.0$ and $\delta = 1/F_{R_{50}}$, the corresponding bounds are found to be:

$$F_{R_L} = \frac{2.47}{\delta} - 1.47$$

$$F_{R_U} = 1.47 - \frac{0.47}{\delta} \tag{2.6}$$

As expected and confirmed by the results presented in Subsection 2.4.1, the NEP for the SRSS combined response increases with the increasing dispersion δ when each of the individual responses are defined at 84 percent, i.e., $F_{R_{84}} = 1.0$ or greater. Thus, this study concentrated primarily on cases with small dispersion. Note that the time phase CDF curve corresponds to $\delta = 1.0$. In this study, the following dispersions were used:

δ = 1.0, 1.1, 1.2, 1.3

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For earthquakes and other dynamic responses, δ is generally greater than 1.2. Thus, the δ values considered in this study have been biased onto the conservative side.

All CDF curves used for this study were generated using random amplitudes as well as random time phasing as shown in Figure 2.2. A Monte Carlo procedure was used to generate the CDF curves for peak combined response for a specified PDF on time lag, specified individual response time histories, $A_{i(t)}$, and specified individual PDF curves for each amplitude scale factor, F_{R_i}. A series of peripheral studies (Appendix C) was conducted to study the relative accuracy of the resultant CDF curve as a function of the number of Monte Carlo trials. The conclusion was that the CDF curves could be very accurately generated within the region of interest (10 to 90 percent NEP) with 100 trials and the potential error was only minor at higher NEP. Since the purpose of this study was to verify whether the NEP for the SRSS combined reponse exceeded 84 percent, no reason existed to increase the accuracy of the CDF curves for an NEP greater than 90 percent. Thus, all new analyses presented in this report were generated using 100 trials. Results for time phase only CDF curves obtained from Reference 3 were typically generated with a greater number of trials.

2.3 RESPONSE COMBINATION CASES STUDIED

For the purpose of demonstrating that Criterion 2 achieves the intent that the approximate SRSS combined response has a NEP of approximately 84 percent or greater, six combination cases were chosen from the 291 cases studied in Reference 3. The following criteria were used to select these six cases:

a. Only cases in which the absolute sum (AS) combined response exceeded the SRSS combined response by more than 25 percent were considered. It was judged that when the difference was less than this amount, then the impact of using an SRSS combination versus an AS combination was not very significant and such cases were not critical.

b. Three cases should include those time phase CDF curves that marginally passed the first part of Criterion 2, i.e., the time phase NEP for the SRSS value should lie between 0.4 and 0.6.

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c. Three cases should include those time phase CDF curves that marginally passed the second part of Criterion 2, i.e., the time phase only NEP for 1.2 times SRSS should lie as close to 85 percent as possible.

d. One case should be a three response combination case.

Using this criterion, the following 6 cases were selected from the 291 cases:

a. Main Steam - 46I - SRSS2, OBE + SRVBDG, Moment at Point A

b. Main Steam - 46I - SRSS2, OBE + SRVBDG, Moment at Point B

c. RHR - Wetwell - 1I - SRSS1, OBE + SRVBUB, Moment at Point A

d. Zimmer Plant, OBE (EW) + SRV (ALL), Containment Wall at Drywell Floor Elevation.

e. Zimmer Plant, OBE (EW) + SRV (ALL), Containment Wall at Drywell Floor Elevation

f. LaSalle Unit 1, OBE (NS) + SRV (ADS) + CHUG (30 Hz), Containment Wall at Drywell Floor Elevation

Table 2-1 is a summary of the response combination components, peak amplitude of each component and the SRSS combination of the responses for each case. The time phasing CDF curves of peak combined response (positive and negative) of these 6 cases are shown in Figures 2-3 through 2-14. From these CDF curves, the probabilities of nonexceedance of the SRSS combined value and 1.2 times SRSS were determined. Table 2-2 presents the ratio of AS/SRSS, and the NEP for the SRSS and 1.2 times SRSS combined response. The time history of each individual response component of all six selected cases are shown in figures 2-15 through 2-27.

Cases 1 through 3 have the SRSS combined response NEP ranging from 40 to 60 percent for at least one response sign (plus or minus) to represent cases which adequately test the first part of the SRSS combined response. These cases have the lowest NEP on the SRSS combined response for any of the interesting cases (AS/SRSS > 1.25) in Reference 3. Cases 4 and 5 have the lowest NEP of about 91 percent on the 1.2 times SRSS combined response for at least one response sign and thus represent the best cases for testing the second portion of Criterion 2. Case 6 represents the three response combination case with the lowest NEP for SRSS and 1.2 times SRSS. These 6 cases represent the best test of the adequacy of Criterion 2.

2.4 INFLUENCE OF AMPLITUDE DISPERSION

The original Newmark-Kennedy Criteria (Appendix B) required individual responses to be defined at approximately the 84 percent NEP and did not specify a factor on the median response. The adequacy of this original criteria is investigated in this subsection.

For the purpose of this investigation, the random amplitude scaling factors, F_{R_i}, for each response were assumed lognormally distributed with dispersion δ_i and with each $F_{R_{84}} = 1.0$, i.e., for the individual amplitude time histories $A_{i(t)}$ defined at the 84 percent NEP. The following dispersion cases were investigated:

Dispersion Case	RESPONSE COMBINATION CASES Cases 1 through 5	Added Data Case 6
A	$\delta_1 = \delta_2 = 1.1$	$\delta_3 = 1.1$
B	$\delta_1 = \delta_2 = 1.2$	$\delta_3 = 1.2$
C	$\delta_1 = \delta_2 = 1.3$	$\delta_3 = 1.3$
D	$\delta_1 = 1.1, \delta_2 = 1.2$	$\delta_3 = 1.2$
E	$\delta_1 = 1.2, \delta_2 = 1.1$	$\delta_3 = 1.1$

In addition, the time phase CDF curve corresponds to all $\delta = 1.0$.

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2.4.1 Effect of Increasing Amplitude Dispersion (Cases A through C)

Figures 2-28 through 2-39 present general CDF (random amplitude and time phase) curves for all six response combination cases for dispersion cases A (all δ = 1.1), B (all δ = 1.2), and C (all δ = 1.3) as well as the time phase CDF (all δ = 1.0). Note that up to a NEP of about 85 percent, the NEP obtained accounting for amplitude randomness generally increases with increasing random amplitude scale factor dispersion (see Table 2-3). Accounting for randomness of amplitude results in a very substantial increase in the NEP associated with the SRSS value whenever the SRSS value has a time phase (δ = 1.0) NEP less than 0.75 even when the dispersion is as low as 1.1. This forms the basis for accepting a time phase NEP as low as about 50 percent for the SRSS value. The SRSS NEP results are tabulated in Table 2-3 for the various dispersions on amplitude.

Note that the SRSS combined response has a NEP of approximately 84 percent or greater in every case where the dispersion is 1.2 or greater. Thus, with an amplitude dispersion of 1.2 or greater, the Newmark-Kennedy Criteria (as originally written) achieves the goal of an SRSS combined response NEP of approximately 84 percent or greater. For cases with abnormally low dispersion (δ = 1.1), the original criteria do not universally achieve their goal. This potential deficiency is easily corrected by specifying that the individual responses being combined must be specified greater than both approximately their 84 percent NEP value and approximately F times their median value where F should have a value between 1.1 and 1.2. This correction is further studied in Subsection 2.5.

2.4.2 Effects of Different Amplitude Dispersions for Each Response (Cases D and E)

In Subparagraph 2.4.1, each response in the combination was assumed to have the same amplitude dispersion. Dispersion cases D (δ_1 = 1.1, δ_2 = δ_3 = 1.2), and E (δ_1 = 1.2, δ_2 = $\delta3$ = 1.1) were investigated to determine the effect of different dispersions for each response. Figures 2-40 through 2-51 compare the general CDF curves for all six response combination cases for dispersion cases A (all δ = 1.1), B (all δ = 1.2), D, and E.

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The following points can be noted:

a. When the individual peak responses differ substantially, the amplitude dispersion associated with the larger individual response totally predominates and the general CDF curve is nearly identical to that obtained assuming this same dispersion on amplitude for all responses. For instance, in Cases 1 through 3, the peak or response 2 is about 3 times the peak of response 1 and so response 2 predominates. In each case, the CDF curve obtained with different dispersions δ_1, and δ_2 corresponds almost exactly to the case where all dispersions are equal δ_2. Similar results are seen for the negative response of Cases 4 through 6 where one peak response predominates, although to a lesser extent.

b. When peak responses are nearly equal, the CDF curve obtained with different dispersions δ_1 and δ_2 lies between those obtained with all dispersions equal to δ_1 and δ_2, respectively. This can be seen for Cases 4 and 5 in which the positive peak responses are nearly equal.

Therefore, conclusions reached assuming equal dispersion for all response amplitudes are equally valid for the case of nonequal dispersions so long as an equivalent equal dispersion is weighted toward the dispersion of the response with the greater peak value. Additionally, the NEP for the SRSS value will be conservatively underestimated if the smaller amplitude dispersion is assumed for each of the responses.

2.4.3 Effect in Variation in Shape of Probability Density Function on Random Amplitude

The previous results were generated assuming a lognormal distribution for the random amplitude scale factor. In order to check the sensitivity of the results to the shape of the PDF on the amplitude scale factor, the CDF curves were also generated using the bounded uniform PDF curves on amplitude shown in Figure 2-2 and discussed in Subsection 2.2. For the bounded uniform distribution, $F_{R_{84}}$ was set equal to 1.0, and the dispersion δ_i was set to 1.2 for each response amplitude scaling factor. The results were compared to those for dispersion

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case B in which the lognormal distribution also had $^{F}R_{84} = 1.0$ and $\delta_i = 1.2$ for each response amplitude.

Figures 2-52 through 2-63 compare the CDF and complementary CDF curves obtained for $\delta_i = 1.2$ on amplitude dispersion obtained for the lognormal distribution with those obtained for the bounded uniform distribution. Also shown is the random time phase only ($\delta = 1.0$) CDF curve for comparison.

Note the $\delta = 1.2$ CDF curves are nearly identical for the lognormal versus the bounded uniform PDF curves on amplitude for every case. The conclusion was that the shape of the PDF curve on the random amplitude scale factor is of very little importance. The dispersion $\delta = ({}^{F}R_{84}/{}^{F}R_{50})$ is sufficient to define the influence of the random amplitude scale factor on the NEP for the SRSS combined response so long as each individual response in the combination is defined at the 84 percent NEP.

2.5 RECOMMENDED FACTOR F ON MEDIAN RESPONSE

In the previous section, it was shown that so long as the effective dispersion of the individual response amplitudes exceed 1.2, the original Newmark-Kennedy Criteria achieve their goal of approximately an 84 percent NEP for the SRSS combined response. This conclusion appears to be insensitive to the shape of the PDF for the amplitude scale factor. Even though lesser dispersion than 1.2 are unlikely, it is desirable to guard against the possibility by requiring that the individual responses be defined at the greater of approximately the 84 percent NEP or F times their median value where F should be selected between 1.1 and 1.2. With this modification, the Newmark-Kennedy Criteria are expected to also achieve their goal even for cases of low amplitude dispersion. In this subsection, results are presented from studies to determine the appropriate value for F.

With individual responses defined at the 84 percent NEP, the SRSS combined response is given by:

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$$SRSS_{84} = \sqrt{\sum_{i=1}^{N} {}^{A}P_{84_i}^{\,2}} \tag{2.7}$$

where ${}^{A}P_{84_i}$ represents the peak individual response defined at the 84 percent NEP. In the previous section, the individual response time histories were taken to represent the 84 percent NEP response amplitudes so that the 84 percent NEP amplitude scale factor ${}^{F}R_{84}$ was set to unity. The SRSS values presented in Tables 2-2 and 2-3 and shown in Figures 2-28 through 2-39 for the six response combination cases correspond to peak individual amplitudes defined at the 84 percent NEP and are given by Equation 2.7.

If the individual responses are required to be defined at either the 84 percent NEP or F times their median, whichever is greater, then the design load $SRSS_D$ combined response can be expressed as:

$$SRSS_D = \sqrt{\sum_{i=1}^{N} \left(C_i \cdot {}^{A}P_{84_i}\right)^2} \tag{2.8}$$

where

$$\begin{aligned} C_i &= 1.0 \text{ when } \delta_i \geq F \\ C_i &= F/\delta_i \text{ when } \delta_i < F \end{aligned} \tag{2.9}$$

Table 2-3 present results for the NEP for $SRSS_{84}$ combined response based on individual responses defined at the 84 percent NEP for the six response combination cases studied with various assumed dispersions of $\delta = 1.0$ (time phase randomness only), 1.1, 1.2, and 1.3. It was shown that $SRSS_{84}$ had approximately an 84 percent NEP or greater in every case where the dispersion δ was 1.2 or greater, but not necessarily so when δ was 1.1 or less. However, with the individual responses also required to exceed F times their median value, the $SRSS_D$ combined response can be defined in terms of the $SRSS_{84}$ combined response for each case in this table from:

$$SRSS_D = C\,(SRSS_{84}) \tag{2.10}$$

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where C is given as a function of the amplitude dispersion δ and F by Equation 2.9. The problem is to determine what value of F is sufficient to result in $SRSS_D$ having approximately an 84% NEP under conditions of low dispersion (δ = 1.0, and 1.1).

Table 2.4 presents $SRSS_D$ (obtained from Equation 2.10) for various values of F (1.1, 1.15, and 1.2) and low dispersions (δ = 1.0, and 1.1) for each of the six response combination cases being studied. An F value of 1.1 is shown as not large enough because it results in several cases in which the NEP for the $SRSS_D$ combined response is low (as low as 74 percent) for these cases of very little amplitude dispersion. On the other hand, an F value of 1.2 over-compensates for these cases of low dispersion. An F value of 1.15 is judged to be sufficiently conservative. For the case of a dispersion factor δ of 1.1, this F value leads to a mean NEP of 90 percent and a minimum of 81 percent for the 12 combinations considered (6 cases, 2 signs each). Similarly, with no amplitude dispersion (δ = 1.0), this F value leads to a mean NEP of 95 percent and a minimum of 88 percent. Considering that these six response combination cases have been biasedly selected as those limiting cases which came closest to failing the Newmark-Kennedy Criterion 2, an F value of 1.15 is judged more than adequate.

For SRSS combined responses, it is recommended that the individual peak responses in the combination should be conservatively defined at approximately the 84 percent NEP, or <u>at 1.15 time the median level, whichever is greater</u>. This provides more than adequate protection against the possibility of low amplitude dispersion when the Newmark-Kennedy Criteria are used to justify the SRSS combination.

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Table 2-1
SUMMARY OF CASES STUDIED

CASE	DESCRIPTION	LOAD COMBINATION	PEAK AMPLITUDE +	PEAK AMPLITUDE -	SRSS COMBINATION +	SRSS COMBINATION -	COMMENT *
1	Main Steam - 46I M_a	OBE	4.13	4.16	12.89	13.27	Moment (in-kips)
		SRVBDG	12.21	12.60			
2	Main Steam - 46I M_c	OBE	2.484	2.451	8.107	7.884	Moment (in-kips) X10^{1}
		SRVBDG	7.717	7.493			
3	RHR-Wetwell-1I M_a	OBE	16.09	20.37	47.15	44.56	Moment (in-kips) X10^{1}
		SRVBUB	44.32	39.63			
4	Zimmer Plant - Containment Wall at Drywell Floor Elevation	OBE(NS)	14.28	17.85	19.64	20.90	Meridional Force (kips/ft)
		SRV(ALL)	13.49	10.87			
5	Zimmer Plant - Containment Wall at Drywell Floor Elevation	OBE(EW)	14.00	17.45	19.44	20.56	Meridional Force (kips/ft)
		SRV(ALL)	13.49	10.87			
6	LaSalle Unit 1 - Containment Wall at Drywell Floor Elevation	OBE(NS)	11.46	19.81	19.44	22.52	Meridional Force (kips/ft)
		SRV(ADS)	15.30	9.88			
		CHUG(30HZ)	3.52	4.15			

* For ease of tabulation, the numerical values presented in the Table have been normalized to values between 1 and 100 by multiplication of the actual value by the factor of 10 shown. These normalized values will be used throughout the majority of the report.

Table 2-2
RESPONSE RATIOS FOR CASES STUDIED

CASE	SIGN	AS/SRSS	TIME PHASE ONLY NEP	
			SRSS	1.2 * SRSS
1	+	1.27	0.40	0.98
	-	1.26	0.47	1.0
2	+	1.26	0.66	1.0
	-	1.26	0.61	1.0
3	+	1.28	0.54	0.95
	-	1.35	0.74	0.99
4	+	1.41	0.70	0.91
	-	1.37	0.90	0.99
5	+	1.41	0.74	0.91
	-	1.38	0.94	0.98
6	+	1.56	0.73	0.96
	-	1.50	0.97	1.00

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Table 2-3
RESULTS OF INCREASED DISPERSION OF RANDOM AMPLITUDE
SCALE FACTOR WHEN INDIVIDUAL RESPONSES ARE DEFINED
AT 84 PERCENT NEP

CASE	SIGN	TIME PHASE ONLY, NEP		NEP FOR SRSS VALUE WITH RANDOM AMPLITUDE		
		SRSS	1.2 SRSS	δ = 1.1	δ = 1.2	δ = 1.3
1	+	0.40	0.98	0.74*	0.81	0.82
	-	0.47	1.00	0.77*	0.81	0.84
2	+	0.66	1.00	0.80	0.85	0.85
	-	0.61	1.00	0.78*	0.83	0.82
3	+	0.54	0.95	0.79*	0.82	0.87
	-	0.74	0.99	0.86	0.86	0.87
4	+	0.70	0.91	0.82	0.86	0.89
	-	0.90	0.99	0.94	0.93	0.92
5	+	0.74	0.91	0.86	0.88	0.88
	-	0.94	0.98	0.96	0.93	0.93
6	+	0.73	0.96	0.84	0.90	0.90
	-	0.97	1.00	0.96	0.93	0.91

* Unaccepably Low NEP

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Table 2-4
RESULTS OF LOW ISPERSION OF THE RANDOM AMPLITUDE SCALE FACTOR WHEN INDIVIDUAL RESPONSES ARE DEFINED AT THE 84 PERCENT NEP OR F TIMES THEIR MEDIAN, WHICHEVER IS GREATER

CASE	SIGN	$\delta = 1.0$						$\delta = 1.1$					
		F = 1.1		F = 1.15		F = 1.2		F = 1.1		F = 1.15		F = 1.2	
		$SRSS_D$	NEP	$SRSS_D$	NEP	$SRSS_D$	NEP	$SRSS_D$	NEP	$SRSS_D$	NEP	$SRSS_D$	NEP
1	+	14.18	0.85	14.82	0.96	15.47	0.98	12.89	0.74*	13.48	0.81	14.06	0.90
	-	14.60	0.89	15.26	0.95	15.92	1.0	13.27	0.77*	13.87	0.82	14.48	0.92
2	+	8.918	0.95	9.323	0.99	9.728	1.00	8.107	0.80	8.475	0.92	8.844	0.97
	-	8.672	0.93	9.066	0.98	9.460	1.00	7.884	0.78*	8.242	0.92	8.600	0.95
3	+	51.87	0.85	54.22	0.89	56.58	0.95	47.15	0.79*	49.29	0.84	51.44	0.90
	-	49.02	0.89	51.24	0.93	53.47	0.99	44.56	0.86	46.58	0.89	48.61	0.93
4	+	21.61	0.77*	22.59	0.88	23.57	0.91	19.64	0.82	20.54	0.86	21.43	0.87
	-	22.99	0.96	24.04	0.99	25.08	0.99	20.90	0.94	21.85	0.95	22.80	0.97
5	+	21.39	0.83	22.36	0.89	23.33	0.91	19.44	0.86	20.33	0.83	21.21	0.90
	-	22.62	0.95	23.64	0.98	24.67	0.98	20.56	0.96	21.49	0.97	22.43	0.98
6	+	21.38	0.87	22.36	0.92	23.33	0.96	19.44	0.84	20.32	0.92	21.20	0.94
	-	24.78	0.98	25.90	0.98	27.02	1.00	22.52	0.96	23.55	0.99	24.57	1.00

* Unacceptably Low NEP

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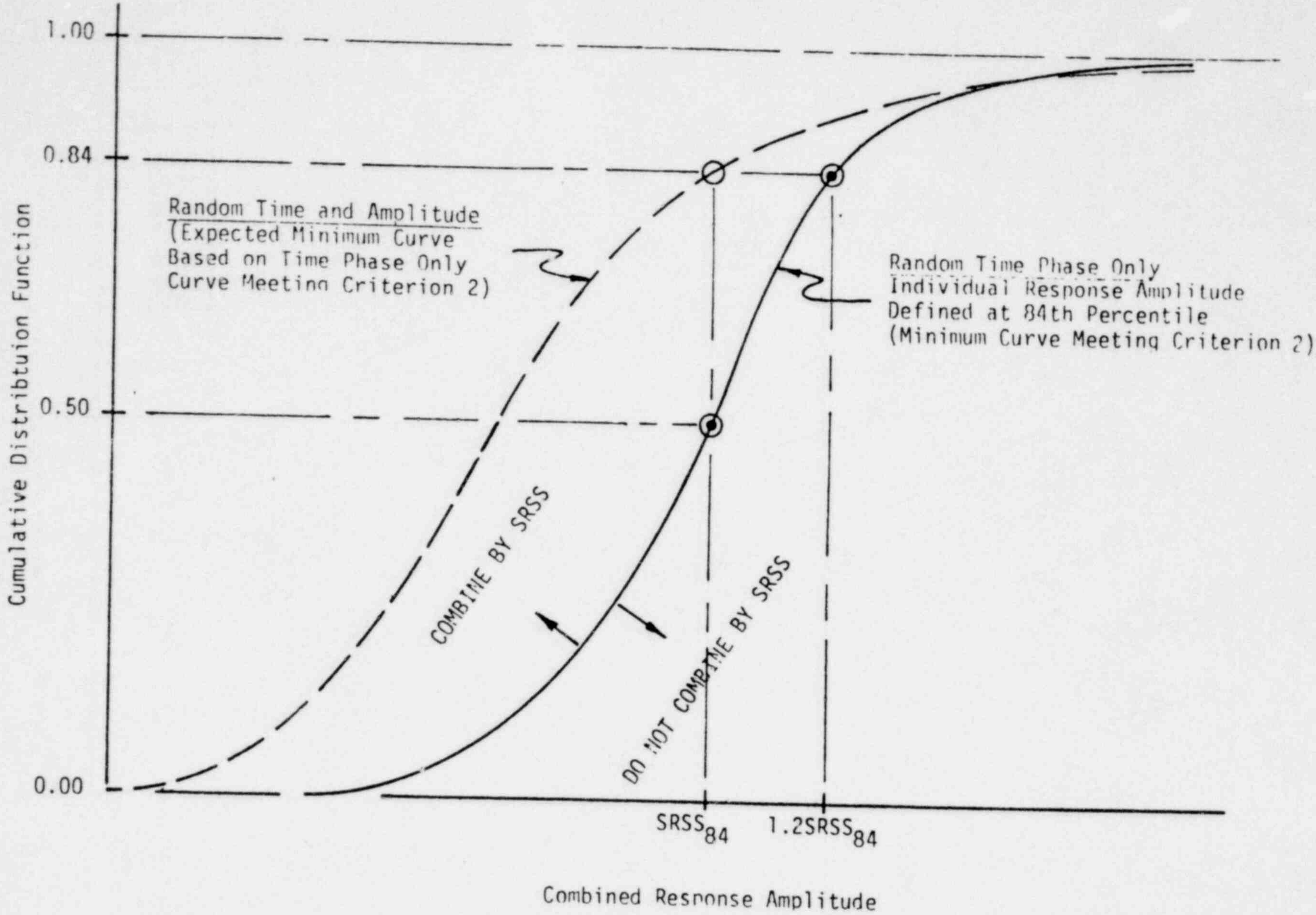


Figure 2-1. Comparison of Random Time Phase Only CDF Curves with Random Time Phase and Amplitude CDF Curves

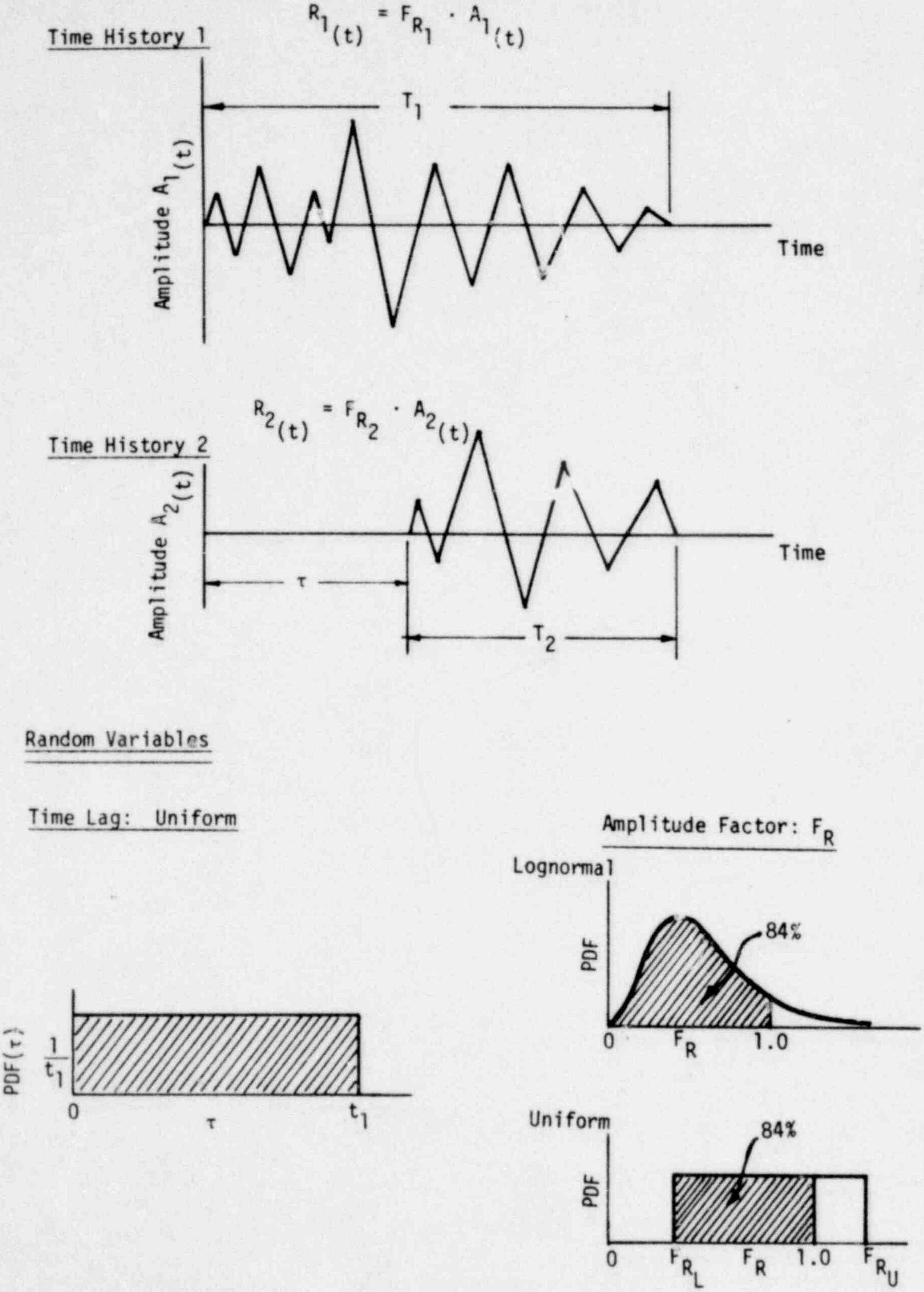


Figure 2-2. Response Combination Assumptions

CUMULATIVE DISTRIBUTION FUNCTION

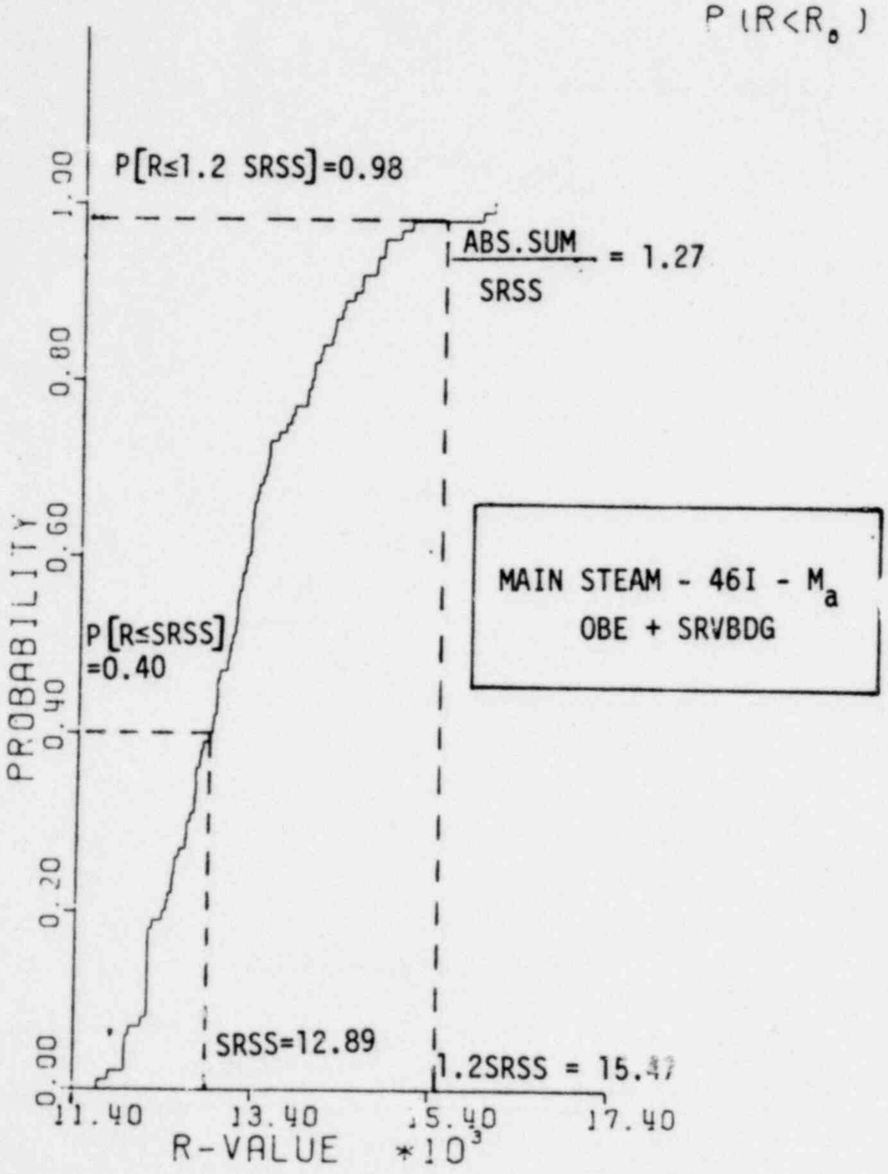


Figure 2-3. Time Phasing Only CDF (Positive) of Case 1

1323 195

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

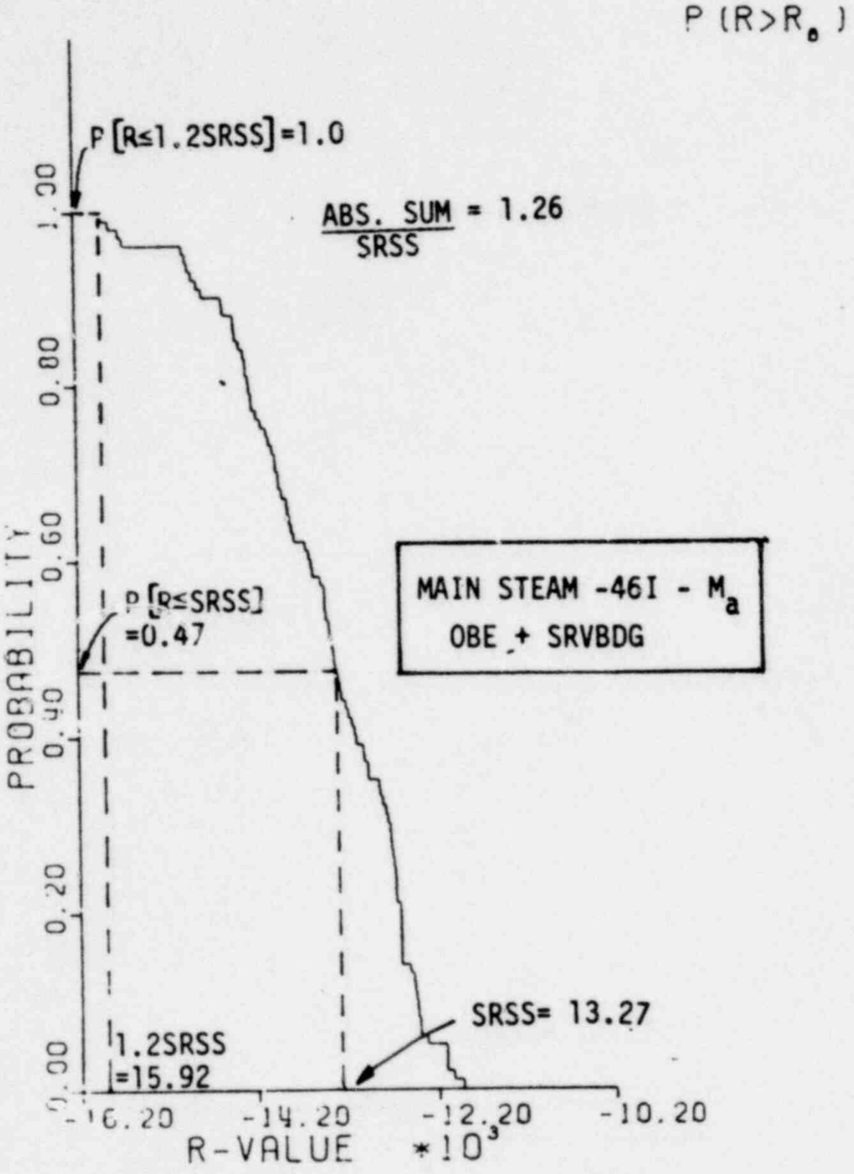


Figure 2-4. Time Phasing Only CDF (Negative) of Case 1

1323 196

CUMULATIVE DISTRIBUTION FUNCTION

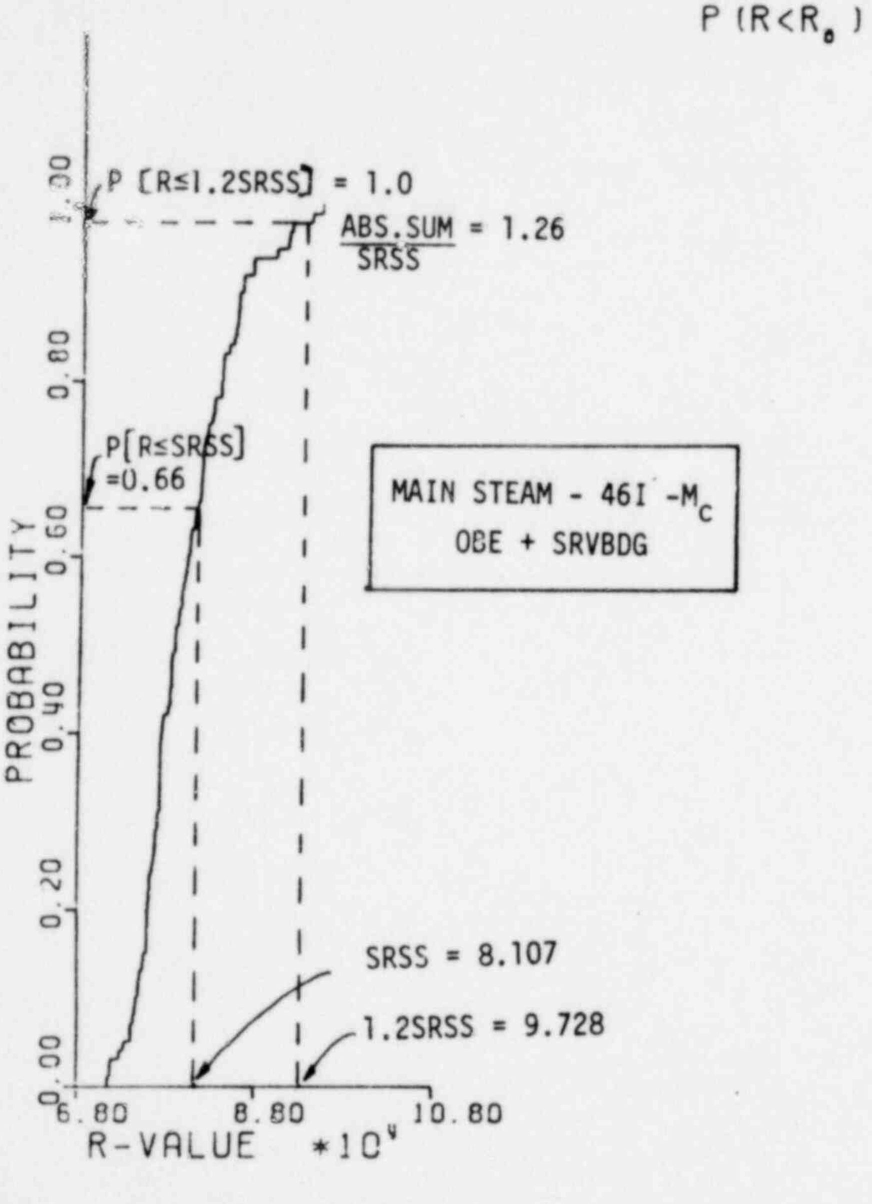


Figure 2-5. Time Phasing Only CDF (Positive) of Case 2

1323 197

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

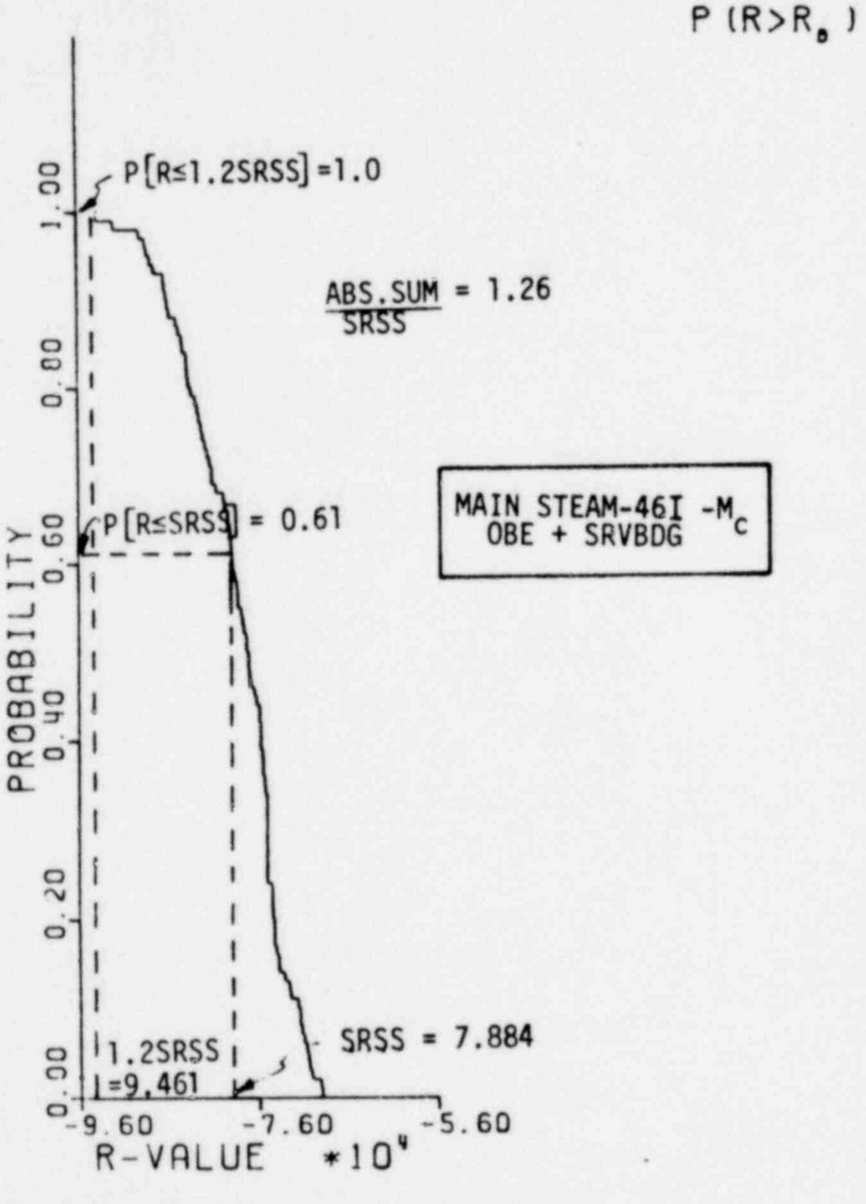
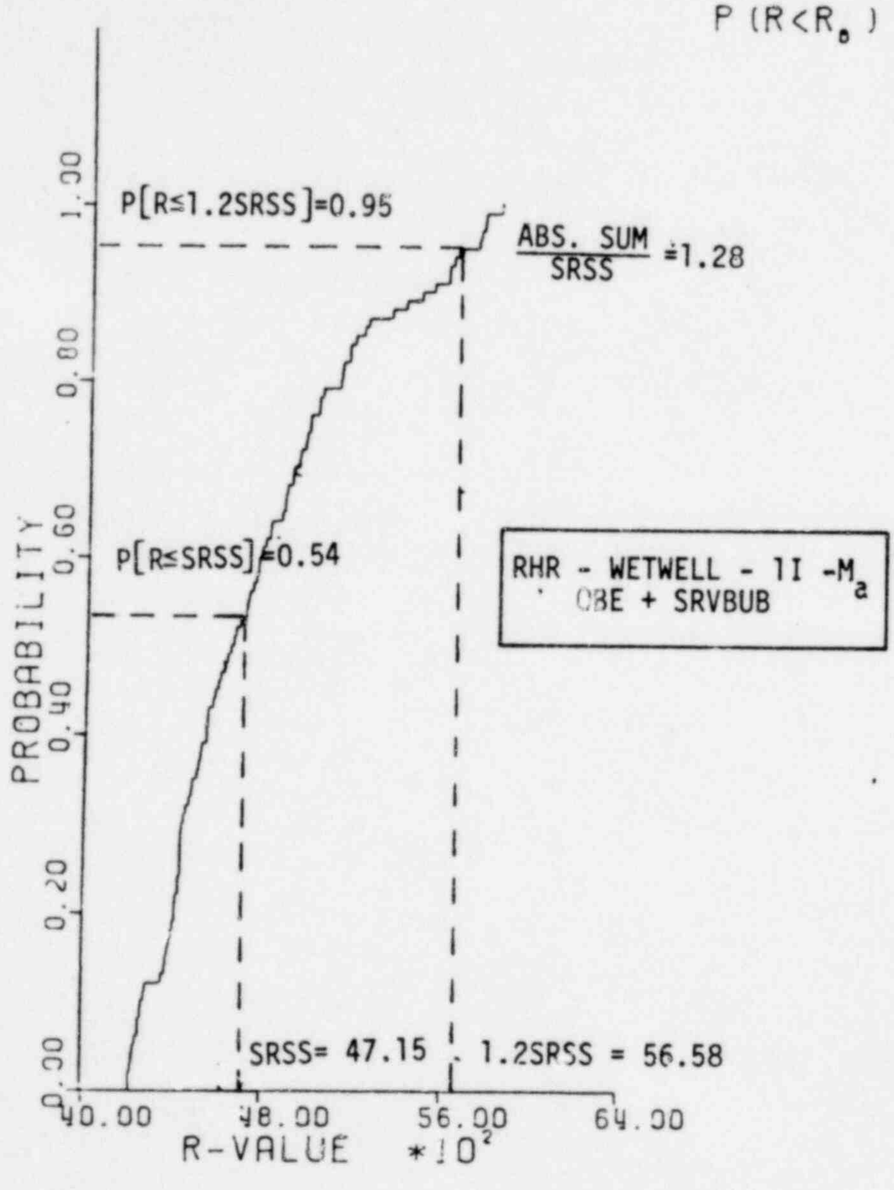


Figure 2-6. Time Phasing Only CDF (Negative) of Case 2

1323 198

CUMULATIVE DISTRIBUTION FUNCTION



Fiure 2-7. Time Phasing Only CDF (Positive) of Case 3

1323 199

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

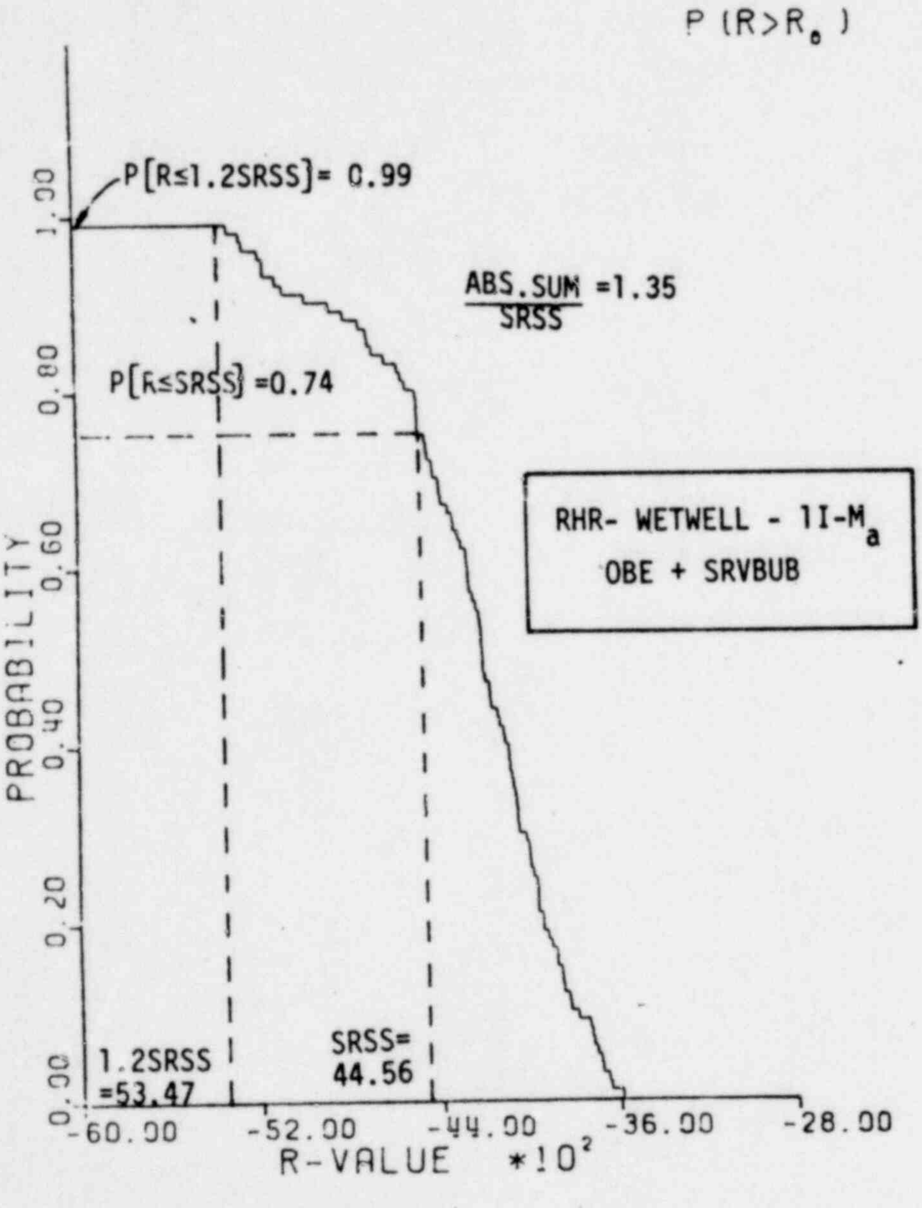


Figure 2-8. Time Phasing Only CDF (Negative) of Case 3

1323 200

CUMULATIVE DISTRIBUTION FUNCTION

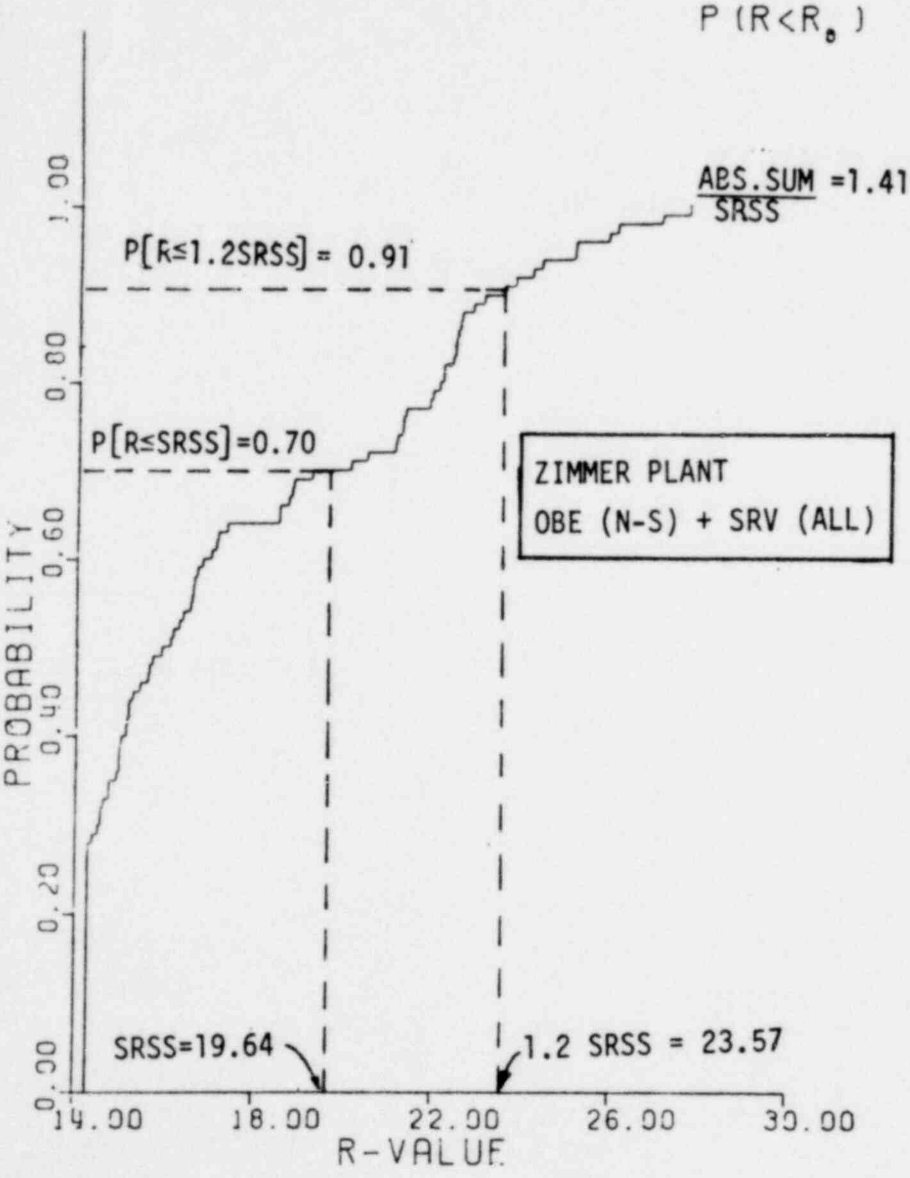


Figure 2-9. Time Phasing Only CDF (Positive) of Case 4

1323 201

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

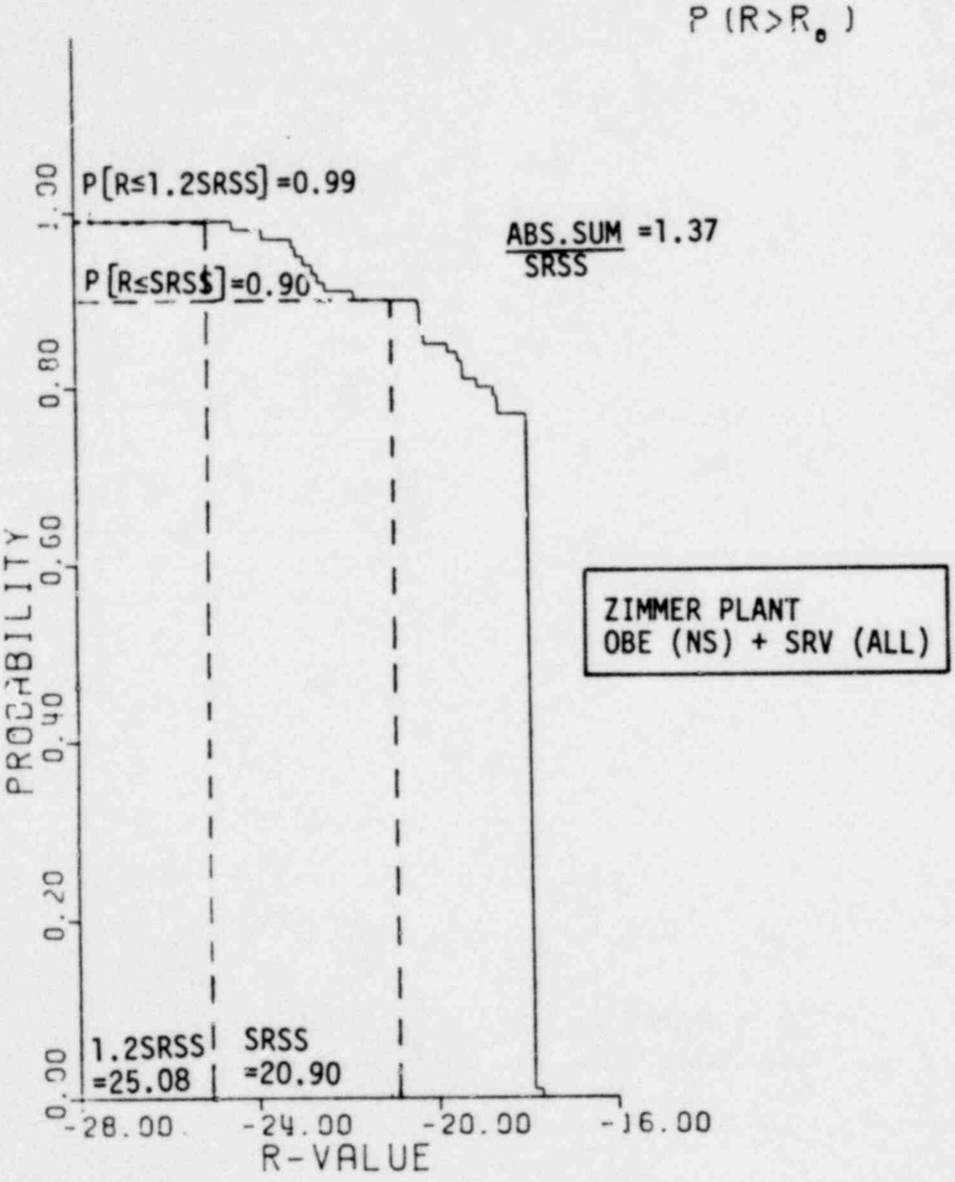


Figure 2-10. Time Phasing Only CDF (Negative) of Case 4

1323 202

CUMULATIVE DISTRIBUTION FUNCTION

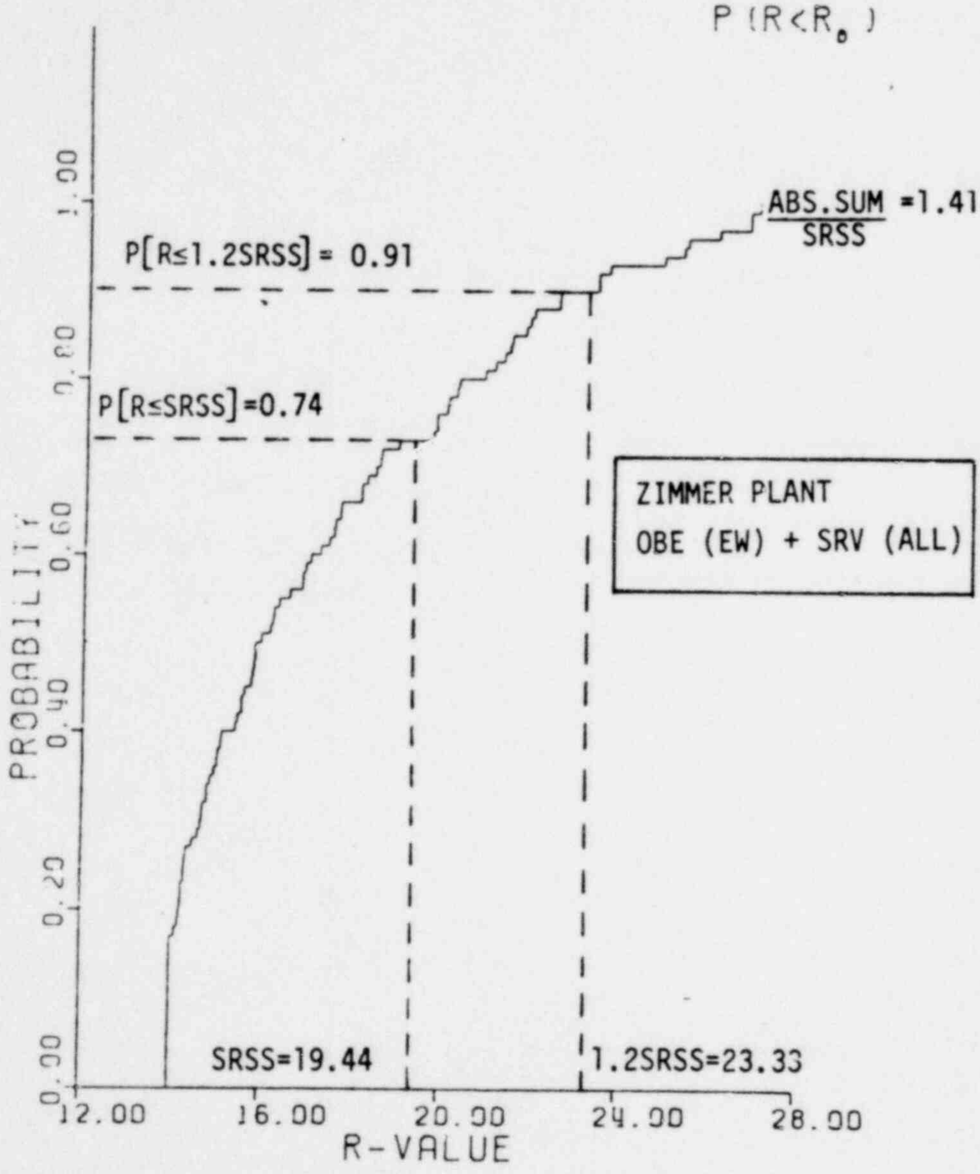


Figure 2-11. Time Phasing Only CDF (Positive) of Case 5

1323 203

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

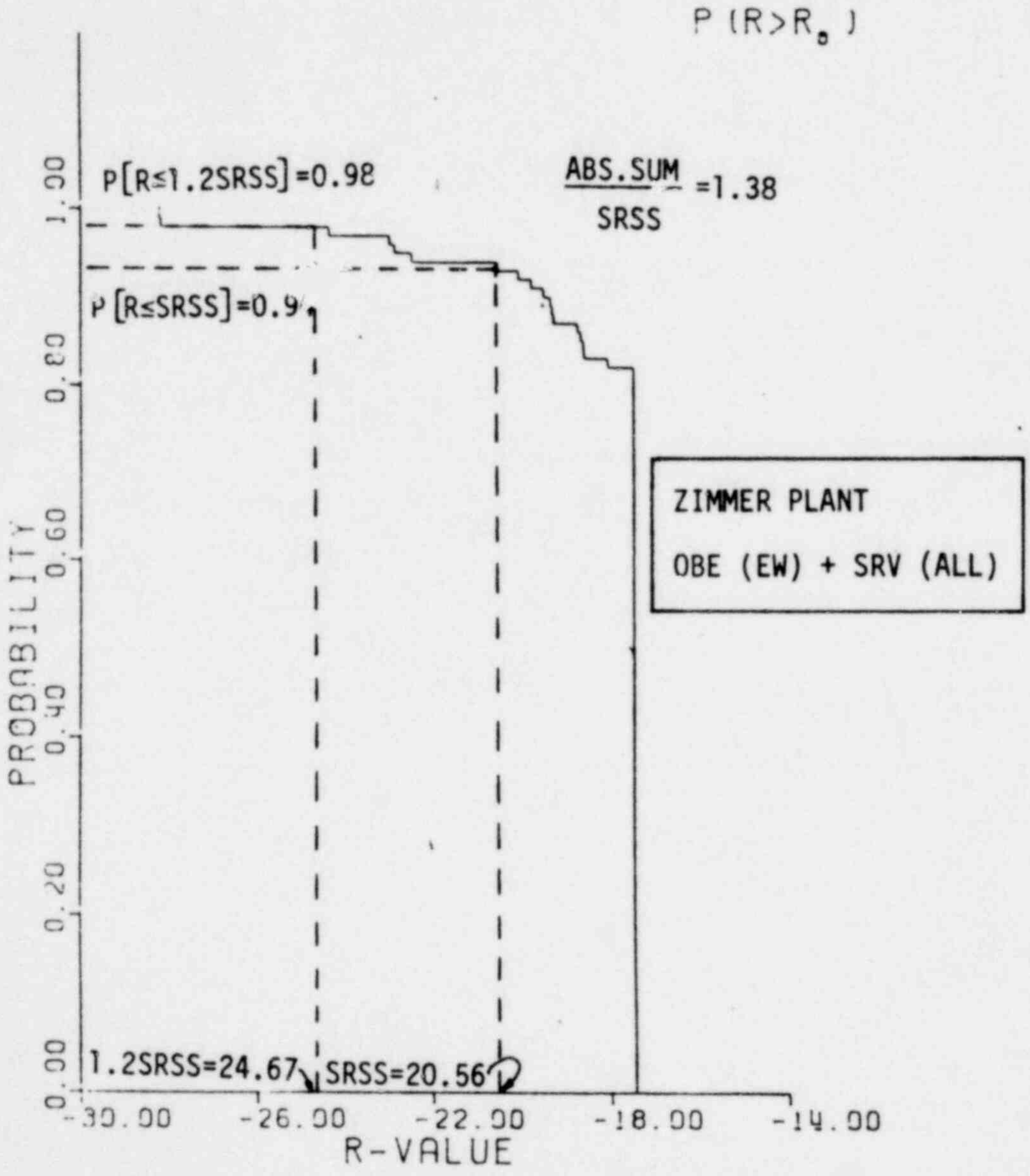


Figure 2-12. Time Phasing Only CDF (Negative) of Case 5

1323 204

CUMULATIVE DISTRIBUTION FUNCTION

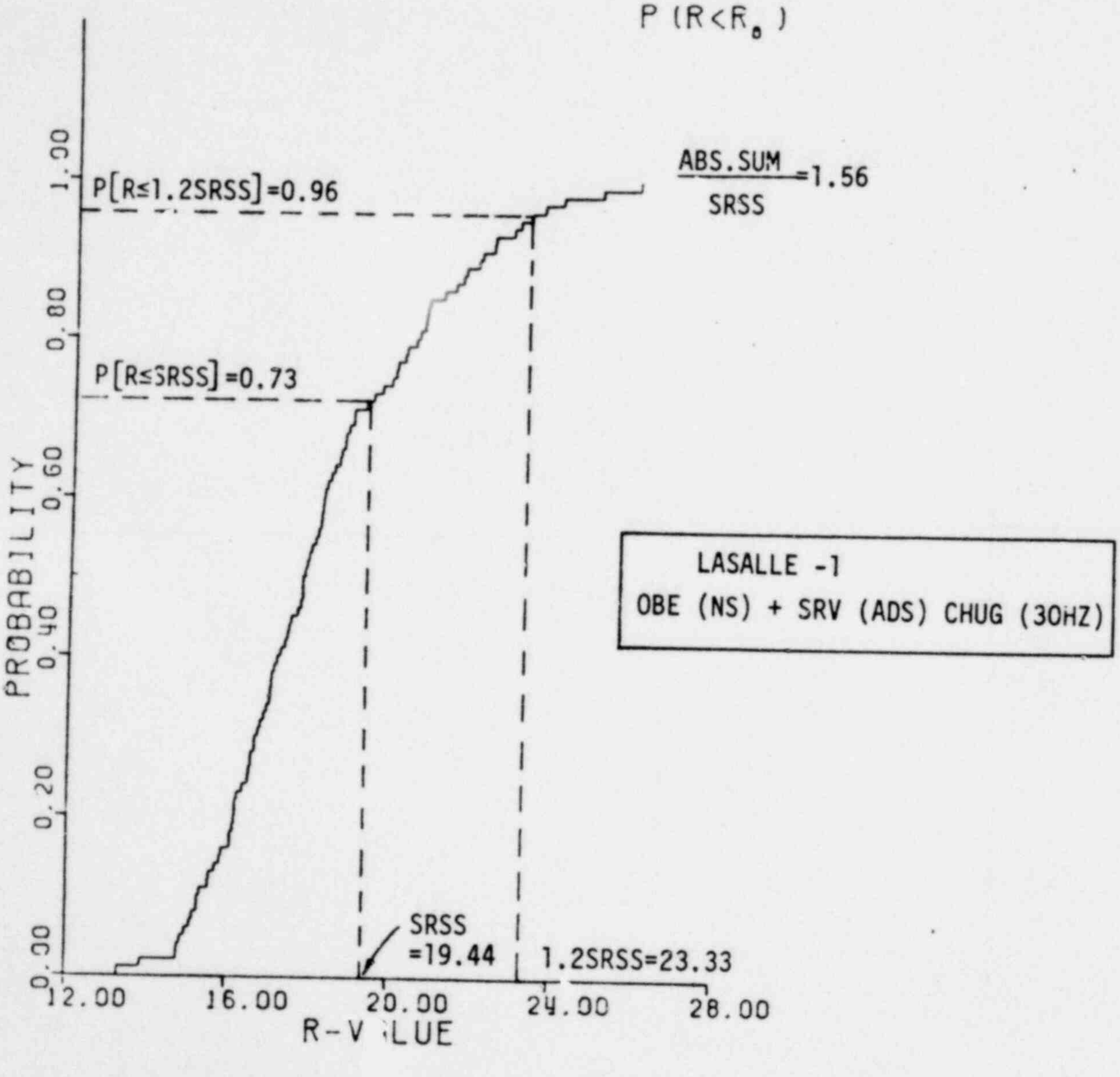


Figure 2-13. Time Phasing Only CDF (Positive) of Case 6

1323 205

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

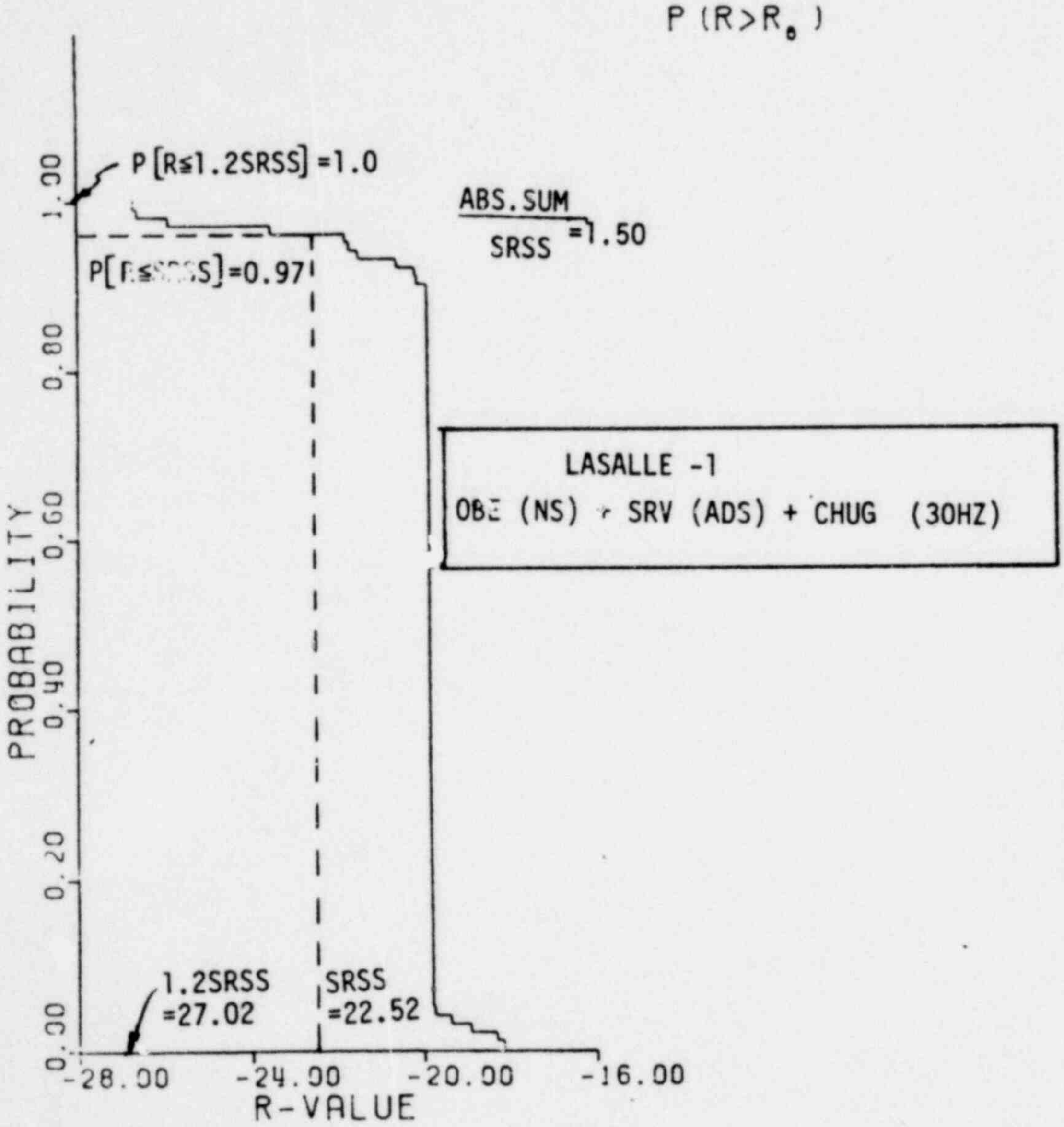


Figure 2-14. Time Phasing Only CDF (Negative) of Case 6

1323 206

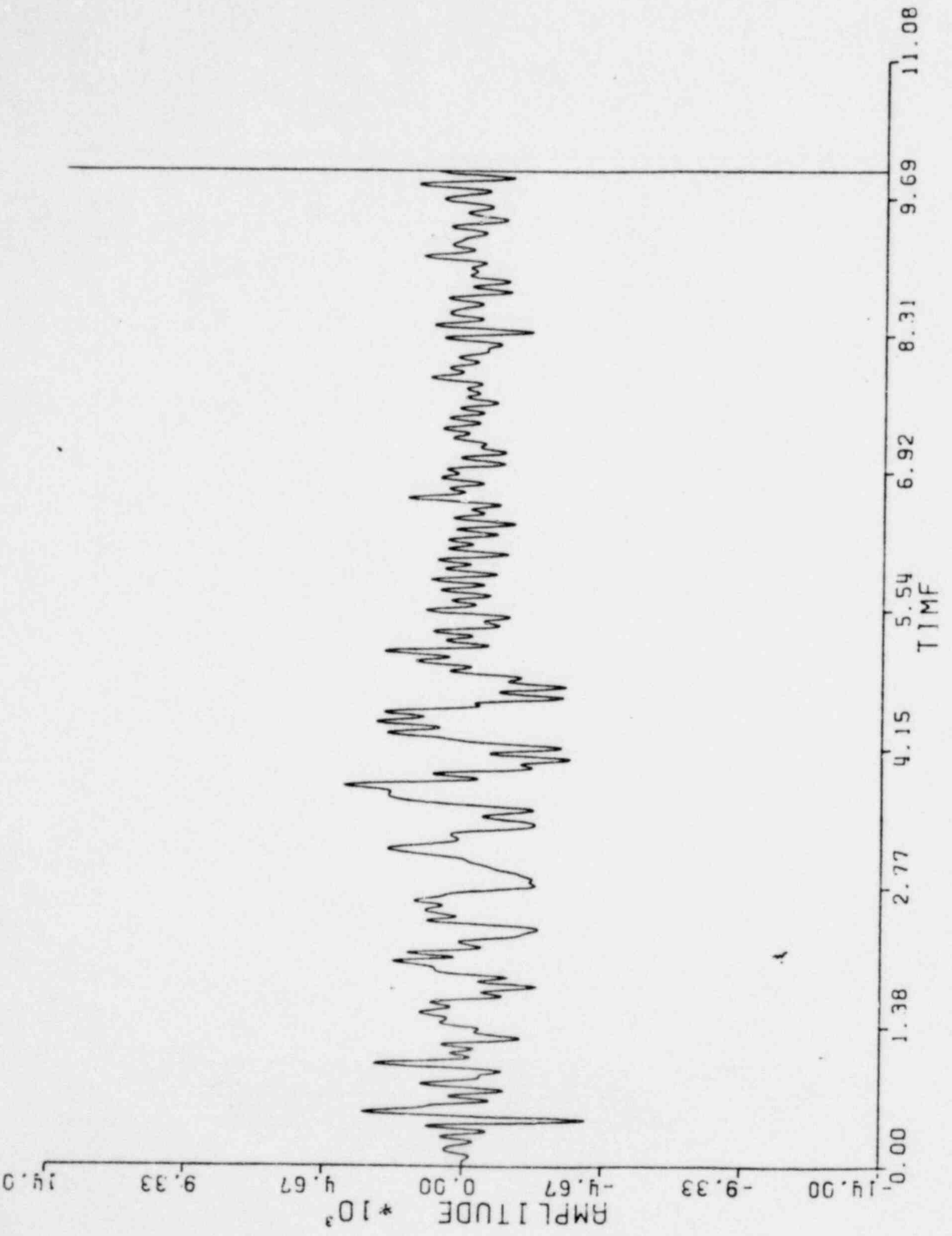


Figure 2-15. Main Steam 461 OBE, M_a Reference Case

1323 207

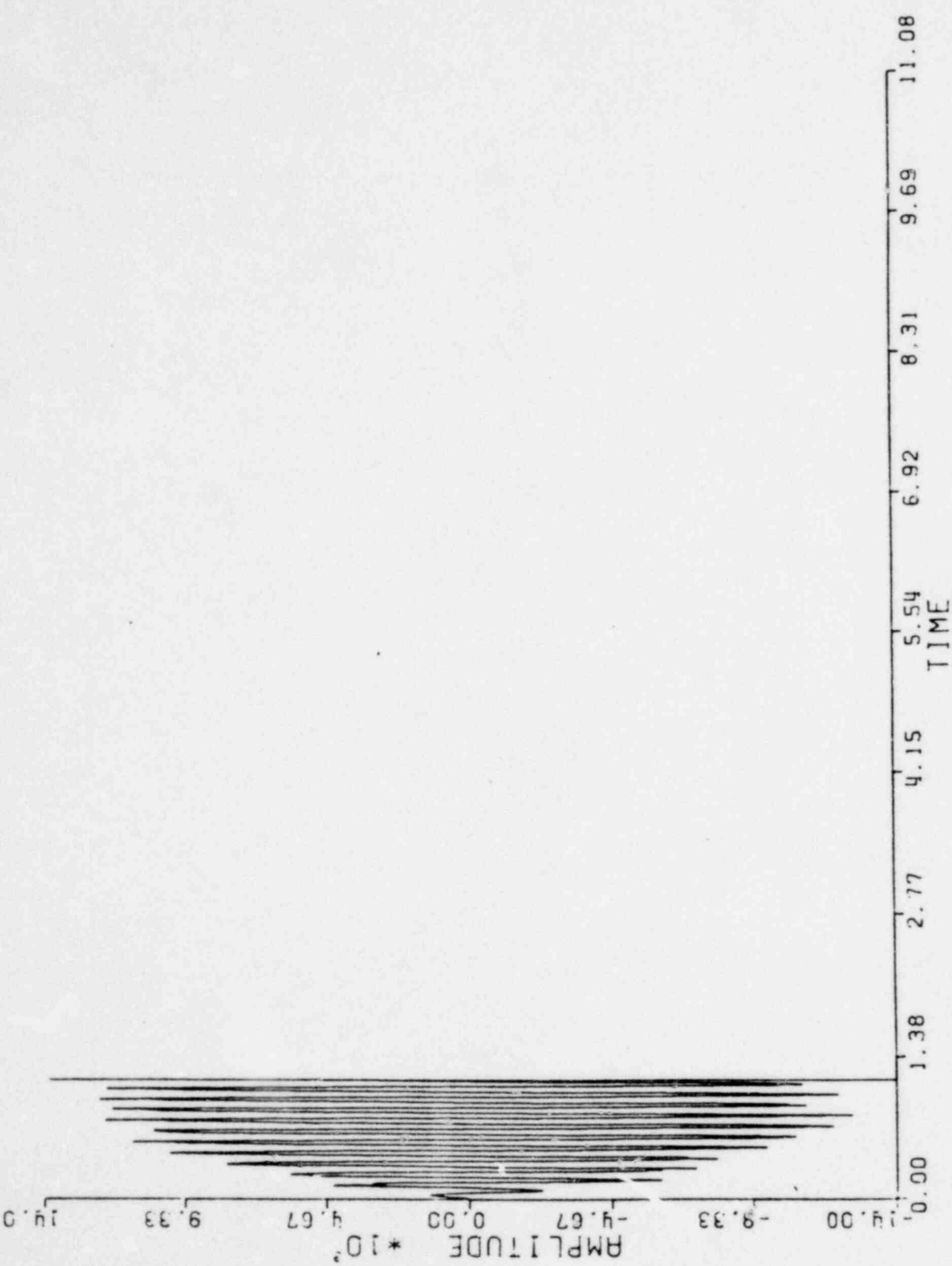


Figure 2-16. Main Steam 461 SRVBDG, M_a Case 2

1323 208

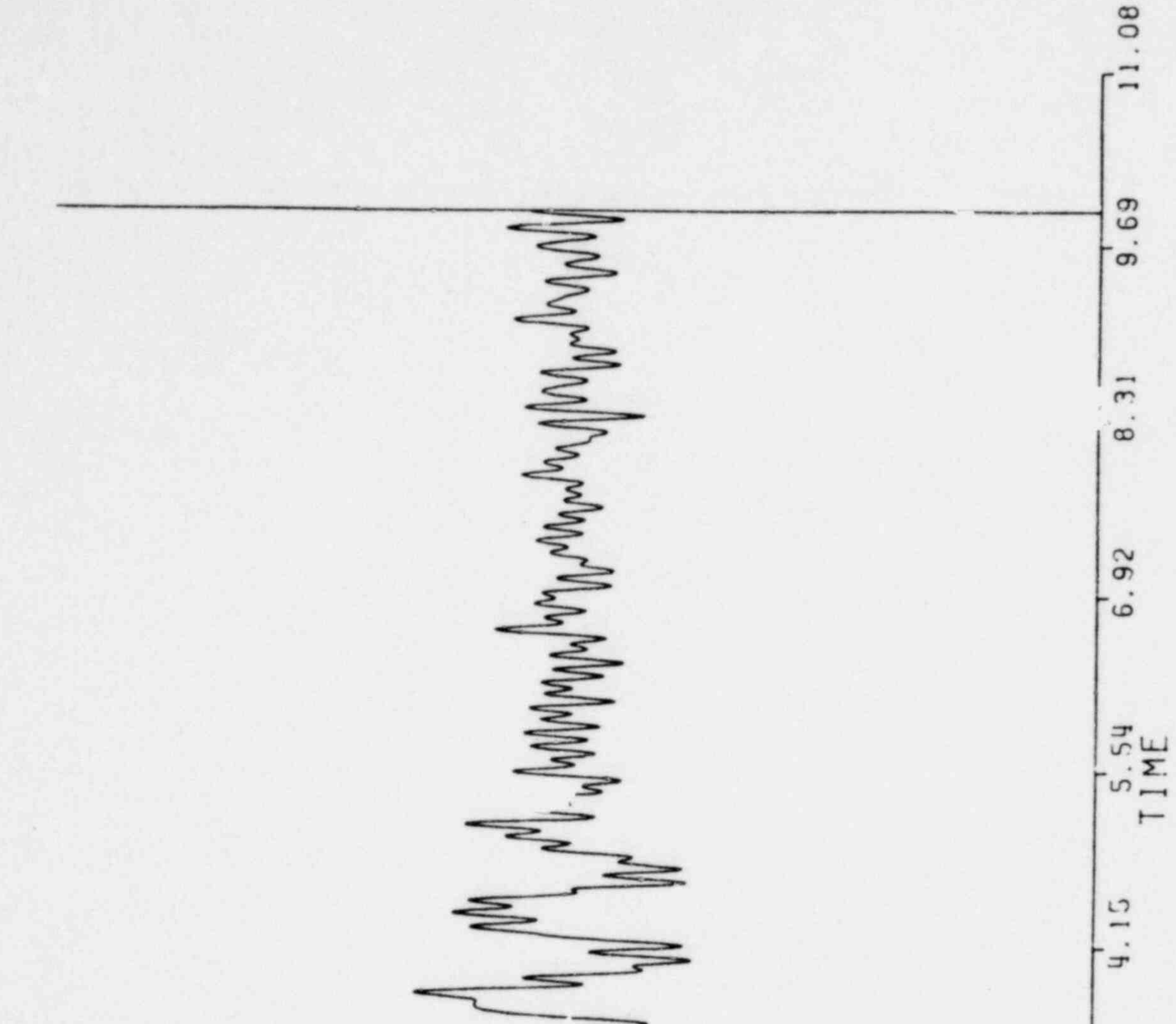


Figure 2-17. Main Steam 461 OBE, M_c Reference Case

1323 209

Figure 2-18. Main Steam 461 SRVBDG, M_C Case 2

1323 210

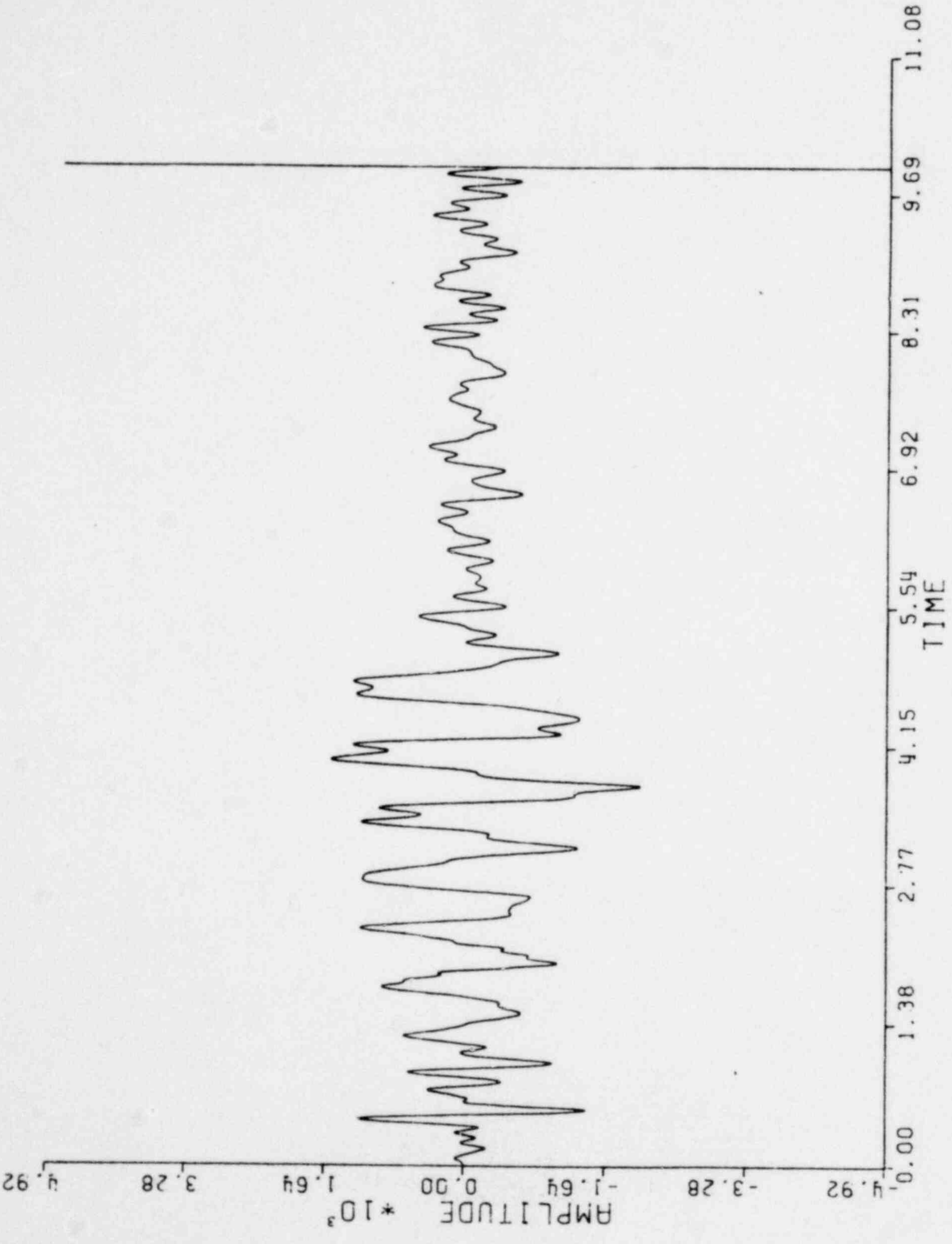


Figure 2-19. RHR Wetwell-1I OBE, M_a Reference Case

1323 211

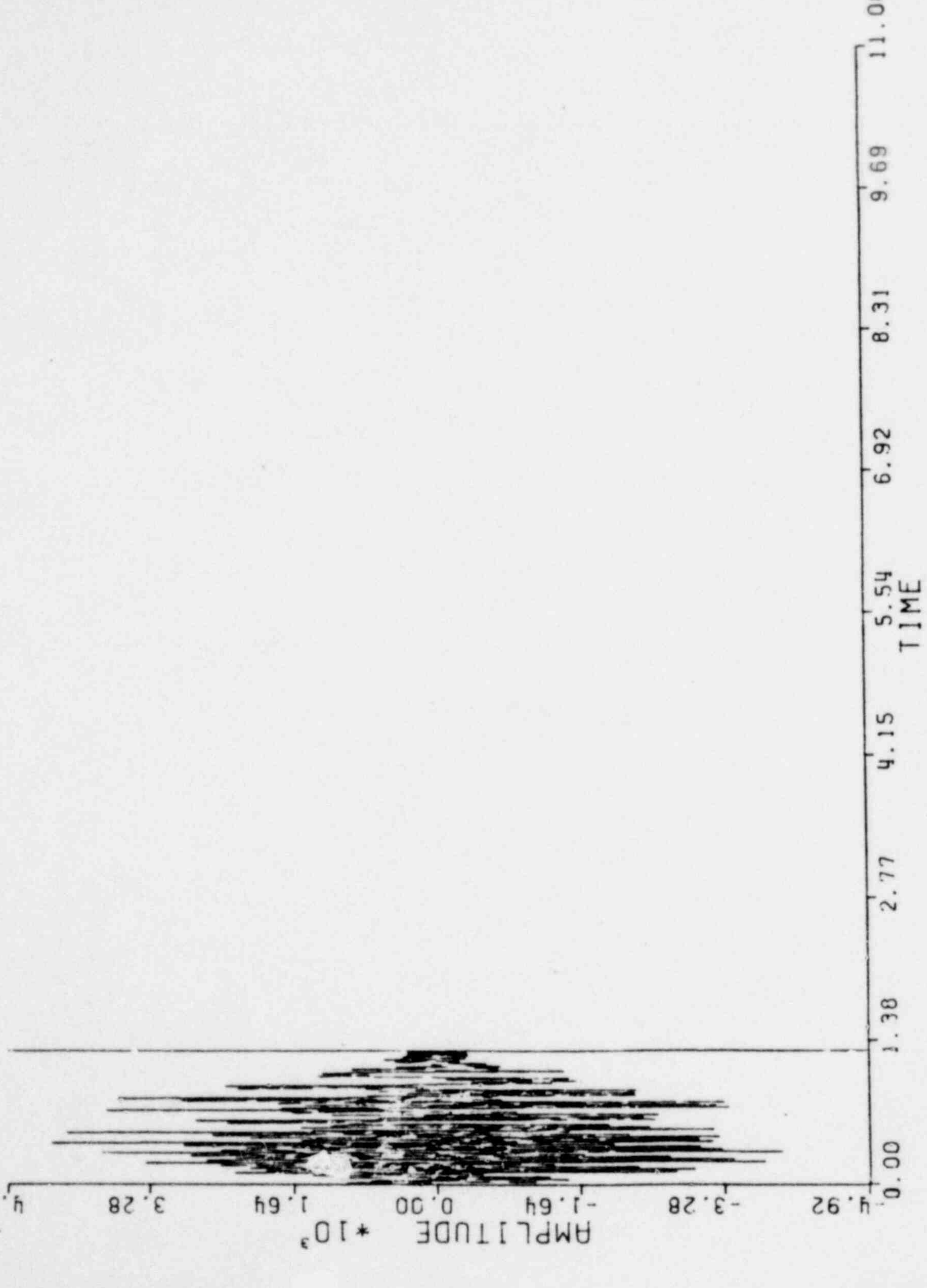


Figure 2-20. RHR Wetwell-1I SRVBUB, M_a Case 2

1323 212

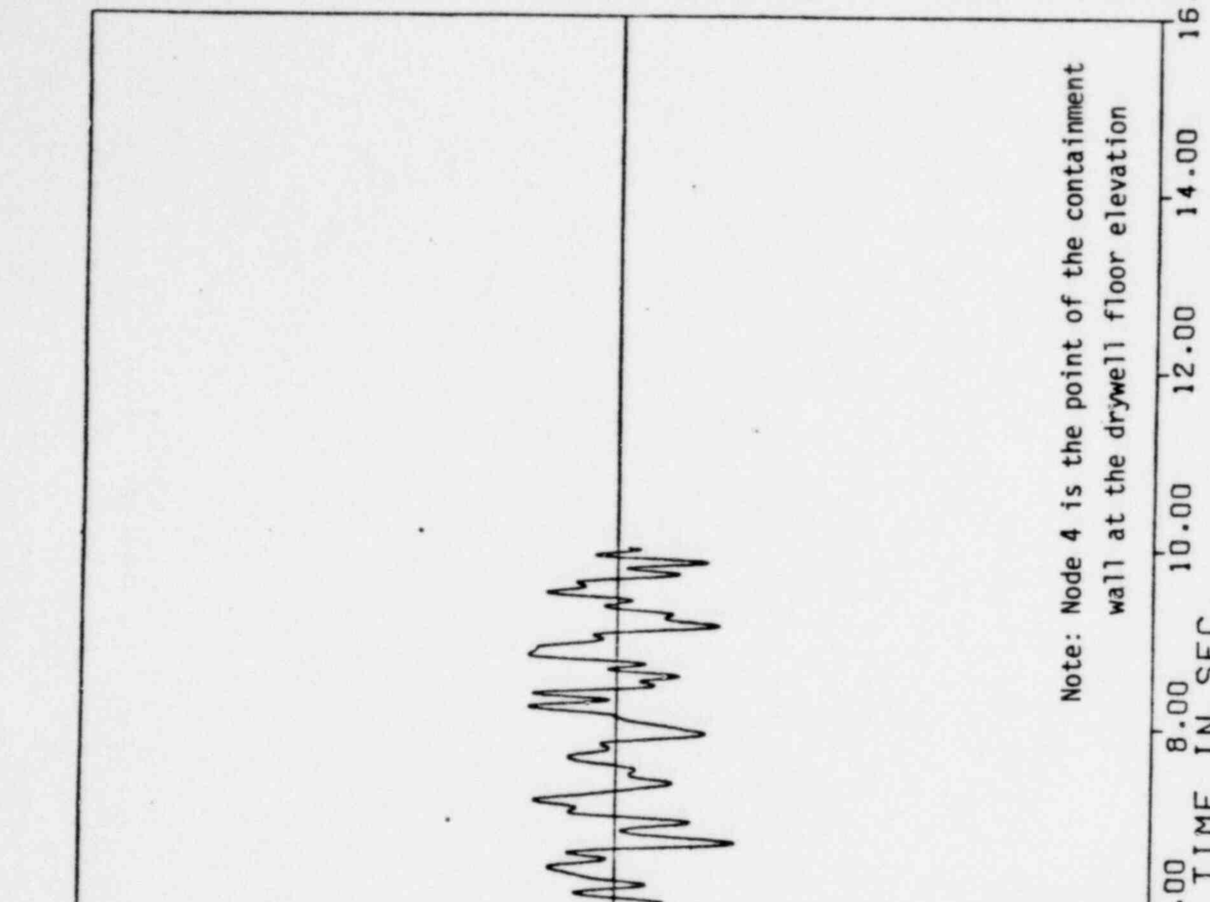


Figure 2-21. Zimmer Node 4 OBE(NS)

1323 213

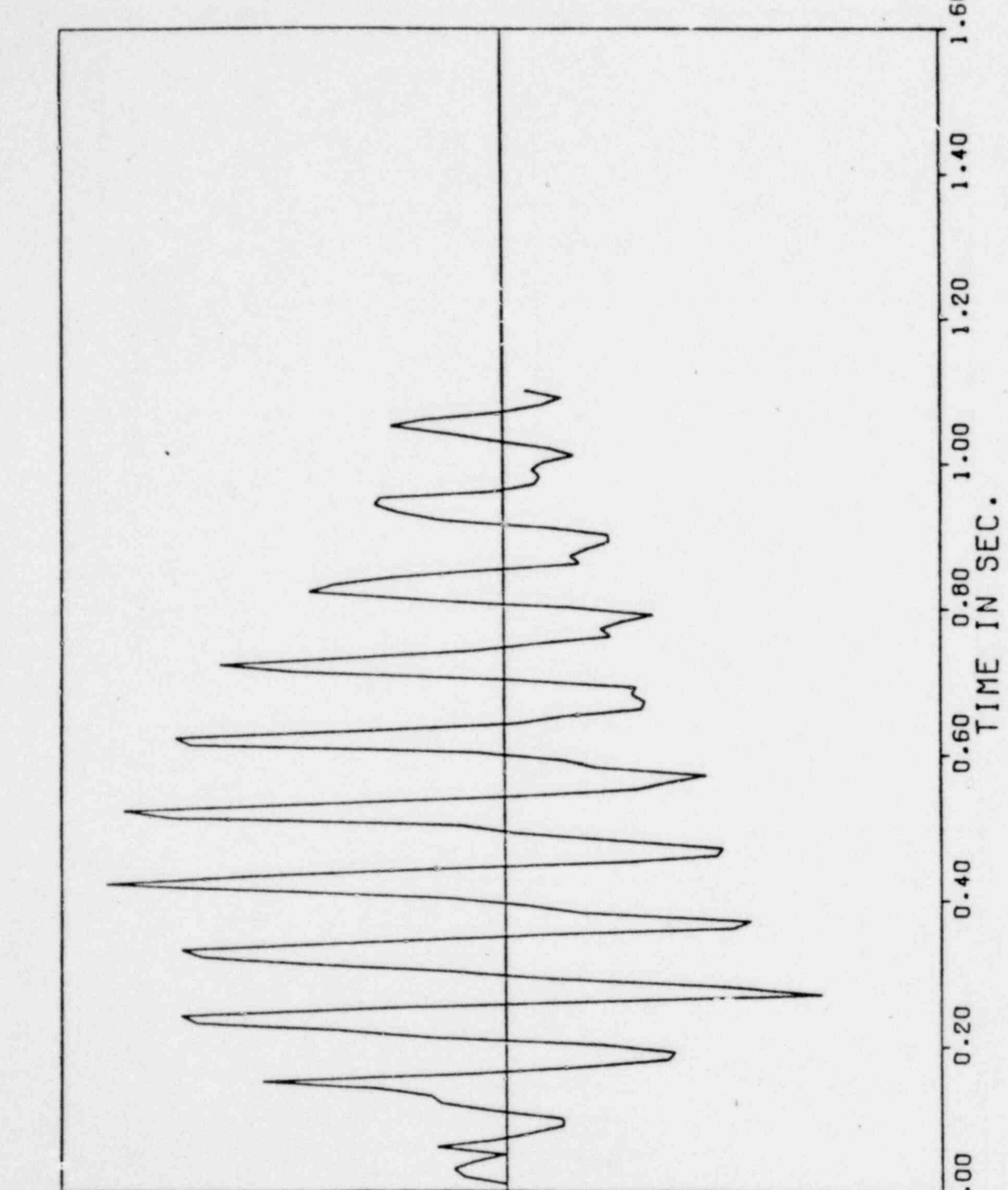


Figure 2-22. Zimmer Node 4 SRV(All)

1323 214

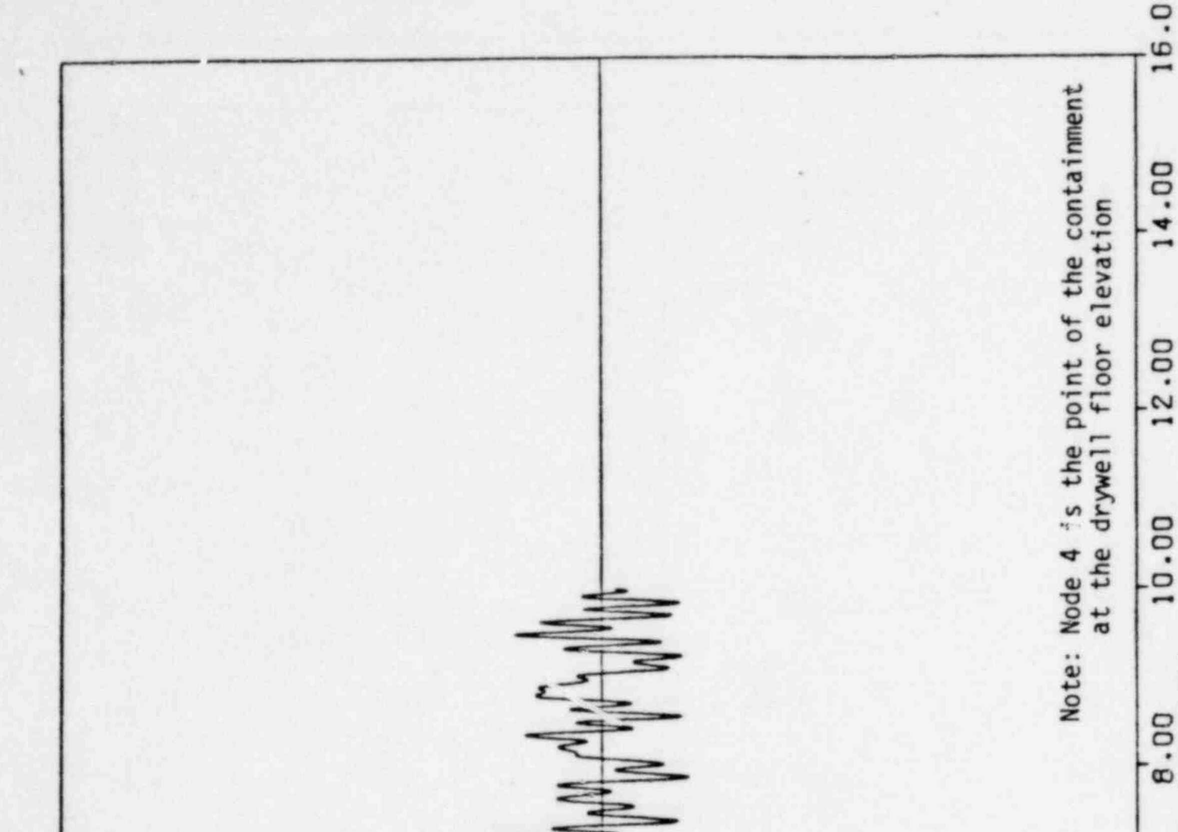


Figure 2-23. Zimmer Node 4 OBE(EW)

1323 215

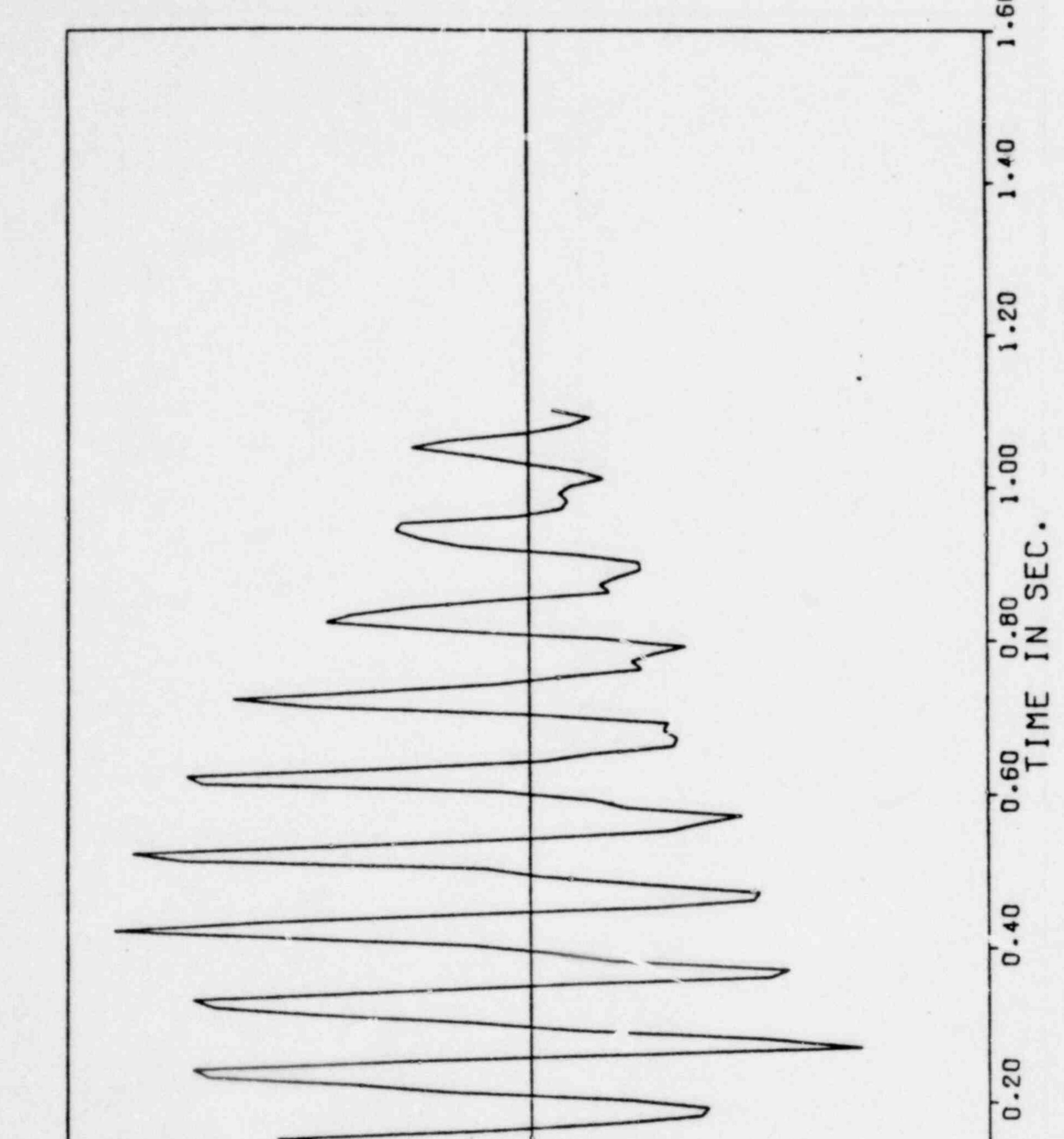


Figure 2-24. Zimmer Node 4 SRV(All)

1323 216

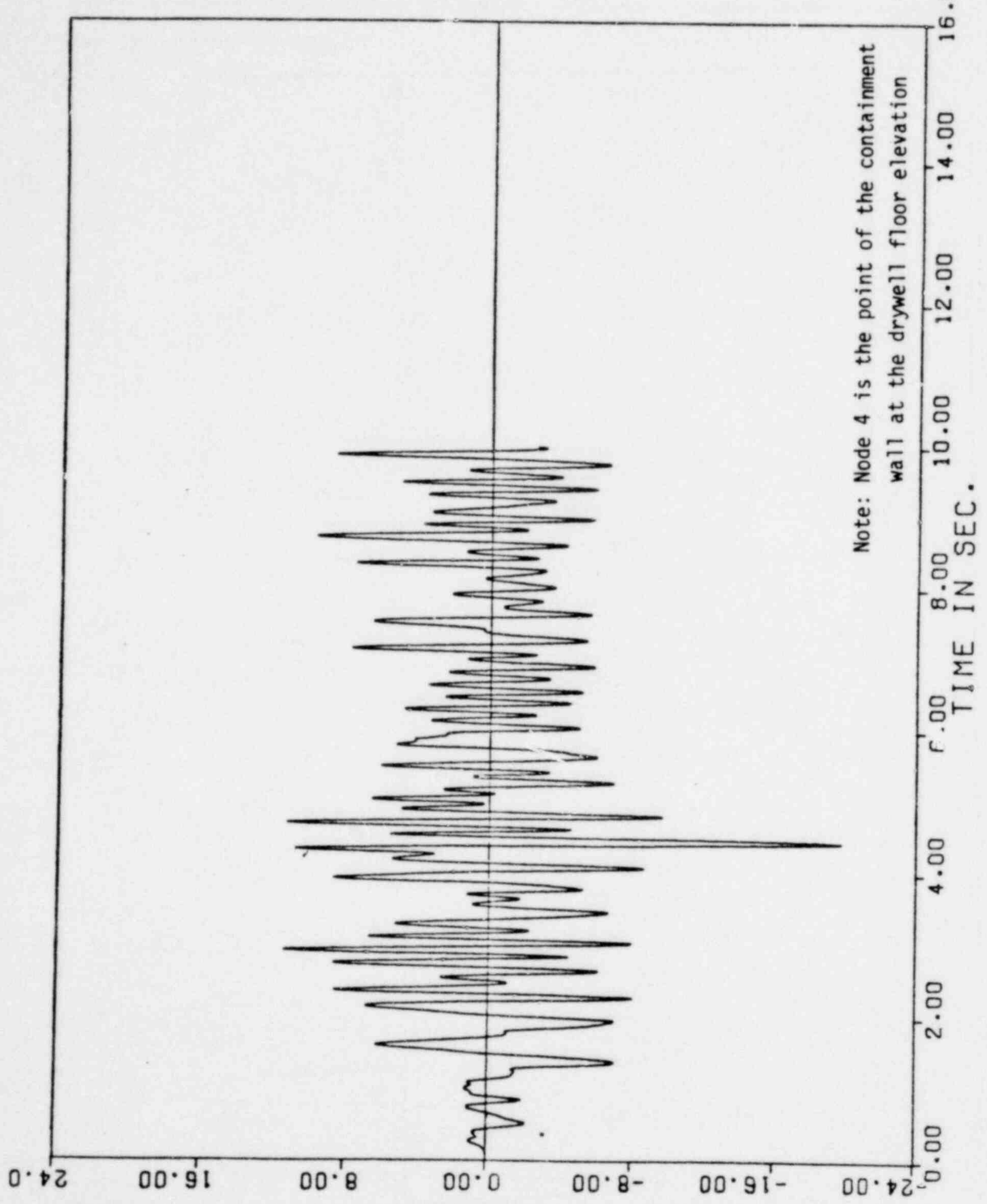


Figure 2-25. LaSalle-1 Node 4 OBE(NS)

1323 217

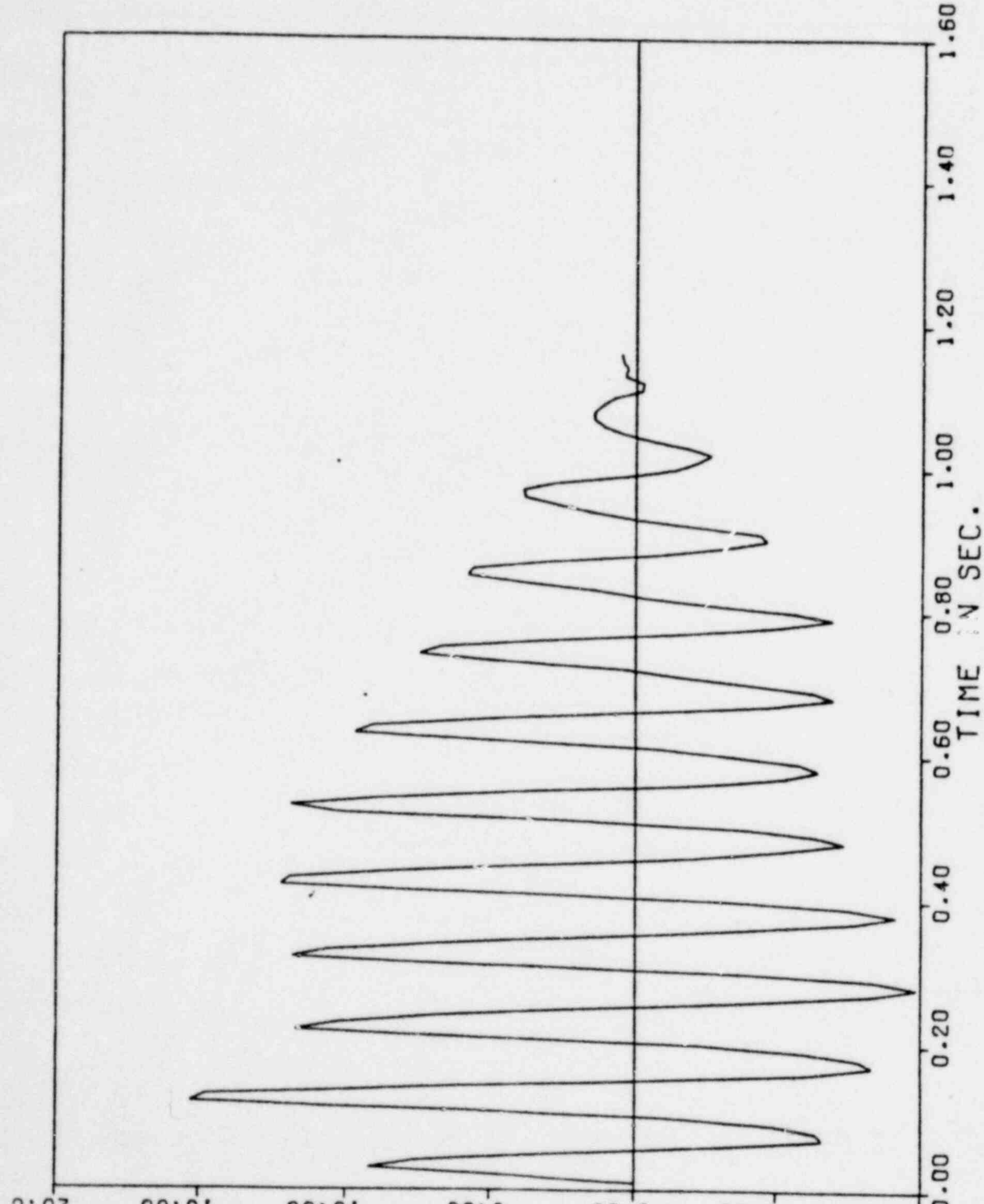


Figure 2-26. LaSalle-1 Node 4 SRV(ADS)

1323 218

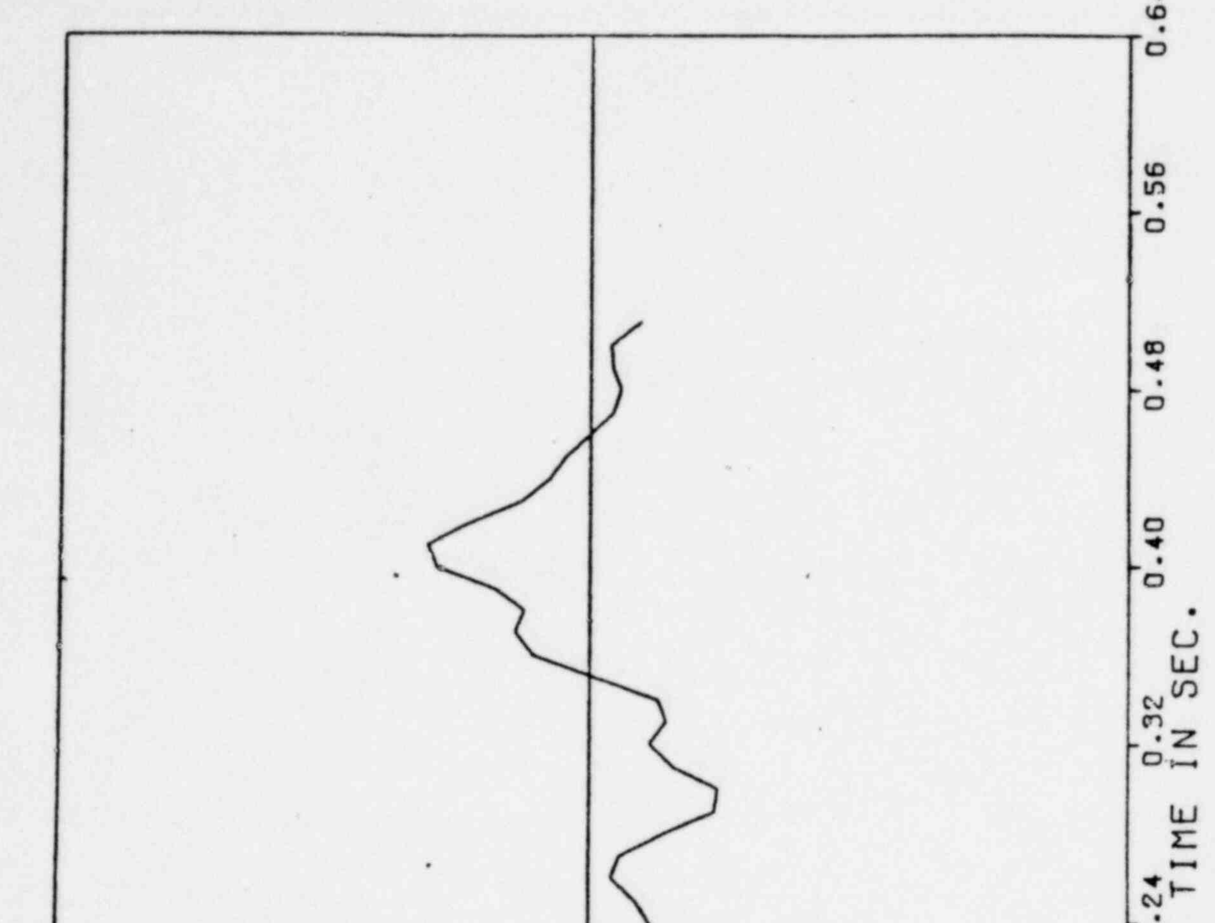


Figure 2-27. LaSalle-1 Node 4 CHUG(30 Hz)

1323 219

CUMULATIVE DISTRIBUTION FUNCTION

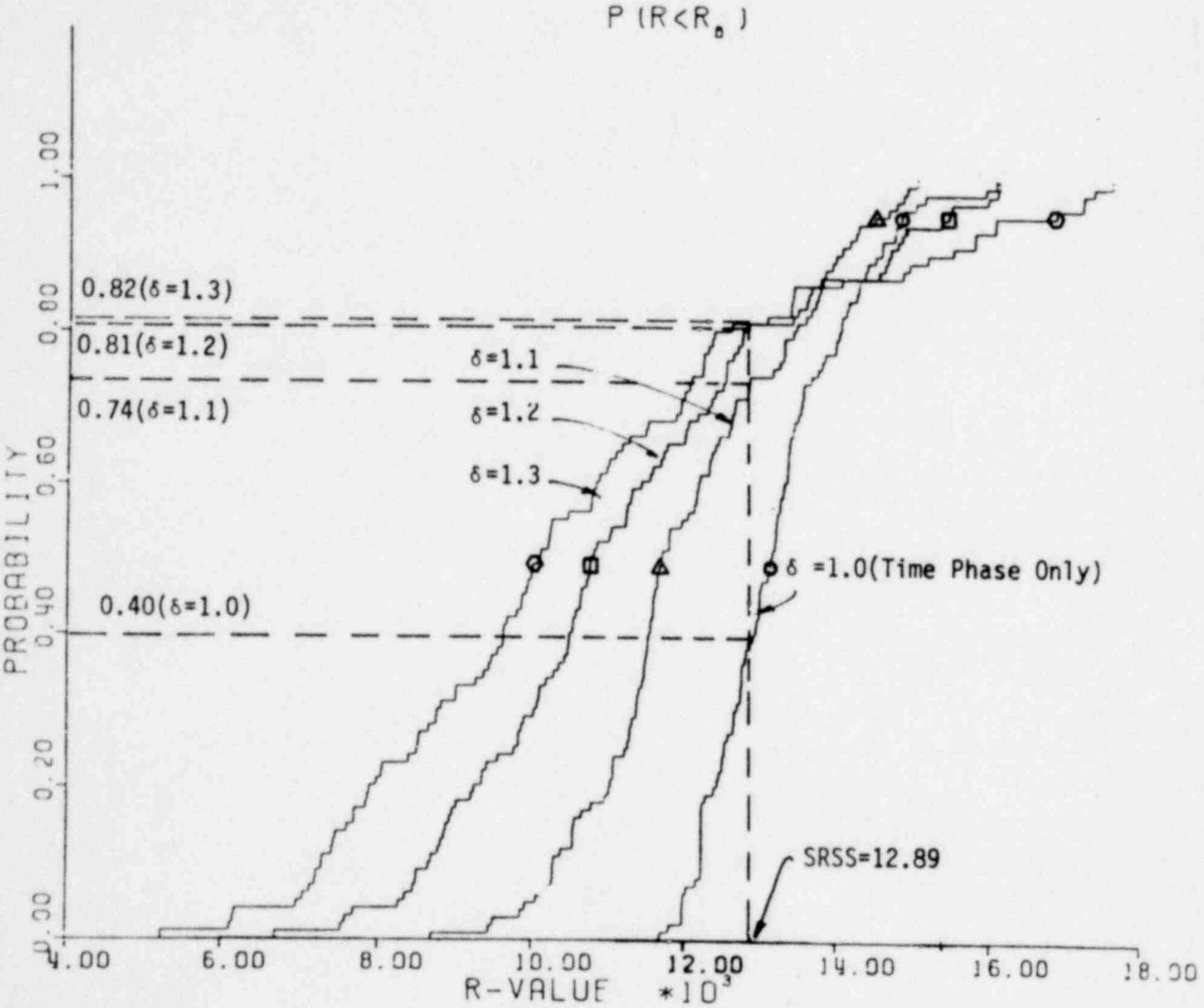


Figure 2-28. Case 1: Main Steam 461 OBE + SRVBDG M_a (Positive) Lognormal Amplitude PDF All Dispersions Equal

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

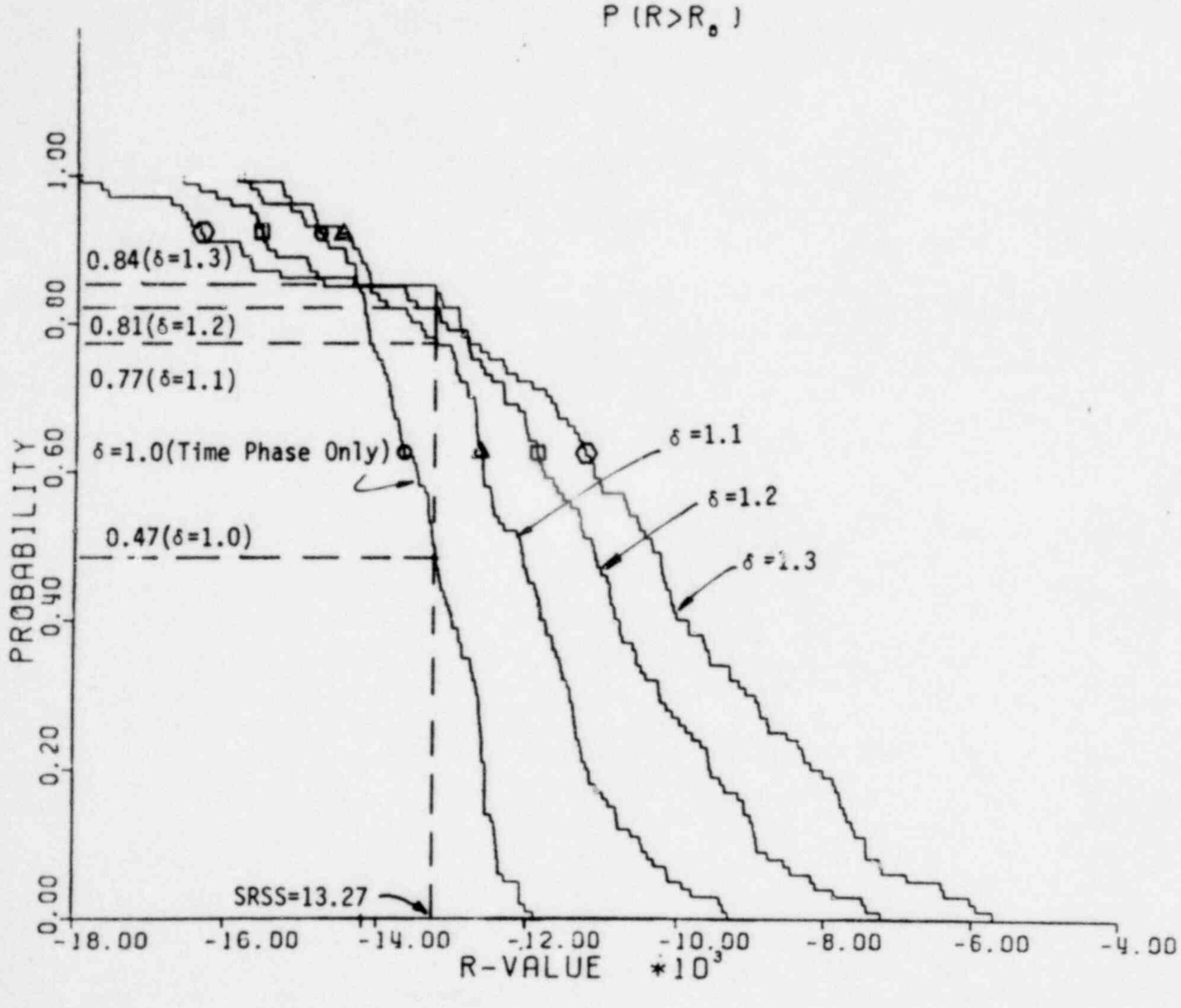


Figure 2-29. Case 1: Main Steam 461 OBE + SRVBDG M_a (Negative) Lognormal Amplitude PDF All Dispersions Equal

1323 221

CUMULATIVE DISTRIBUTION FUNCTION

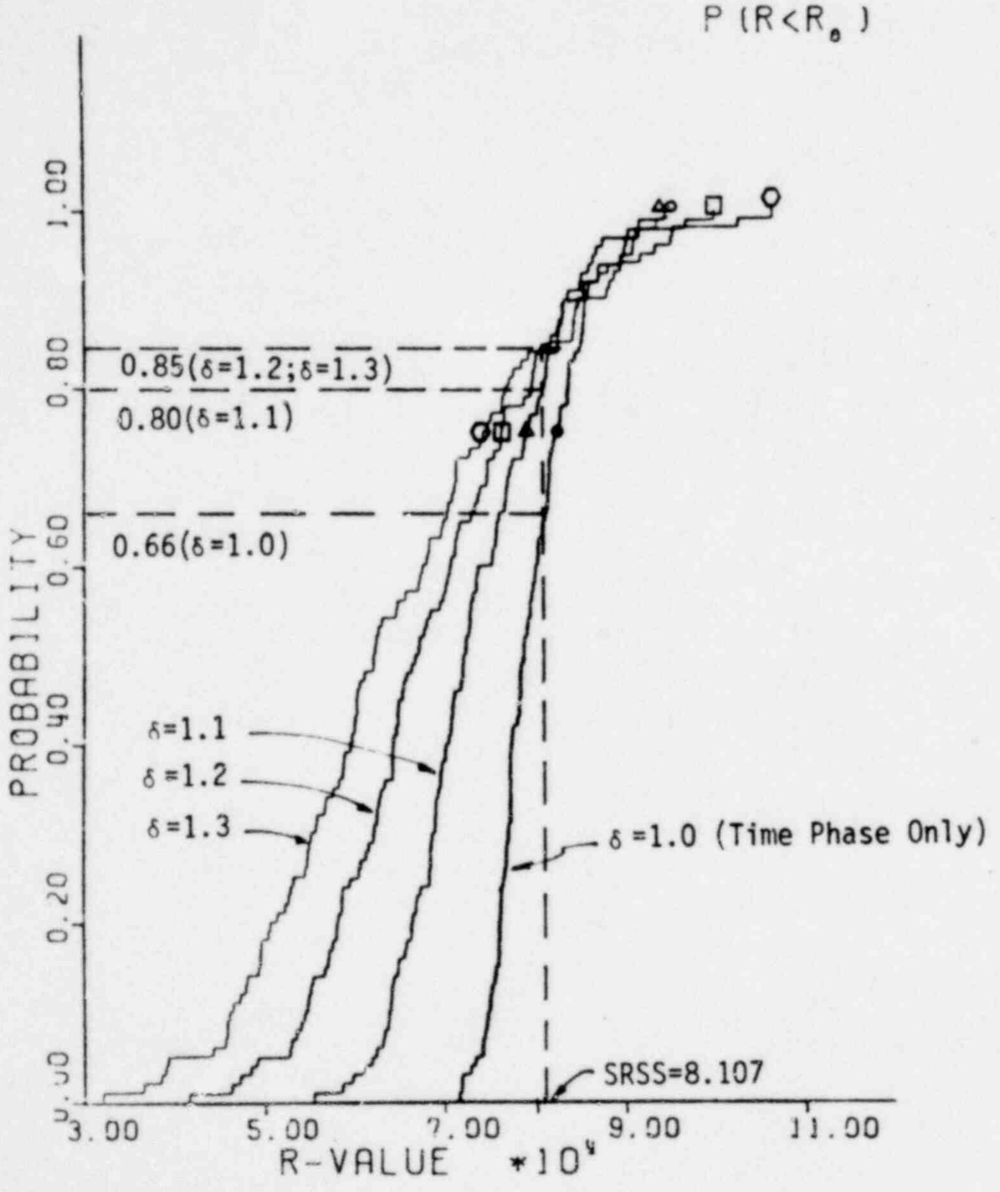


Figure 2-30. Case 2: Main Steam 461 OBE + SRVBDG M_C (Positive)
Lognormal Amplitude PDF All Dispersions Equal

1323 222

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

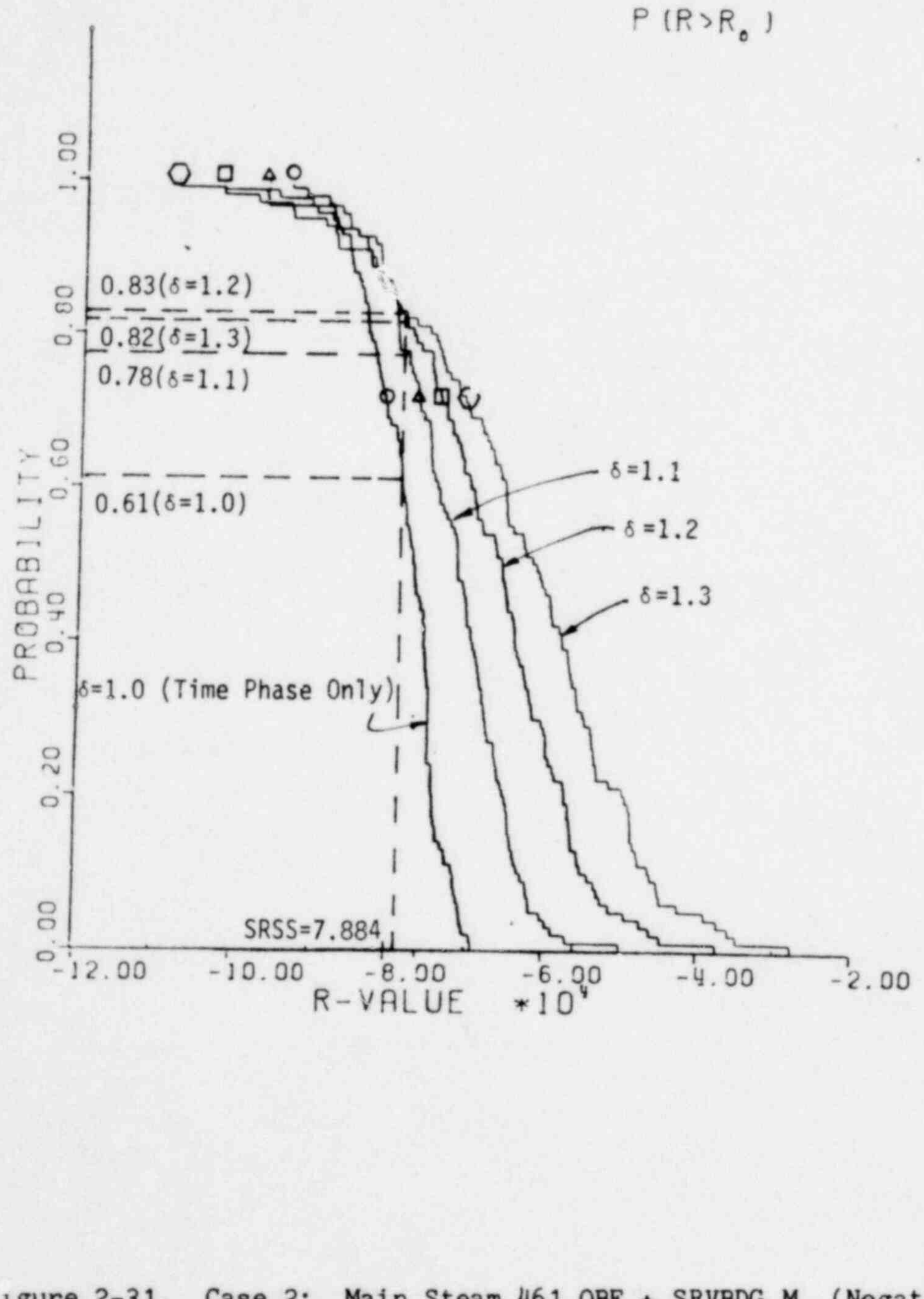


Figure 2-31. Case 2: Main Steam 461 OBE + SRVBDG M_c (Negative) Lognormal Amplitude PDF All Dispersions Equal

1323 223

CUMULATIVE DISTRIBUTION FUNCTION

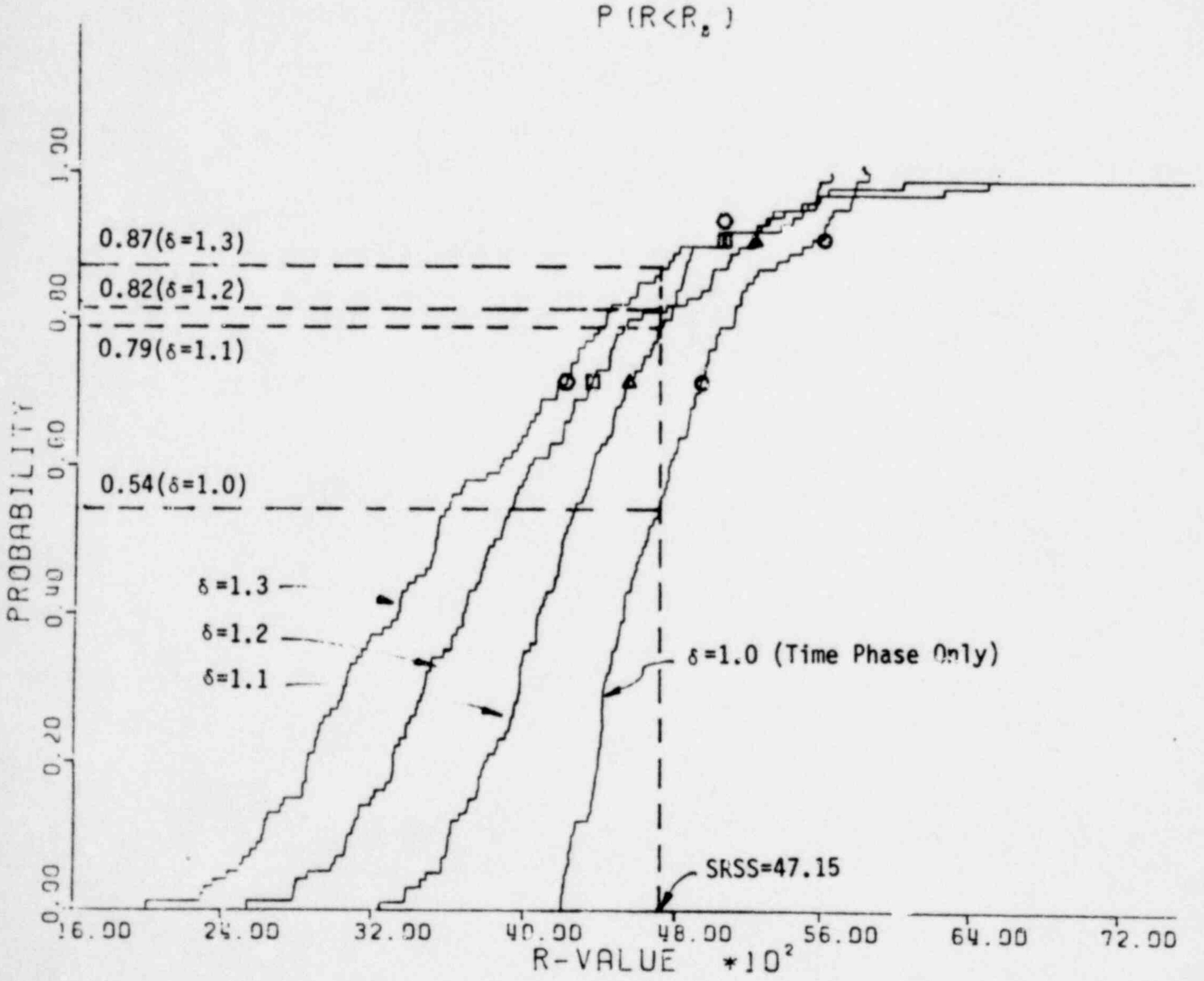


Figure 2-32. Case 3: RHR Wetwell OBE + SRVBDG M_a (Positive) Lognormal Amplitude PDF All Dispersions Equal

1323 224

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

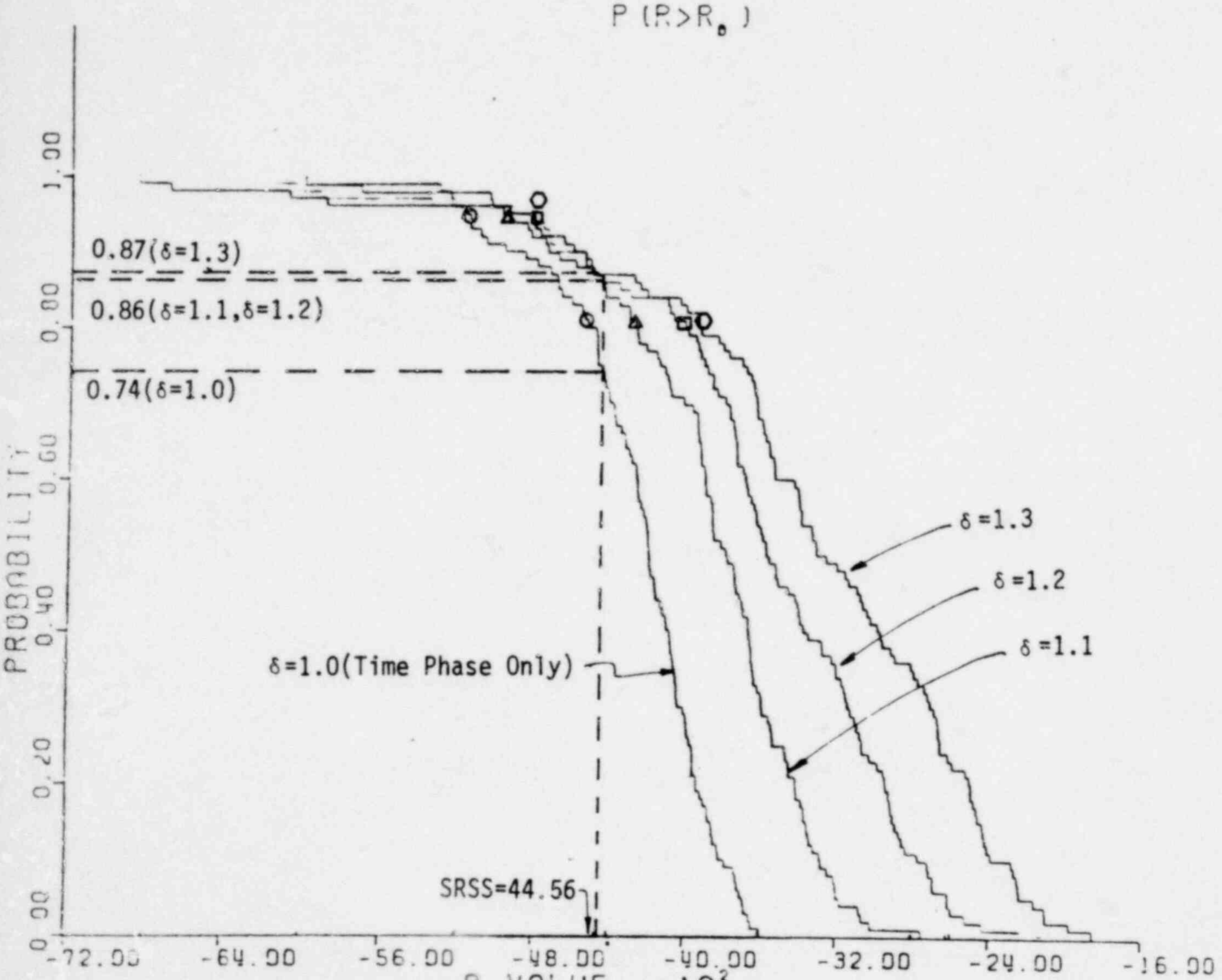


Figure 2-33. Case 3: RHR Wetwell OBE + SRVBUB M_a (Negative) Lognormal Amplitude PDF All Dispersions Equal

1323 225

CUMULATIVE DISTRIBUTION FUNCTION

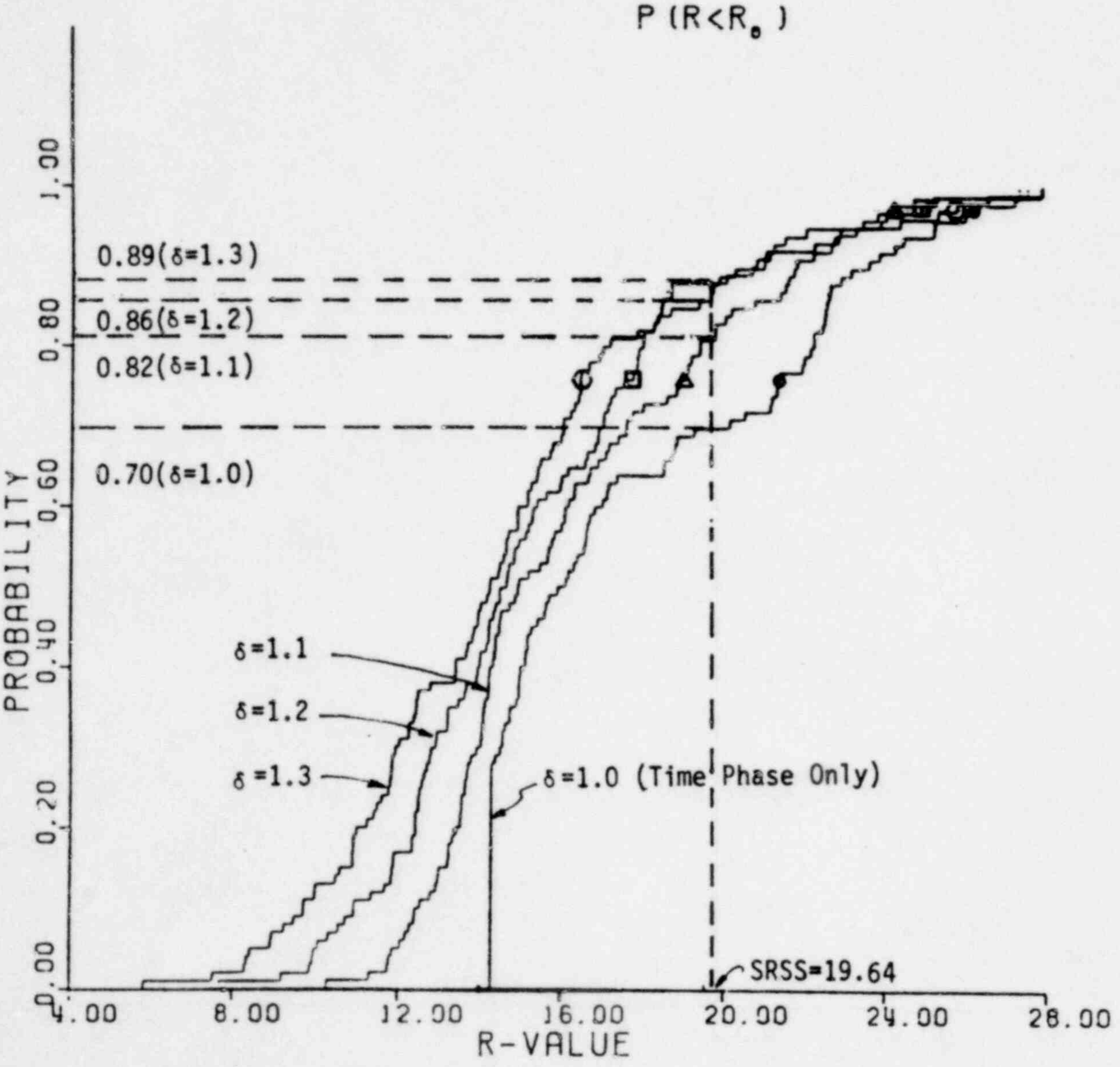


Figure 2-34. Case 4: Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 226

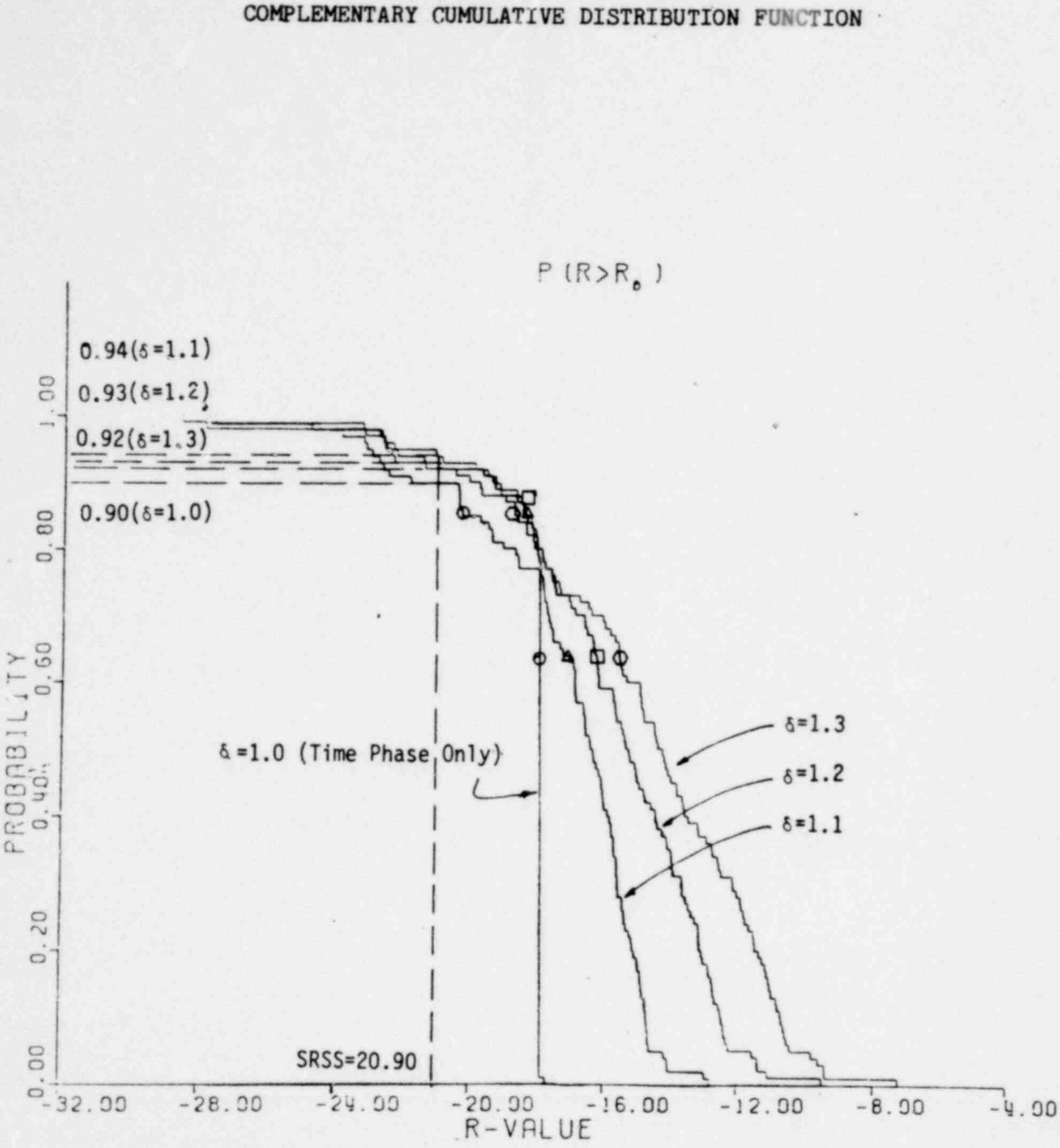


Figure 2-35. Case 4: Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 227

CUMULATIVE DISTR:BUTION FUNCTION

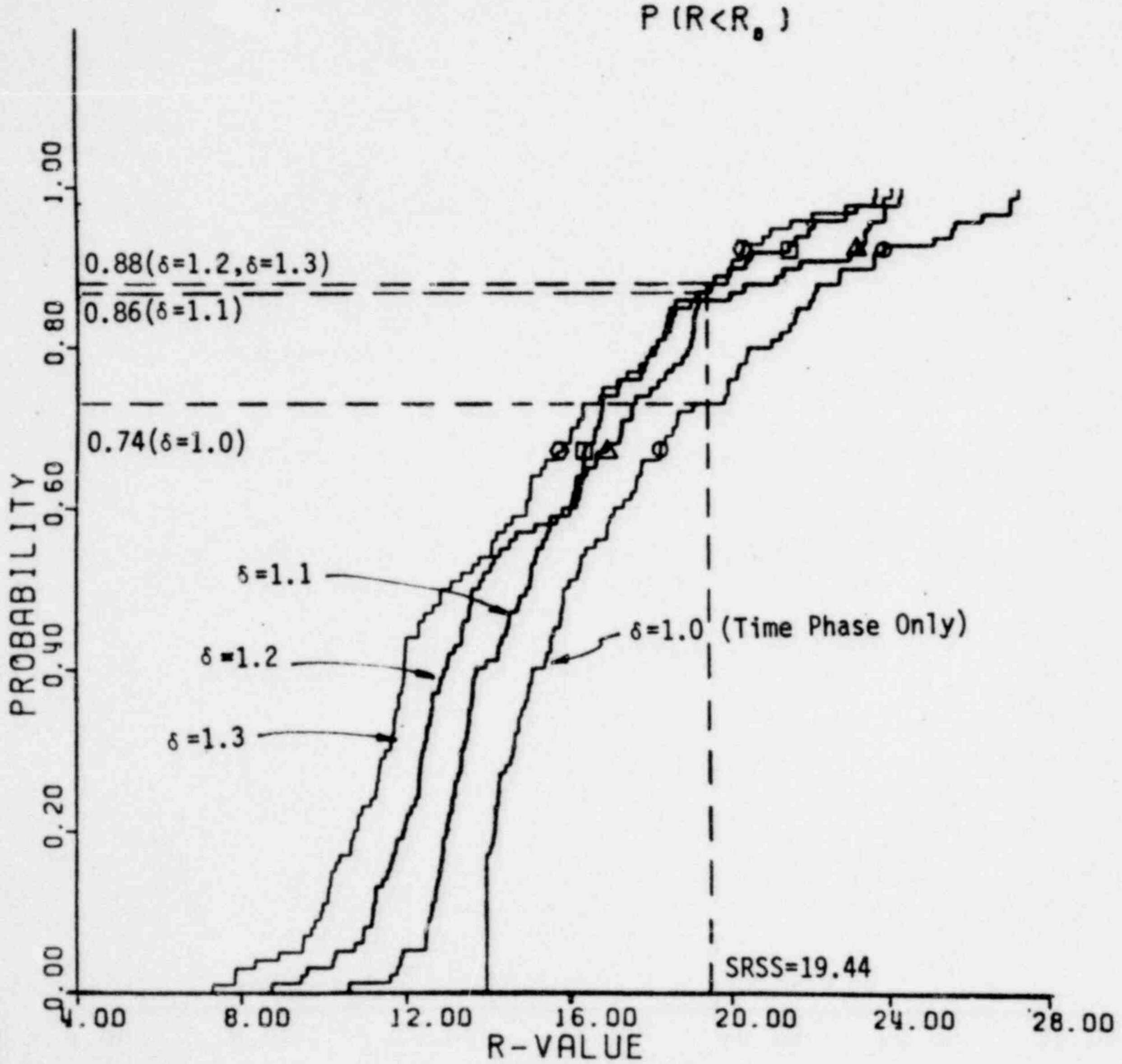


Figure 2-36. Case 5: Zimmer Plant OBE(EW) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 228

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

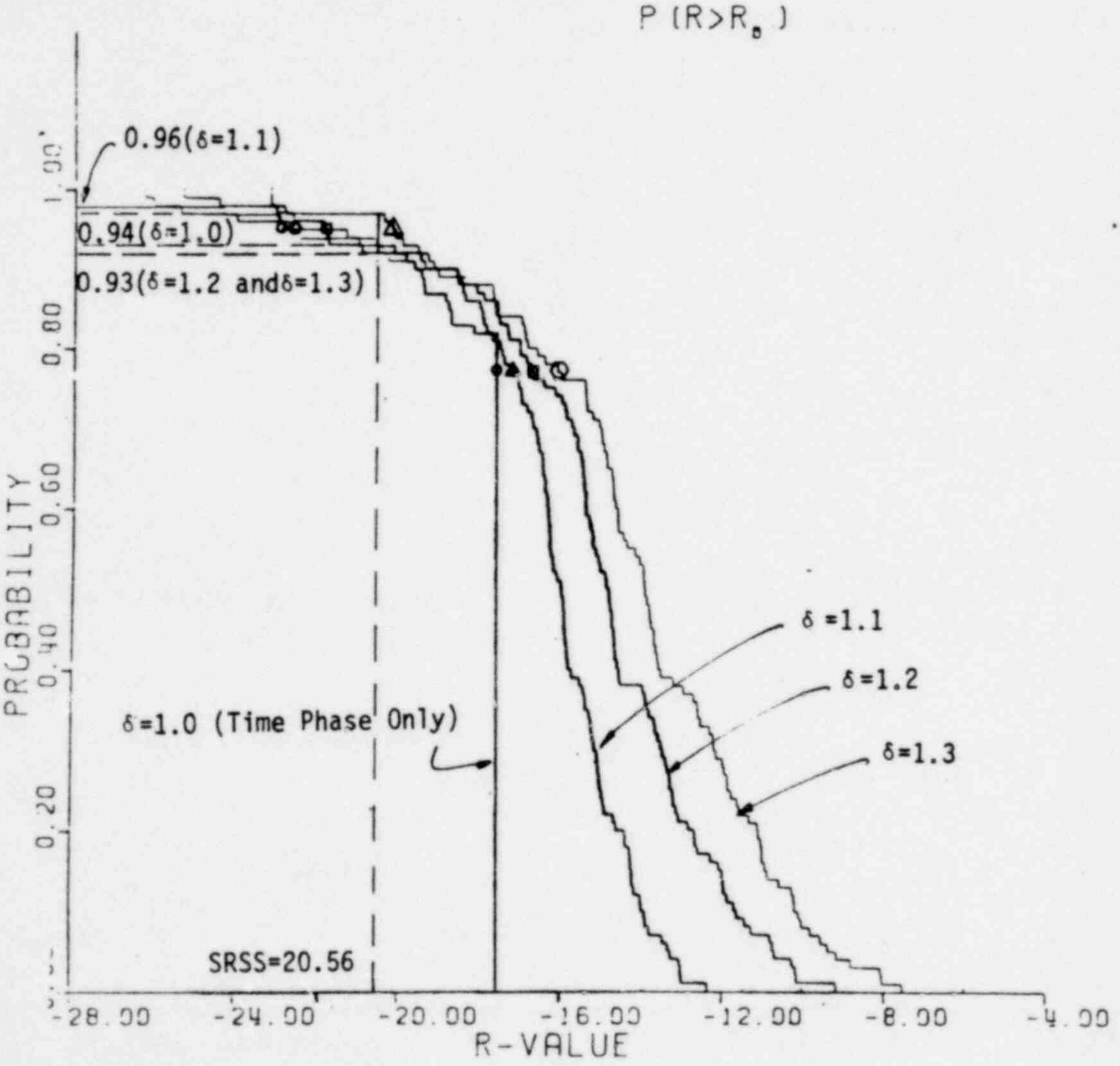


Figure 2-37. Case 5: Zimmer Plant OBE(EW) + SRV(All), Containment Wall at Dry-well Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 229

CUMULATIVE DISTRIBUTION FUNCTION

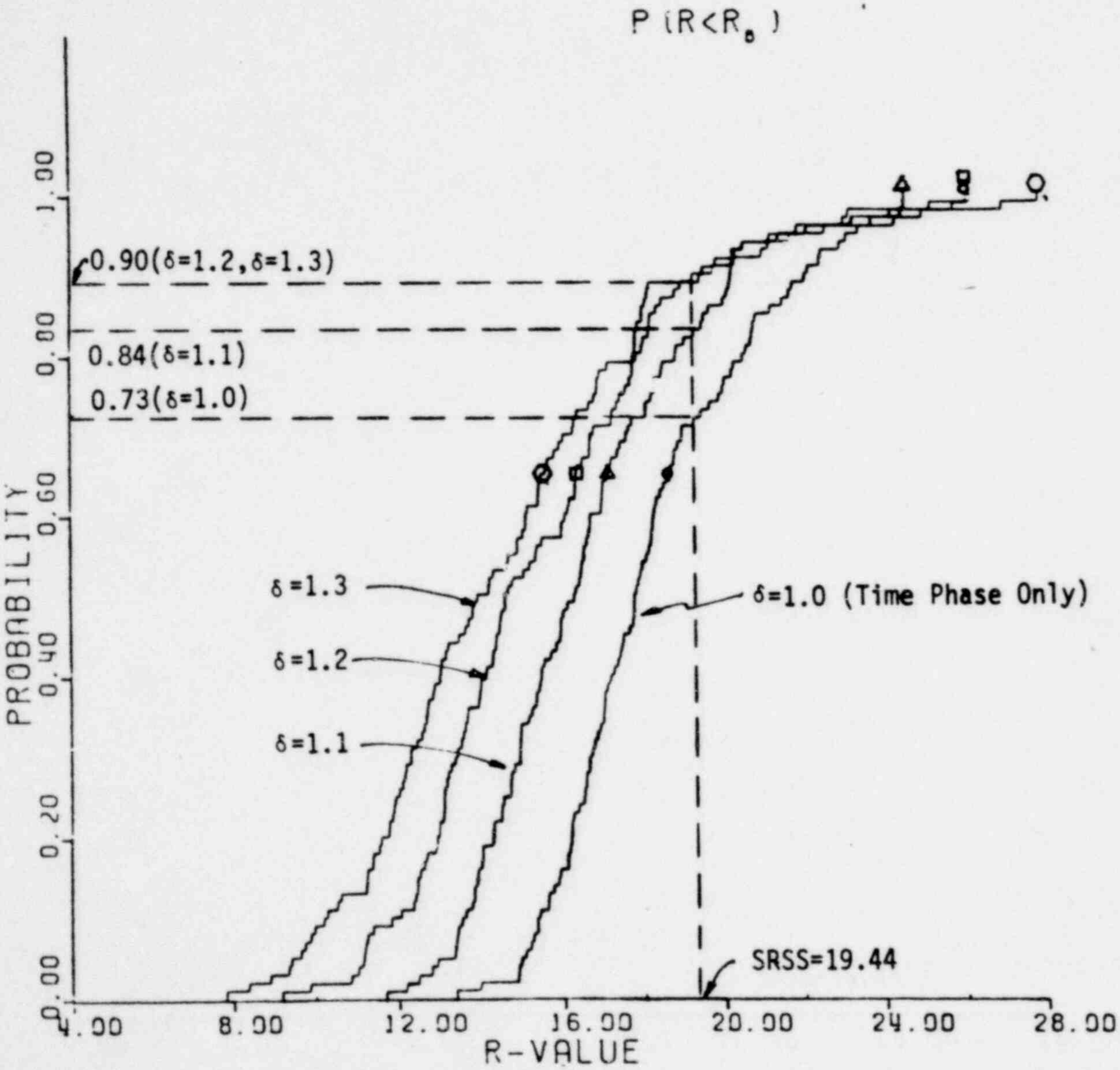


Figure 2-38. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 230

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

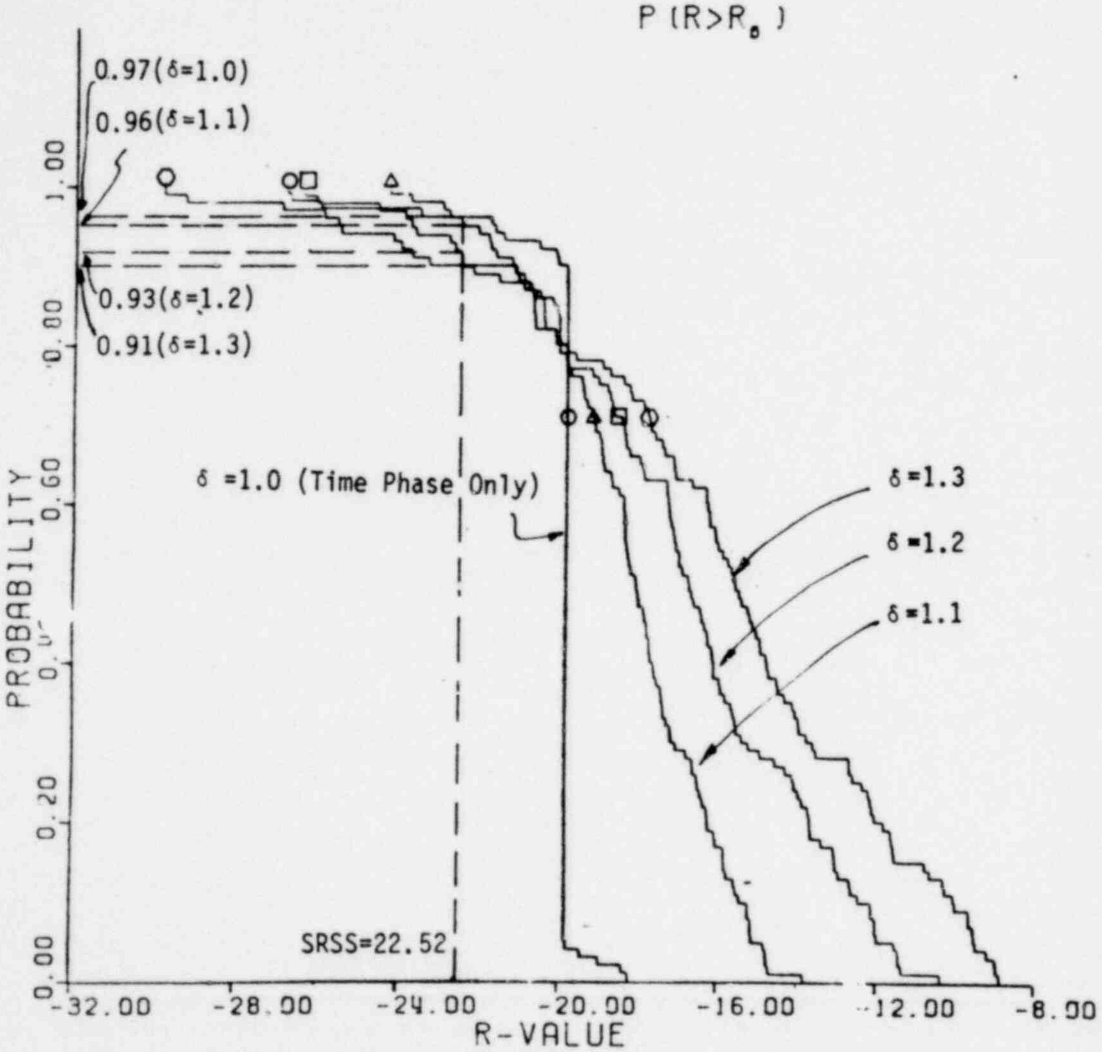


Figure 2-39. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz) Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF All Dispersions Equal

1323 231

CUMULATIVE DISTRIBUTION FUNCTION

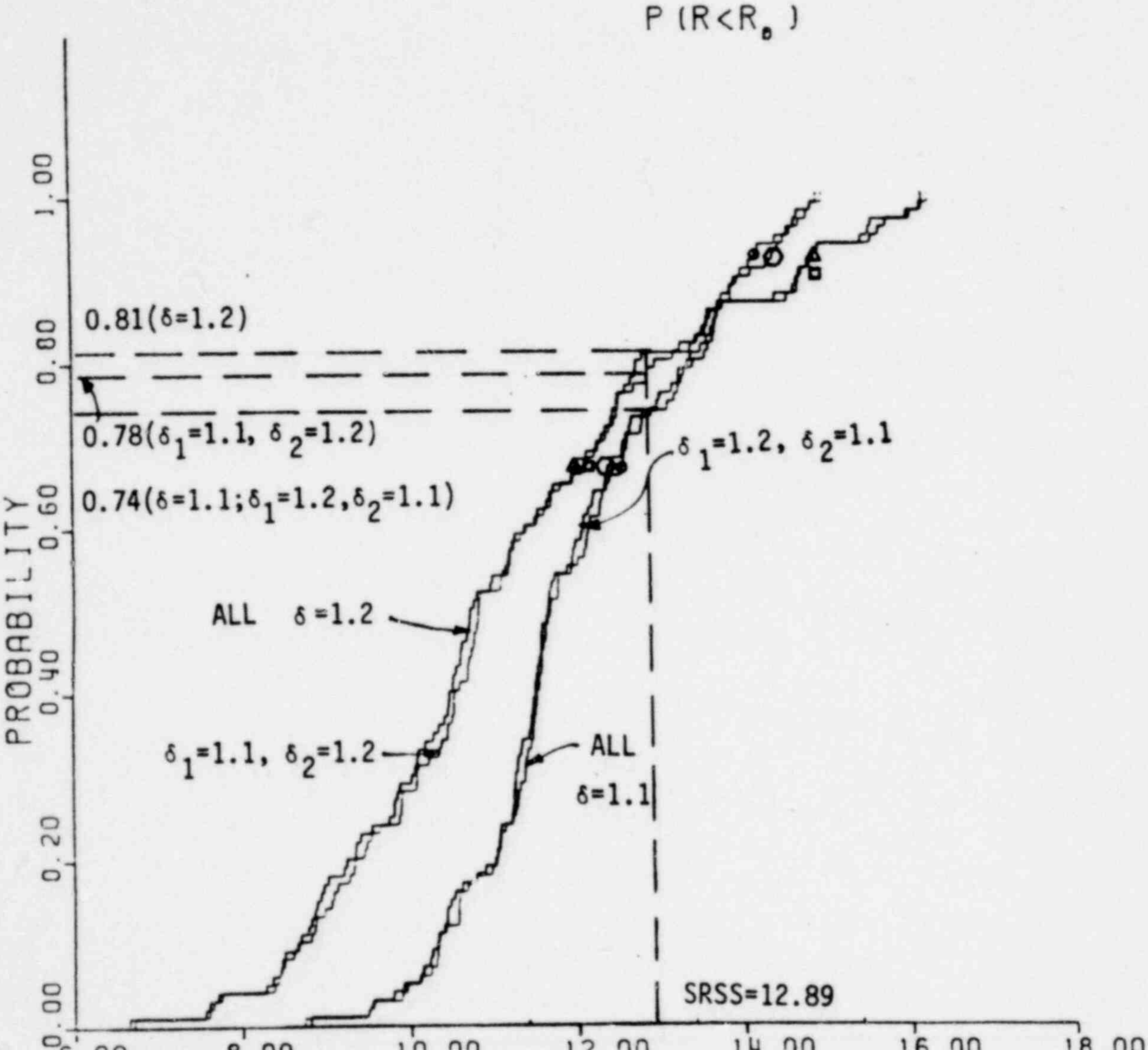


Figure 2-40. Case 1: Main Steam 461 OBE + SRVBDG M_k (Positive) Lognormal Amplitude PDF Each Response has Different Dispersion

1323 232

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

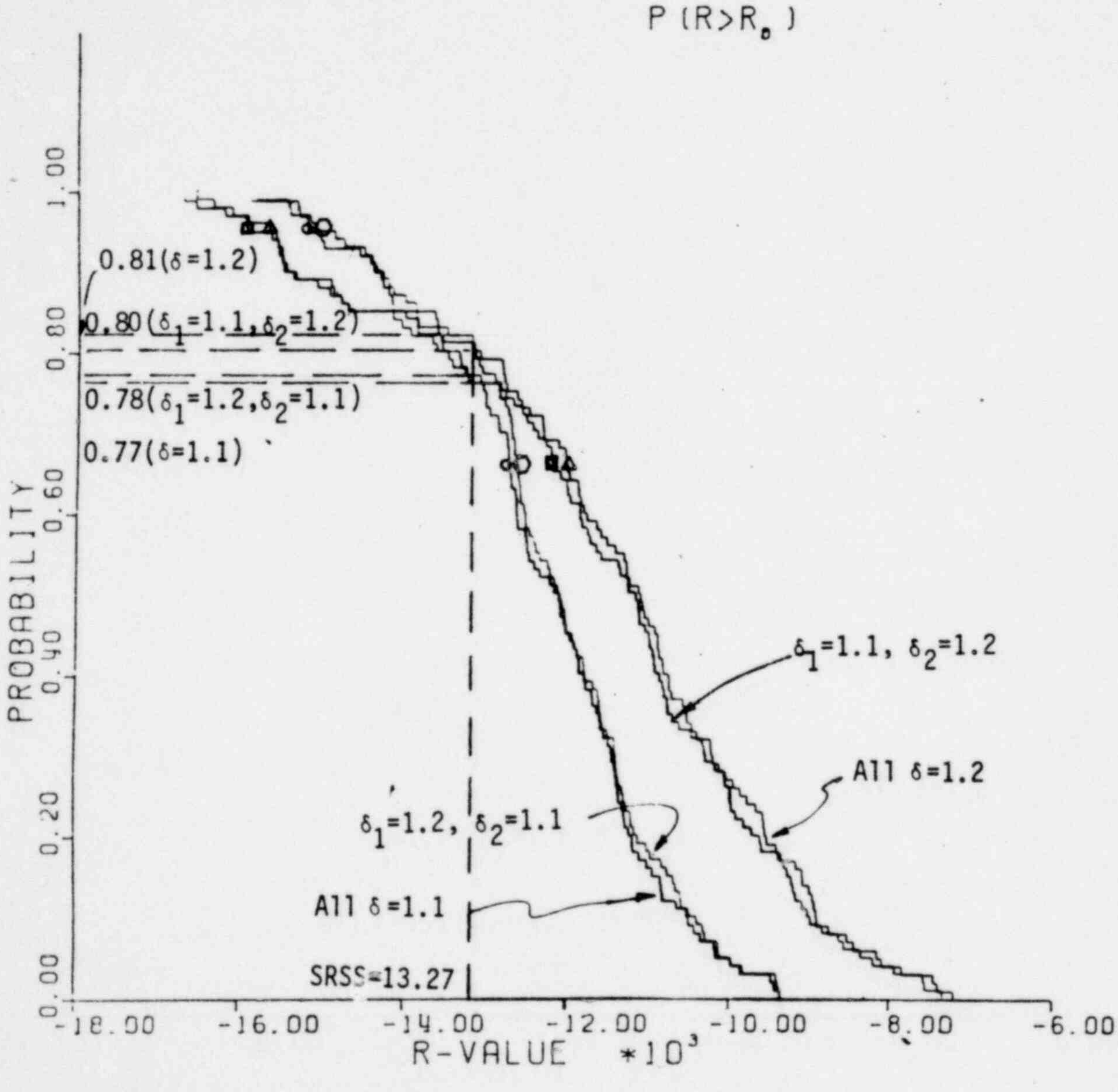


Figure 2-41. Case 1: Main Steam 461 OBE + SRVBDG M_a (Negative)
Lognormal Amplitude PDF Each Response has Different Dispersion

1323 233

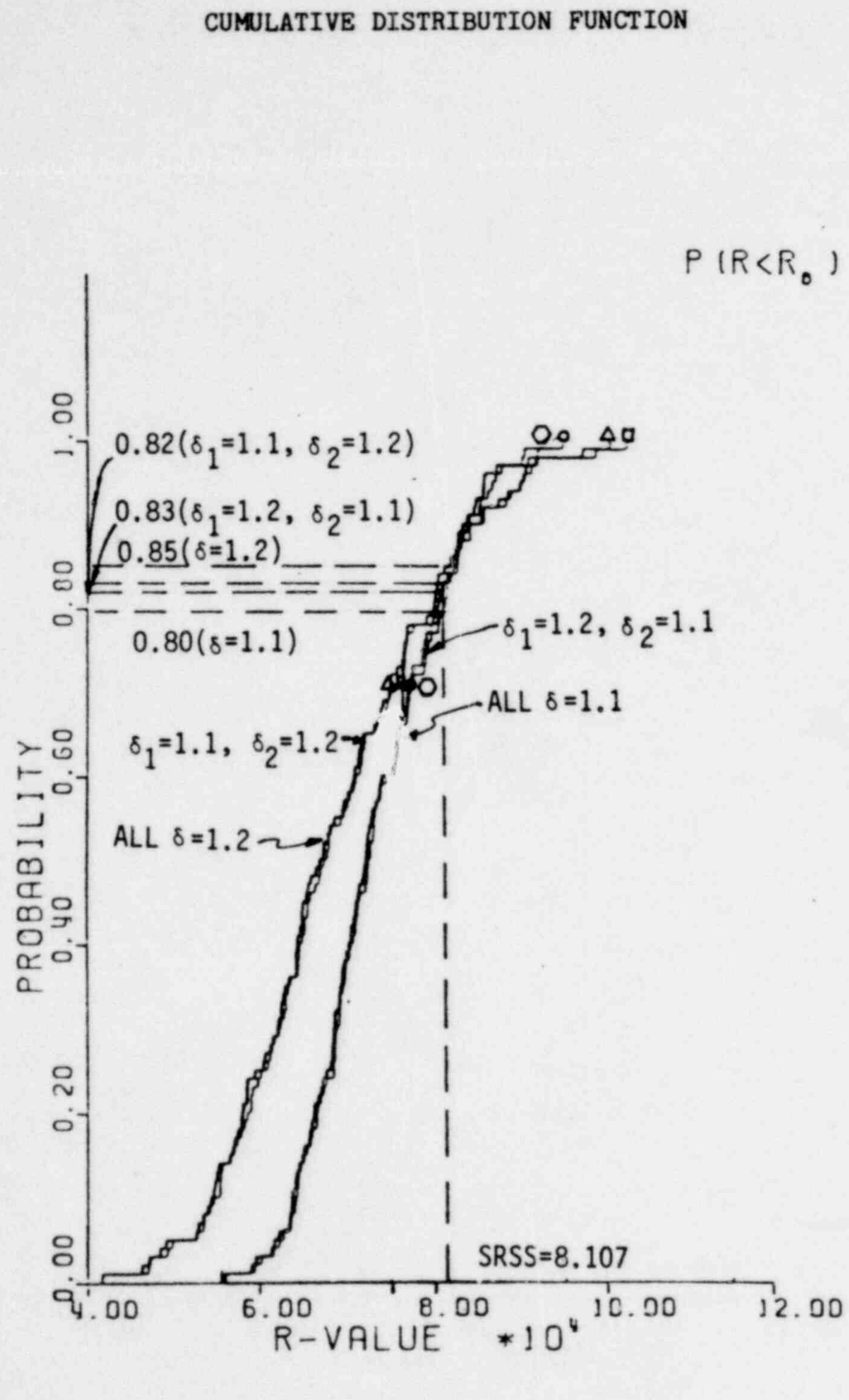


Figure 2-42. Case 2: Main Steam 461 OBE + SRVBDG M_C (Positive) Lognormal Amplitude PDF Each Response has Different Dispersion

1323 234

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

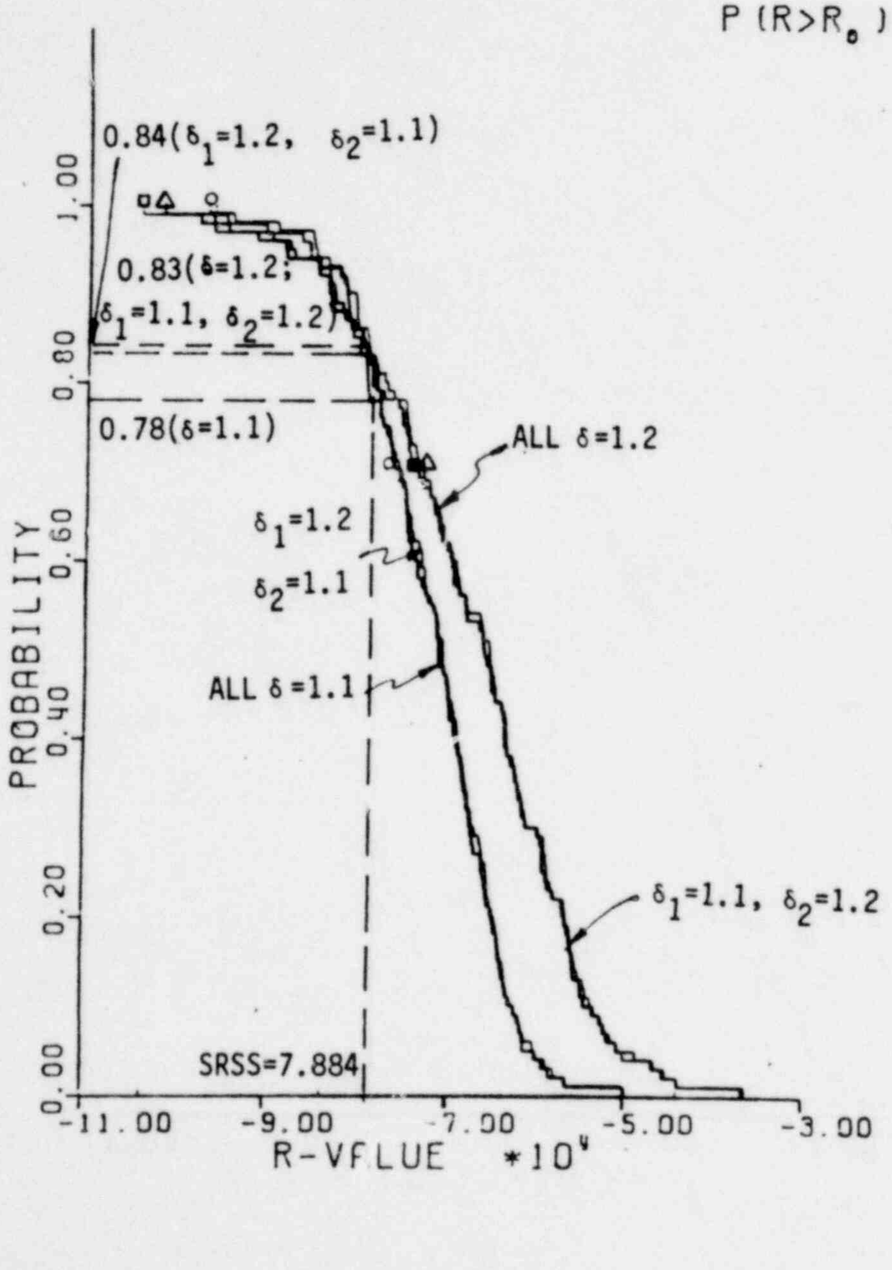


Figure 2-43. Case 2: Main Steam 461 OBE + SRVBDG M_c (Negative) Lognormal Amplitude PDF Each Response has Different Dispersion

1323 235

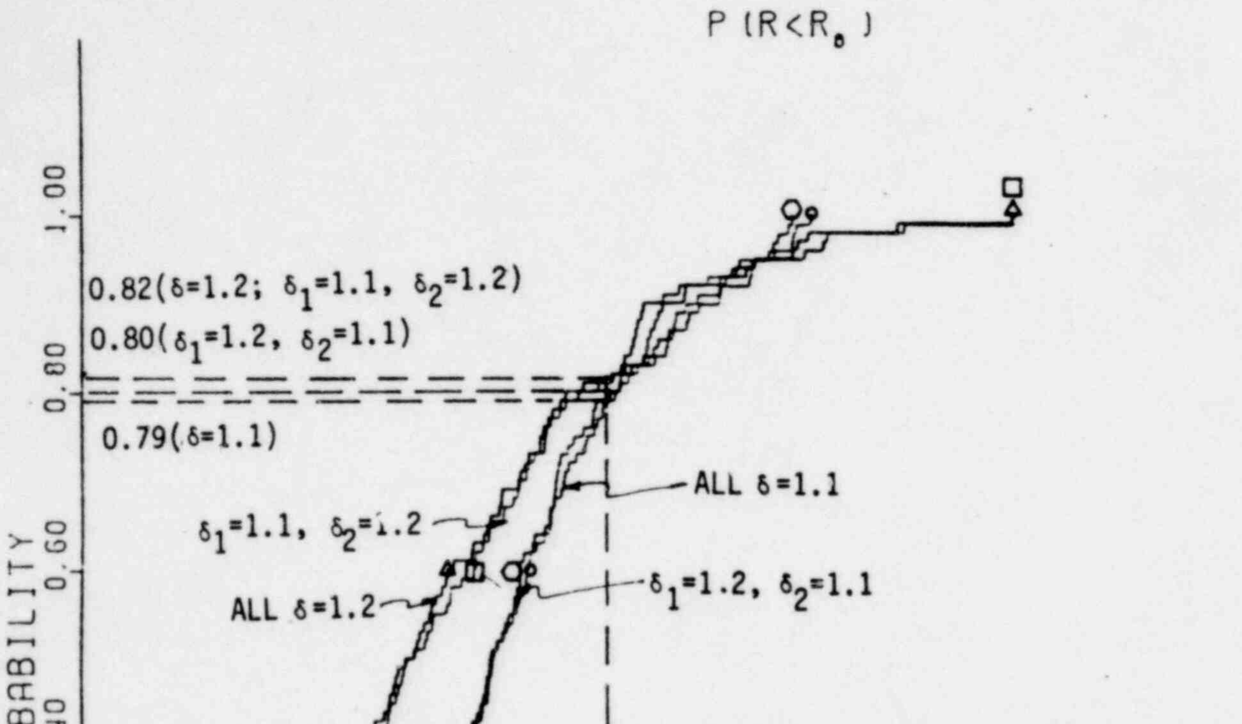


Figure 2-44. Case 3: RHR Wetwell OBE + SRVBUB M_a (Positive) Lognormal Amplitude PDF Each Response has Different Dispersion

1323 236

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

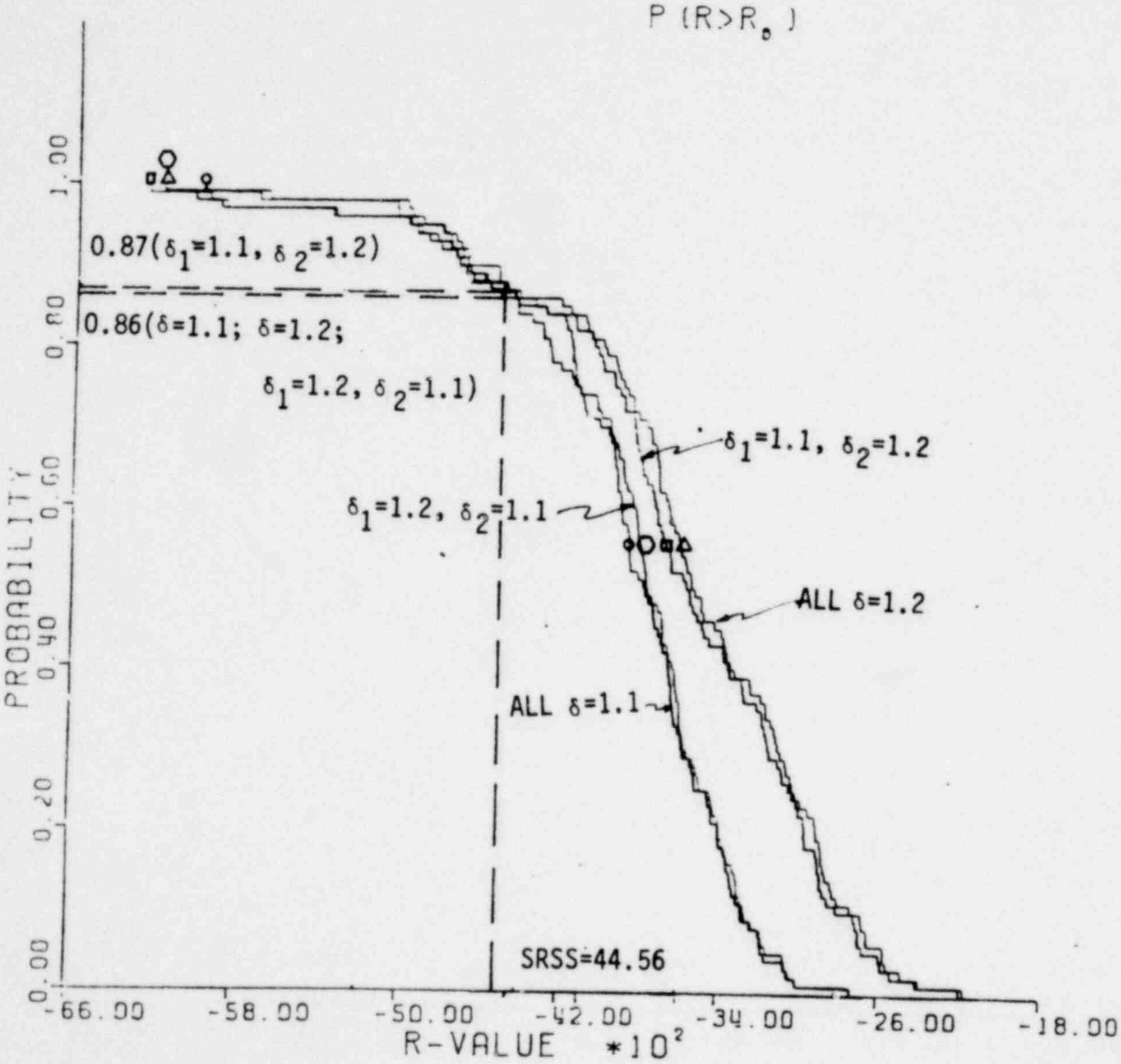


Figure 2-45. Case 3: RHR Wetwell OBE + SRVBUB M_a (Negative) Lognormal Amplitude PDF Each Response has Different Dispersion

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CUMULATIVE DISTRIBUTION FUNCTION

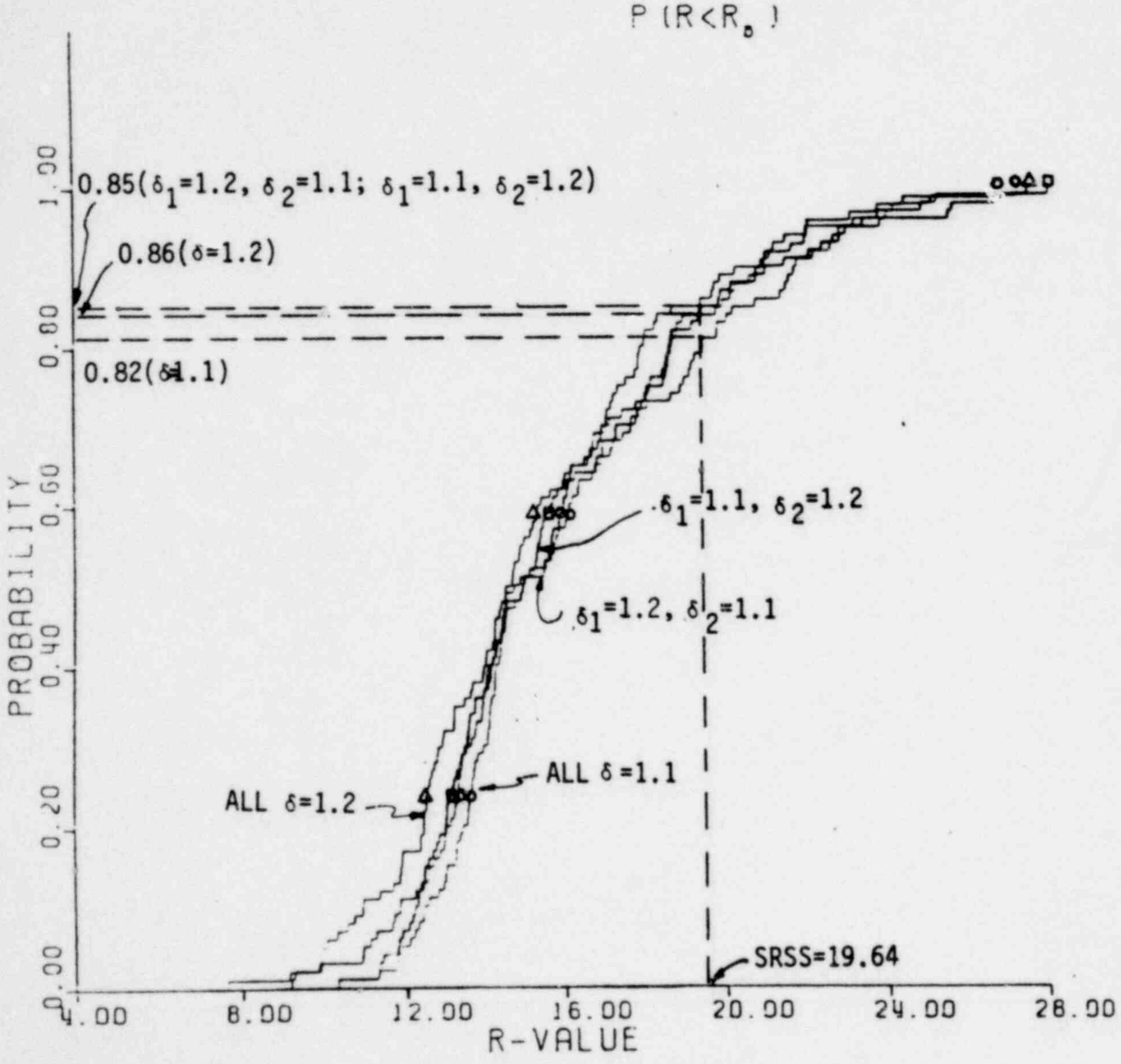

Figure 2-46. Case 4: Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF Each Response has Different Dispersion

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

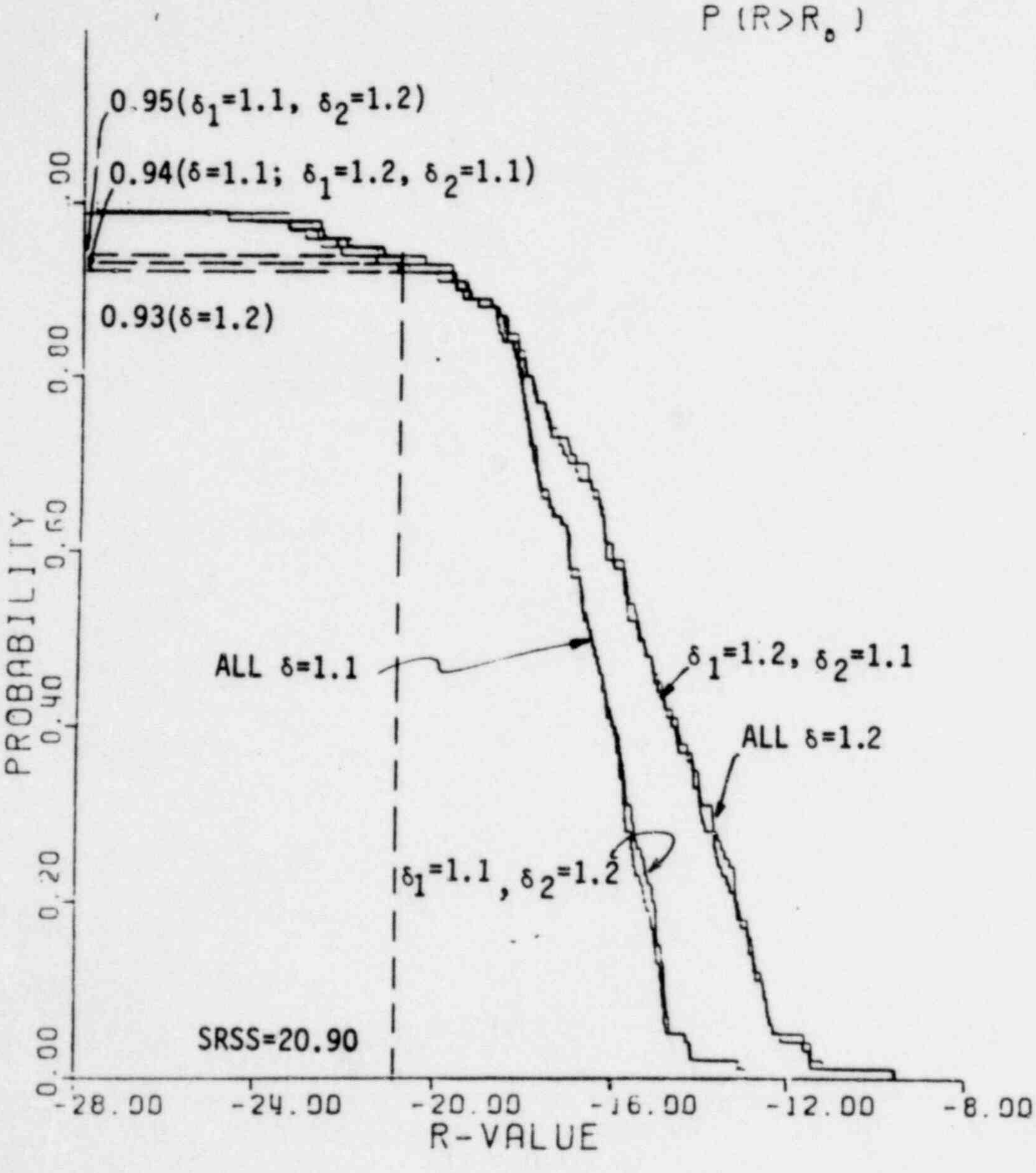

Figure 2-47. Case 4. Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF Each Response has Different Dispersion

1323 239

CUMULATIVE DISTRIBUTION FUNCTION

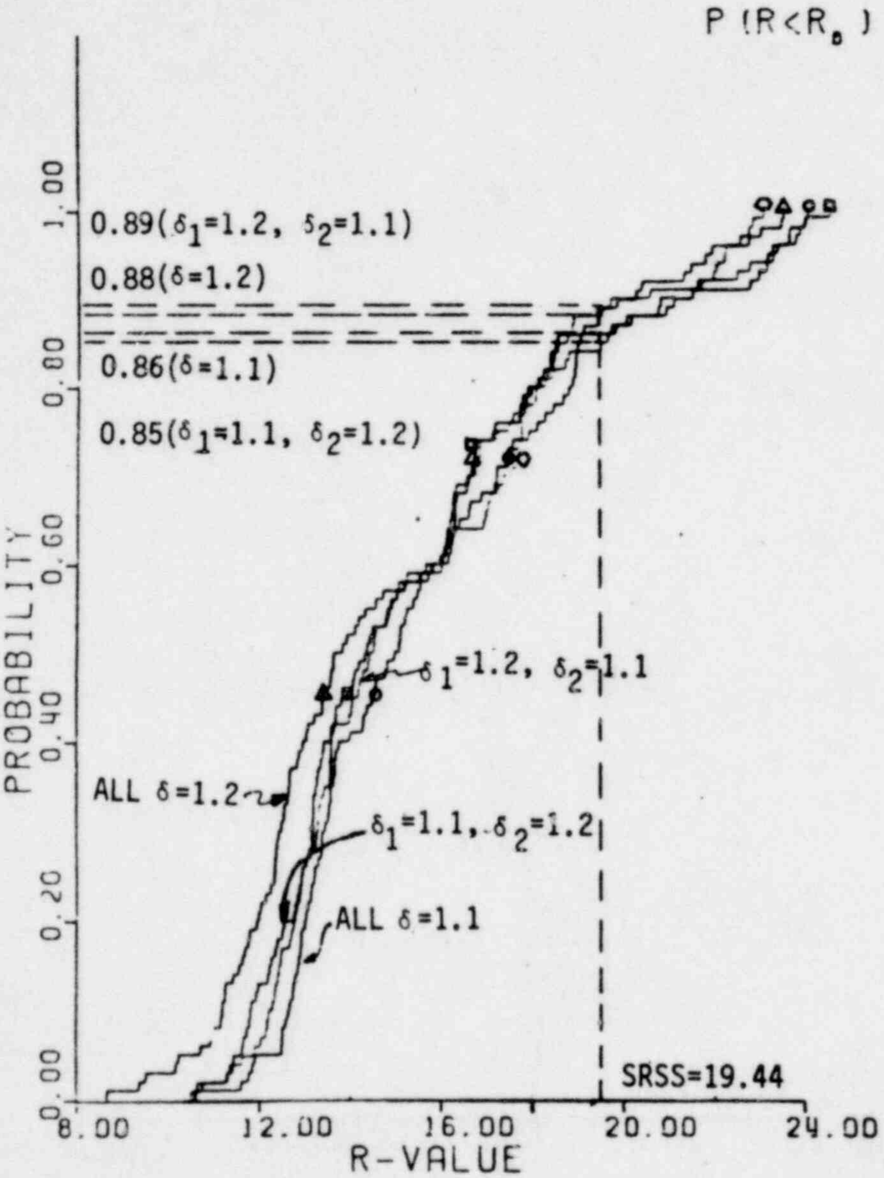

Figure 2-48. Case 5: Zimmer Plant OBE(EW) + SRV(All), Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF Each Response has Different Dispersion

1323 240

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

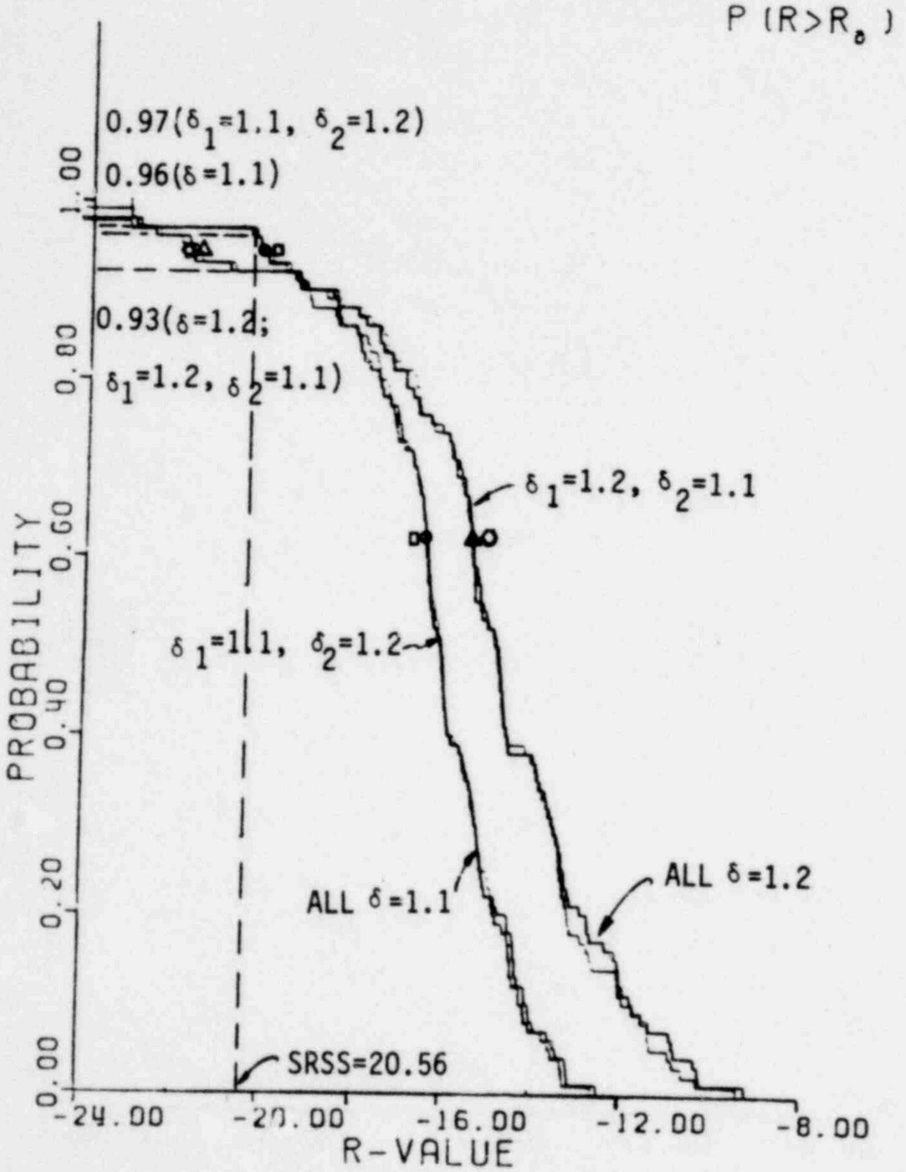

Figure 2-49. Case 5: Zimmer Plant OB⁻ EW) + SRV(All), Containment Wall at Drywell Floor Elevation. L. normal Amplitude PDF Each Response has Different Dispersion

1323 241

CUMULATIVE DISTRIBUTION FUNCTION

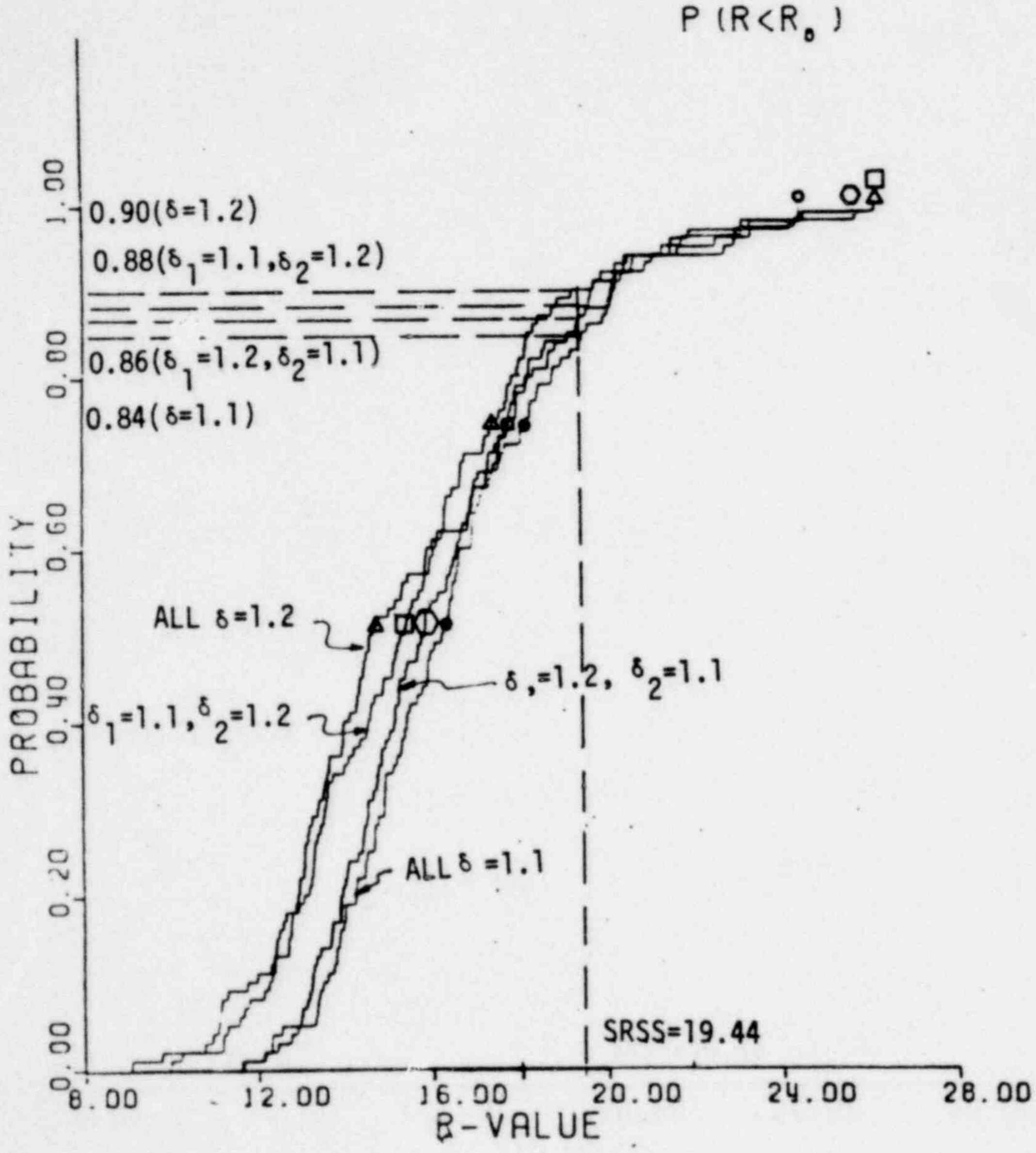

Figure 2-50. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz) Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF Each has Different Dispersion

1323 242

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

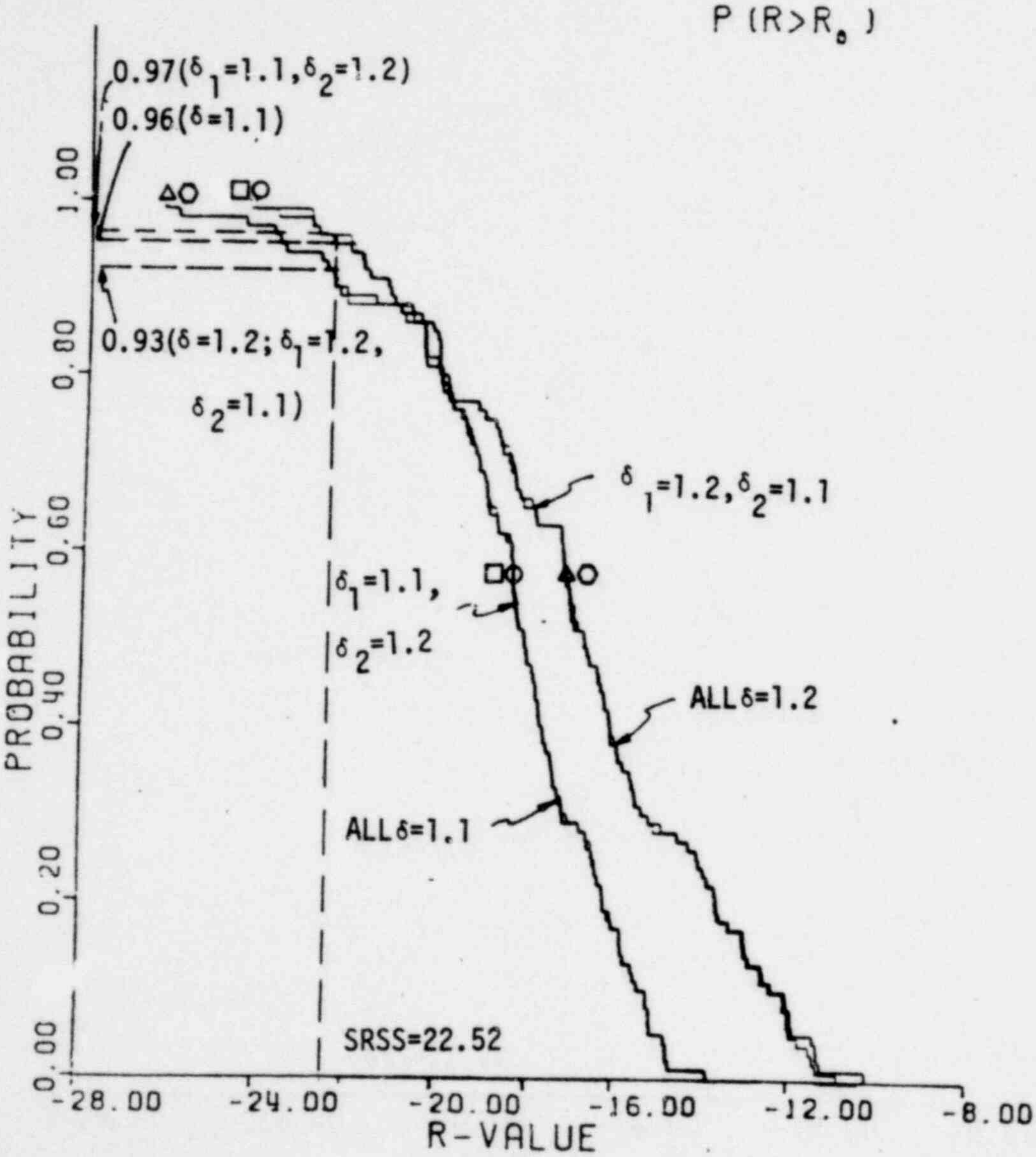

Figure 2-51. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz) Containment Wall at Drywell Floor Elevation. Lognormal Amplitude PDF Each has Different Dispersion

1323 243

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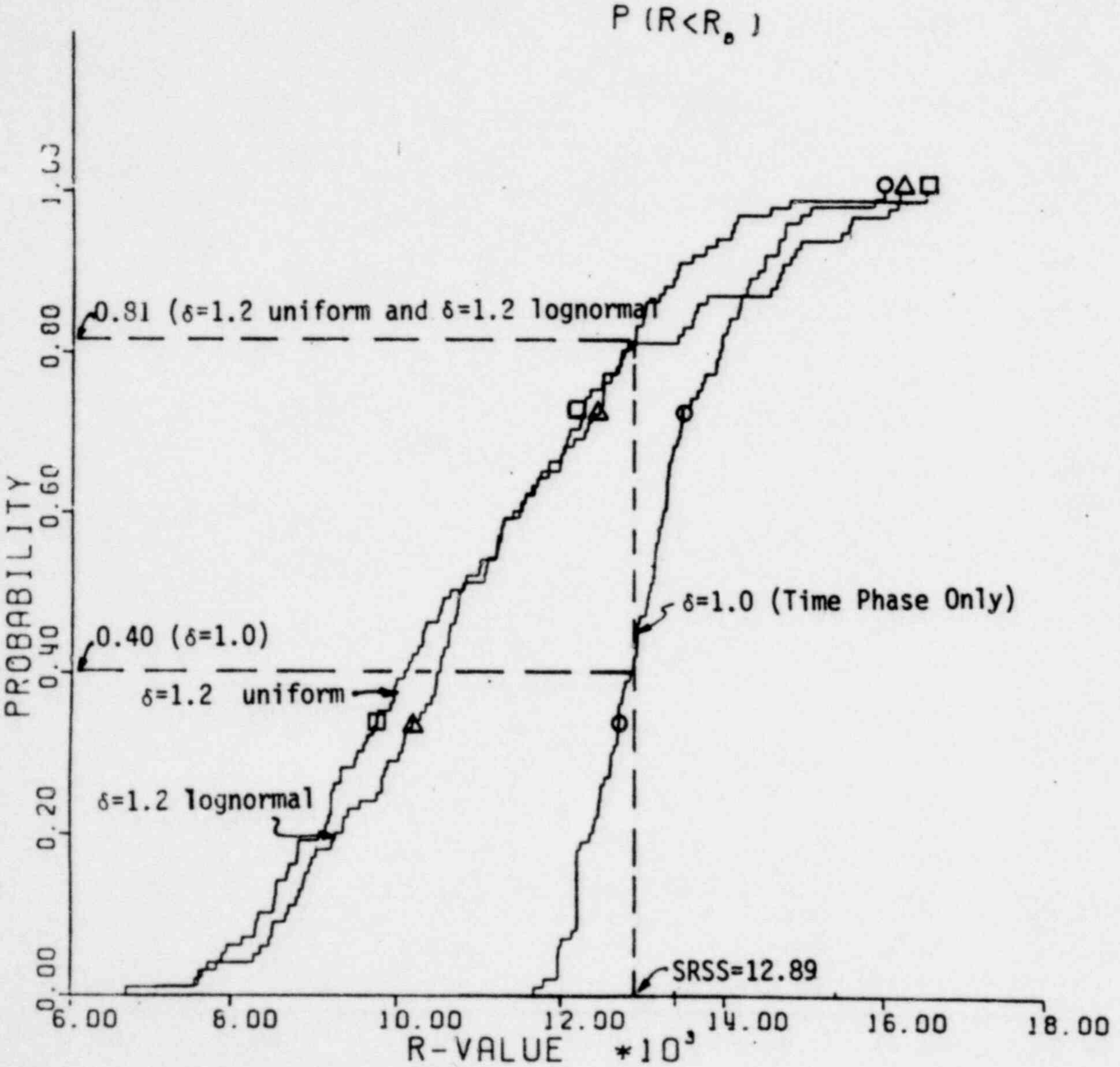

Figure 2-52. Case 1: Main Steam 461 OBE + SRVBDG M_a (Positive) Influence of Shape of Amplitude PDF

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

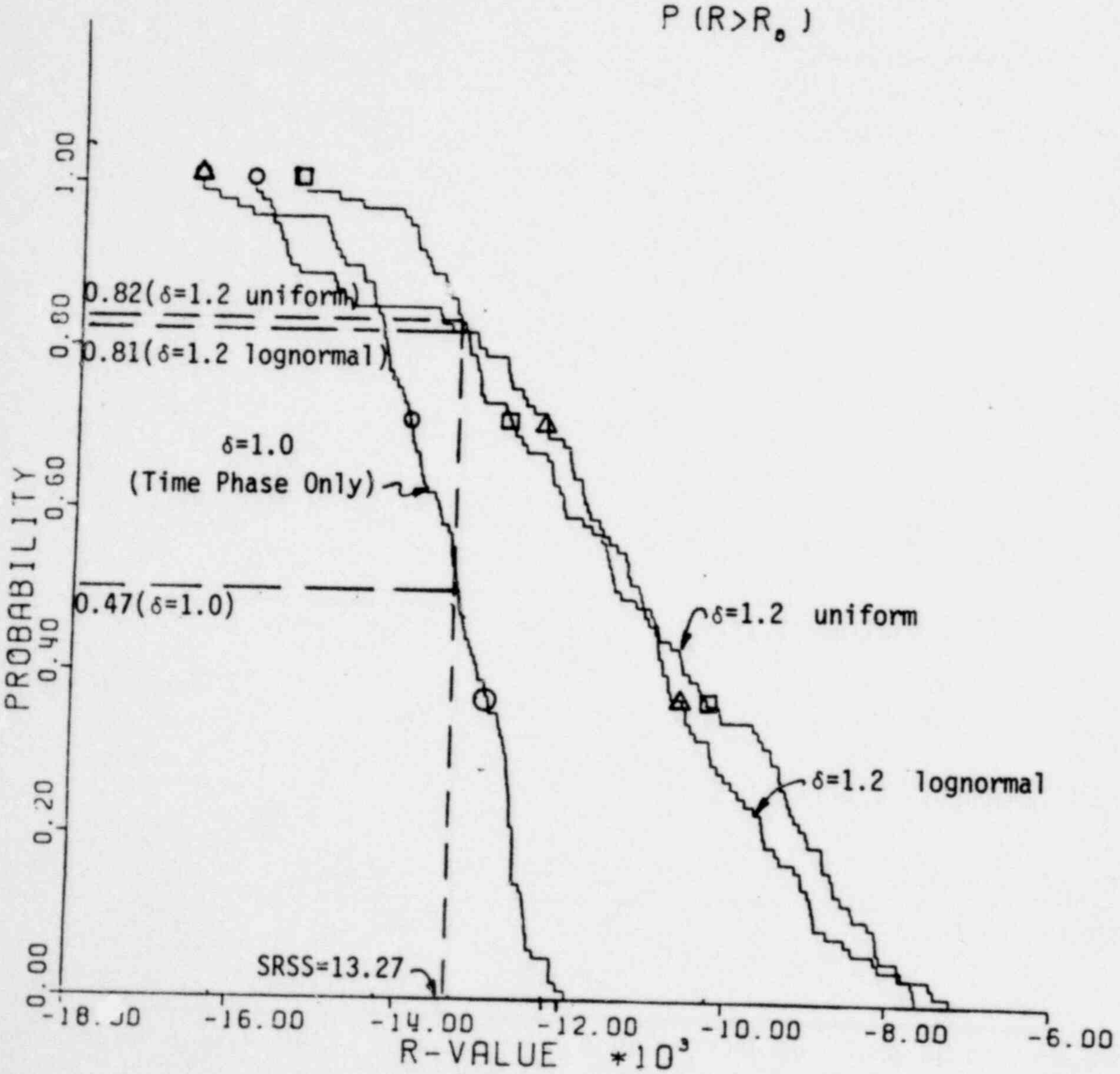

Figure 2-53. Case 1: Main Steam 461 OBE + SRVBDG M_a (Negative) Influence of Shape of Amplitude PDF

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CUMULATIVE DISTRUBUTION FUNCTION

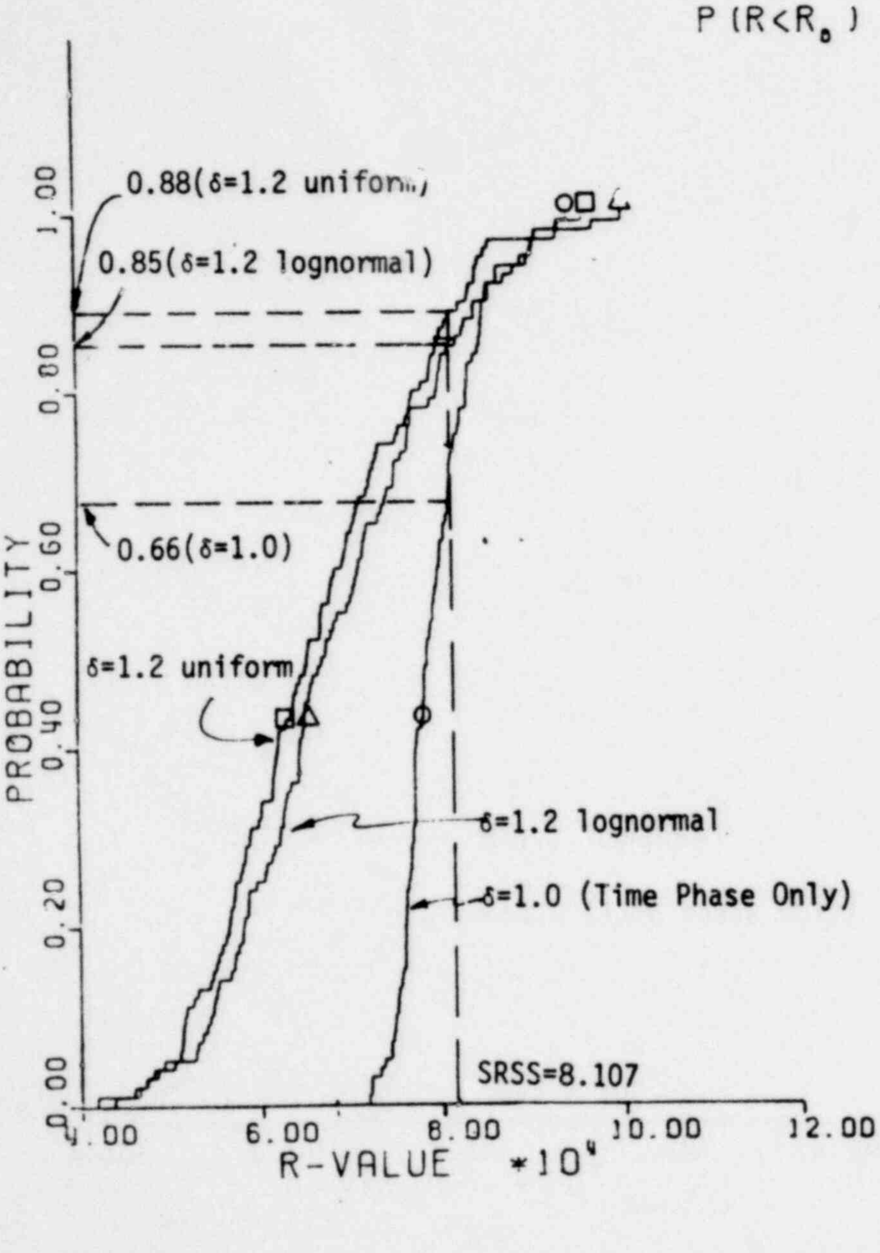

Figure 2-54. Case 2: Main Steam-461 OBE + SRVBDG M_c (Positive) Influence of Shape of Amplitude PDF

1323 246

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

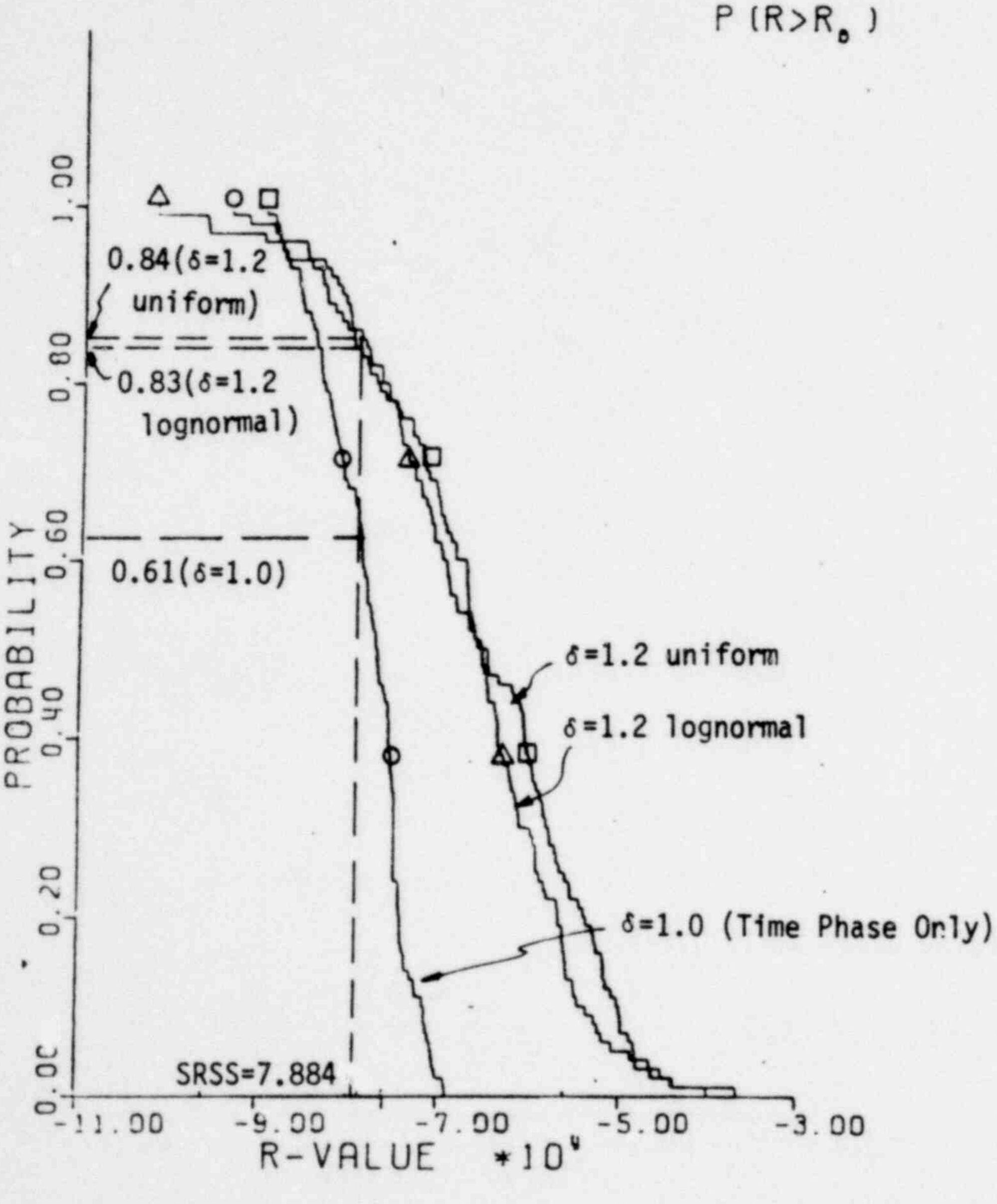

Figure 2-55. Case 2: Main Steam 461 OBE + SRVBDG M_C (Negative) Influlence of Shape of Amplitude PDF

1323 247

CUMULATIVE DISTRIBUTION FUNCTION

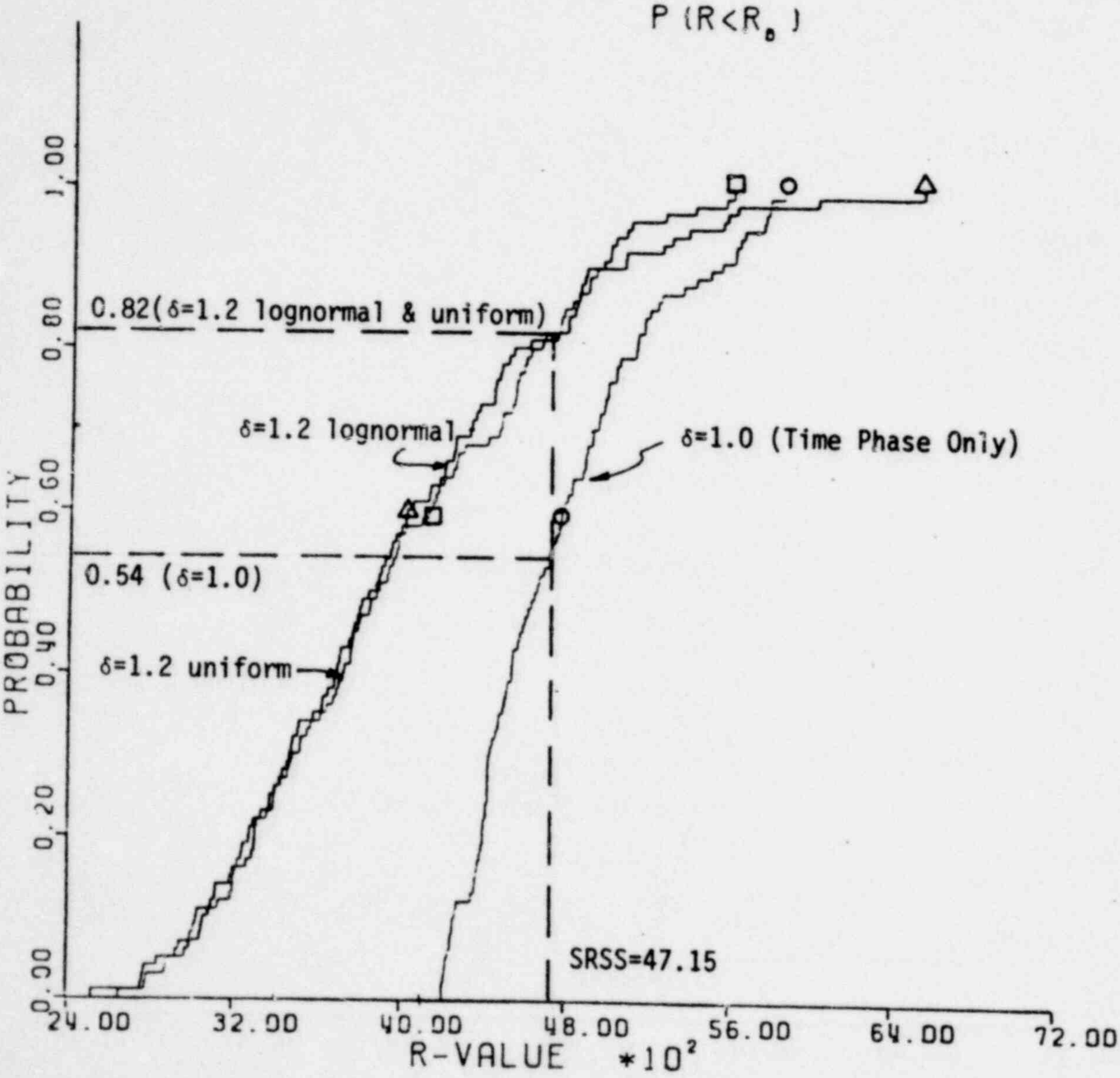

Figure 2-56. Case 3: RHR Wetwell OBE + SRVBLB M_a (Positive) Influence of Shape of Amplitude

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

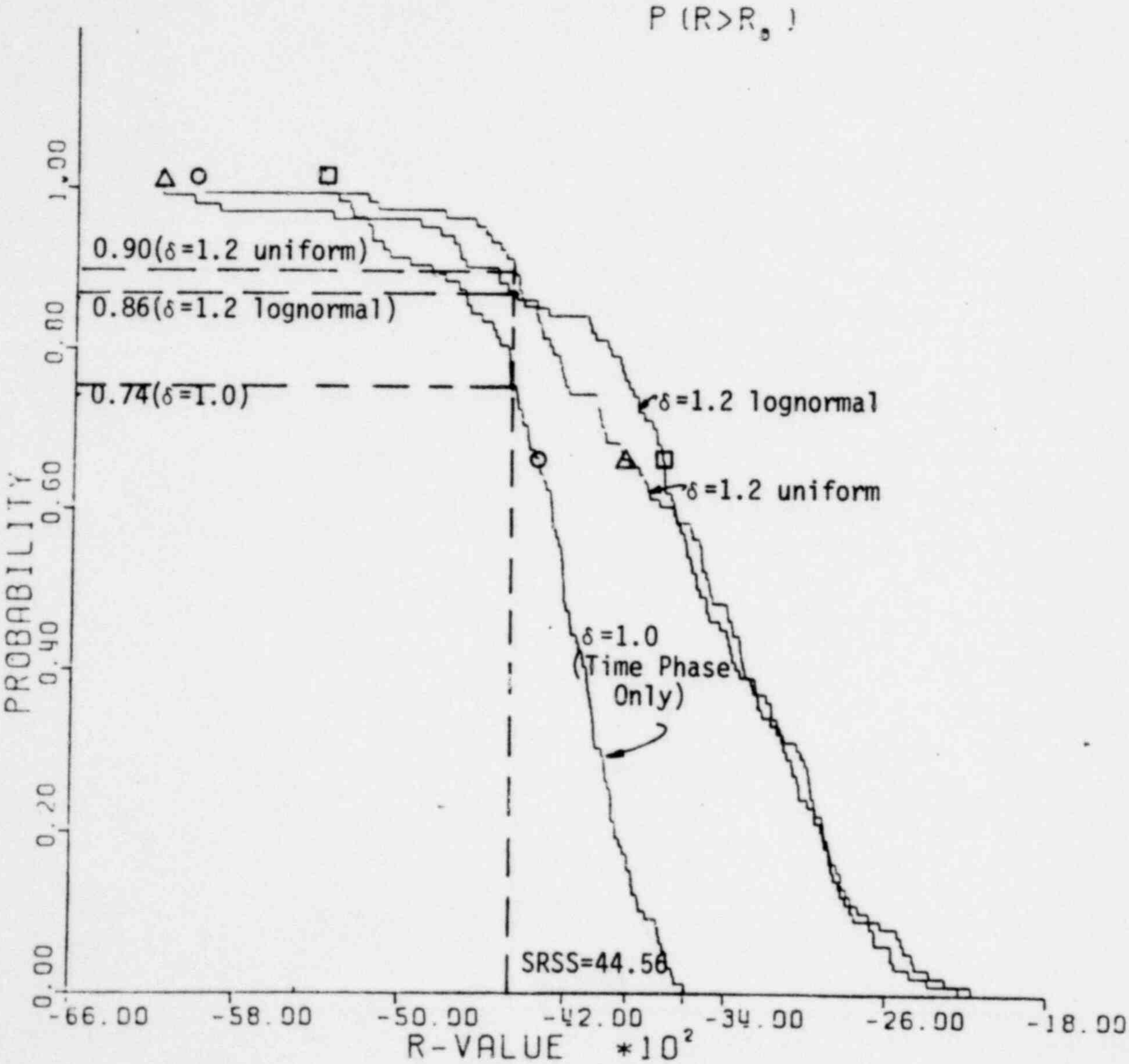

Figure 2-57. Case 3: RHR Wetwell OBE + SRVBUB M_a (Negative) Influence of Shape of Amplitude PDF

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CUMULATIVE DISTRIBUTION FUNCTION

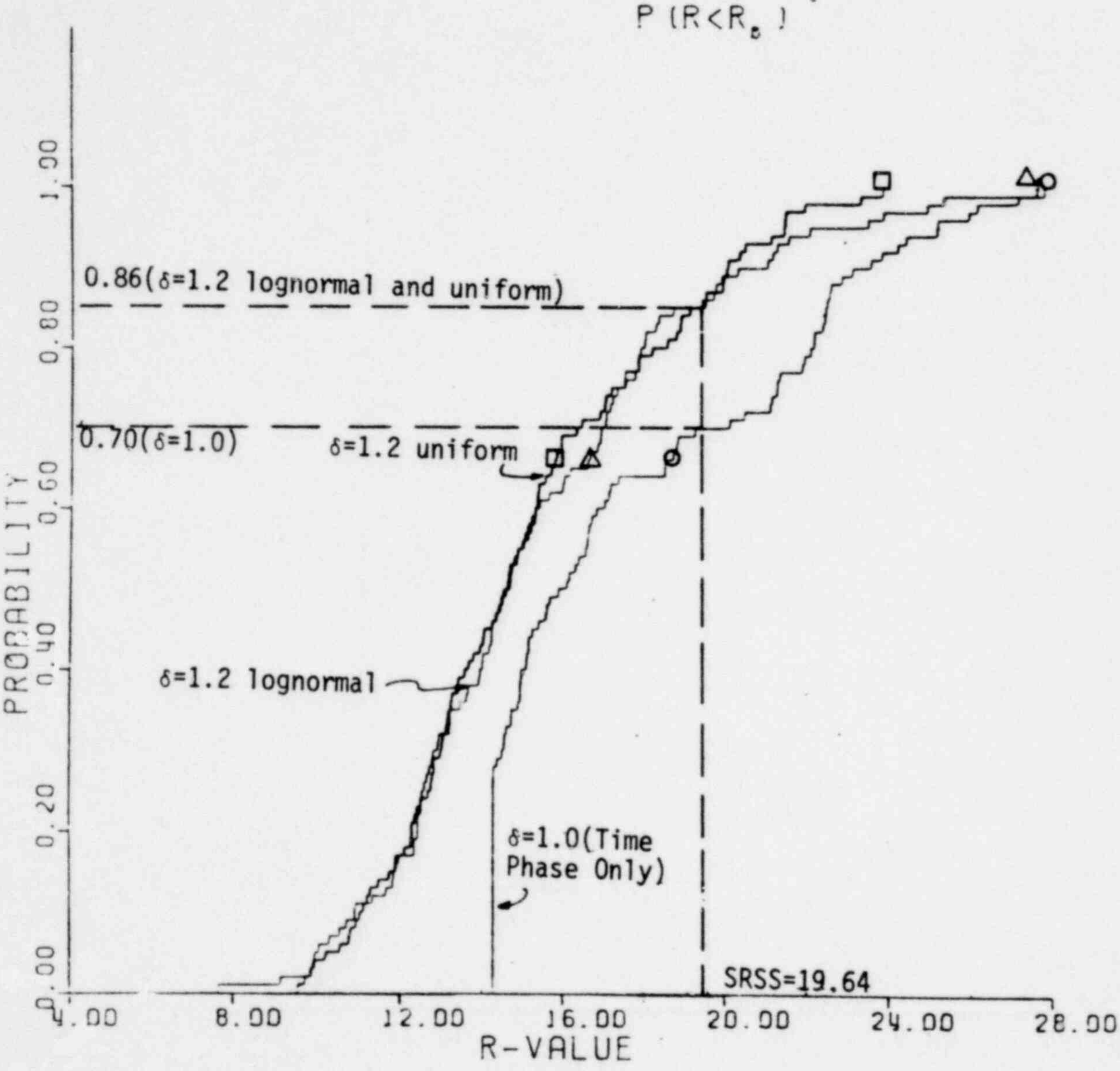

Figure 2-58. Case 4: Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

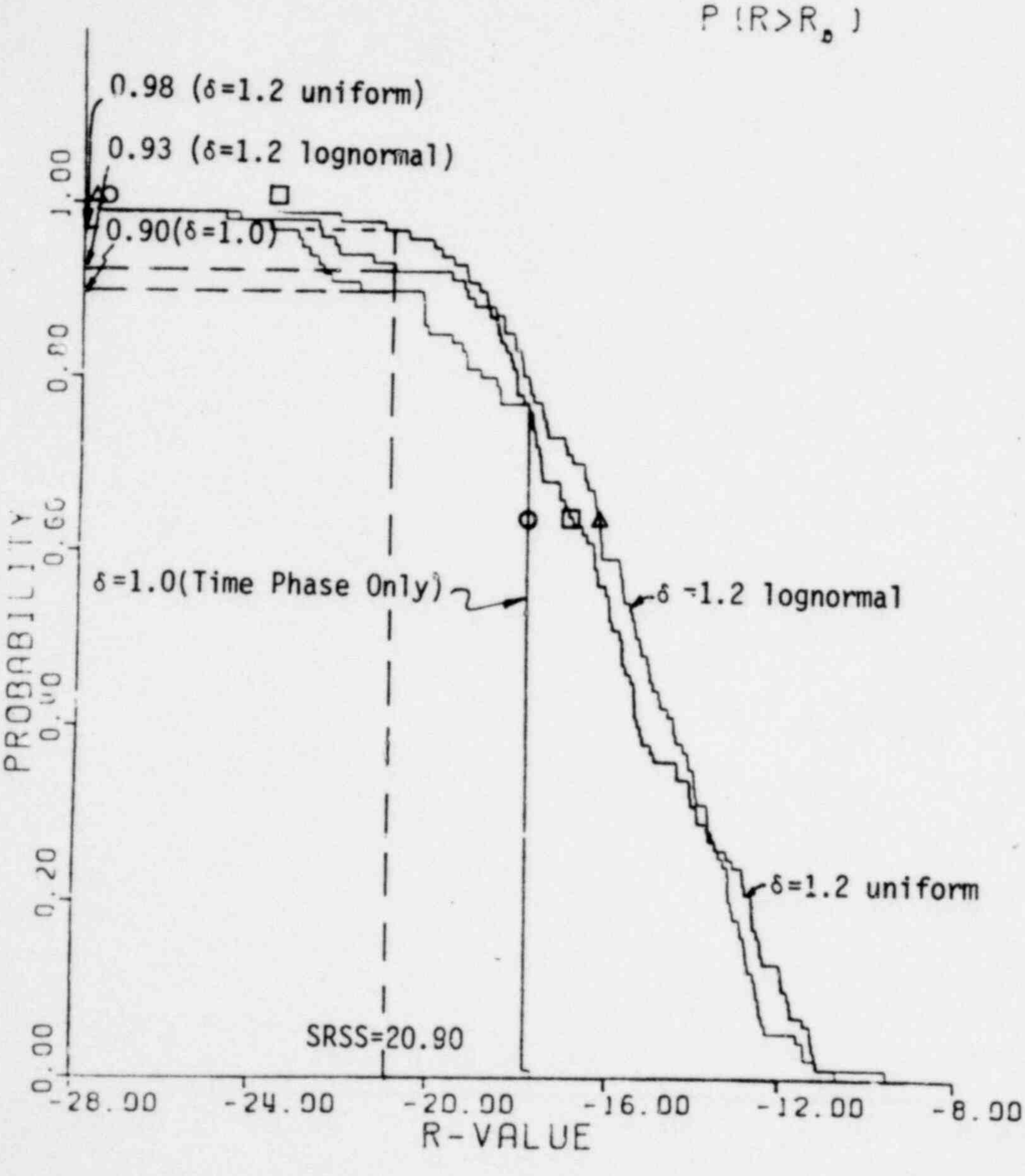

Figure 2-59. Case 4: Zimmer Plant OBE(NS) + SRV(All), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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CUMULATIVE DISTRIBUTION FUNCTION

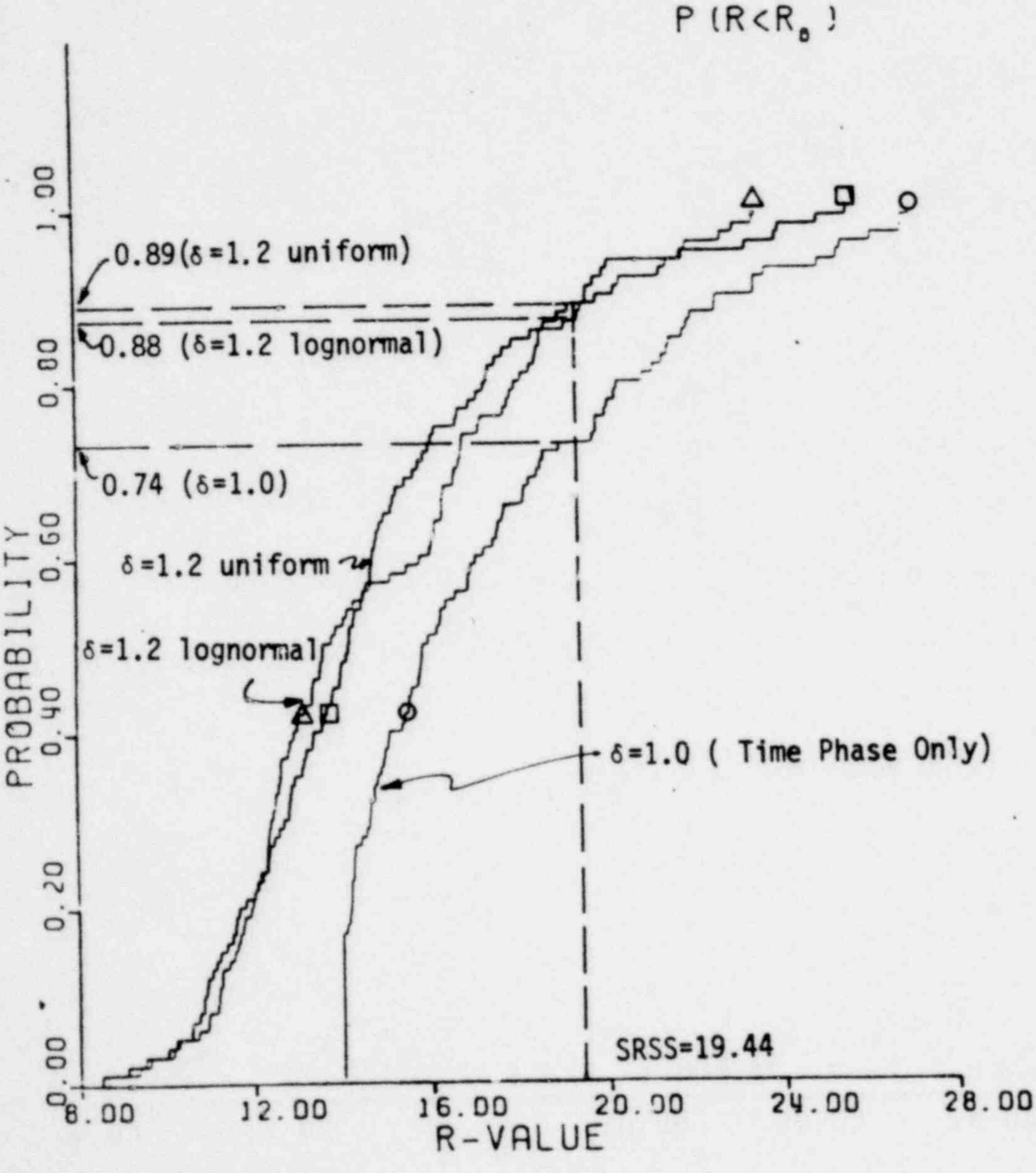

Figure 2-60. Case 5: Zimmer Plant OBE(EW) + SRV(All), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

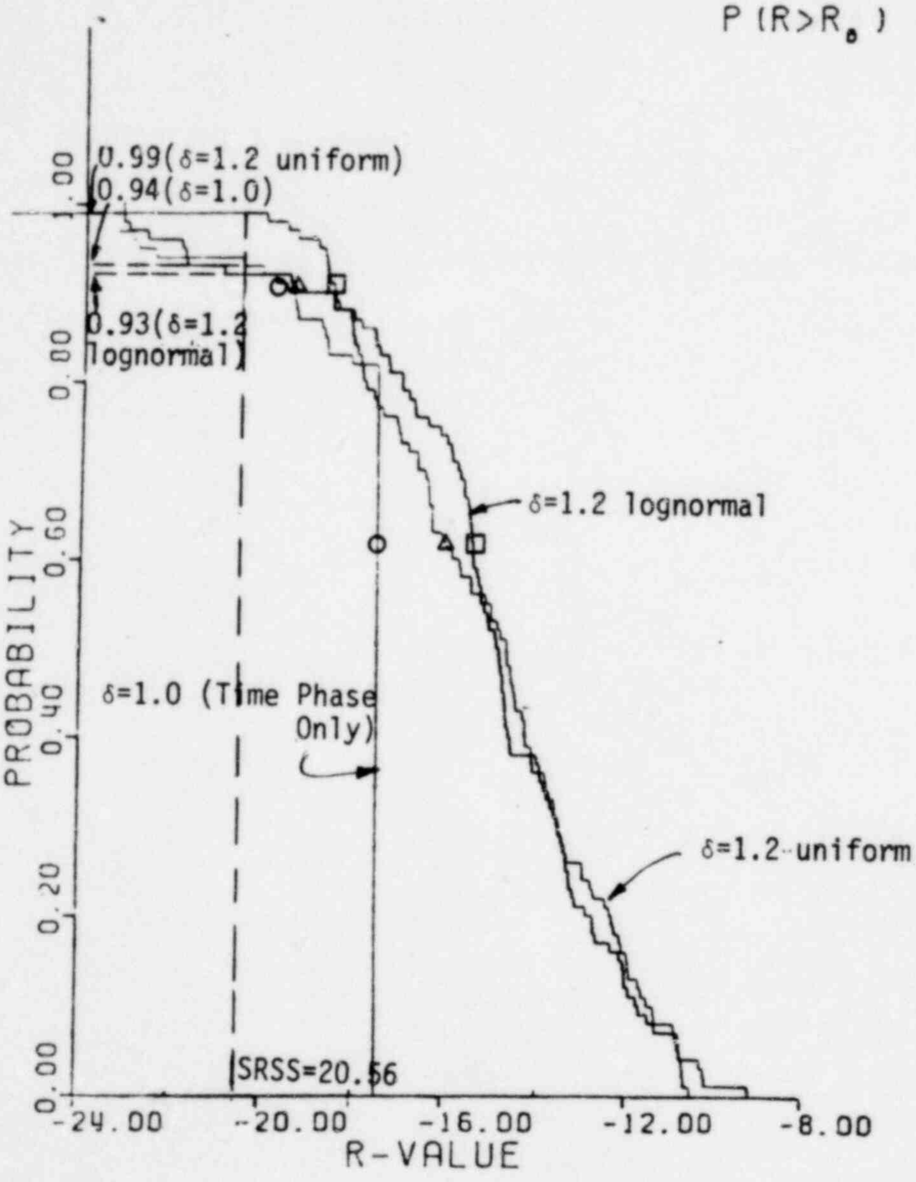

Figure 2-61. Case 5: Zimmer Plant OBE(EW) + SRV(All), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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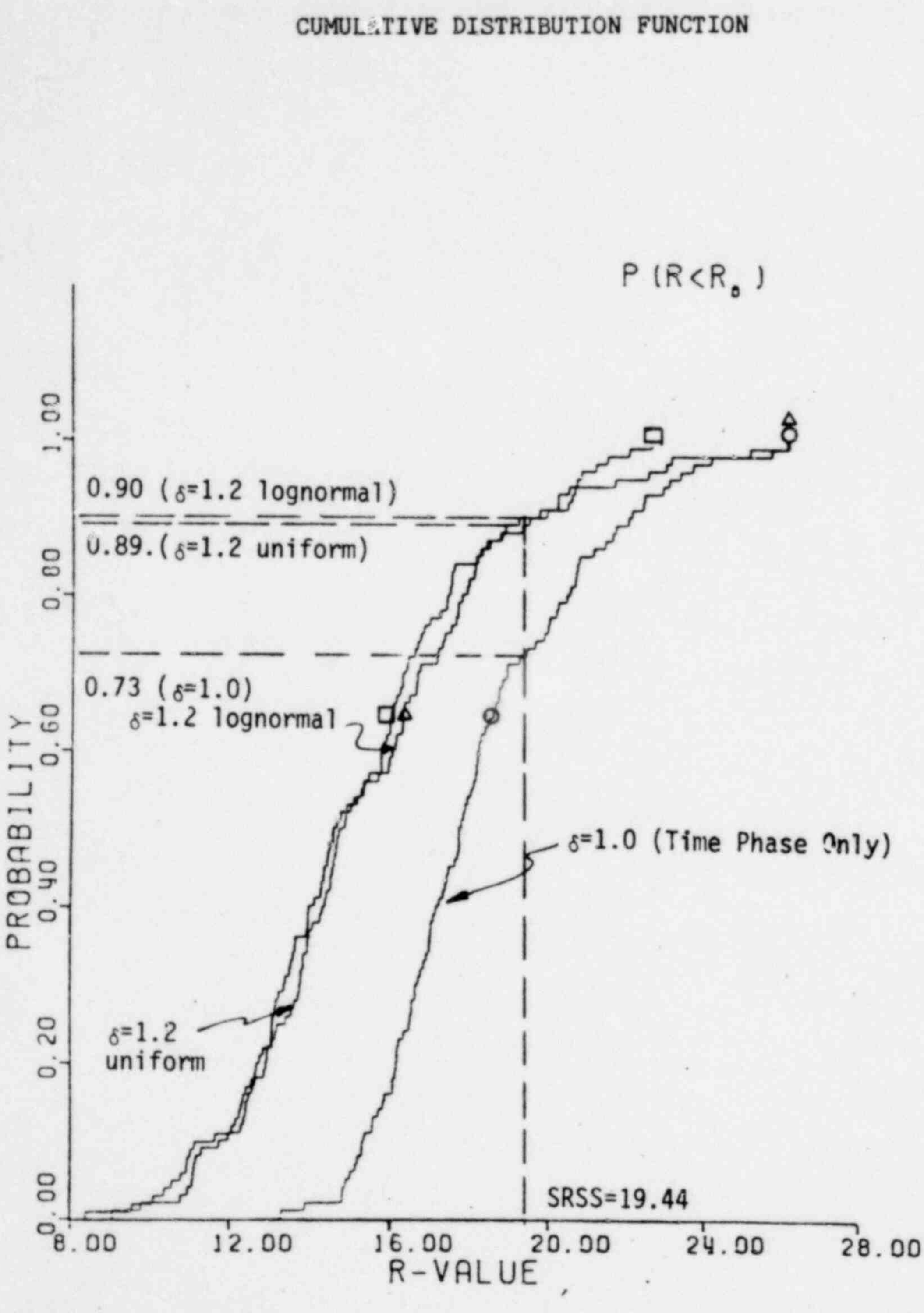

Figure 2-62. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

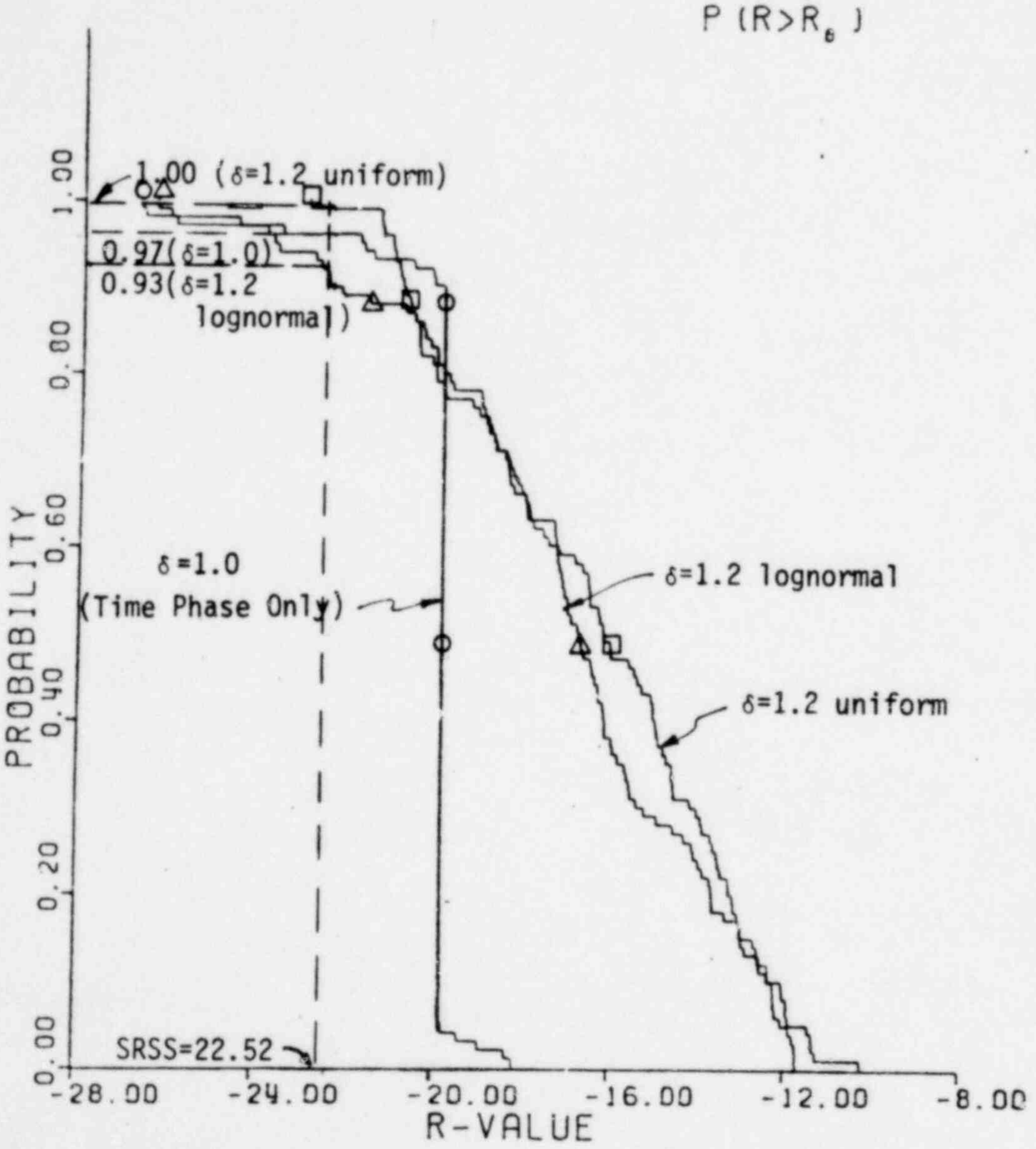

Figure 2-63. Case 6: LaSalle-1 OBE(NS) + SRV(ADS) + CHUG(30 Hz), Containment Wall at Drywell Floor Elevation. Influence of Shape of Amplitude PDF

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3. SIMPLIFIED METHOD TO APPROXIMATE THE GENERAL CDF FROM THE TIME PHASE CDF

3.1 INTRODUCTION

In the previous section, CDF curves were generated for six different response combination cases accounting for both randomness of amplitude as well as random relative time phasing. These curves were compared with CDF curves obtained for random time phasing only. All CDF curves were generated using the Monte Carlo technique.

Based upon several simplifying assumptions, it is possible to generate an approximate CDF curve accounting for random amplitude and time phasing directly from the random time phase CDF curve. As long as these approximate CDF curves can be shown to reasonably fit the Monte Carlo generated curves, one could justify this approximate procedure as being reasonable. This will be demonstrated to be true in this section.

This simplified procedure can be used to greatly extend our data base for demonstration cases which demonstrate the adequacy of the Newmark-Kennedy Criterion 2 to provide high confidence that the SRSS combined response has a NEP of approximately 84 percent or greater. A time phase CDF curve which barely passes the Criterion 2 can be generated. This curve would show a 50 percent NEP for the SRSS response and an 84 percent NEP for 1.2 times the SRSS response based upon time phase randomness only. From this time phase CDF curve, the NEP associated with the $SRSS_D$ can be directly computed for any combination of amplitude dispersion factors, δ, and factor F times the median at which the individual responses are specified. This will enable one to assess the adequacy of the Newmark-Kennedy Criterion 2 for any combination of δ and F.

3.2 ASSUMPTIONS

(a) The amplitude dispersion factor δ_i for each of the individual responses being combined are assumed to be equal to δ which represents an effective amplitude dispersion. This assumption is easily supported by the results presented in Subparagraph 2.4.2 which show that

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different amplitude dispersions for each response can be represented by a single effective dispersion δ obtained in accordance with the rules presented in that section.

b. The random amplitude scale factor can be reasonably approximated as a lognormal distribution. This assumption is supported by the results presented in Subparagraph 2.4.3 which show that vastly different shape PDF curves for random amplitude (lognormal versus bounded uniform) do not significantly influence the resultant CDF curves for peak combined response.

c. The time phase CDF curve can be approximated as a lognormal distribution at least within the region of primary interest from about 30 to 90 percent NEP. This assumption is generally reasonable for most time phase CDF curves as will be shown.

d. The random amplitude scale factors F_{R_i} for each individual response in the response combination are dependent on a single random amplitude scale factor F_R. This assumption is rather severe but can be justified on the basis that it does not appear to seriously impact the resultant general CDF curves, as will be subsequently demonstrated.

3.3 SIMPLIFIED METHOD

Using the assumption of dependency between the individual response amplitude scale factors, the peak combined response C_R accounting for both random amplitude and time phasing can be defined in terms of the peak combined response T_R obtained assuming only random time phasing using:

$$C_R = F_R \cdot T_R \tag{3.1}$$

where F_R is the random amplitude scale factor. The time phase peak combined response T_R is defined by the time phase CDF curve for peak response. The resultant peak combined response C_R can be used to define the CDF curve associated with random amplitude and time phasing.

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Assuming lognormal distributions:

$$F_R = F_{R_{50}} \cdot \exp(f \cdot \beta_F)$$

$$T_R = T_{R_{50}} \cdot \exp(f \cdot \beta_T) \qquad (3.2)$$

$$C_R = C_{R_{50}} \cdot \exp(f \cdot \beta_C)$$

where $F_{R_{50}}$, $T_{R_{50}}$, and $C_{R_{50}}$ represent the median values, β_F, β_T, and β_C represent the corresponding logarithmic standard deviations, and f represents the standardized Gaussian random variable (zero mean, unit standard deviation). Based upon the properties of the lognormal distribution and Equation 3.1:

$$C_{R_{50}} = F_{R_{50}} \cdot T_{R_{50}}$$

$$\beta_C = \sqrt{\beta_F^2 + \beta_T^2} \qquad (3.3)$$

Thus, the general CDF curve for peak combined response (C_R) can be obtained directly from the corresponding time phase CDF curve (T_R), and the median value and logarithmic standard deviation of the random amplitude scale factor ($F_{R_{50}}$ and β_F).

3.4 RESULTS

Figures 3-1 through 3-12 present a lognormal fit of the time phase CDF curves for the 6 response combination cases being investigated. The lognormal CDF has been selected to provide an estimated "best fit" of the actual time phase only CDF curve between the range from 30 to 90 percent NEP. Excellent agreement is shown to exist within this range for Cases 1 through 3 and for the positive CDF curves for Cases 4 through 6. In Cases 4 through 6, the negative CDF curves are relatively poorly fit by the assumed lognormal distribution. It will be subsequently shown that this poor fit of the time phase CDF curve does not seriously affect the ability of this simplified method to predict the NEP of the SRSS combined response when random amplitude and time phasing are considered. Table 3-1 presents the median and logarithmic standard deviation β_T for the lognormal distributions selected. Note that β_T ranges from 0 to 0.35 so that a wide range in dispersion of the time phase only CDF is represented by these cases.

The individual response amplitudes used to generate the time phase CDF curves are considered to be at their 84 percent NEP since this is the requirement of the original Newmark-Kennedy Criteria. Thus, ${}^{F}R_{84} = 1.0$. The dispersion in the amplitude scale factor is again expressed by $\delta = ({}^{F}R_{84}/{}^{F}R_{50})$. Dispersions of $\delta = 1.1$, 1.2, and 1.3 are selected for this study as discussed in Subsection 2.2. The logarithmic standard deviation β_F of the amplitude scale factor is given by Equation 2.4.

The general CDF can be directly generated from Equations 3.2 and 3.3 for any given amplitude dispersion δ. For $\delta = 1.1$, 1.2, and 1.3, Figures 3-13 through 3-48 present the actual CDF curves versus those obtained using the above simplified assumptions for each of the 6 response combination cases being studied. Table 3-2 presents the NEP for the SRSS combined response from the actual CDF curve versus that obtained from the simplified lognormal assumptions.

The following conclusions were reached:

a. When the time phase CDF logarithmic standard deviation β_T is less than 0.16, the general CDF curve is accurately predicted by the simplified procedure throughout the entire range of NEP values from 10 to 95 percent. However, when the time phase CDF shows considerable dispersion ($\beta_T \geq 0.3$), the general CDF curve is not accurately predicted at the lower NEP values.

b. In every case, the simplified procedure accurately predicts the NEP associated with the SRSS combined response. This conclusion is valid even when the lognormal distribution does not closely approximate the actual time phase CDF (see negative CDF for Cases 4, 5, and 6). This conclusion holds throughout the range of time phase logarithmic standard deviations β_T studied (0 through 0.3) and amplitude dispersions ($\delta = 1.1$ through 1.3 which correspond to amplitude logarithmic standard deviations from 0.1 through 0.26).

c. Therefore, this simplified procedure can be used to expand the data base in order to further validate the Newmark-Kennedy Criterion 2 and to further establish the factor F times the median at which the individual responses being combined must be specified.

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3.5 ADDITIONAL VALIDATION OF NEWMARK-KENNEDY CRITERION 2

Criterion 2 requires that:

a. The NEP of approximately the SRSS combined response accounting only for random time phasing must be approximately 50 percent or greater.

b. The NEP of approximately 1.2 times SRSS accounting only for random time phasing must be approximately 85 percent or greater.

Furthermore, as modified in Subsection 2.5, each individual response in the response combination is required to be conservatively defined at either approximately the 84 percent NEP or at 1.15 times their median value, whichever is greater.

A lognormal time phase CDF wh barely meets both requirements of Criterion 2 will have the following properties:

$$T_{R_{50}} = \text{SRSS}$$

$$\beta_T = \ell n\ (1.2) = 0.18 \qquad (3.4)$$

The lognormal amplitude scale factor for individual responses which barely meets the conservatism required by the criteria will have the following properties:

$$F_{R_{50}} = \frac{1}{\delta}$$

or (3.5)

$$F_{R_{50}} = \frac{1}{F}$$

whichever is less, and

$$\beta_F = \ell n\ (\delta)$$

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where δ represents the amplitude dispersion factor and F represents the factor times the median at which the individual responses must be specified.

Using the lognormal time phase CDF properties which barely pass Criterion 2 (Equation 3.4) and the lognormal amplitude scale factors for response which barely pass the response conservatism requirement for any dispersion δ, one can determine the maximum possible ratio K of peak combined response with an 84 percent NEP (${}^{C}R_{84_{max}}$) to SRSS combined response for any case which can pass the Newmark-Kennedy Criterion 2. From the definition of K and Equations 3.2 and 3.3, one obtains:

$$K = \frac{CR_{84_{max}}}{SRSS} = F_{R_{50}} \exp(\beta_C) \qquad (3.6)$$

where

$$\beta_C = \sqrt{(0.18)^2 + (\ln \delta)^2}$$

Table 3-3 presents results of the maximum amount K by which the 84 percent peak combined response can exceed the SRSS combined response for representative values of δ and F. Note that with the original Newmark-Kennedy Criteria (F = 1.0), the 84 percent NEP combined response could exceed the SRSS combined response by up to 19 percent. With the criteria revision (F = 1.[illegible]), for the worst possible case the 84 percent NEP combined response can never exceed the SRSS combined response by more than 9 percent. The likelihood of this exceedance is extremely low because it requires that the time phase CDF pass through both points defined by Criterion 2, and also requires a very specific ratio of the amplitude dispersion factor. With other amplitude dispersions, the maximum possible exceedance is considerably less.

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values of δ and F. Note that with the original Newmark-Kennedy Criteria (F = 1.0), the 84 percent NEP combined response could exceed the SRSS combined response by up to 19 percent. With the criteria revision (F = 1.15), for the worst possible case the 84 percent NEP combined response can never exceed the SRSS combined response by more than 9 percent. The likelihood of this exceedance is extremely low because it requires that the time phase CDF pass through both points defined by Criterion 2, and also requires a very specific ratio of the amplitude dispersion factor. With other amplitude dispersions, the maximum possible exceedance is considerably less.

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Table 3-1
ASSUMED LOGNORMAL APPROXIMATION TO TIME PHASE ONLY CDF CURVES

CASE	SIGN	MEDIAN $T_{R_{50}}$	LOGARITHMIC STANDARD DEVIATION β_T
1	+	13108	0.0744
	-	-13301	0.0717
2	+	78700	0.0714
	-	-77140	0.0858
3	+	4649	0.1064
	-	- 4202	0.1052
4	+	15.884	0.3453
	-	-17.85	0.094
5	+	16.00	0.3054
	-	-17.45	0.0638
6	+	17.769	0.1566
	-	-19.81	0

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Table 3-2
NON-EXCEEDANCE PROBABILITIES FOR SRSS COMBINED RESPONSE FROM ACTUAL CDF VERSUS SIMPLIFIED PROCEDURE CDF CONSIDERING RANDOM AMPLITUDE SCALE FACTOR AND RANDOM TIME PHASING

CASE	SIGN	SRSS NEP					
		δ = 1.1		δ = 1.2		δ = 1.3	
		ACTUAL	SIMPLIFIED	ACTUAL	SIMPLIFIED	ACTUAL	SIMPLIFIED
1	+	0.74	0.74	0.81	0.80	0.82	0.82
	-	0.77	0.78	0.81	0.81	0.84	0.83
2	+	0.80	0.85	0.85	0.86	0.85	0.86
	-	0.78	0.82	0.83	0.85	0.82	0.85
3	+	0.79	0.78	0.82	0.82	0.87	0.84
	-	0.86	0.86	0.86	0.86	0.87	0.87
4	+	0.82	0.80	0.86	0.84	0.89	0.85
	-	0.94	0.97	0.93	0.95	0.92	0.93
5	+	0.86	0.82	0.88	0.86	0.88	0.88
	-	0.96	0.99	0.93	0.96	0.93	0.94
6	+	0.84	0.84	0.90	0.87	0.90	0.87
	-	0.96	0.99	0.93	0.96	0.91	0.93

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Table 3-3
MAXIMUM POSSIBLE RATIO OF 84 PERCENT NON-EXCEEDANCE PROBABILITY PEAK COMBINED RESPONSE TO SRSS COMBINED RESPONSE FOR ANY CASE WHICH CAN PASS CRITERION 2 AS A FUNCTION OF AMPLITUDE DISPERSION AND FACTOR F

Factor of Conservatism on Median Response, F	RATIO $K = \frac{C_{R_{84_{max}}}}{SRSS}$				
	δ = 1.0	1.1	1.15	1.2	1.3
1.0	1.19*	1.11	1.09	1.07	1.06
1.1	1.08	1.11*	1.09	1.07	1.06
1.15	1.04	1.06	1.09*	1.07	1.06
1.2	0.99	1.02	1.04	1.07*	1.06
1.3	0.92	0.94	0.96	0.99	1.06*

*The worst case dispersion at which the maximum ratio is maximized.

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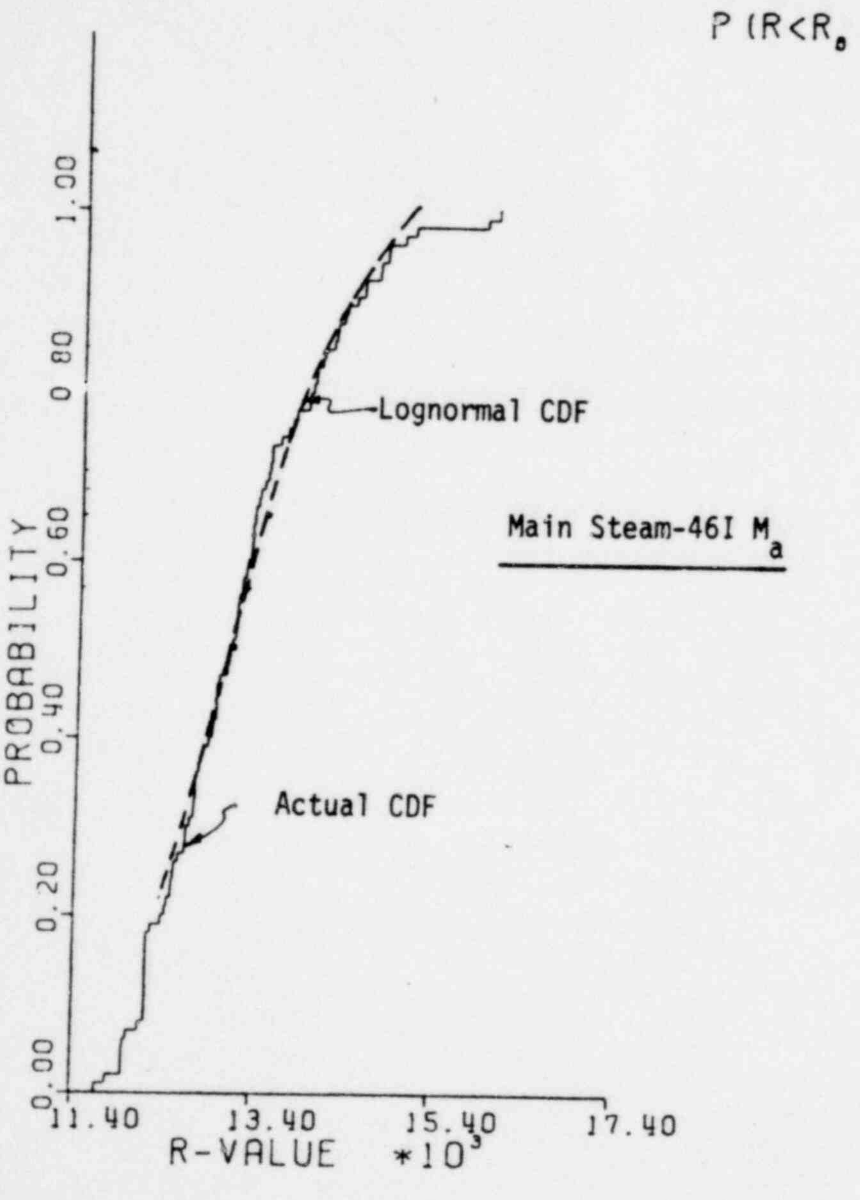

Figure 3-1. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 1

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

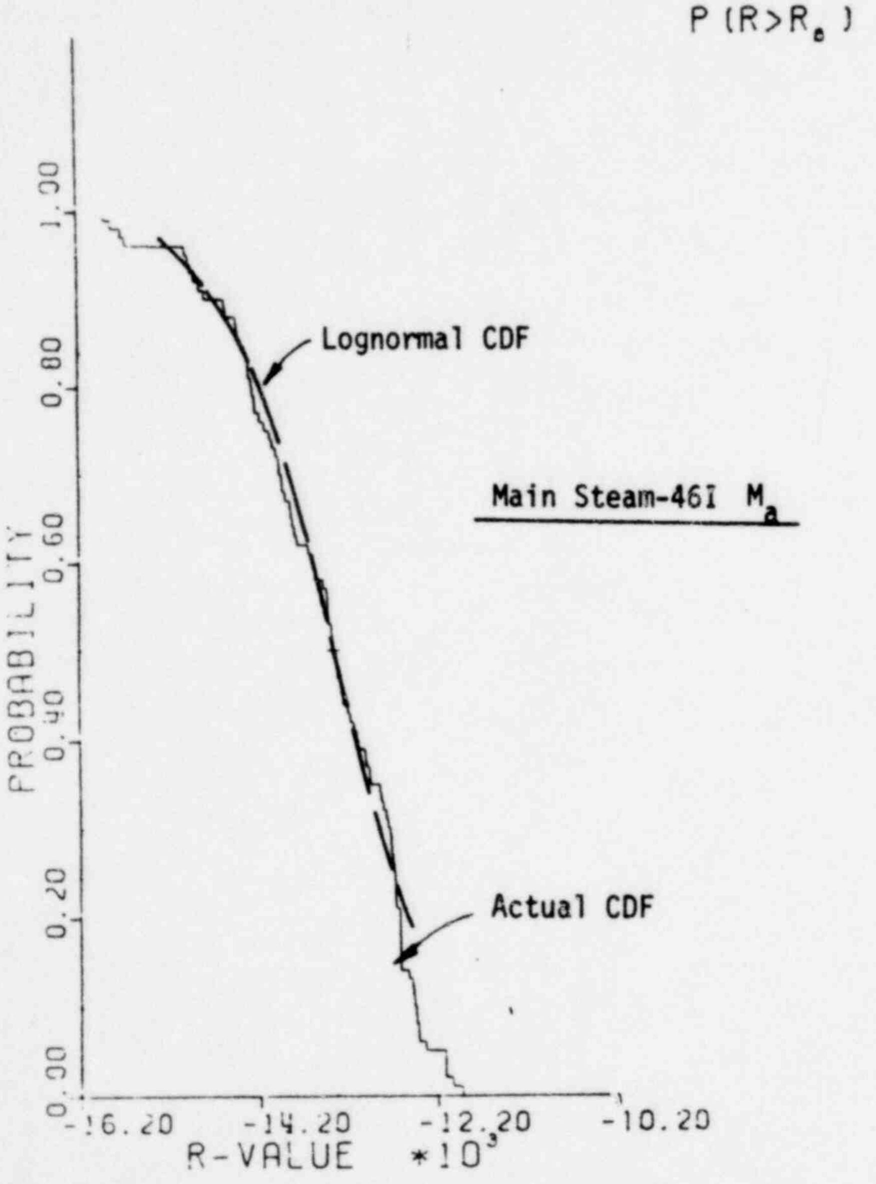

Figure 3-2. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 1

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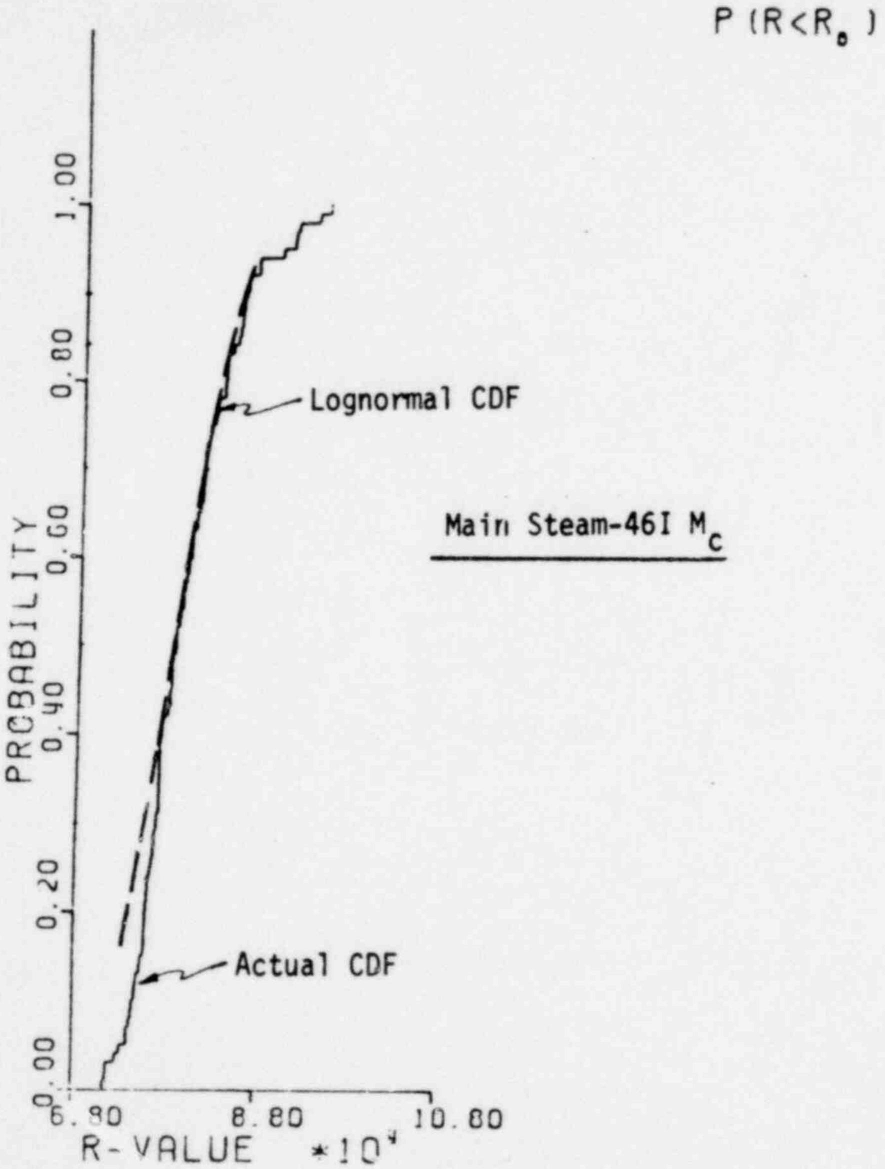

Figure 3-3. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 2

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

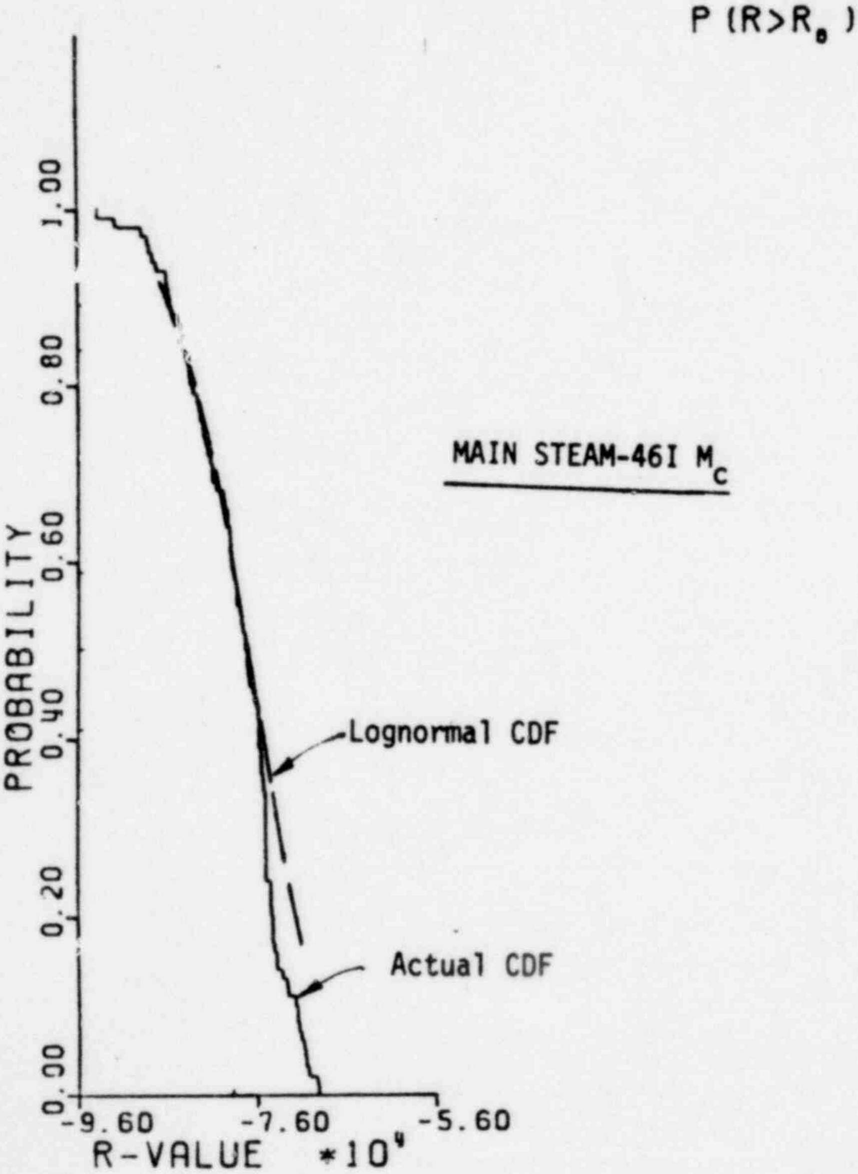

Figure 3-4. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 2

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CUMULATIVE DISTRIBUTION FUNCTION

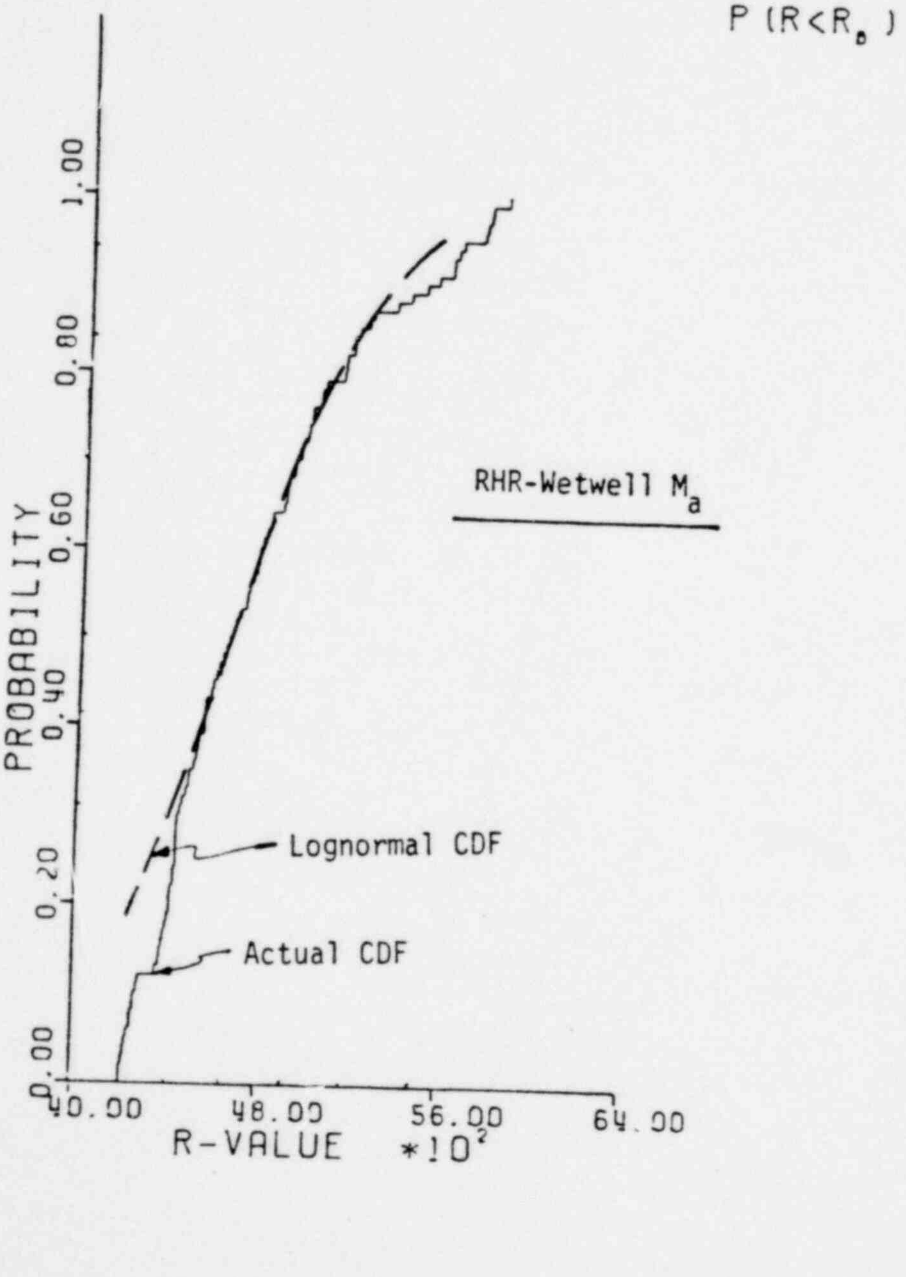

Figure 3-5. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 3

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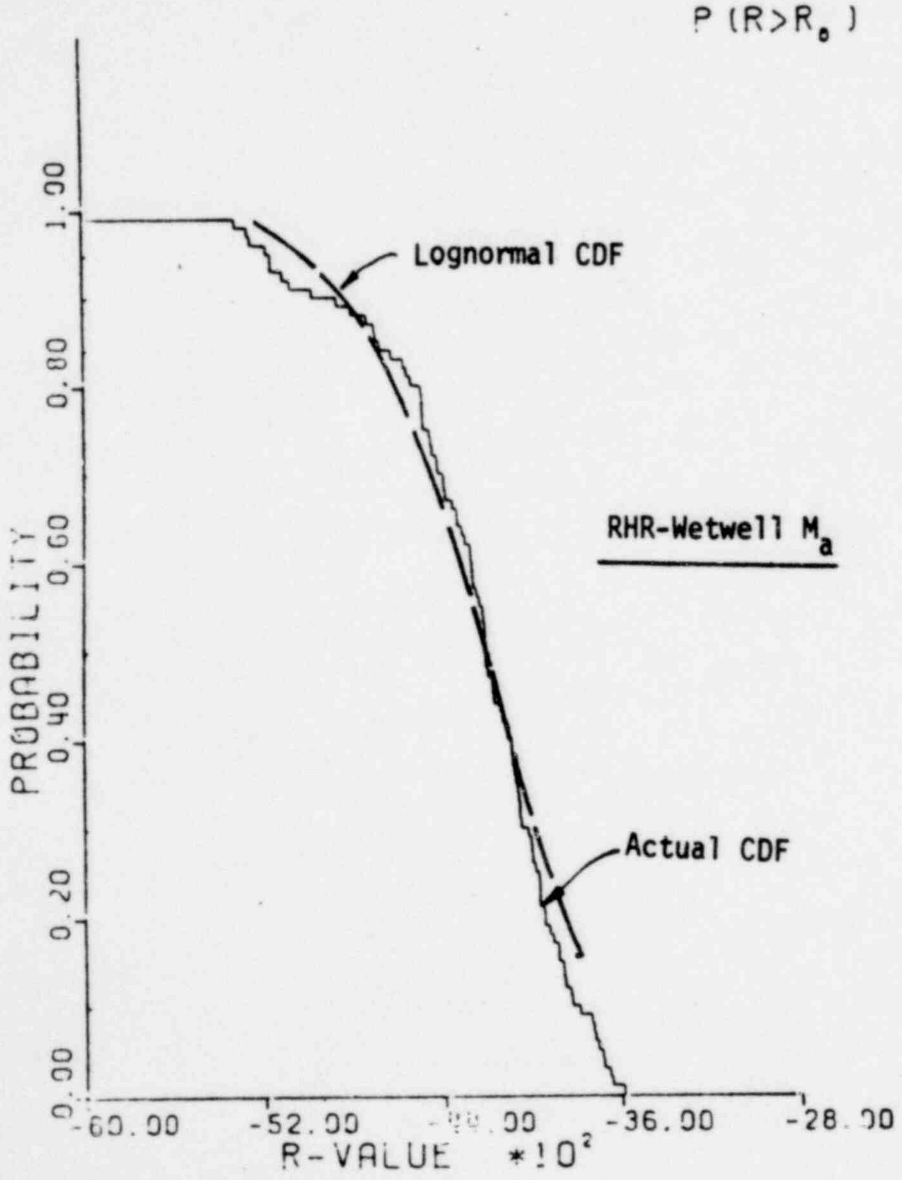
COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION



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1323 271

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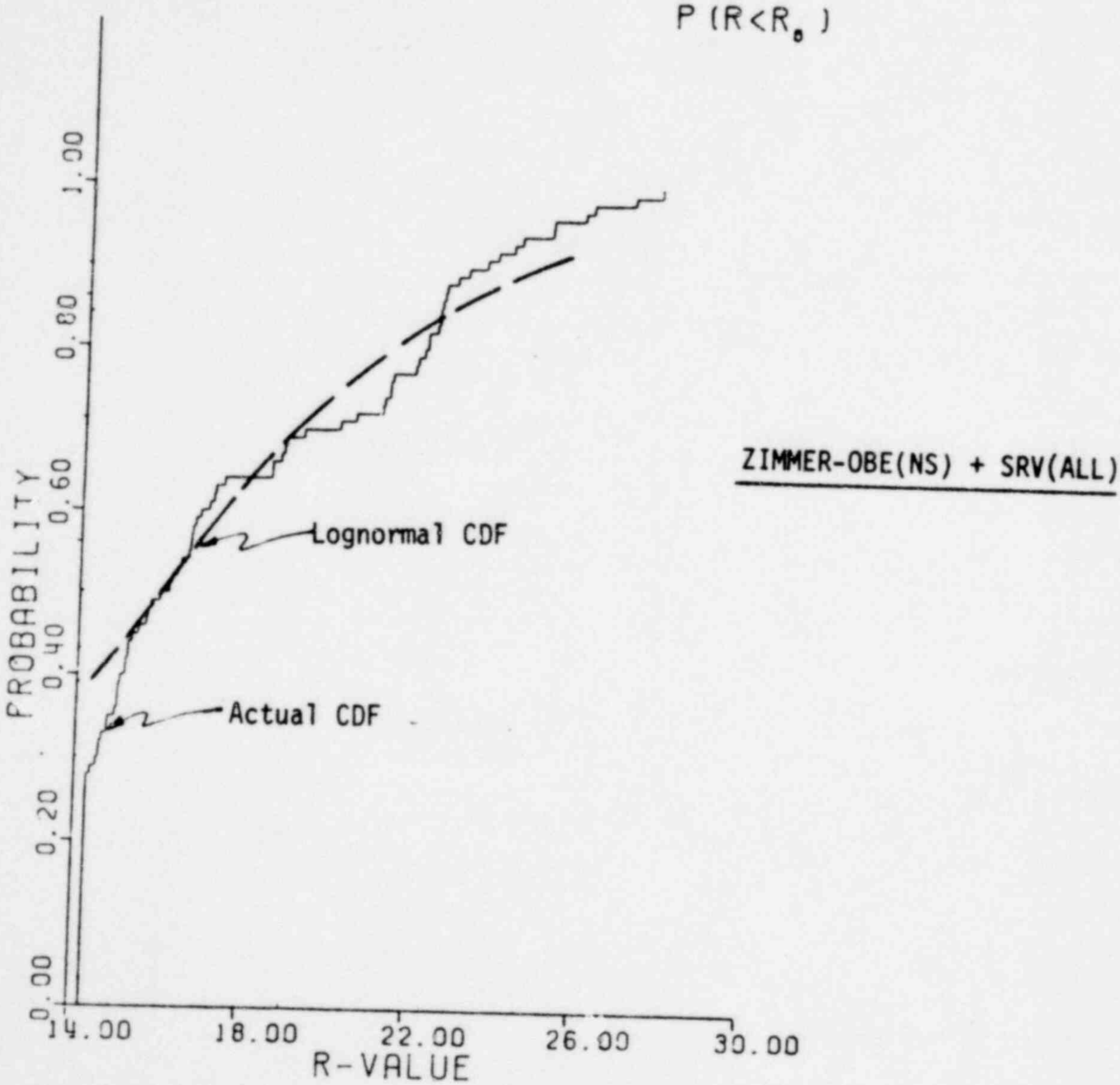

Figure 3-7. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 4

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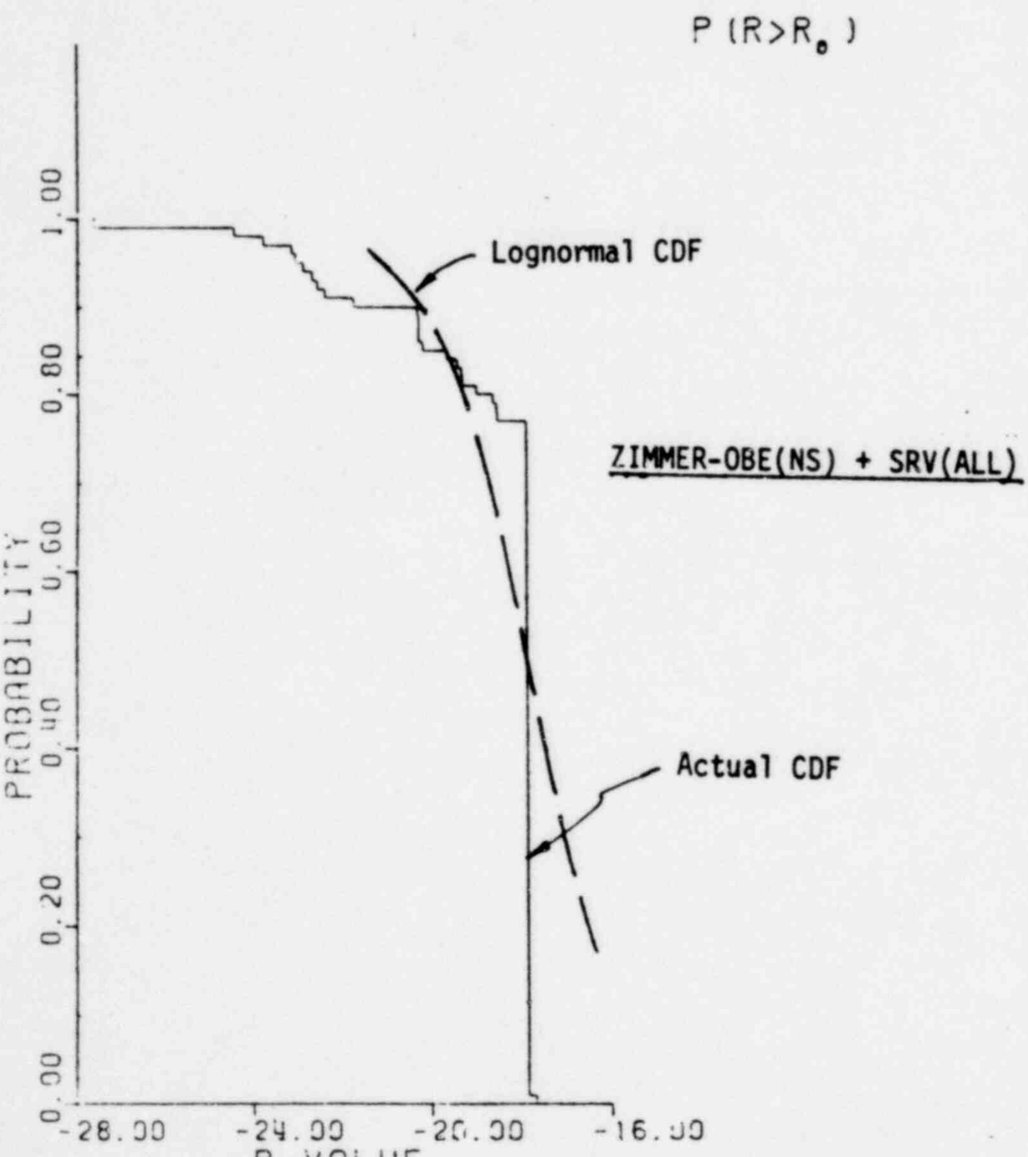

Figure 3-8. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 4

1323 273

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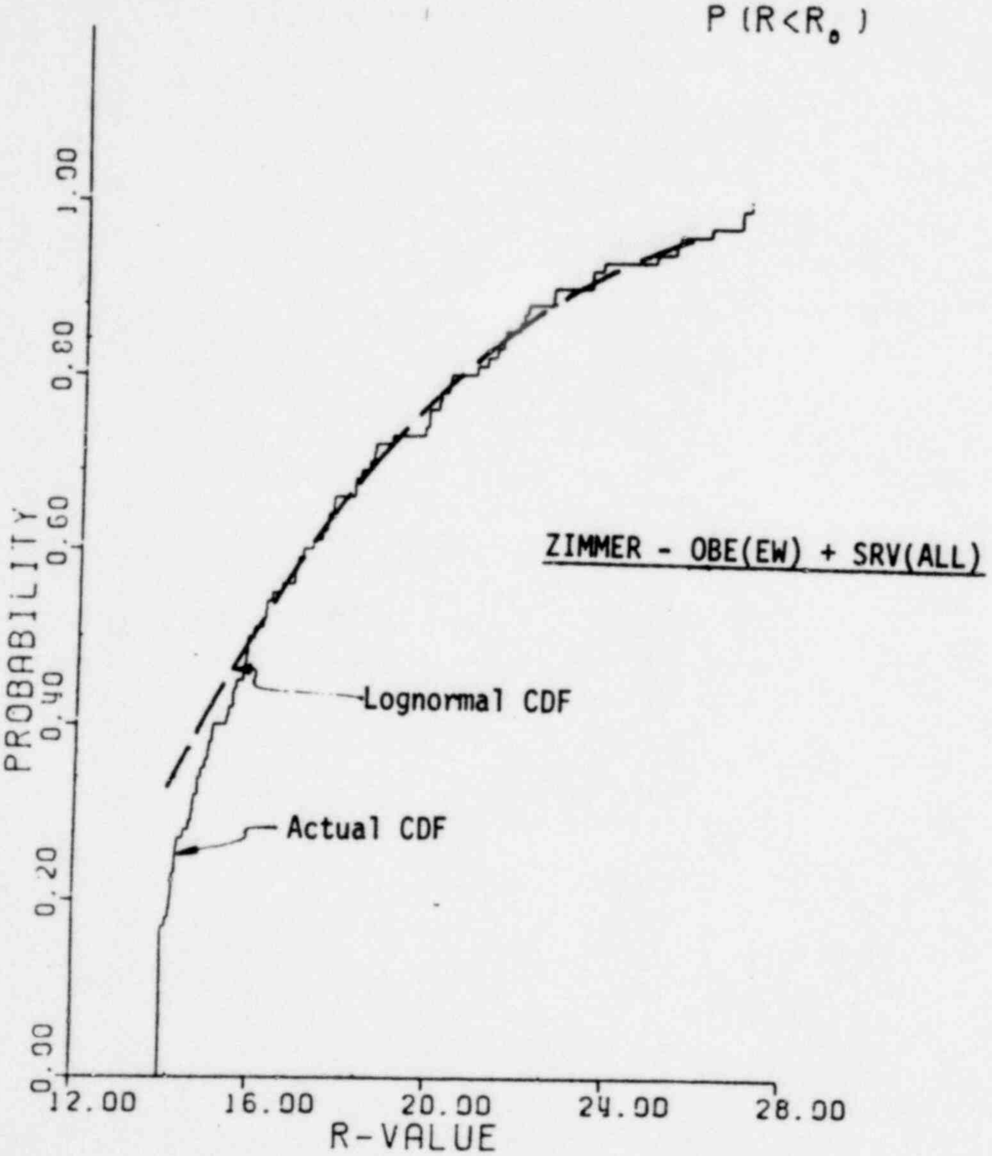

Figure 3-9. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 5

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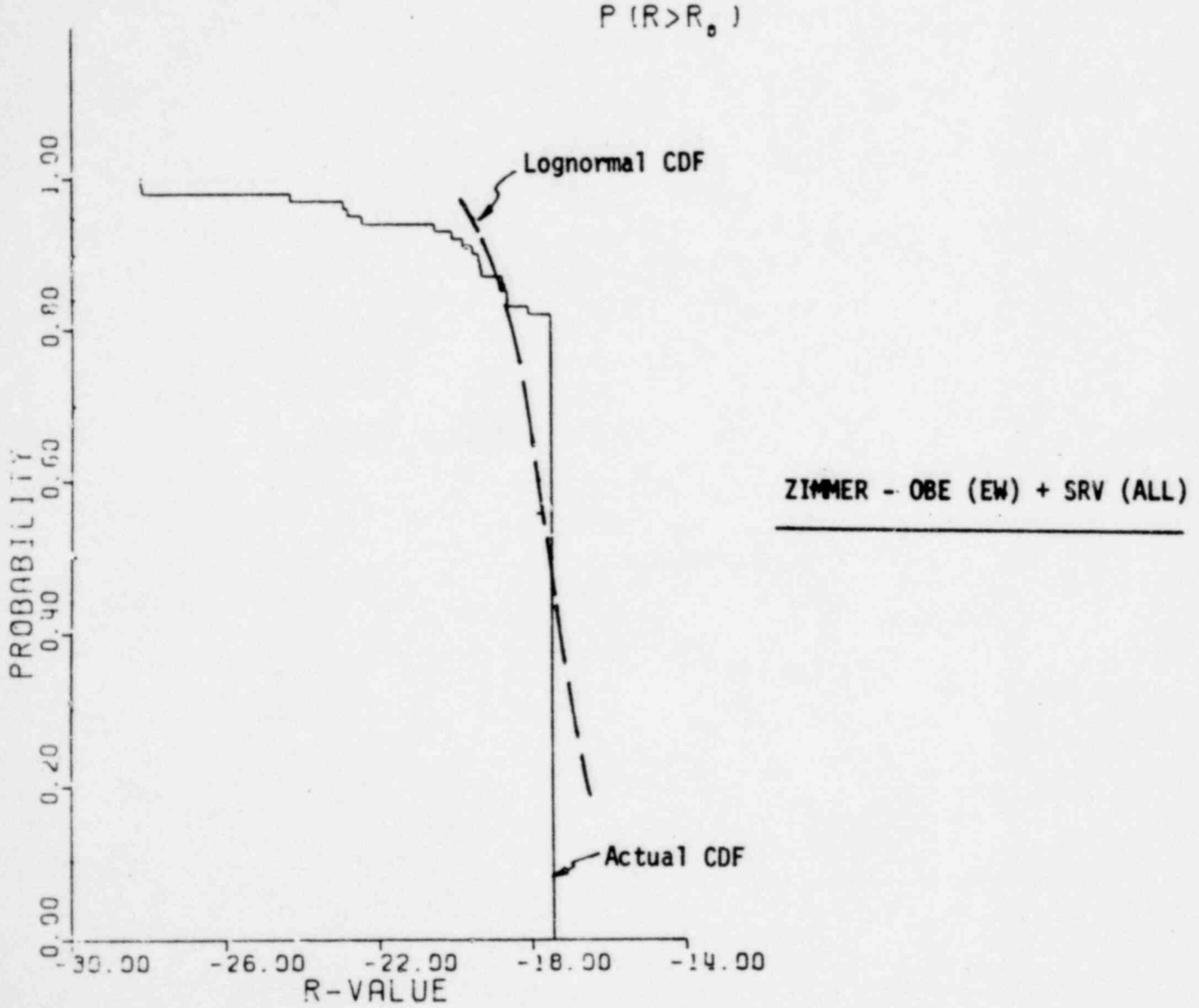

Figure 3-10. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 5

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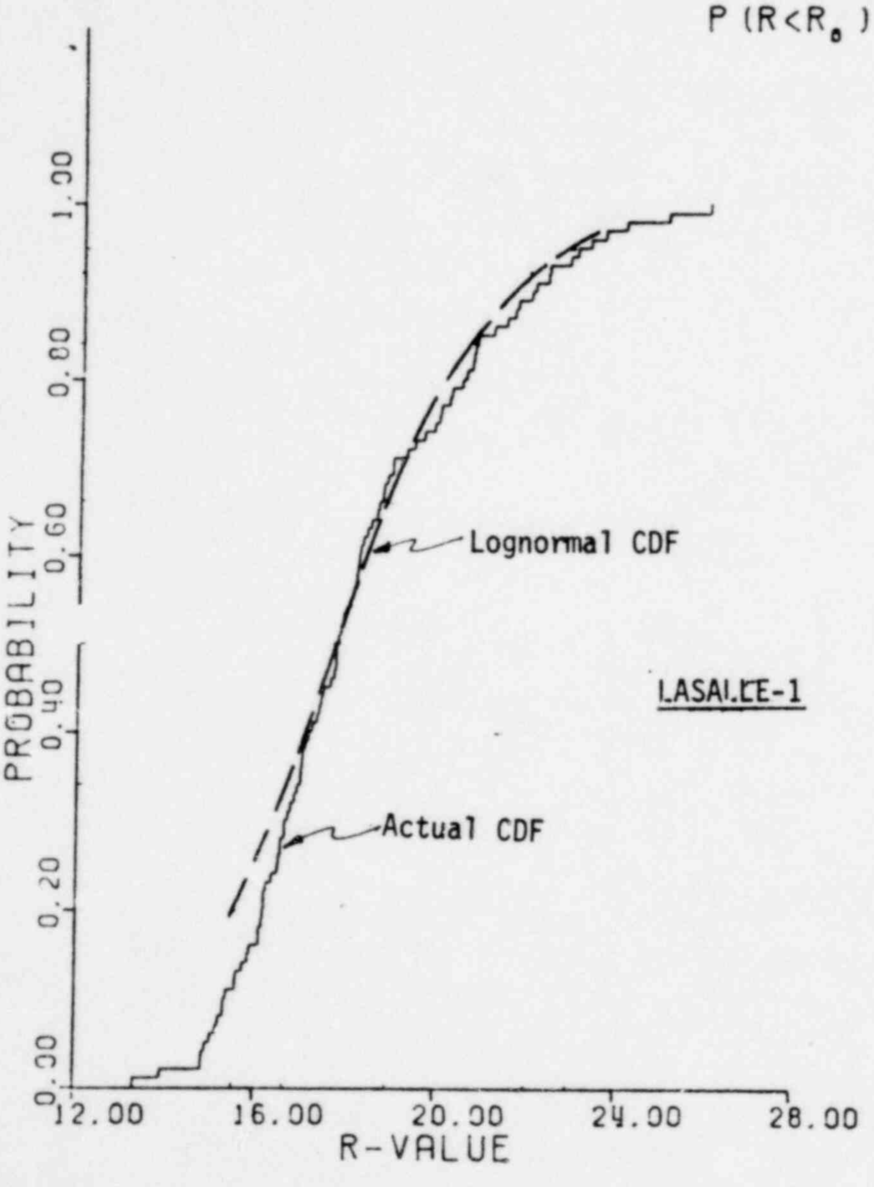

Figure 3-11. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 6

1323 276

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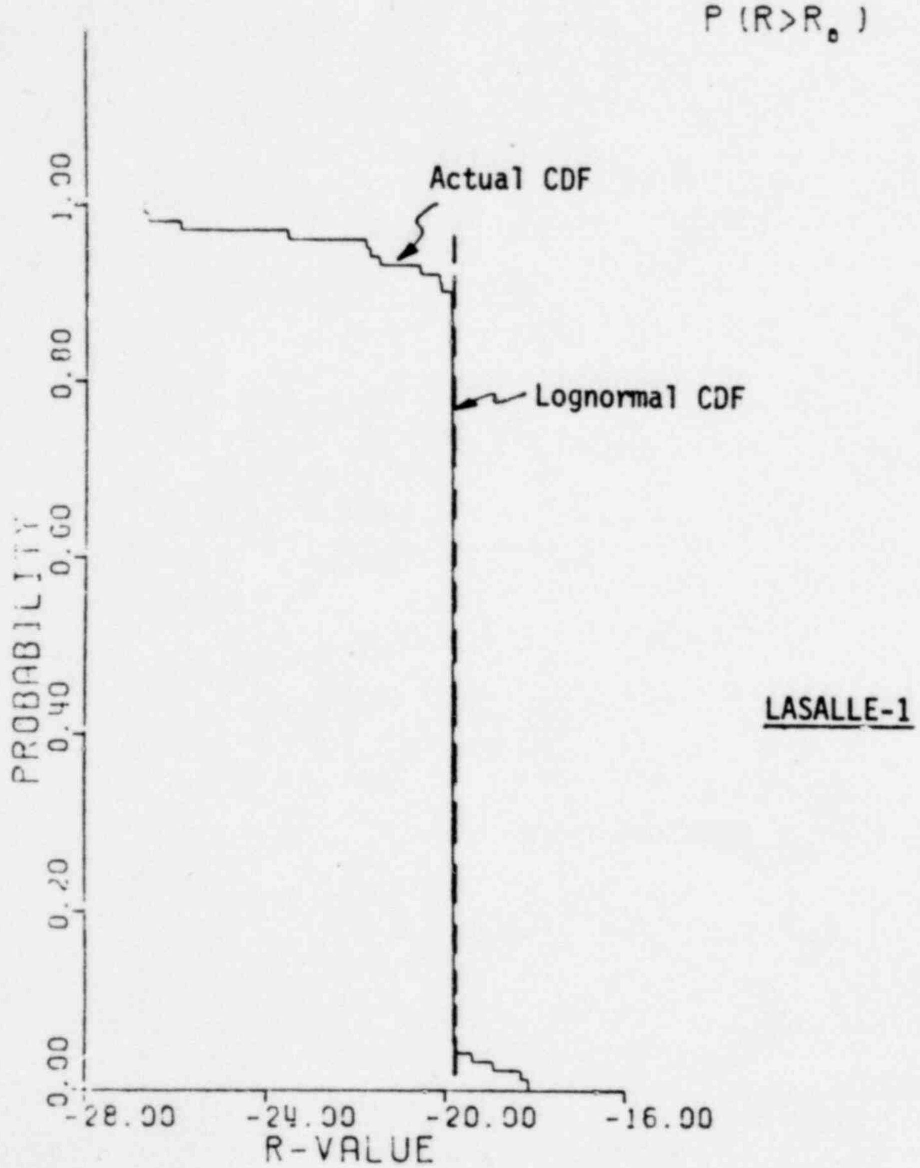

Figure 3-12. Time Phasing Only CDF Curves (Lognormal and Actual) of Case 6

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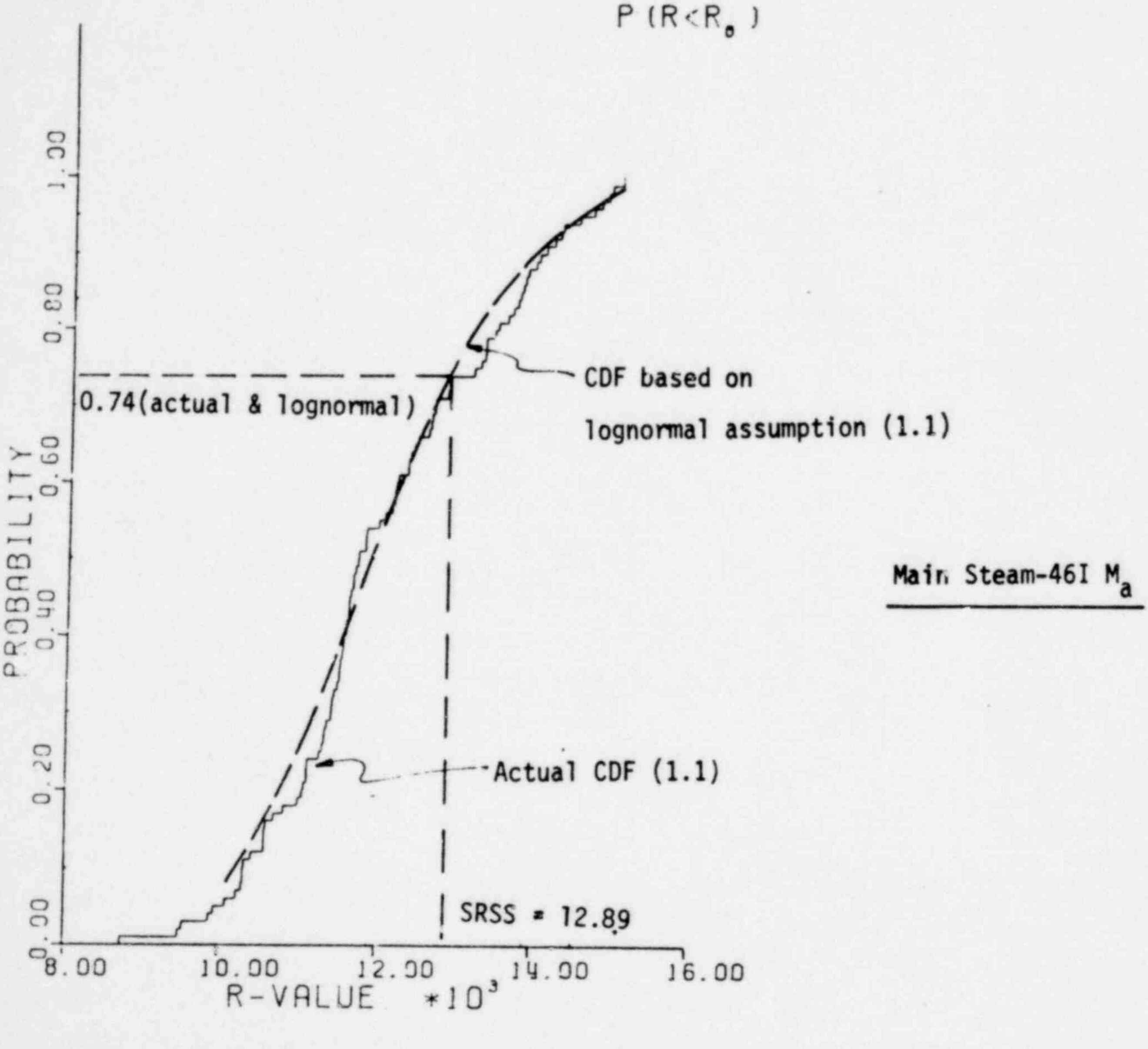

Figure 3-13. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 1

1323 278

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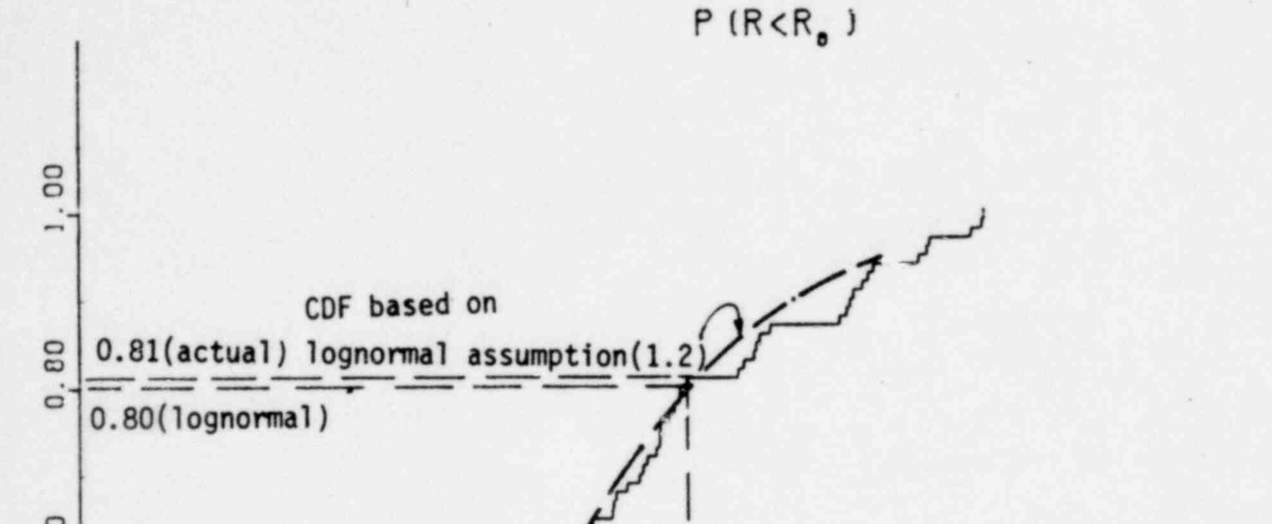

Figure 3-14. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 1

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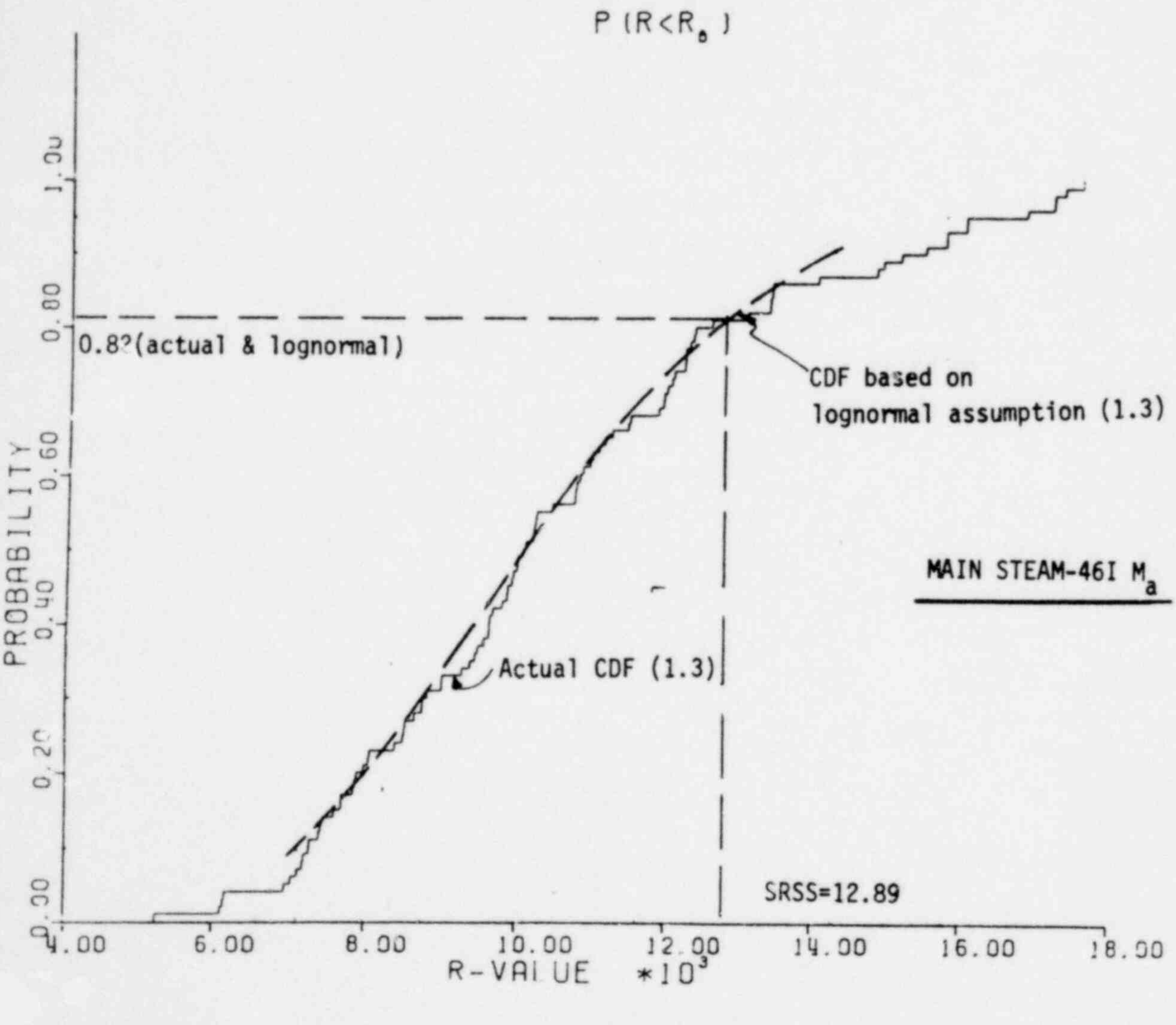

Figure 3-15. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 1

1323 280

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

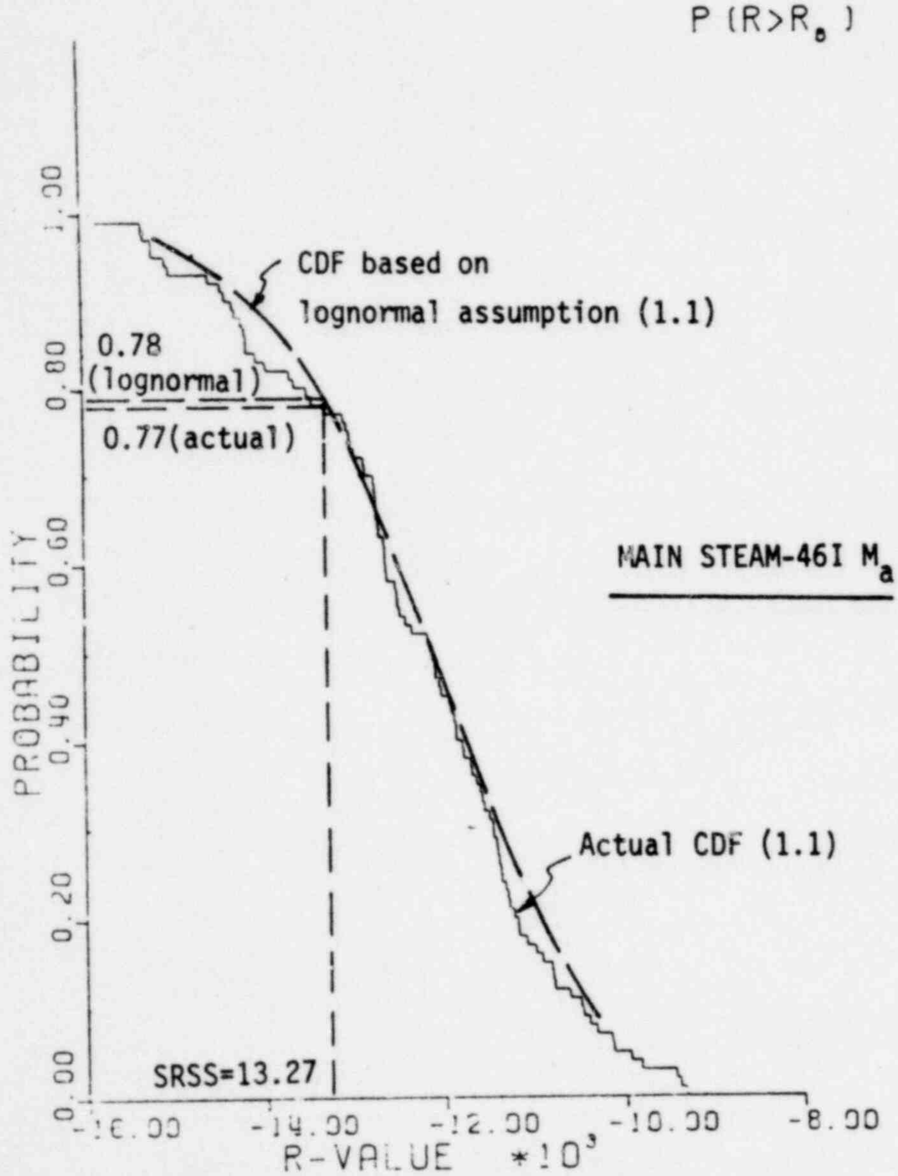

Figure 3-16. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.1) Case 1

1323 201

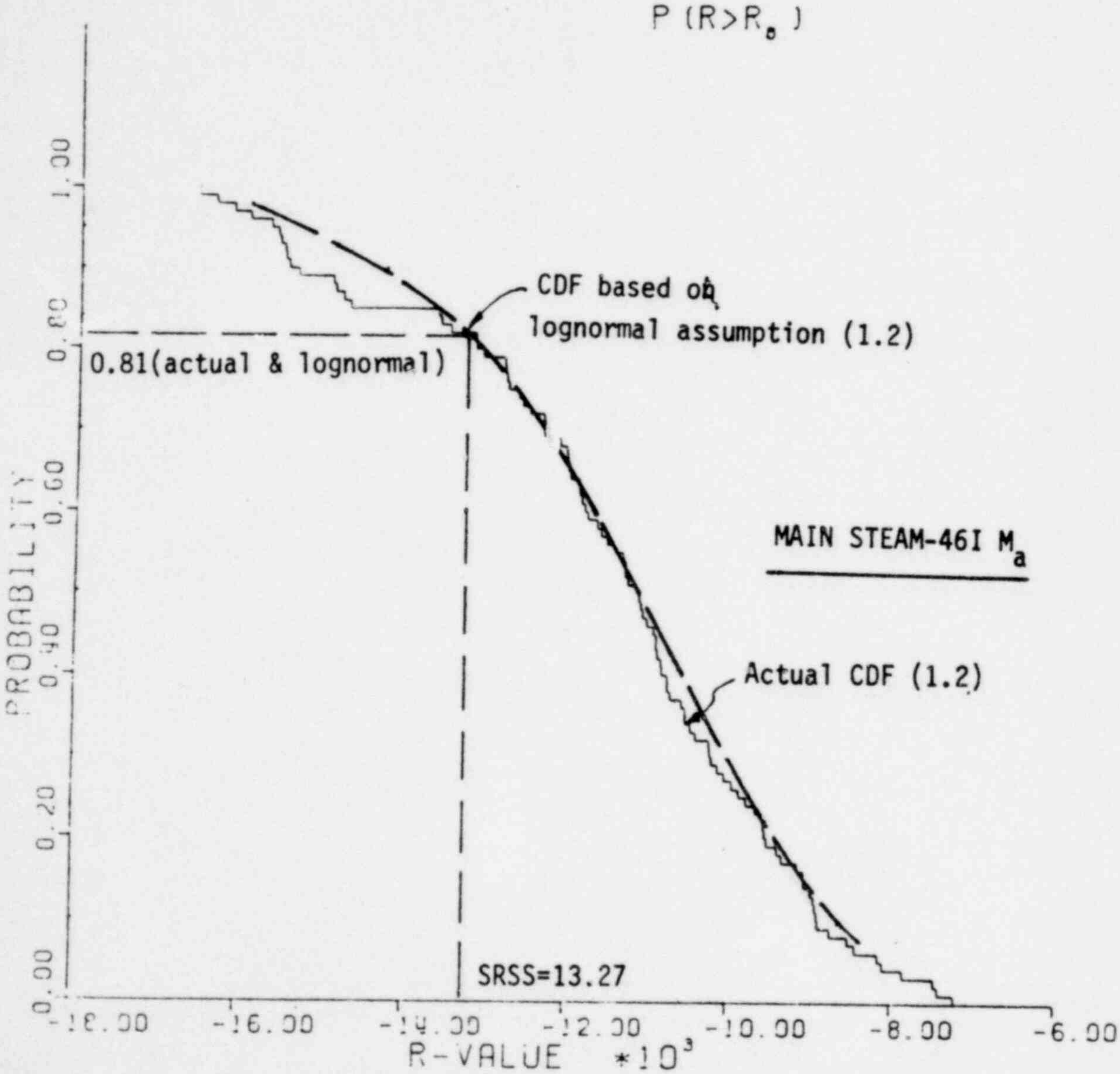

Figure 3-17. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.2) Case 1

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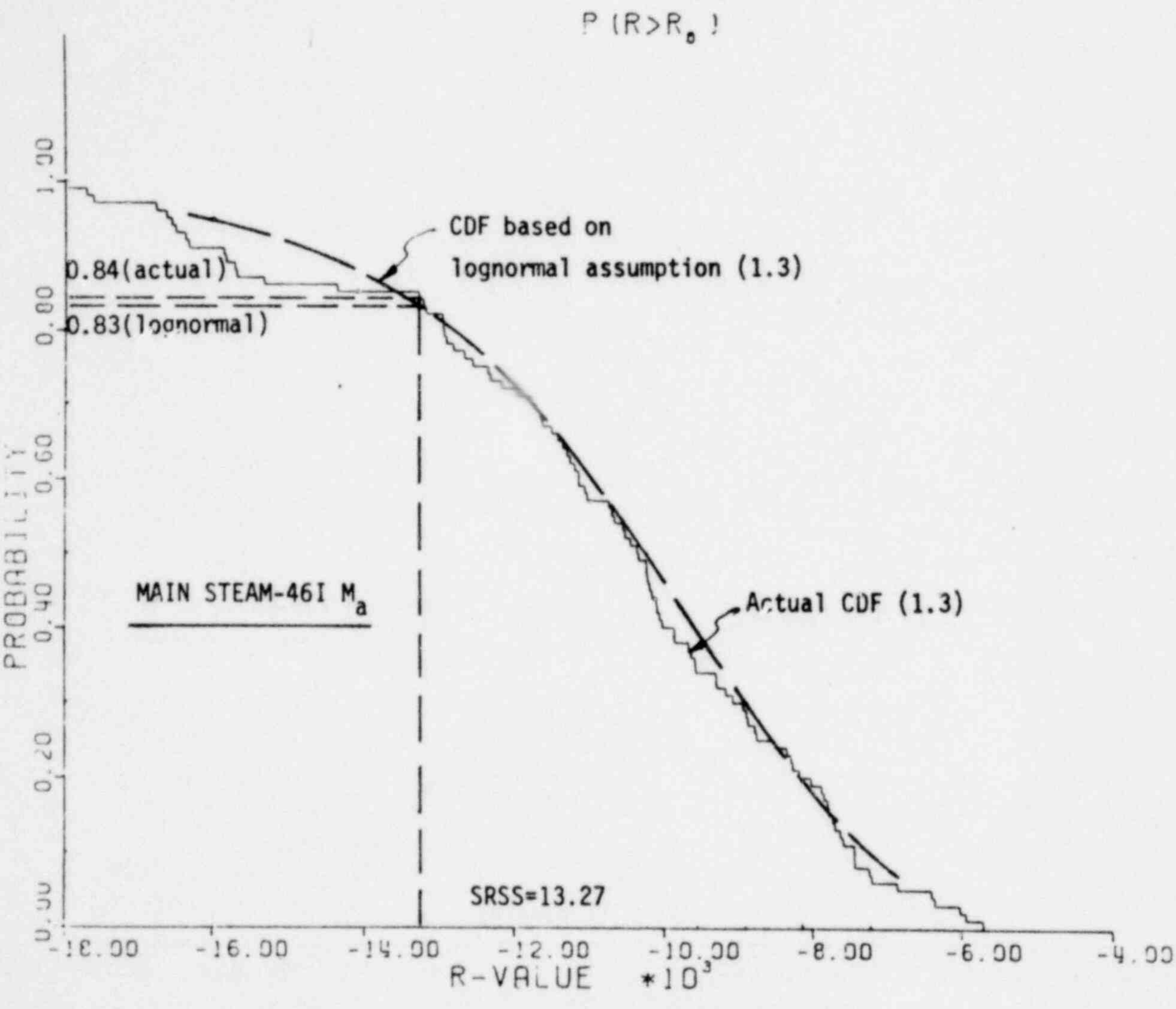

Figure 3-18. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 1

1323 283

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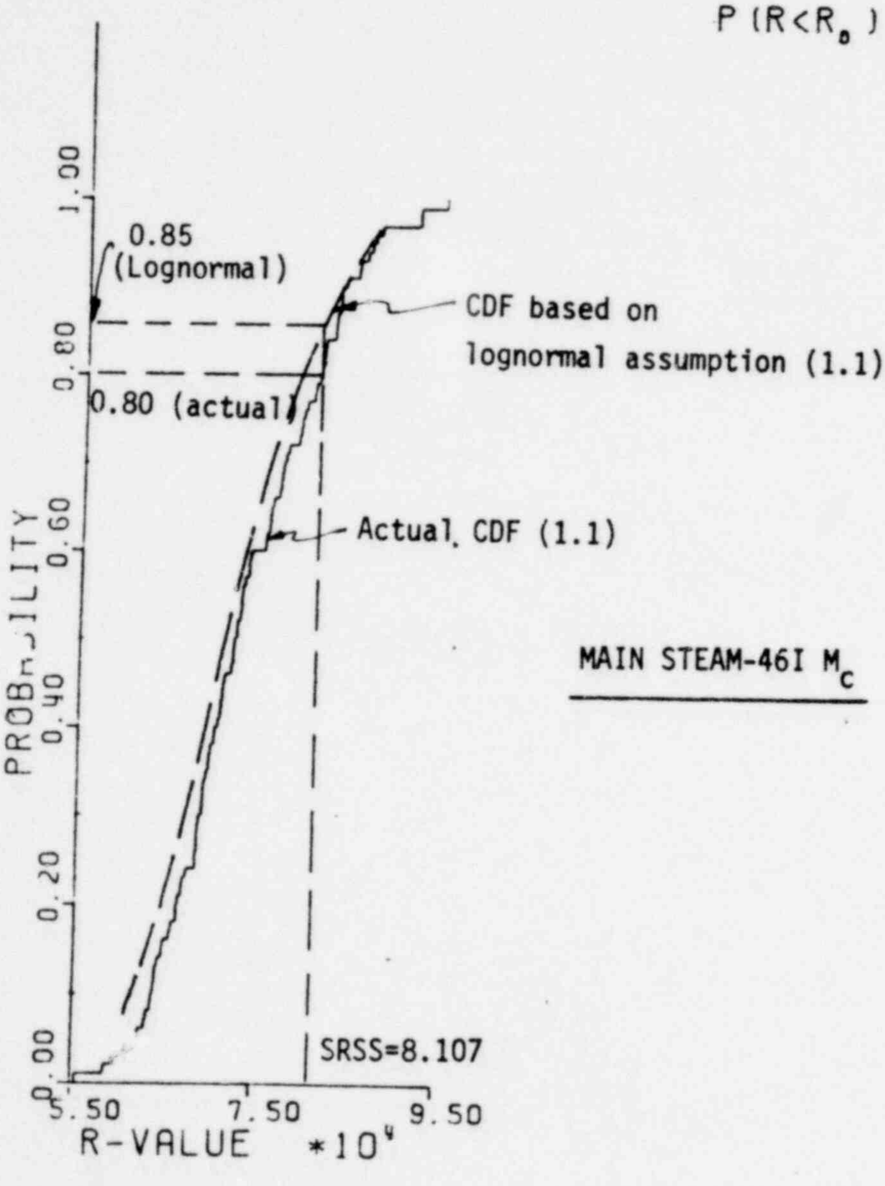

Figure 3-19. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 2

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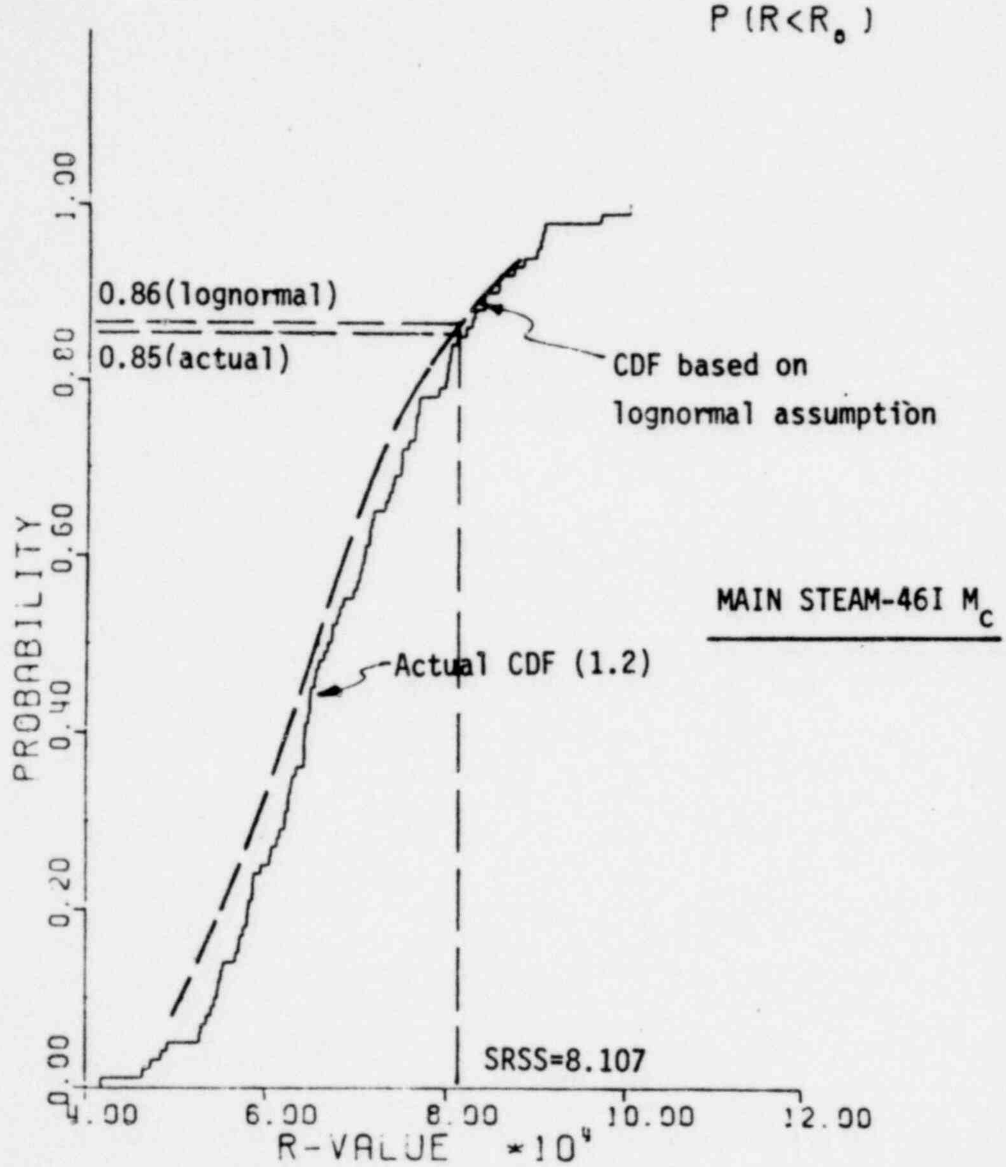

Figure 3-20. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 2

1323 285

CUMULATIVE DISTRIBUTION FUNCTION

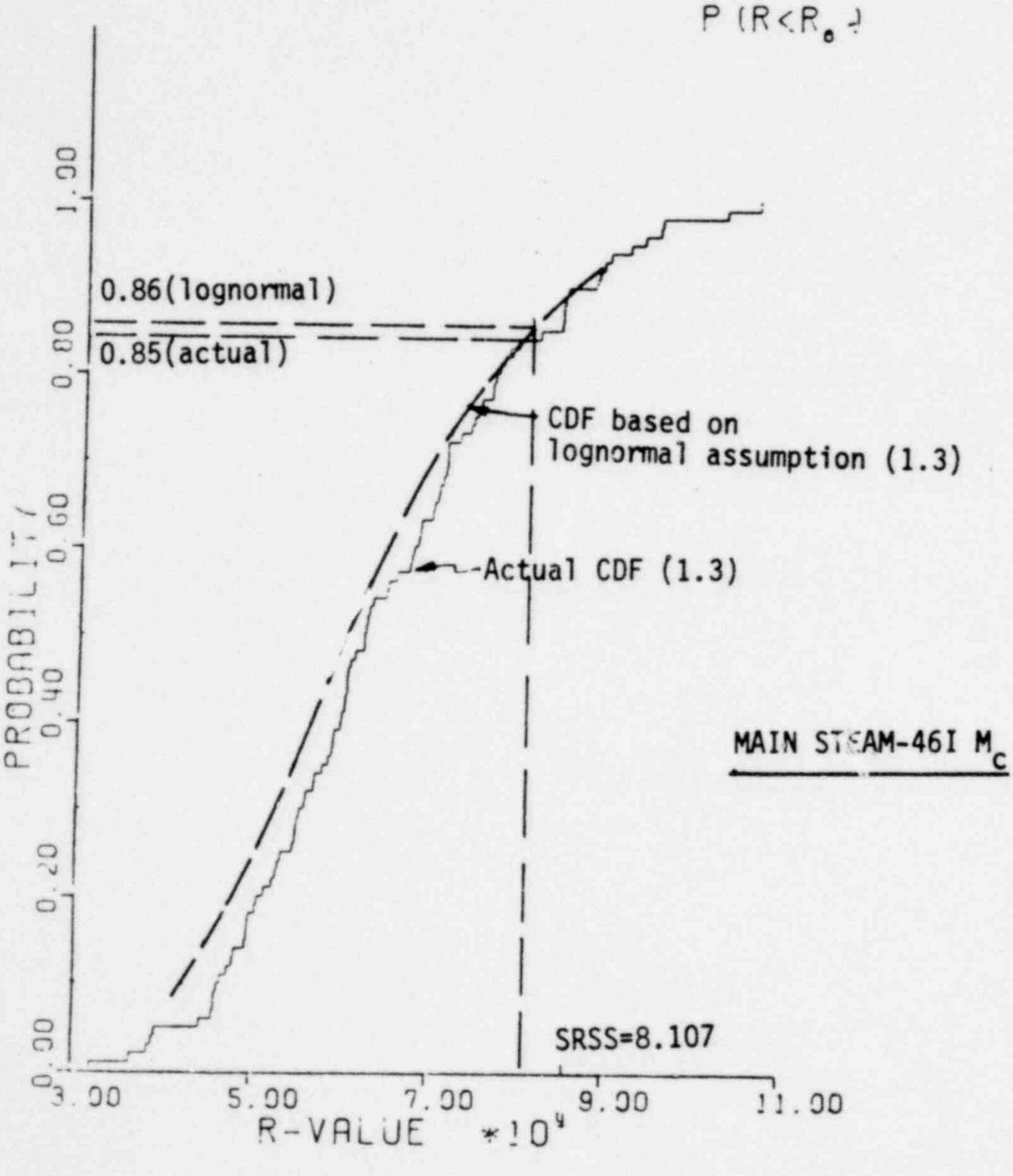

Figure 3-21. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 2

1323 286

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

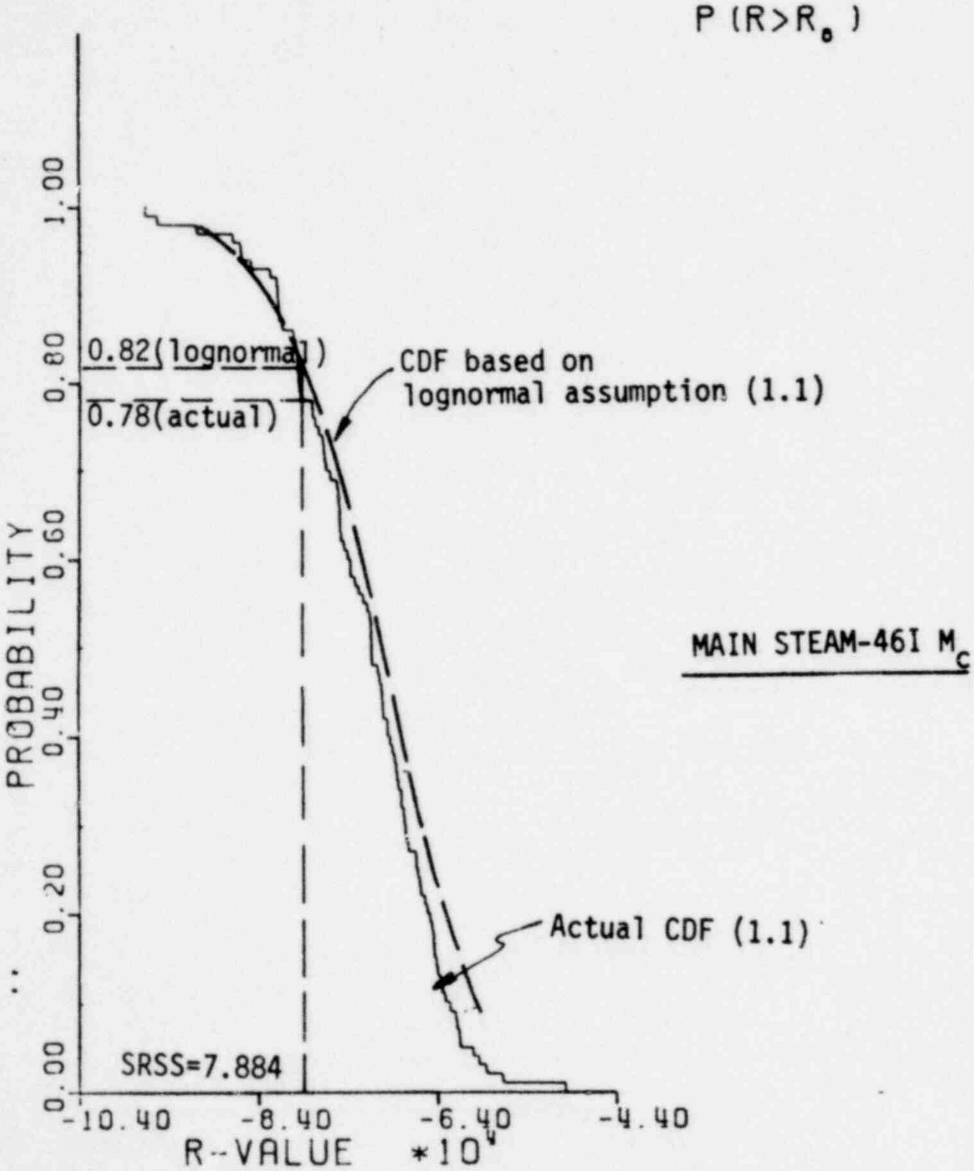

Figure 3-22. Compari on of Actual Complementary CDF and Approximate CDF (δ = 1 1) Case 2

1323 287

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

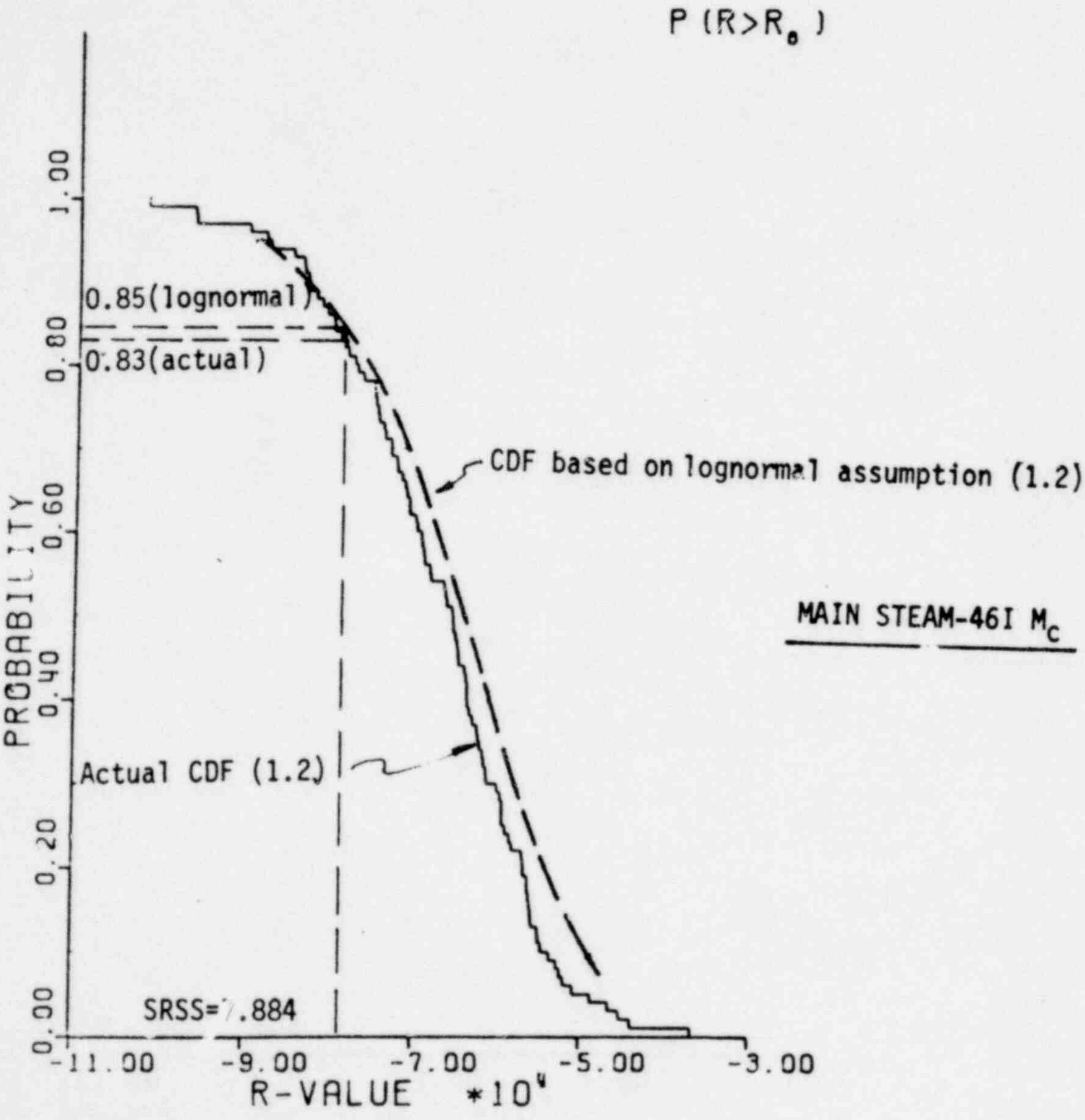

Figure 3-23. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.2) Case 2

1323 288

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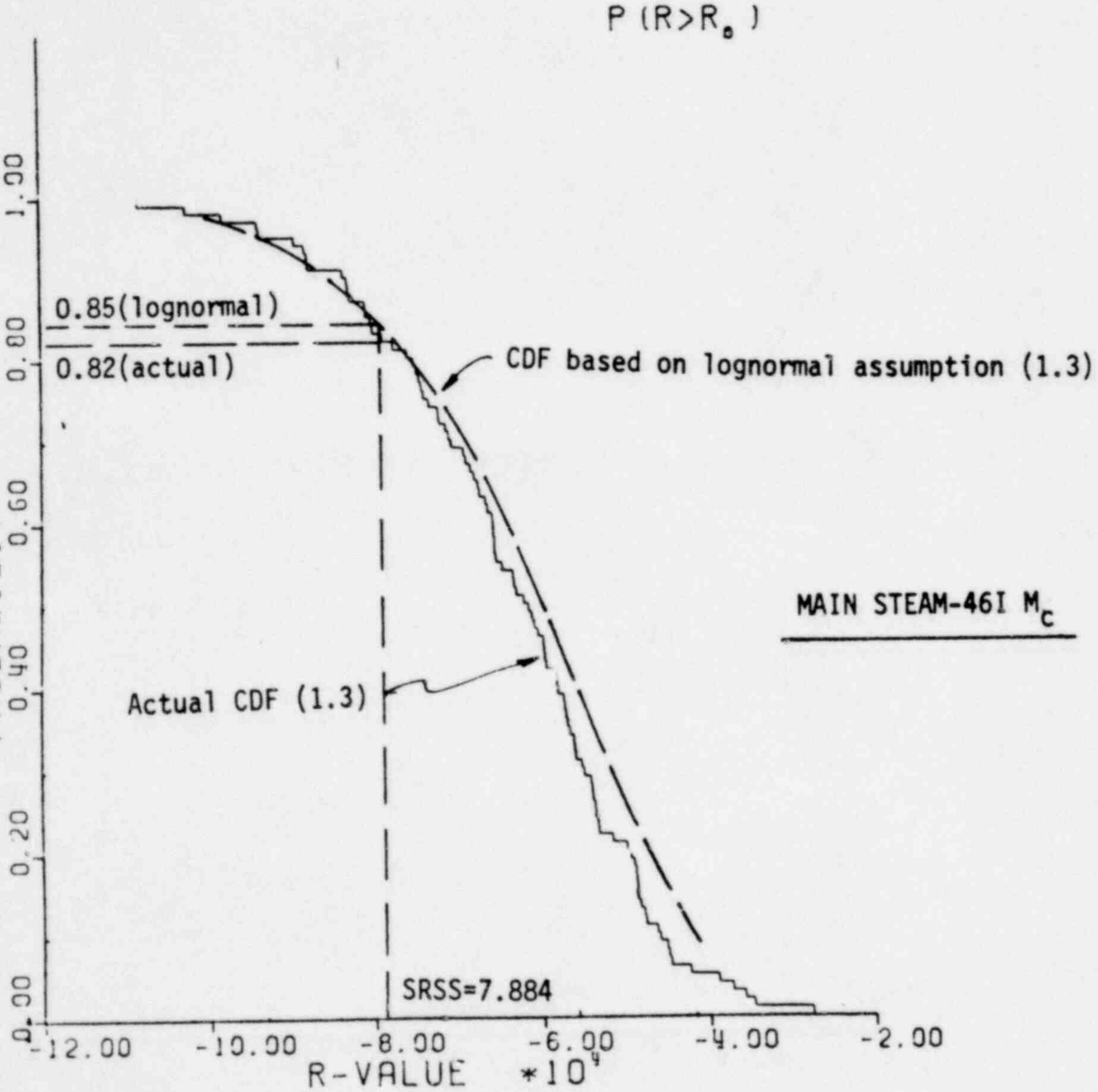

Figure 3-24. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 2

1323 289

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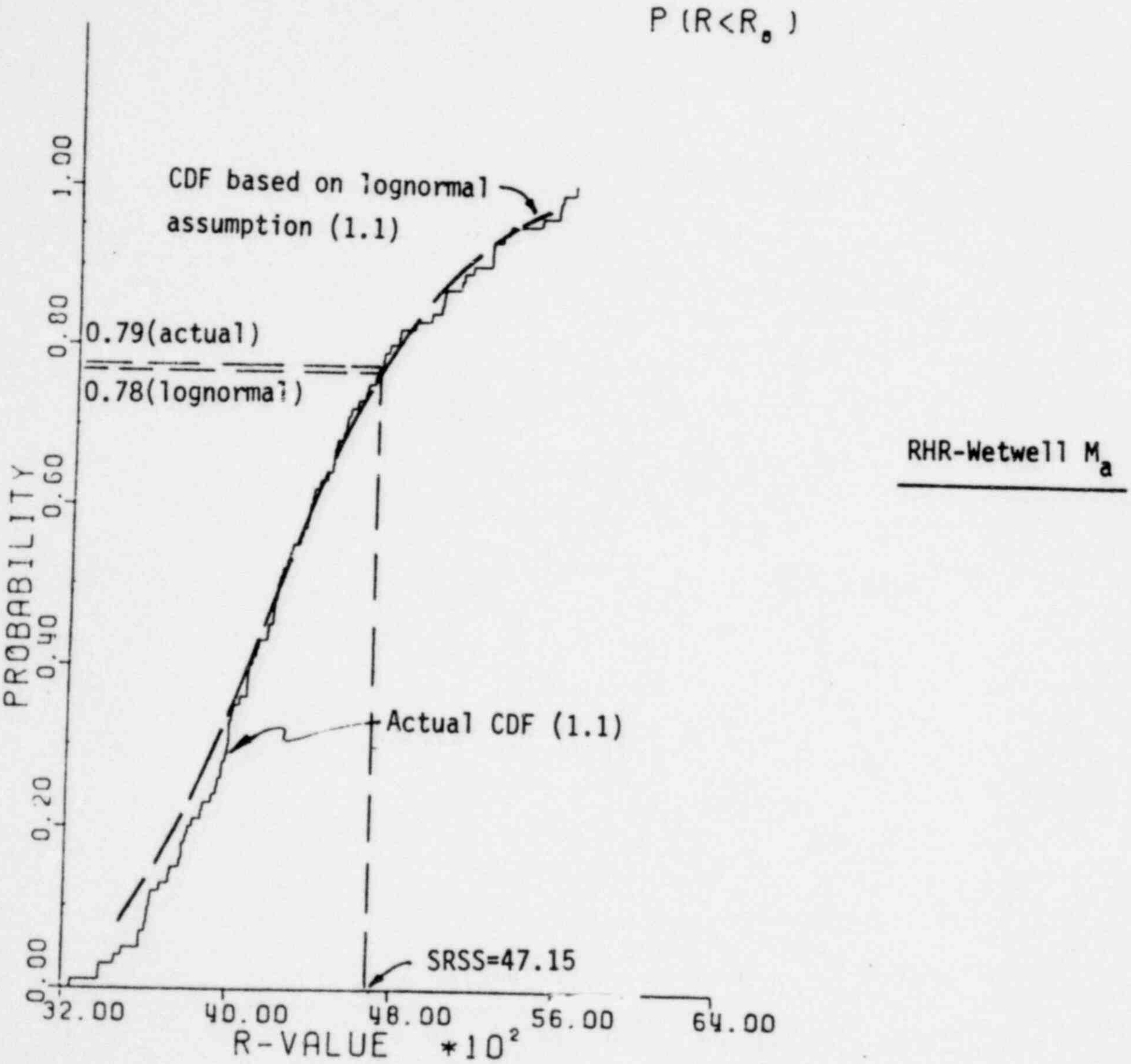

Figure 3-25. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 3

1323 290

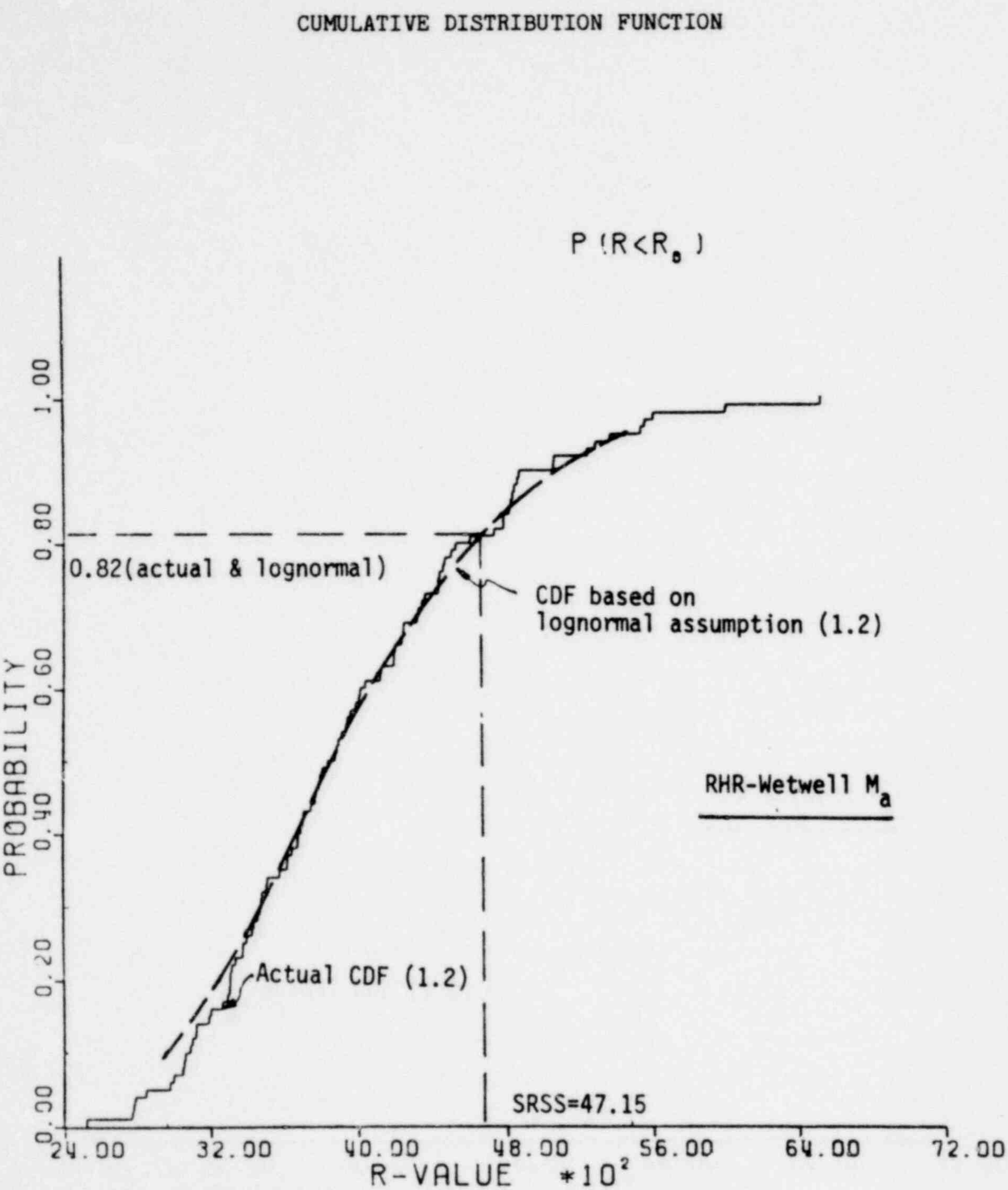

Figure 3-26. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 3

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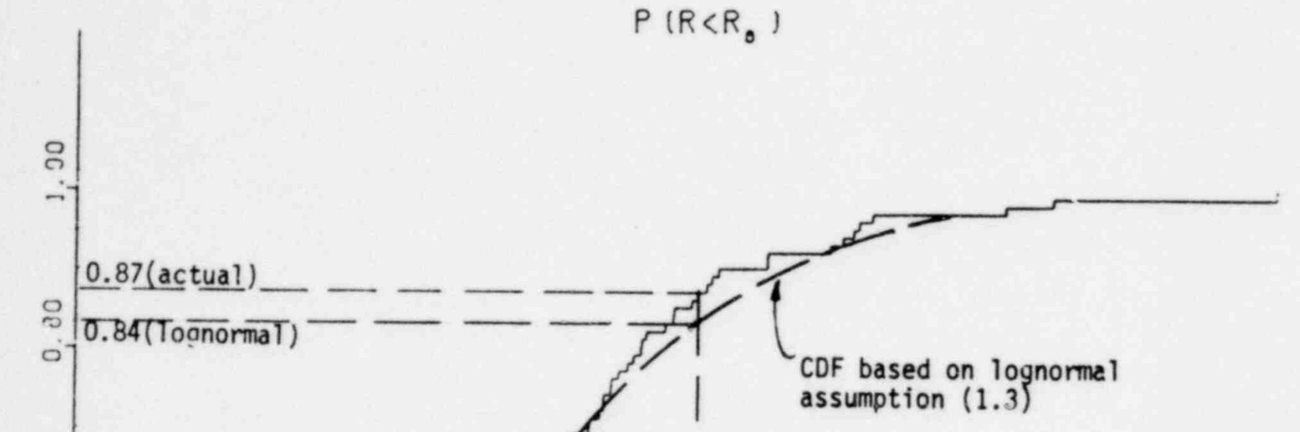

Figure 3-27. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 3

1323 292

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

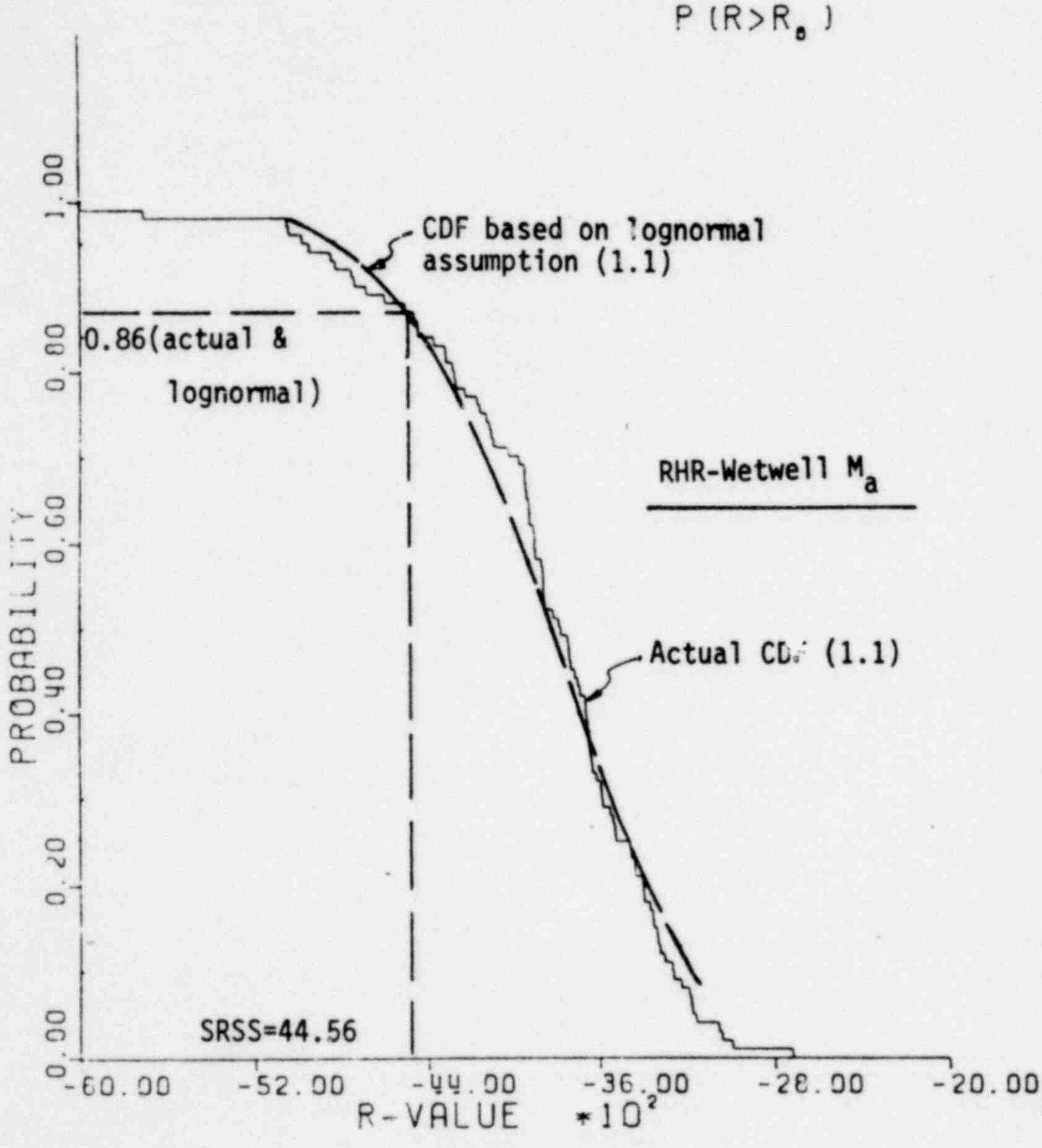

Figure 3-28. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.1) Case 3

1323 293

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

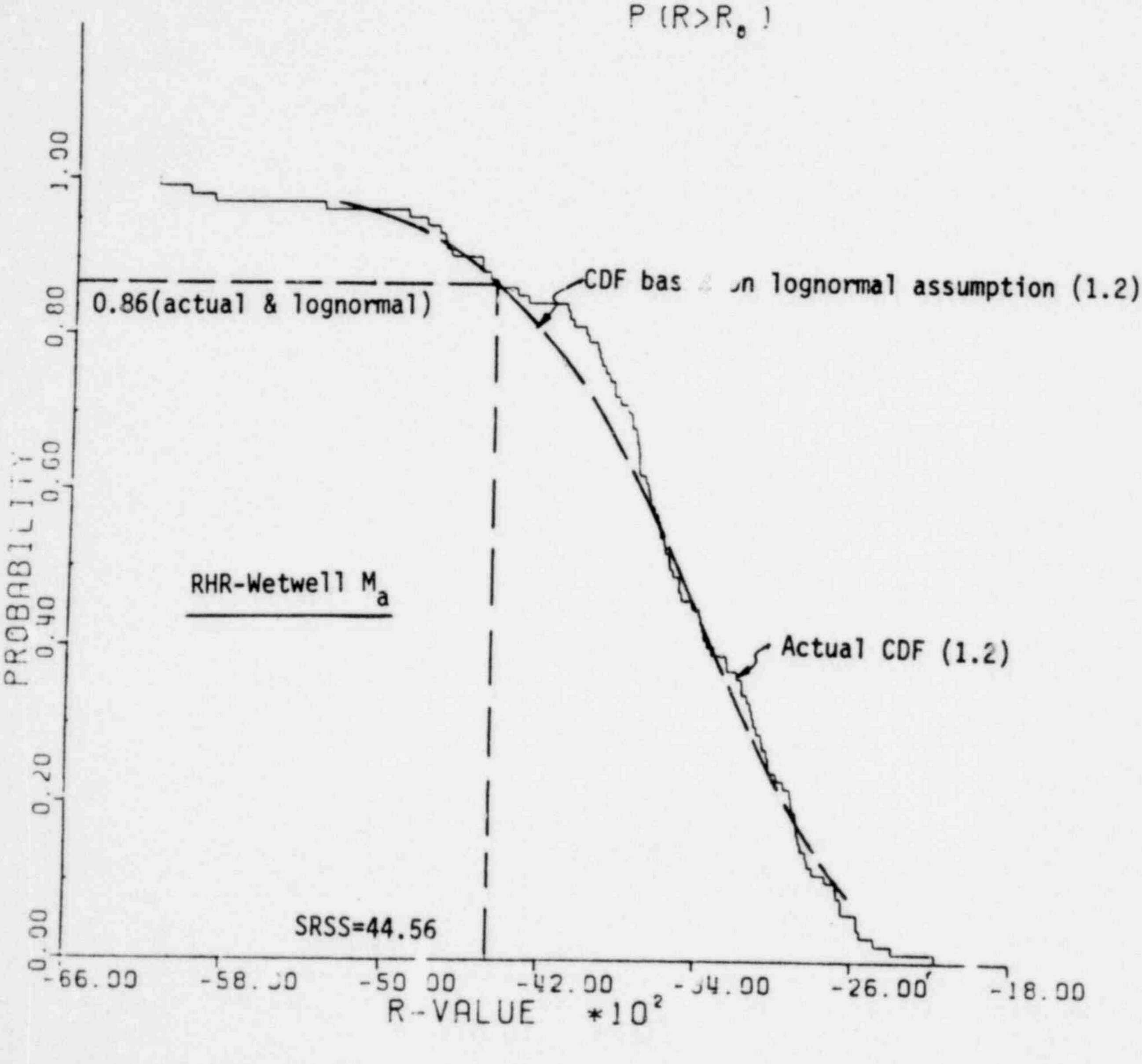

Figure 3-29. Comparison of Actual Complementary CDF and Approximate CDF (δ=1.2) Case 3

1323 294

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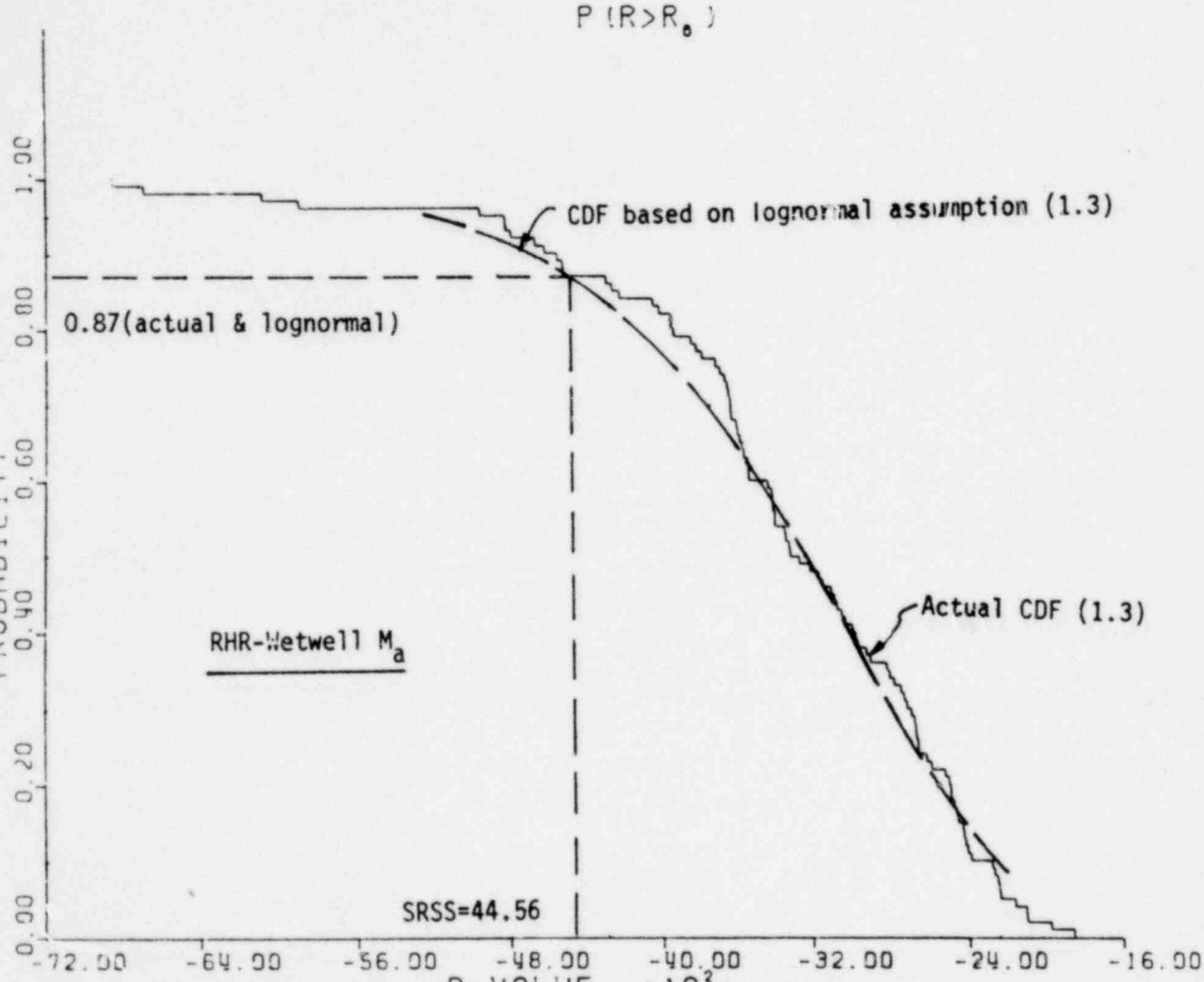

Figure 3-30. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 3

1323 295

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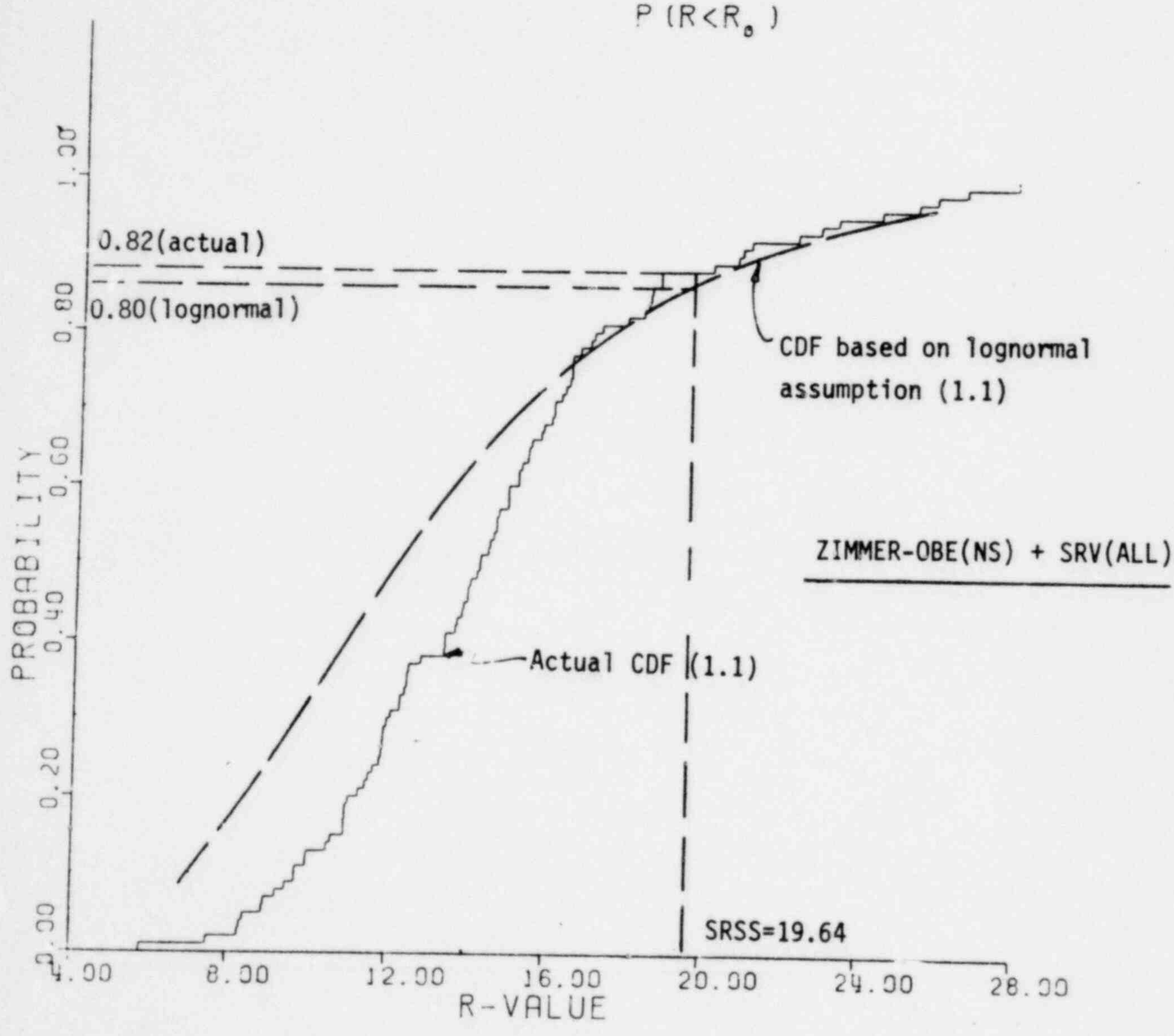

Figure 3-31. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 4

1323 296

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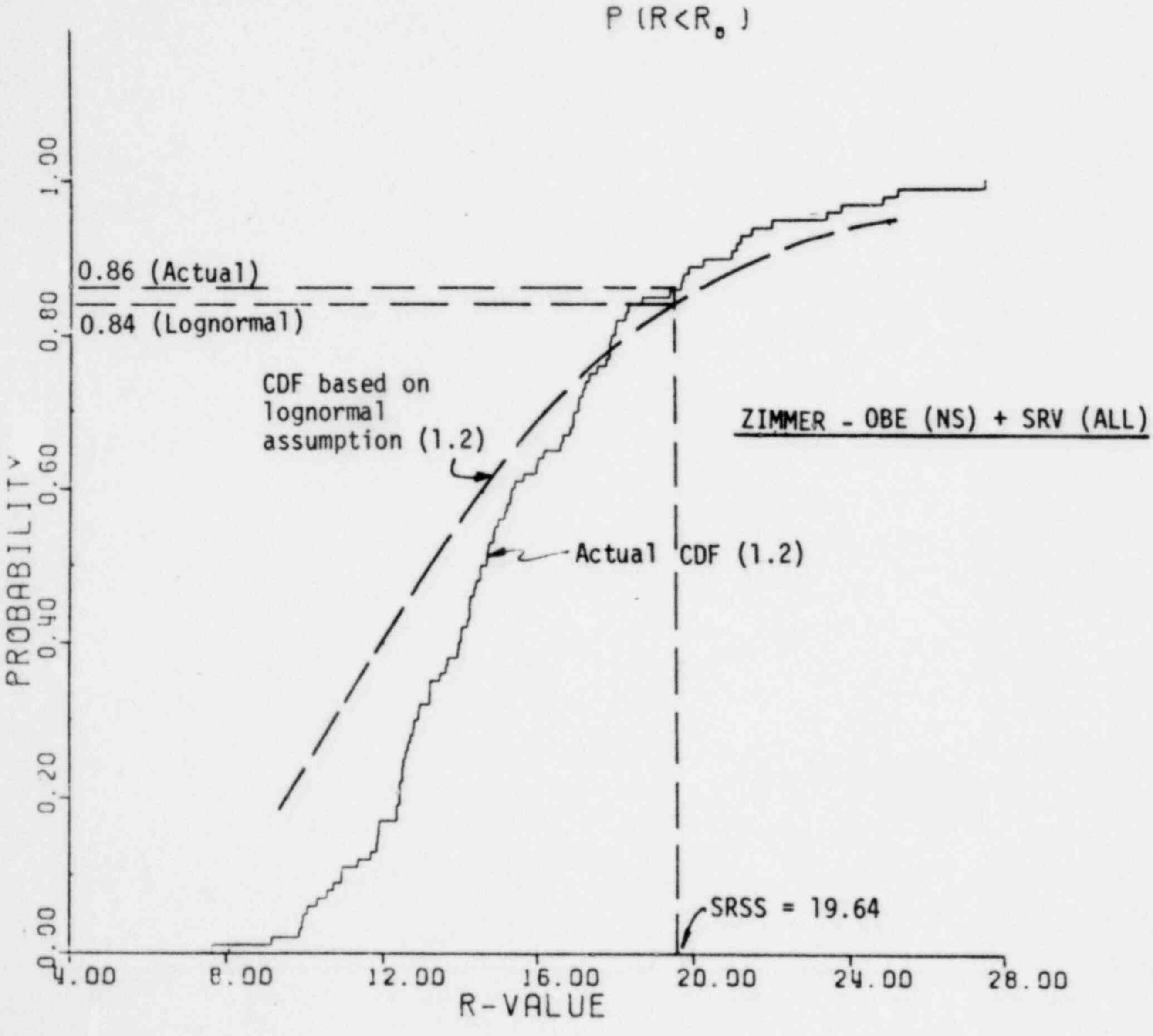

Figure 3-32. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 4

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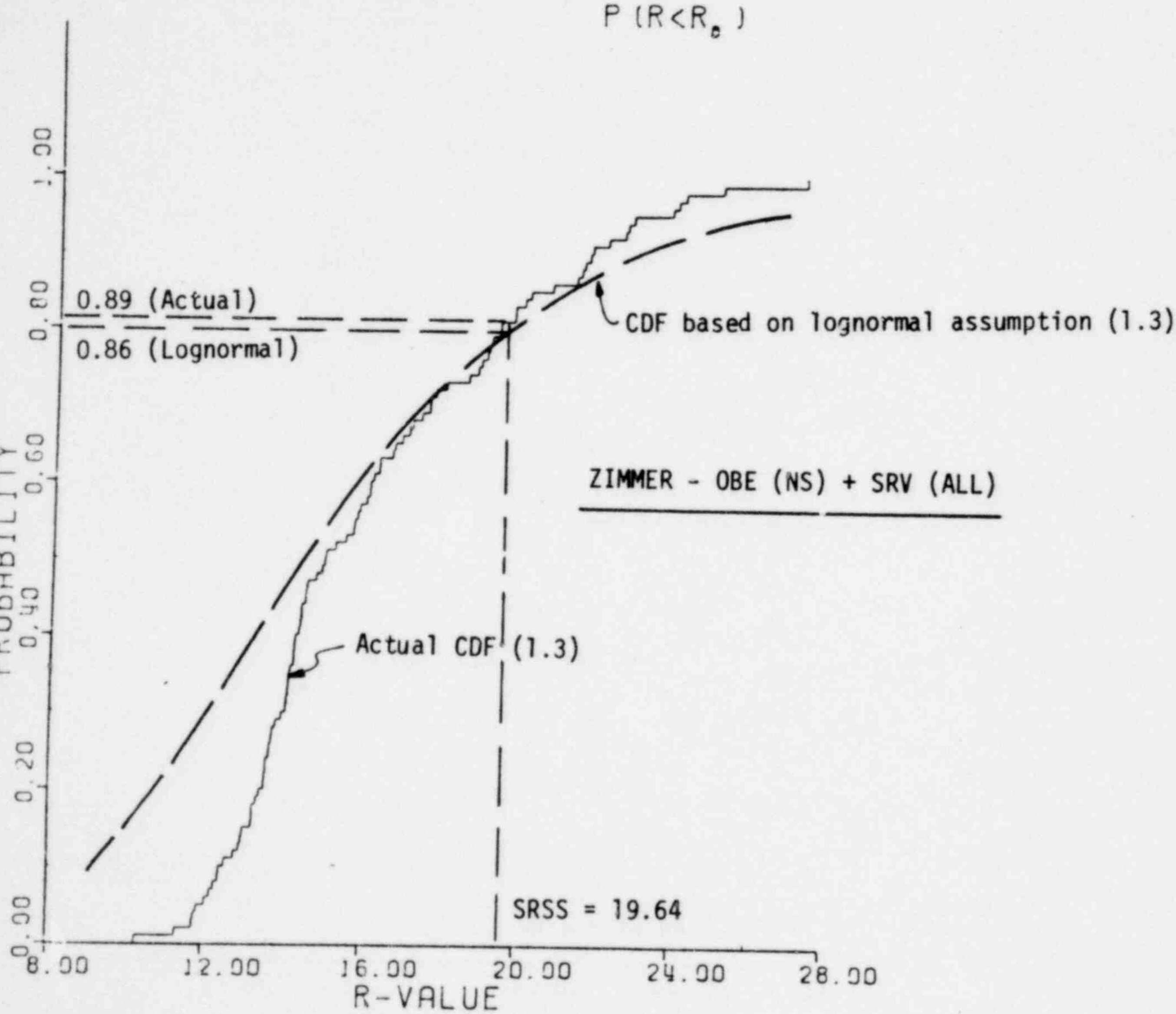

Figure 3-33. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 4

1323 298

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

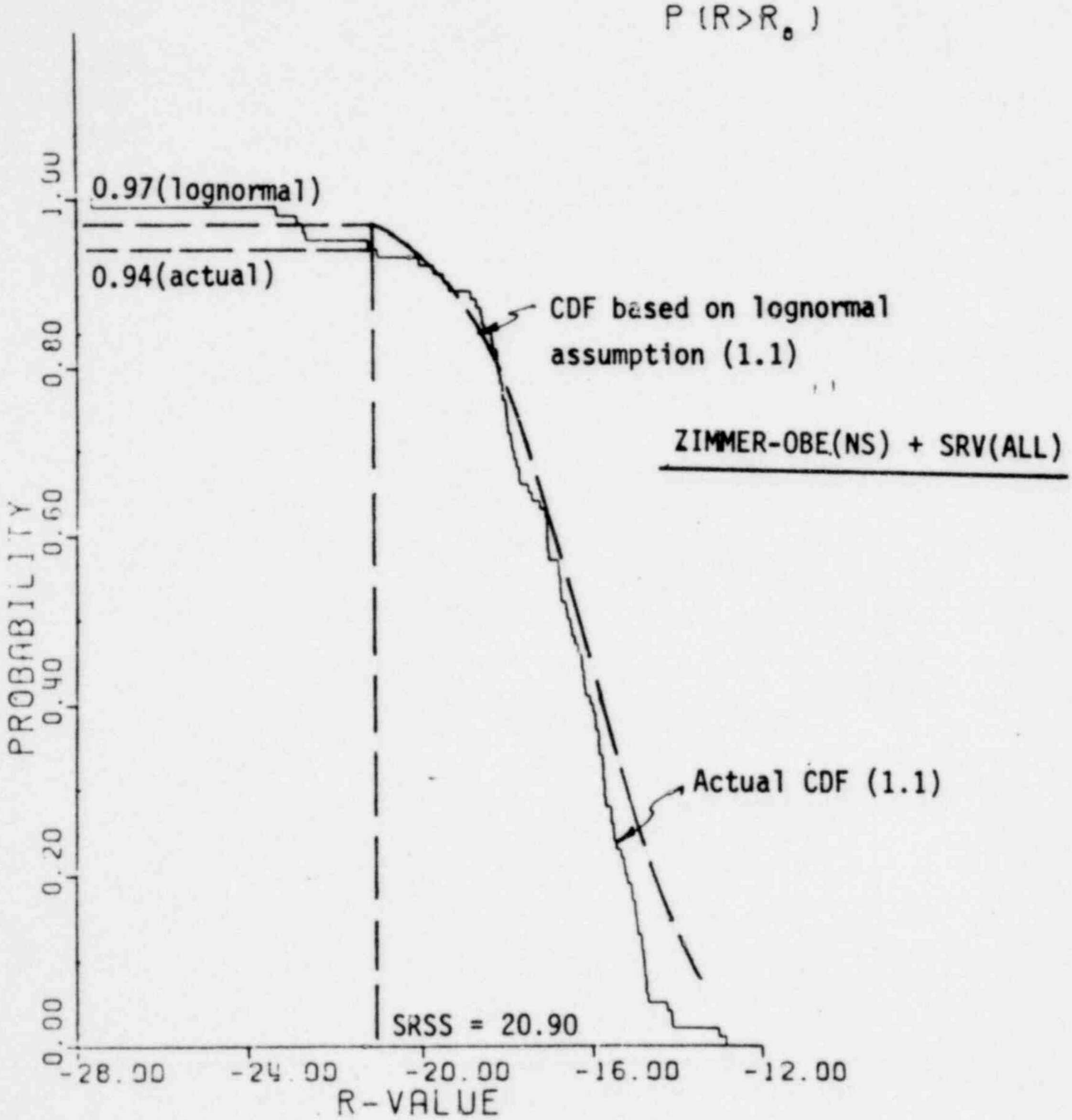

Figure 3-34. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.1) Case 4

1323 299

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

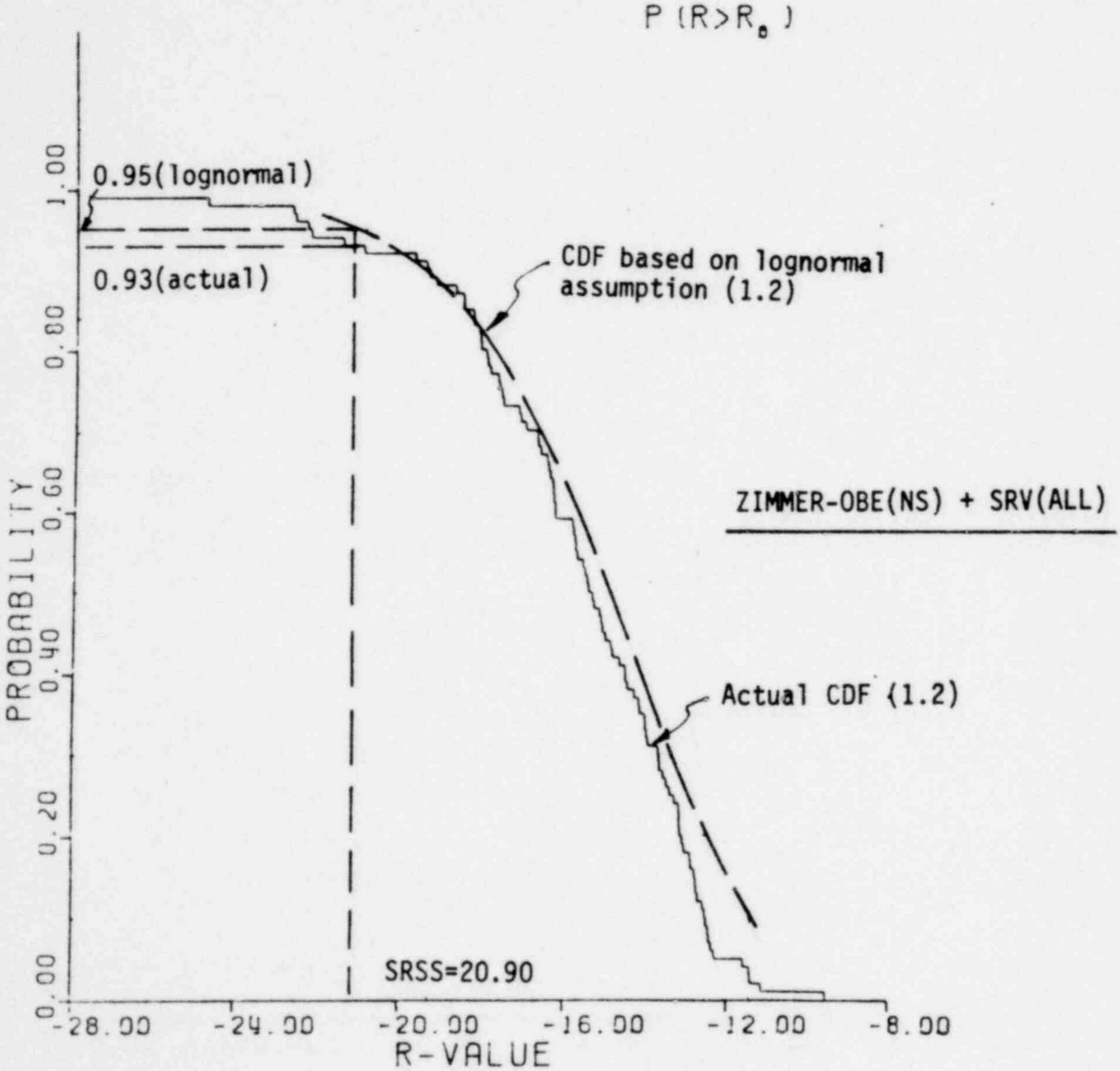

Figure 3-35. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.2) Case 4

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

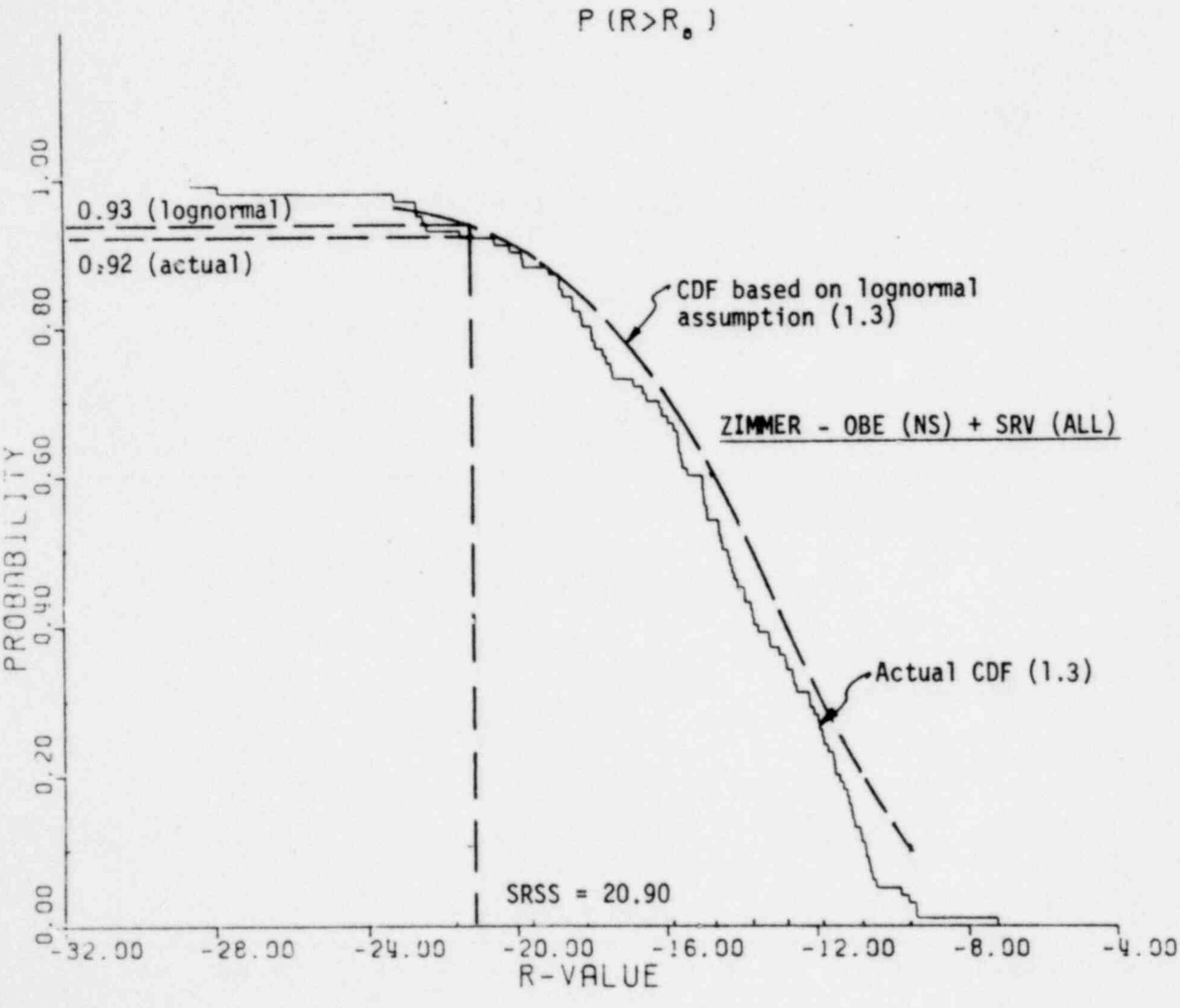

Figure 3-36. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 4

1323 301

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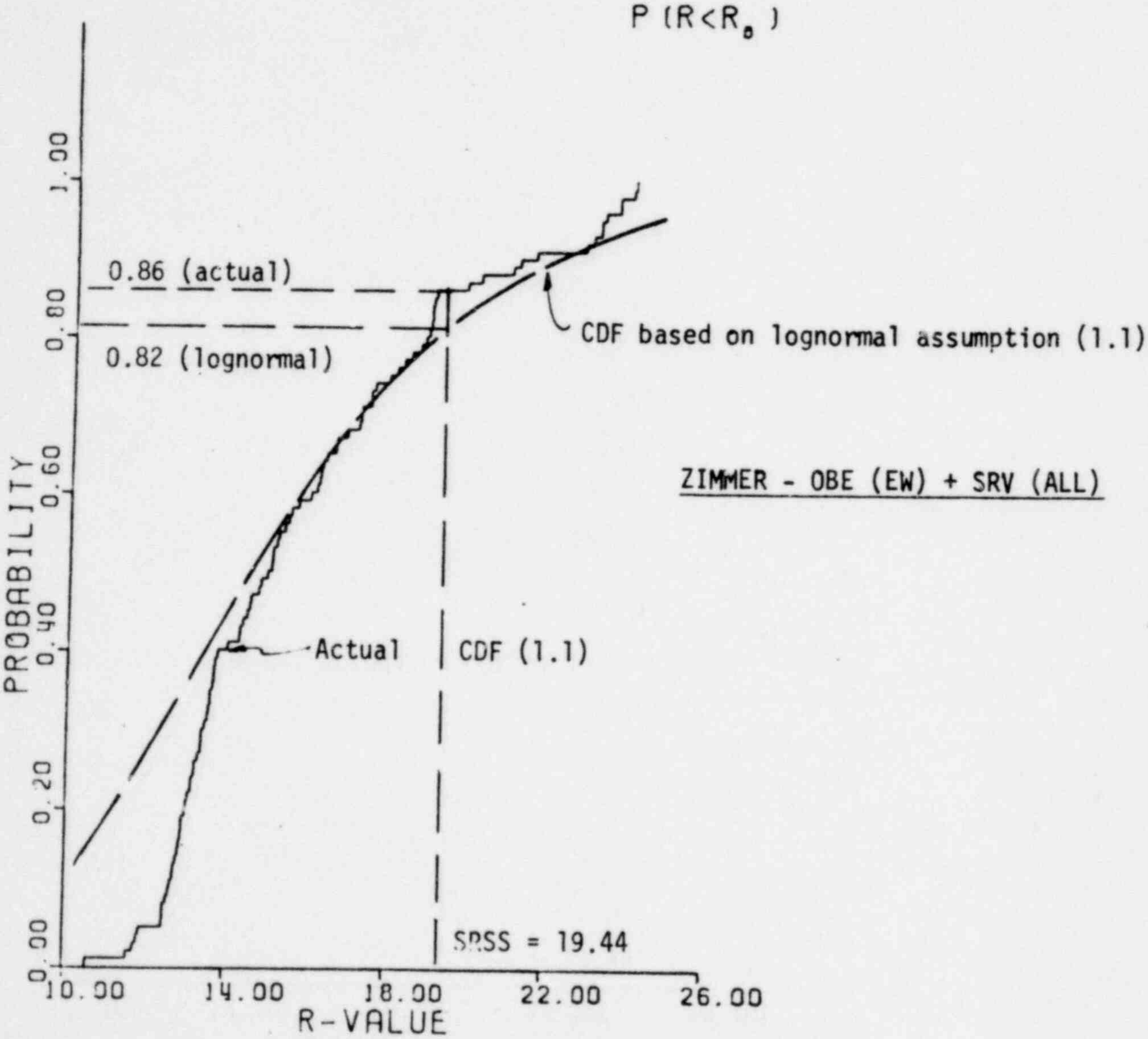

Figure 3-37. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 5

1323 302

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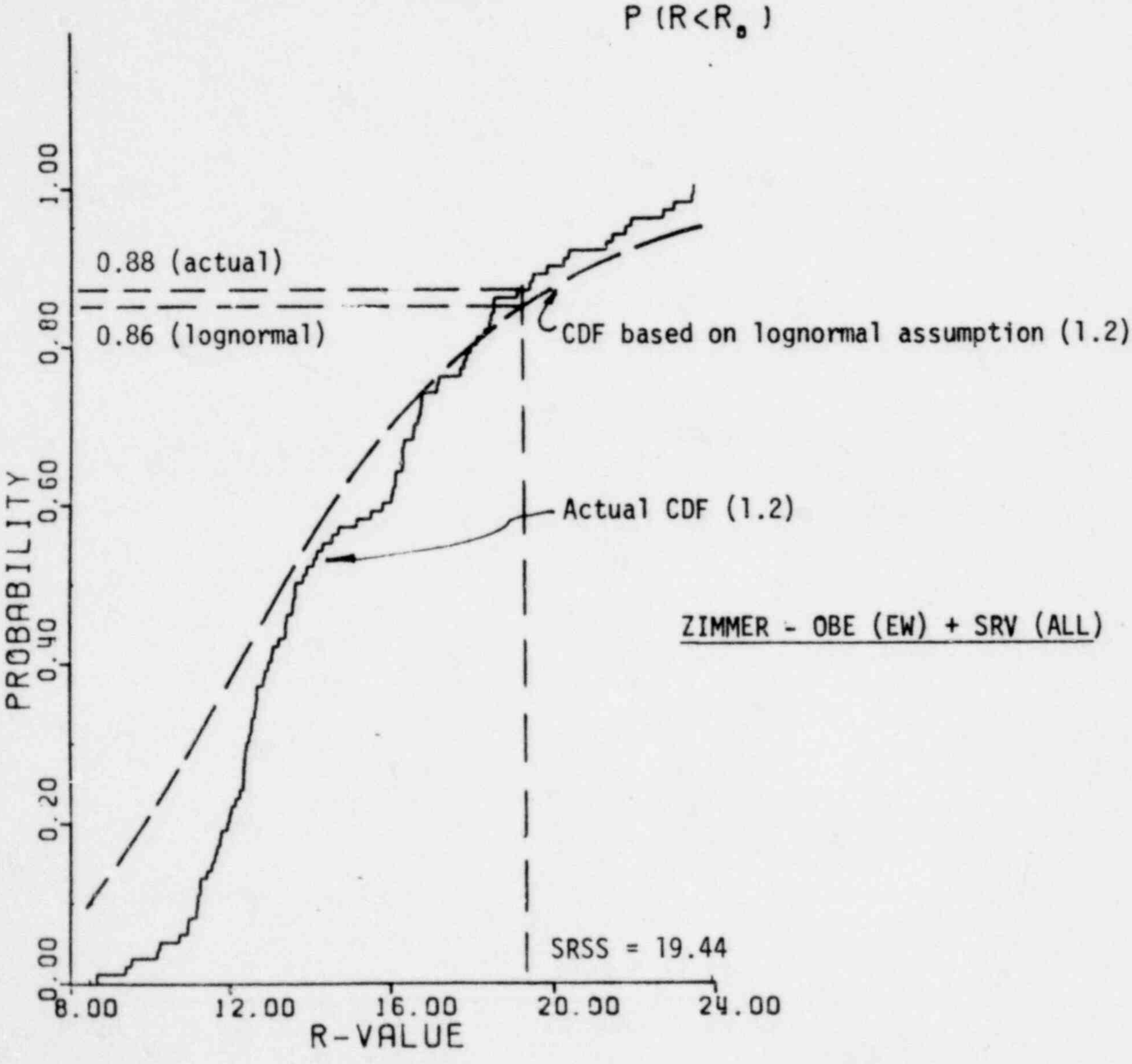

Figure 3-38. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 5

1323 303

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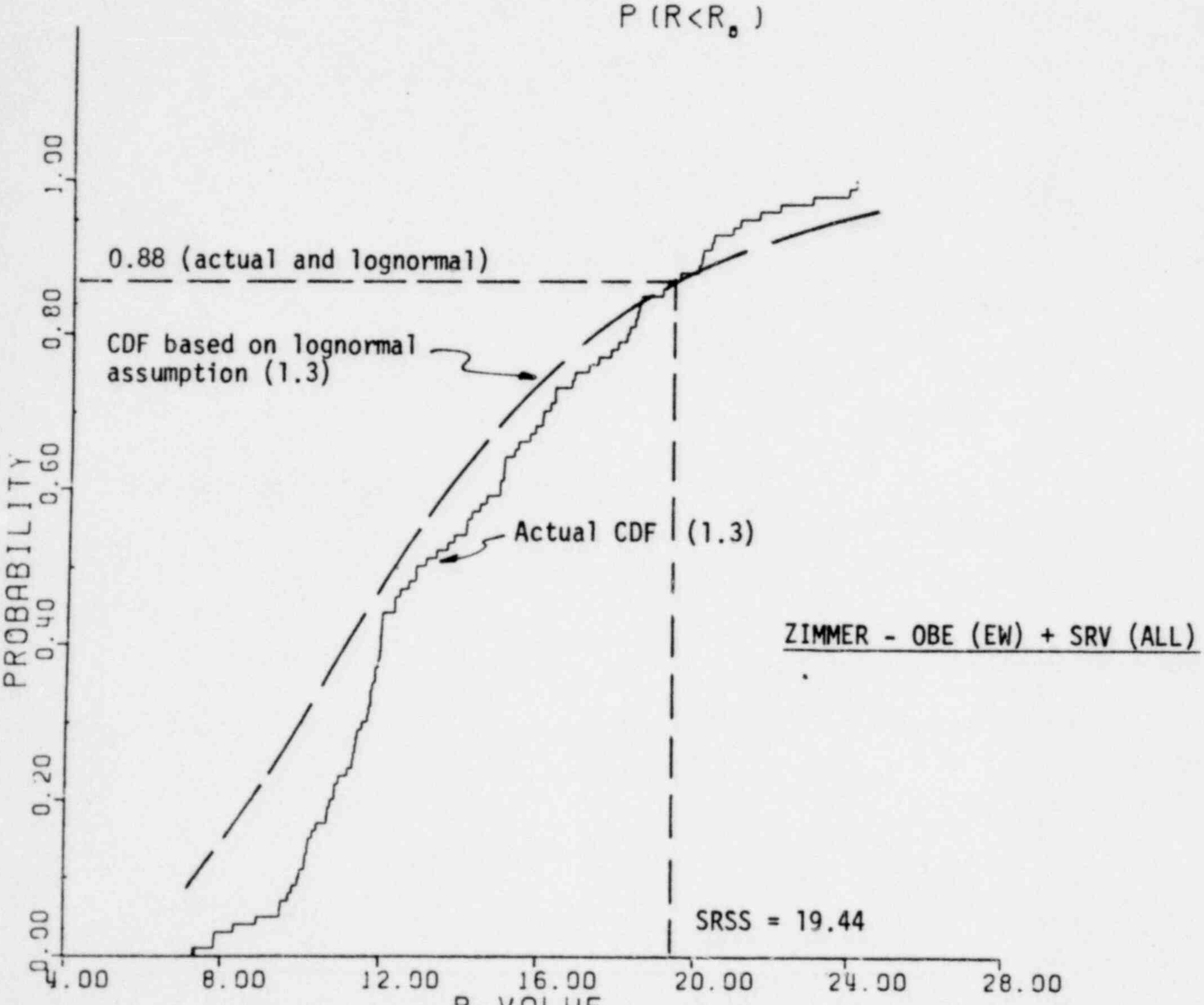

Figure 3-39. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 5

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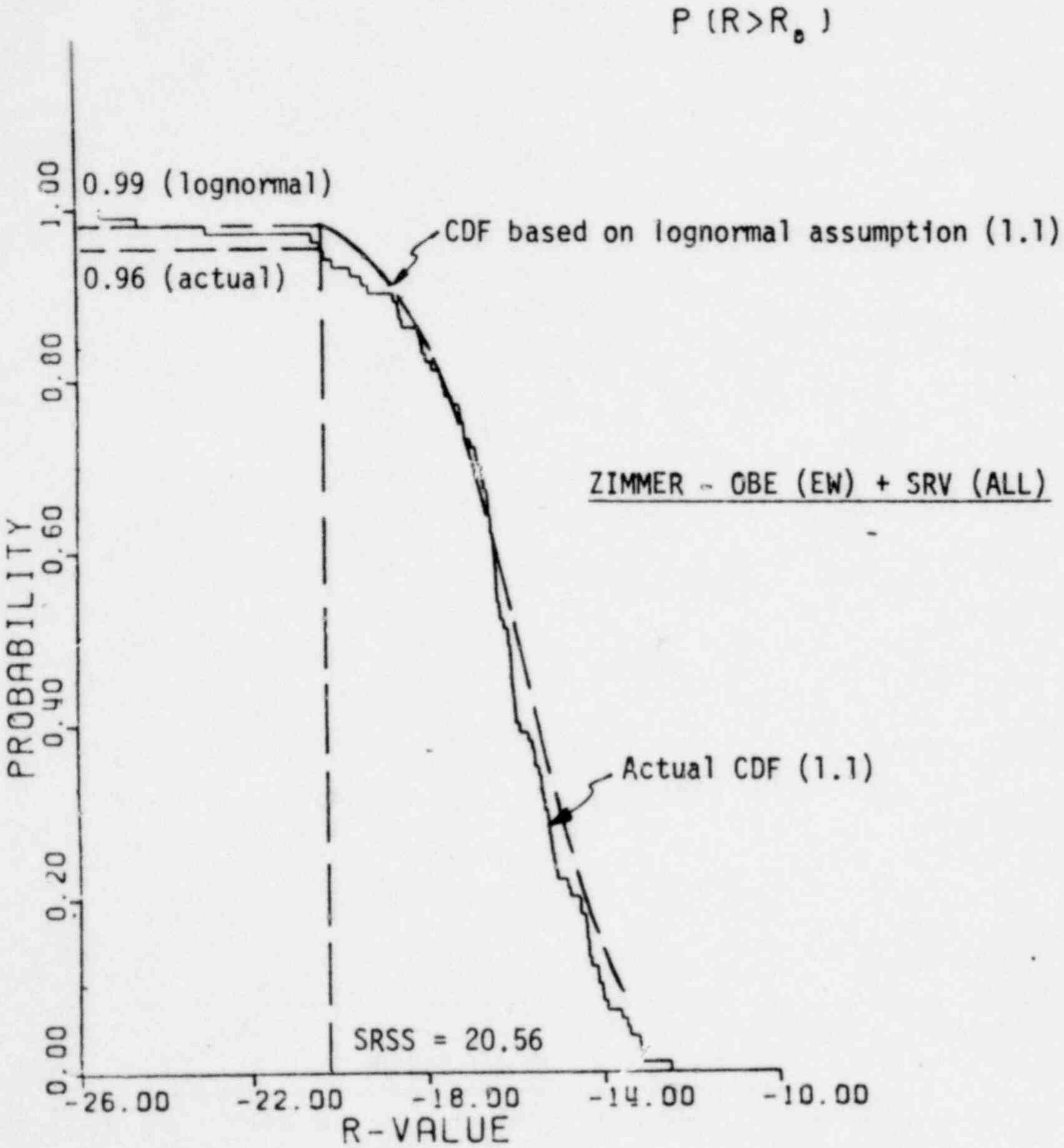

Figure 3-40. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.1) Case 5

1323 305

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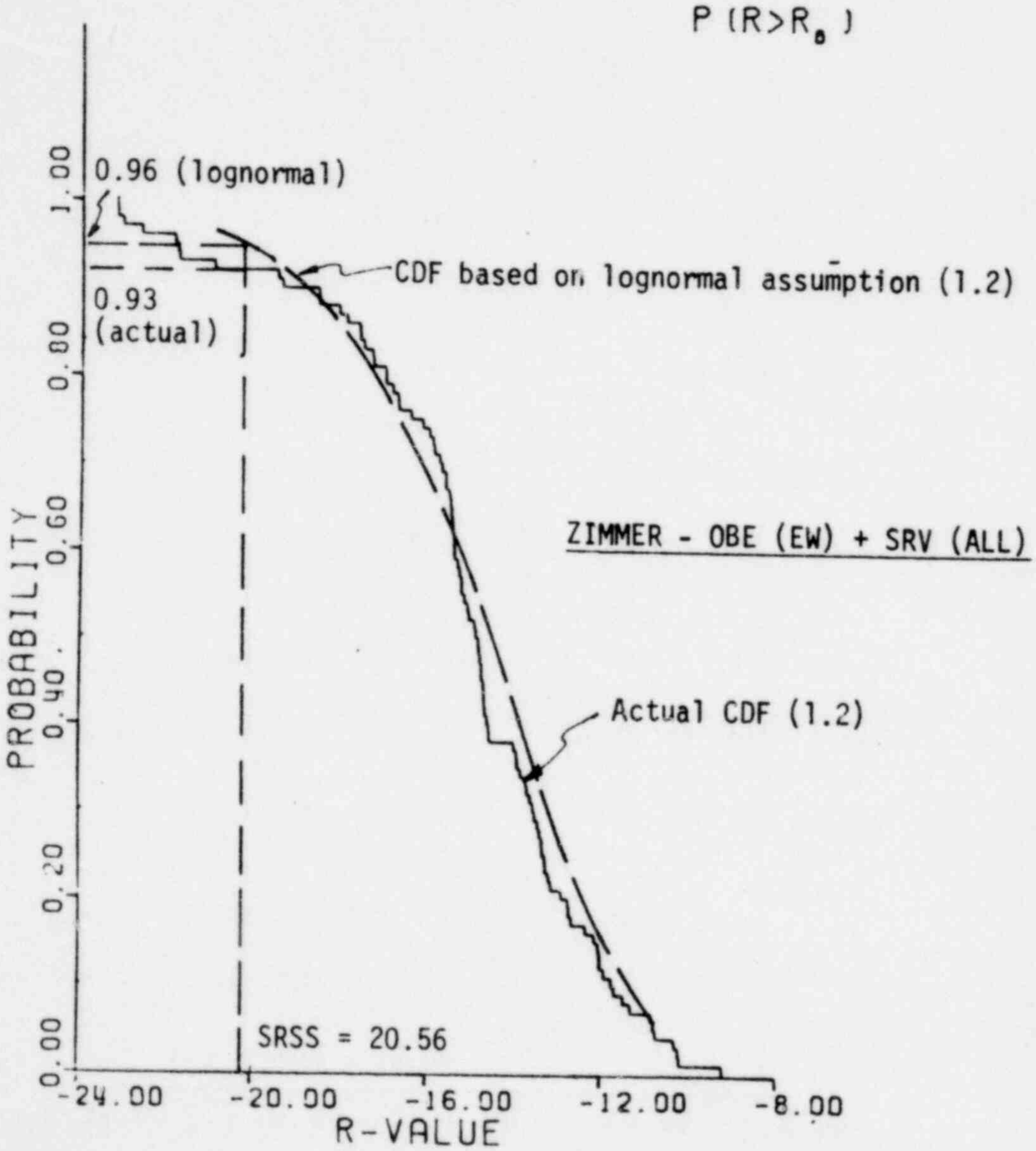

Figure 3-41. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.2) Case 5

1323 306

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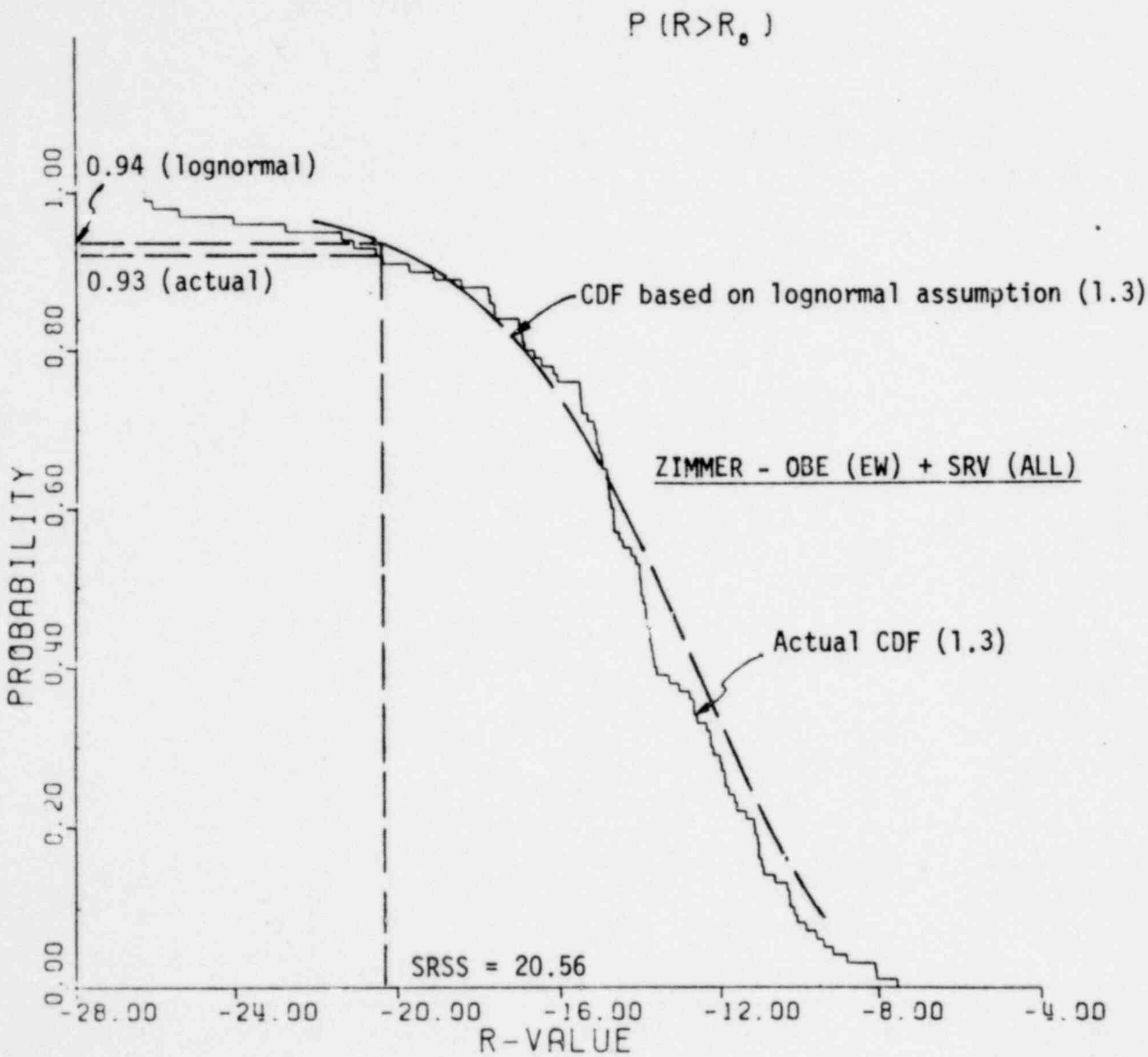

Figure 3-42. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 5

1323 307

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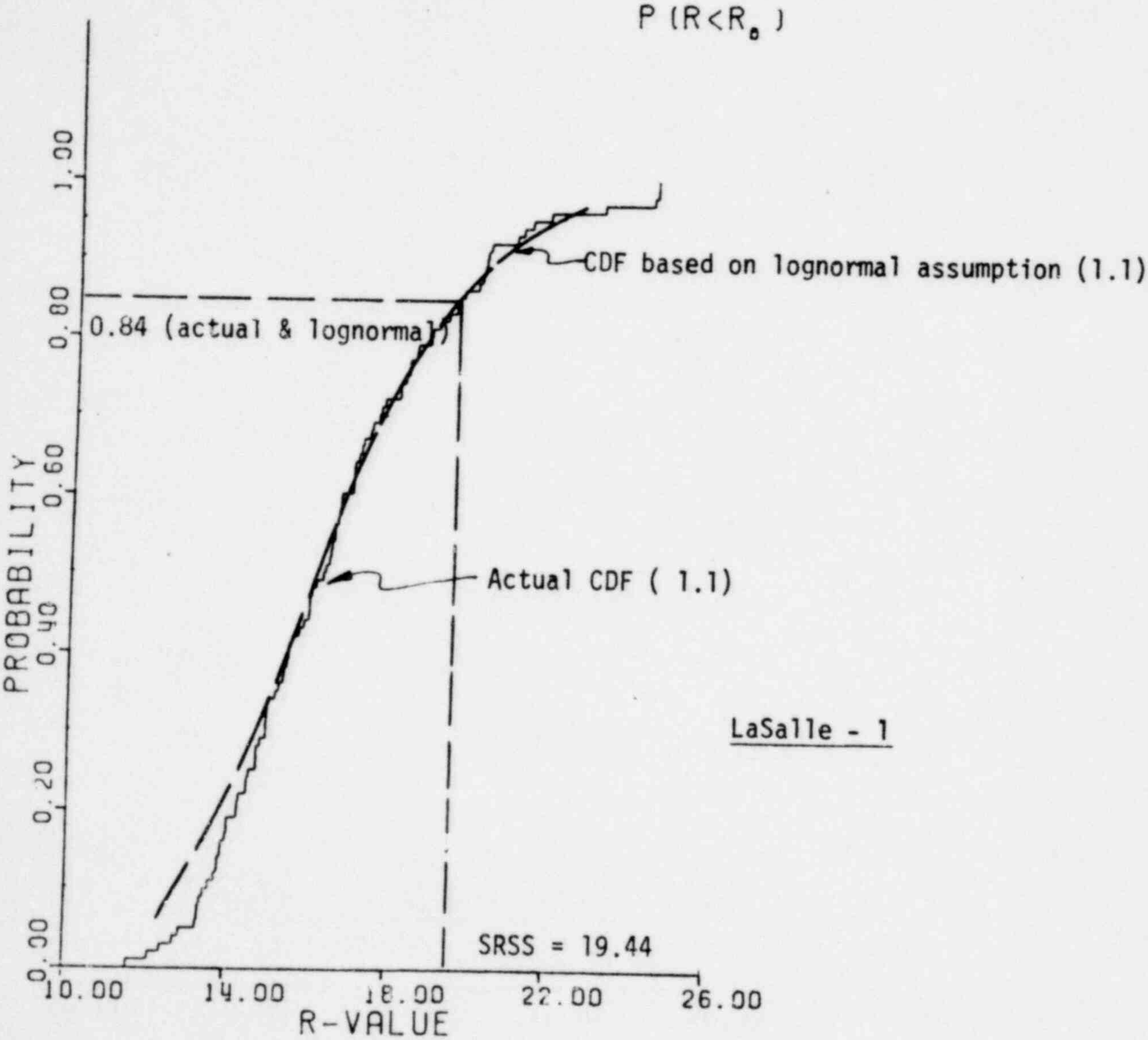

Figure 3-43. Comparison of Actual CDF and Approximate CDF (δ = 1.1) Case 6

1323 308

CUMULATIVE DISTRIBUTION FUNCTION

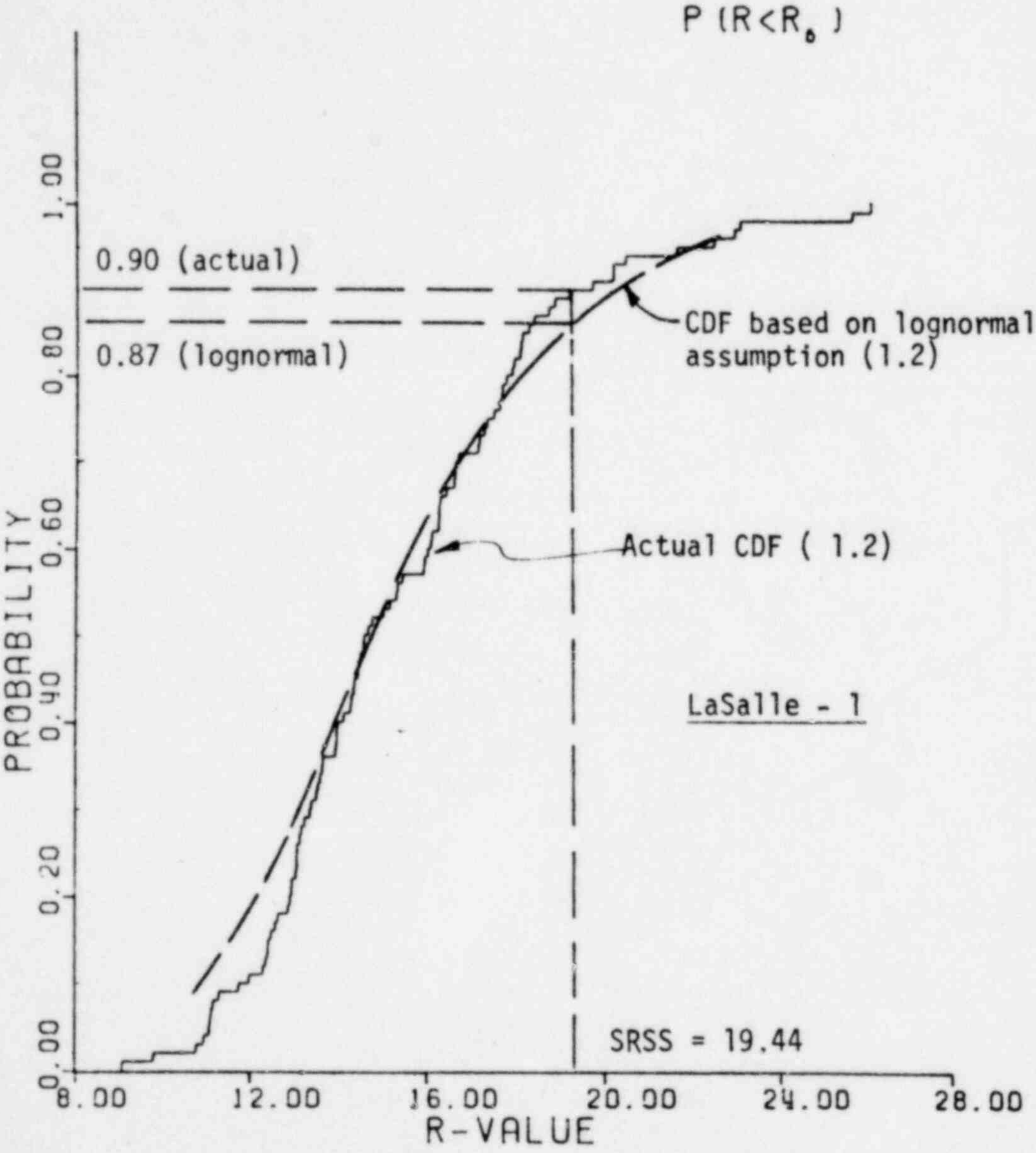

Figure 3-44. Comparison of Actual CDF and Approximate CDF (δ = 1.2) Case 6

1323 309

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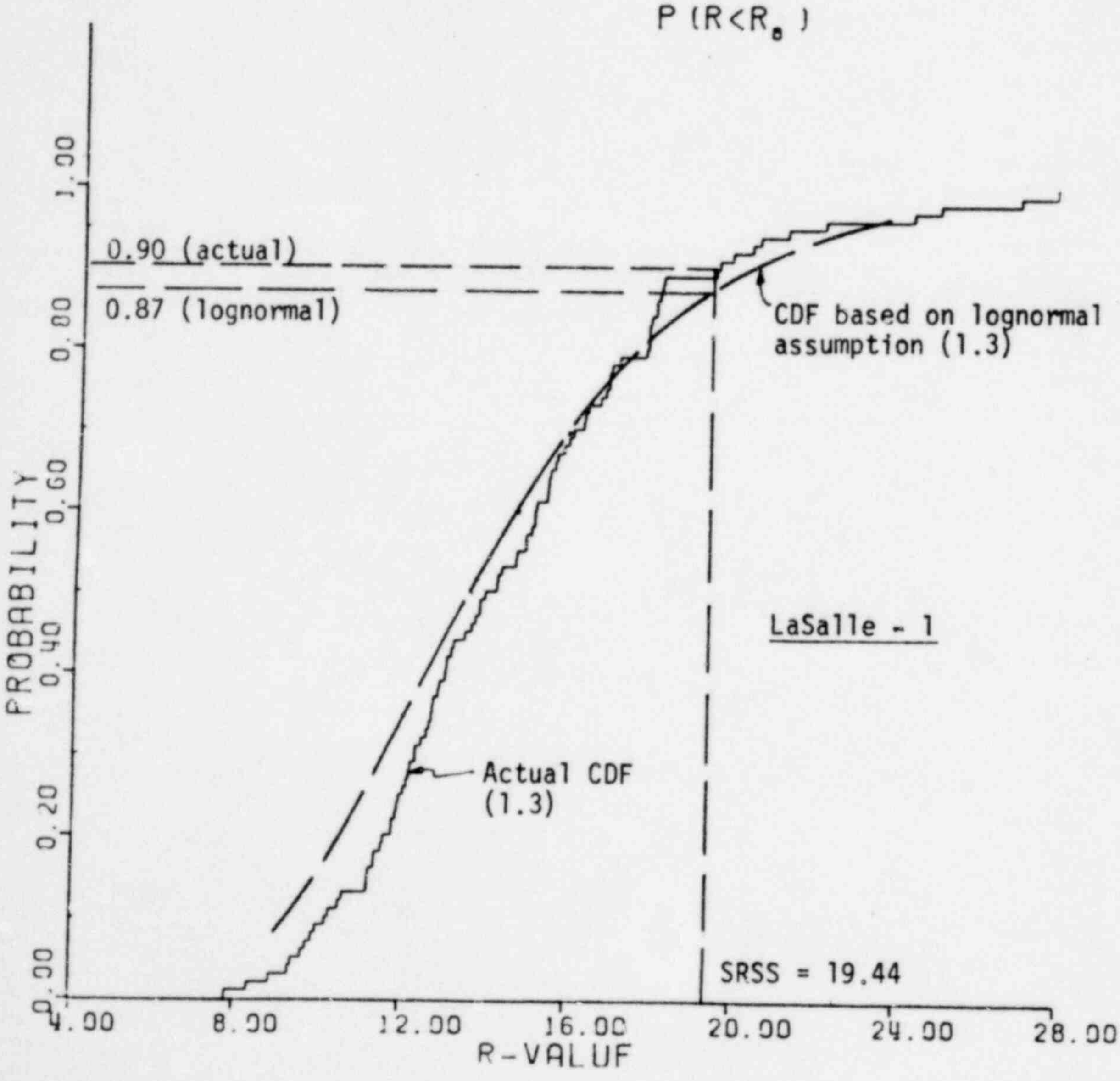

Figure 3-45. Comparison of Actual CDF and Approximate CDF (δ = 1.3) Case 6

1323 310

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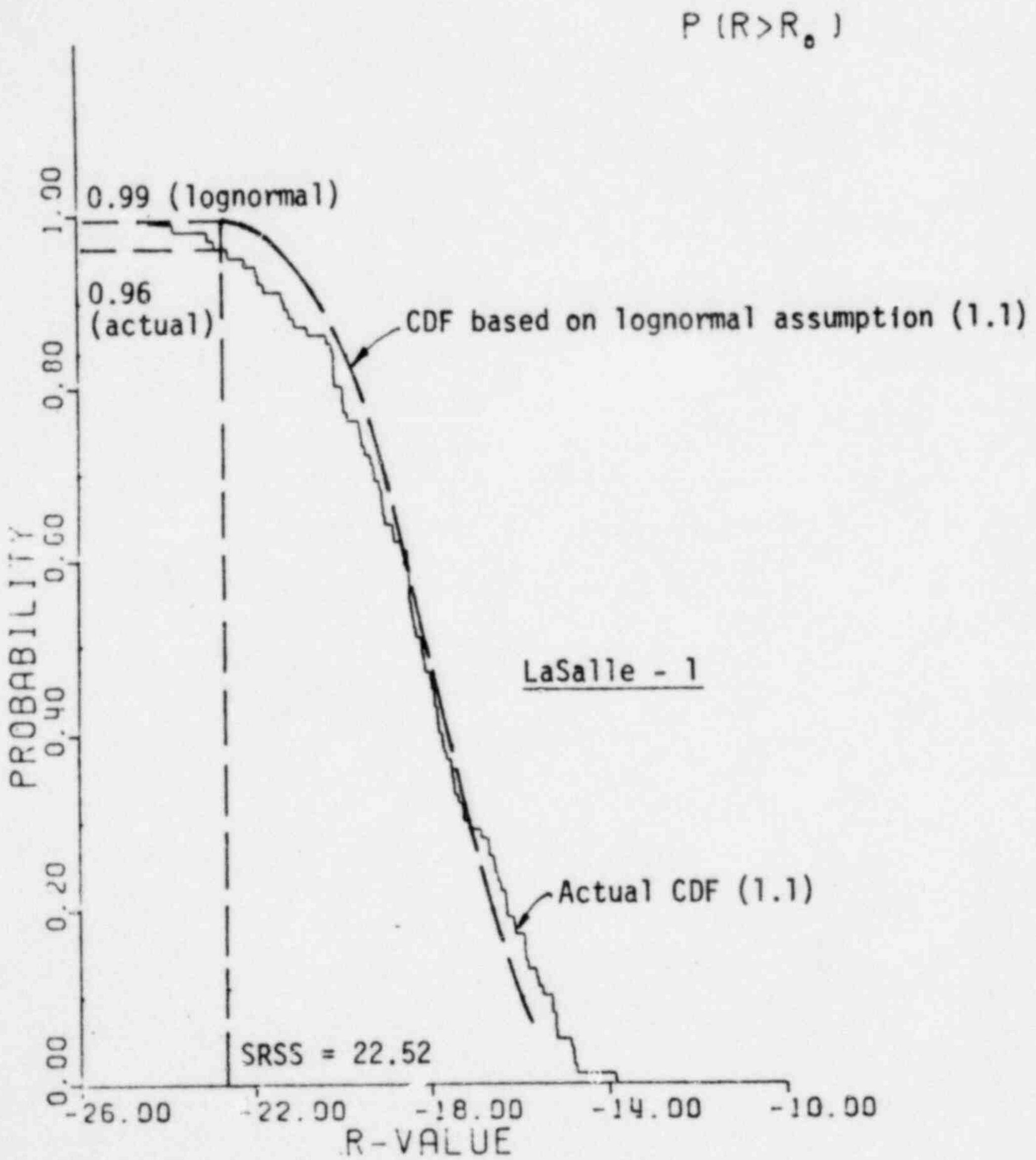

Figure 3-46. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.1) Case 6

1323 311

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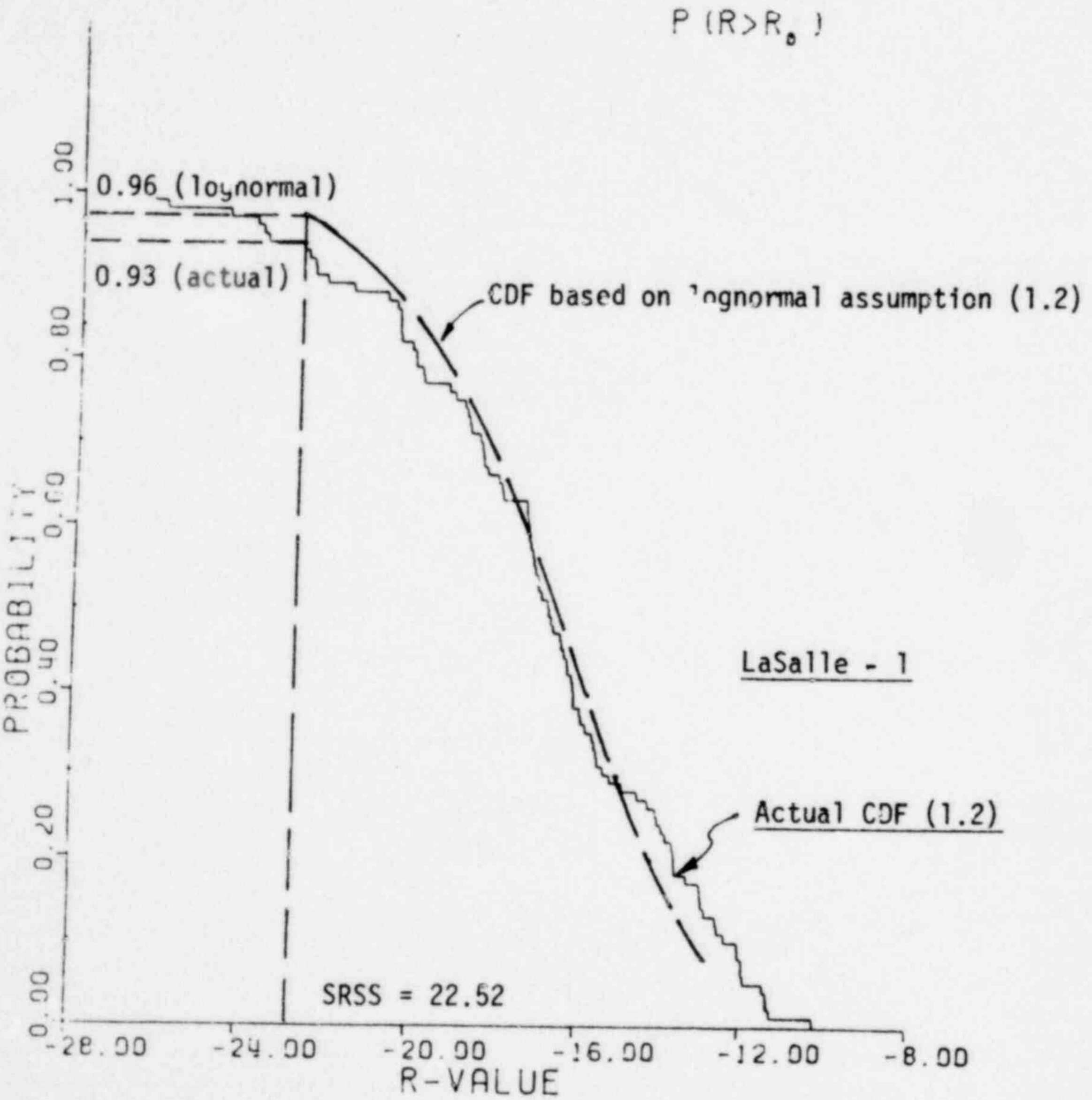

Figure 3-47. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.2) Case 6

1323 312

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

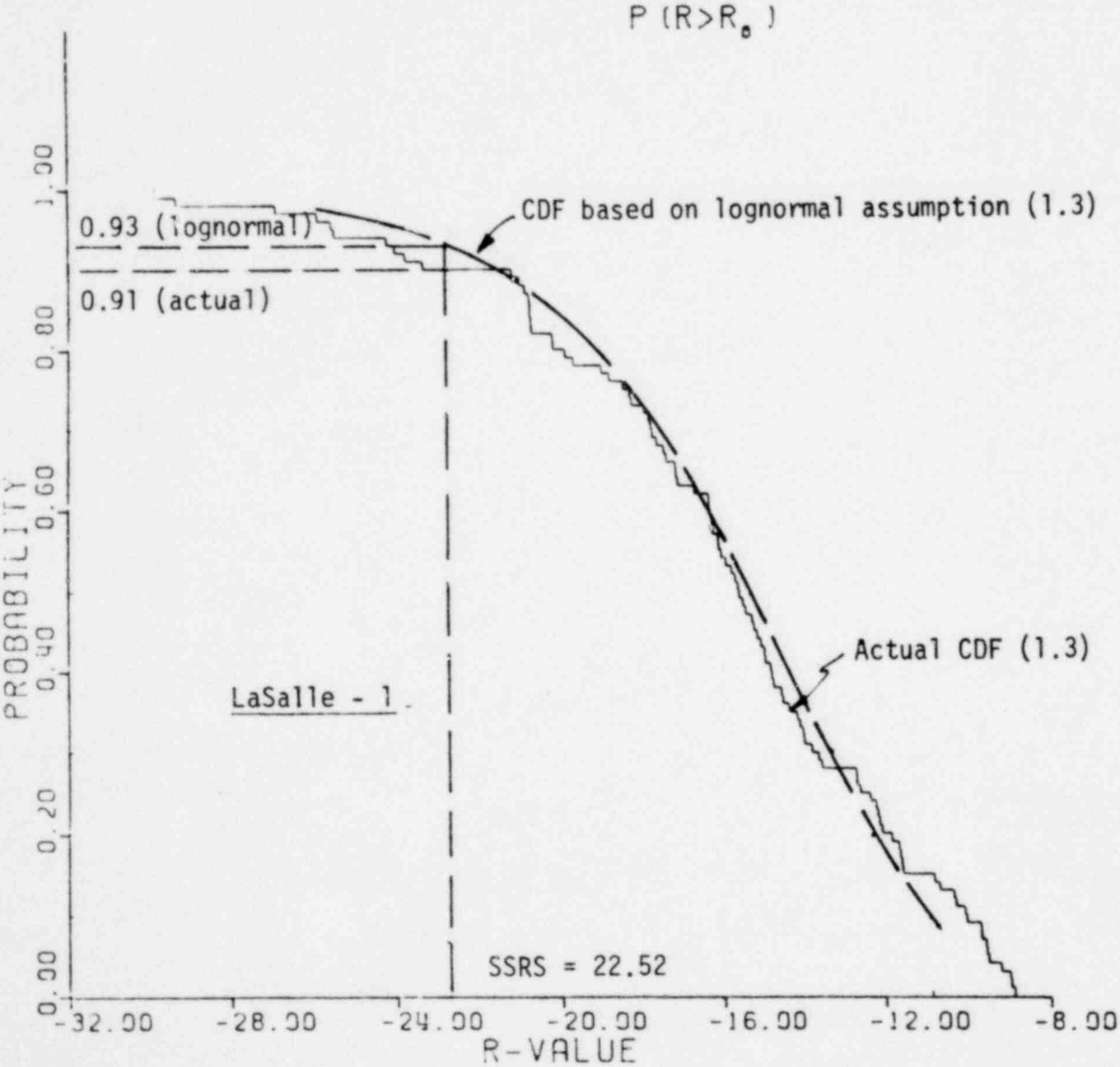

Figure 3-48. Comparison of Actual Complementary CDF and Approximate CDF (δ = 1.3) Case 6

1323 313

4. CONCLUSIONS

1. Defining for each individual response the peak amplitude dispersion δ as the ratio of the 84 percent nonexceedance probability (NEP) peak response to the 50 percent NEP peak response, it has been determined that the original Newmark-Kennedy Criteria (Appendix B) may not achieve its intent in the case of low dispersion. With a dispersion δ of 1.1 or less, the SRSS combined response for cases which meet Criterion 2 may have a NEP less than approximately 84 percent. Real transient response data are unlikely to have such low dispersion in peak response since dispersions are generally greater than 1.2. Still it is recommended that low peak amplitude dispersion be guarded against by a minor revision to the criteria. The last sentence of the preamble to the criteria should be changed to read:

   "This goal is achieved by compliance with any one of the following criteria, or any alternative method that meets the intent stated above, provided that the intensity of loads or accelerations for each input are conservatively represented (approximately at the level of the 84th percentile, or <u>at 1.15 times the median level, whichever is greater</u>)." Underscoring indicates recommended change.

2. Six critical response combination cases were chosen (see Subsection 2.3) from the 291 response combination cases in Reference 3 to be used to demonstrate the adequacy of the Newmark-Kennedy Criterion 2 to provide high confidence that the SRSS combined response has a NEP of approximately 84 percent or greater. Using these six cases with various peak amplitude dispersions δ, it was demonstrated that the revised Newmark-Kennedy Criterion 2 achieves approximately an 84 percent or greater NEP for the SRSS combined response (see Subsection 2.4 and 2.5). The demonstrations mentioned above were performed using a lognormal distribution for the amplitude of peak responses being combined. However, the NEP for peak combined response was shown to be insensitive to the shape of the probability density function (PDF) for amplitude of peak individual responses (see Subparagraph 2.4.3). Therefore, the conclusion on the acceptability of Criterion 2 is equally correct for other shapes of PDF peak amplitude variation.

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3. A simplified procedure was developed for approximating the general CDF directly from the time phase CDF and a knowledge of the peak response amplitude dispersion δ (see Subsections 3.2 and 3.3). It was conclusively demonstrated with the six cases previously discussed that this simplified procedure accurately predicts the 84 percent NEP associated with the SRSS combined response accounting for both random peak amplitude and random time phasing (see Subsection 3.4).

   Using the simplified procedure, it was shown that for any case which meets Criterion 2, the 84 percent NEP peak combined response (${}^{C}R_{84}$) cannot exceed the SRSS combined response by more than 9 percent. The likelihood of this level of exceedance is extremely low and requires the worst possible combination of each parameter involved (see Subsection 3.5).

4. The Newmark-Kennedy Criterion 2 represents a conservative criterion for judging the acceptability for SRSS combination of responses. In some cases, the criterion leads to more conservative results than necessary, i.e., the NEP for the SRSS combined response significantly exceeds 84 percent. In most cases, the criteria leads to the NEP for the SRSS combined response of approximately 84 percent. In no case can the 84 percent NEP peak combined response exceed the SRSS combined response by more than 9 percent.

   In a previous study (see Reference 4), Criterion 1 was demonstrated as being more conservative than Criterion 2. From 235 response combination cases which passed Criterion 1, all 235 cases also passed Criterion 2. Therefore, this study, which has demonstrated the adequacy of Criterion 2, provides additional support to Criterion 1.

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5. REFERENCES

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3. A. K. Singh, S. W. Tagart, and C. V. Subramanian, **"Technical Basis for the Use of the Square-Root-of-the-Sum-of-Squares (SRSS) Method for Combining Dynamic Loads for Mark II Plants,"** NEDE-24010-P, July, 1977.

4. A. K. Singh and C. V. Subramanian, **"SRSS Application Criteria as Applied to Mark II Load Combination Cases,"** NEDO-24010-1, October, 1978.

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6. L. E. Goodman, E. Rosenblueth, and N. M. Newmark, **"Aseismic Design of Firmly Founded Elastic Studies"**, Proceedings - Separate No. 349, ASCE, Novermber, 1953 (also Transactions, Vol. 120, ASCE, 1955, pp. 782-802).

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8. C. V. Subramanian and R. P. Kennedy, **Executive Summary Report and Supplement, Technical Basis for the SRSS Method of Combining Dynamic Responses"**, April, 1978.

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APPENDIX A
BACKGROUND ON SRSS COMBINATION OF PEAK DYNAMIC RESPONSES

Structures and components of nuclear power facilities are designed for a large number of load combinations. These load combinations include both multiple dynamic loads and static loads. In most cases, peak responses from each of the dynamic loads are calculated elastically. These results are then combined to obtain a resultant peak combined dynamic response. Once the resultant peak combined dynamic response has been determined from a proper combination of the multiple peak dynamic responses, the resultant is added absolutely to the elastically calculated static response. This elastically calculated combined maximum response is then compared to code allowable stress levels with the acceptance criterion being that the combined response must be lower than the code allowable level.

The question, "how to combine several multiple peak dynamic responses," has been studied extensively for earthquake and blast response of structures. In 1951, Rosenblueth (see Reference A-1) first proposed that peak dynamic seismic responses be combined using the square-root-sum-of-the-squares (SRSS) method. The statistical basis of this method is that the peak combined response is expected to have approximately the same nonexceedance probability as exists for each of the individual peak responses being combined. The method was first published in 1953 (see Reference A-2). Since that time, this method of response combination has been widely studied and, with a few well-defined exceptions, has been accepted as the preferred method for response combination in the field of earthquake response of structures.

As other dynamic transient loadings on nuclear power facility components have been identified, it has become necessary to combine peak responses from these transient loadings also. Since the characteristics of the responses to these loads are essentially the same as seismic responses, peak responses from such loadings have been generally combined using SRSS based upon extensive experience in earthquake response analysis. However, questions were raised by the Nuclear Regulatory Commission (NRC) as to SRSS being an appropriate method for combining such responses. Several studies were initiated to demonstrate the adequacy of combining peak dynamic responses from other transient loadings using the SRSS method (see References A-3, A-4 and A-5).

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Reference A-3 documents a methodology for developing cumulative distribution function curves (called CDF curves) of the conditional probability of nonexceedance of any peak combined response as a result of multiple input response time histories having random relative time phasing. These nonexceedance probability curves are based upon a defined probability density function for relative time phasing between the multiple dynamic inputs. All of the multiple dynamic responses in the response combination are assumed to occur concurrently. Thus, the resultant nonexceedance probabilities are conservative because they ignore the possibility that events may not occur concurrently.

These CDF curves present nonexceedance probabilities resulting from the randomness of time phasing only and do not consider uncertainty of amplitude of the individual peak response or the nonexceedance probability at which the individual peak responses being combined are defined. The actual nonexceedance probability of the peak combined response is a function of both the nonexceedance probability of the amplitude of the individual peak responses and the nonexceedance probability obtained from the CDF curves resulting from random time phasing. As long as the individual peak responses are conservatively defined, the actual nonexceedance probability of the peak combined response will be greater than that defined by these time phasing only CDF curves.

A total of 291 different load combination cases which included multiple dynamic response time histories generated from actual Mark II plant structures and components were studied in Reference A-3. In the cases studied, evidence presented in References A-3 and A-5 showed that the median probability of nonexceedance of the SRSS combined response associated with random time phasing (i.e., amplitude known) was about 86 percent, with about 98 percent confidence that the nonexceedance probability was greater than 50 percent. Furthermore, it was shown that the median probability of exceeding the SRSS combined response by more than 20 percent was only about 4 percent, with about a 98 percent confidence that the probability of exceeding the SRSS combined response by more than 20 percent was less than 10 percent. In conclusion, for such transient response cases, there is a low conditional probability of exceedance of the SRSS combined response and a very low probability of significant exceedance due to random time phasing.

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Reference A-3 also reported studies which compare the component reliability for components designed using SRSS combination of peak dynamic responses versus those designed using absolute sum combination when both were subject to dynamic loadings. As long as:

a. The design dynamic load events (such as earthquake ground acceleration) are defined with sufficient conservatism to cover reasonable uncertainty in their definition so that there is high confidence that the likelihood of occurrence of more severe load events is no greater than the likelihood of occurrence upon which the corresponding allowable stress criteria are based,

b. The dynamic loadings (such as design response spectrum anchored to the earthquake ground acceleration) for the given dynamic event are also defined with sufficient conservatism to cover reasonable uncertainty, and

c. The allowable stress criteria are designed with sufficient conservatism (low probability of component failure consistent with the likelihood of exceedance of the design load when stresses are held to allowable stress criteria),

then it can be concluded that use of absolute combination of peak dynamic responses does not result in significant increase in component reliability over that obtained from SRSS combination of peak dynamic responses. In other words, a low probability of structural failure can be achieved by the proper application of the sources of conservatism defined above. When this is done, very little added structural reliability is achieved by requiring a conservative response combination procedure (i.e., absolute summation of responses). In fact, requiring excessive conservatism in the response combination (i.e., absolute summation of responses) may lead to lesser reliability under normal expected loading conditions.

Reference A-4 documents the results of a study conducted to show that structures designed elastically to code allowable stress levels generally have much greater margin against failure when subjected to dynamic loadings than when subjected to static loadings. In this study, the dynamic margin, R_D, was defined as the ratio of the dynamic time history load amplitude at failure to the load amplitude corresponding to code allowable stress levels for elastic analysis. Similarly, the static margin, R_S, was defined as the static load at failure divided by the static load corresponding to the same code allowable stress level for elastic analysis. Then, the dynamic to static margin ratio (D/S Margin) is defined by:

$$D/S \text{ Margin} = R_D/R_S$$

For structures with even very moderate ductility (inelastic energy absorption capacity) such as reinforced concrete structures, it is shown that for earthquakes or pulsive dynamic loadings which result in dynamic structural response, this D/S Margin is greater than 1.3 (often much greater than 1.3). Studies documented in Reference A-4 show that this D/S Margin alone is sufficient to cover the possible exceedance of the SRSS combined response for multiple dynamic events. In conclusion, for moderately ductile structures subjected to dynamic loads resulting in dynamic responses, the combination of dynamic responses by SRSS results in greater reserve margin than is obtained for static responses when both responses obtained by elastic analyses are held to the same code allowable stress levels.

The Nuclear Regulatory Commission Working Group on Methodology for Combining Dynamic Responses recently issued a report (see Reference A-6) recommending the approval, on a limited basis, of the SRSS response combination method for combining peak responses from transient loadings. That report also provided guidance for developing justification for a more generic acceptance of the SRSS method. The need for general criteria for determining when transient responses can be reasonably combined using the SRSS method was clearly demonstrated. Such criteria must provide reasonable assurance that the conditional probability of the combination of dynamic responses exceeding the SRSS value is acceptably low (given the condition of simultaneous occurrence of events).

Based on the need for generic criteria with which to judge the applicability of the SRSS method of response combination, Newmark and Kennedy proposed a set of criteria in August 1978. These criteria are reproduced and represented in Appendix B. The bases for these criteria are presented in Reference A-7.

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A-1. E. Rosenblueth, **A Basis for Aseismic Design**, Ph.D. Thesis, University of Illinois, Urbana, Illinois, 19[illegible].

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A-3. A. K. Singh, S. W. Tagart, and C. V. Subramanian, **Technical Basis for the Use of the Square-Root-of-the-Sum-of-Squares (SRSS) Method fo Combining Dynamic Loads for Mark II Plants**, NEDE-24010-P, July 1977.

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A-5. C. V. Subramanian and R. P. Kennedy, **Executive Summary Report and Supplement, Technical Basis for the SRSS Method of Combining Dynamic Responses**, April 1978.

A-6. R. Cudlin, S. Hosford, R. Mattu, and K. Wickman, **Methodology for Combining Dynamic Responses**, Nuclear Regulatory Commission, September 1978 (NUREG-0484).

A-7. R. P. Kennedy and N. M. Newmark, **Bases for Criteria for Combination of Earthquake and Other Transient Responses by the Square-Root-Sum-of-the-Squares Method**, NEDO-24010-2, December 1978.

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APPENDIX B
CRITERIA FOR COMBINATIONS OF EARTHQUAKE AND/OR OTHER TRANSIENT RESPONSES

B.1 PREAMBLE

The intent of the methods proposed for combinations of transient, dynamic responses is to achieve a nonexceedance of approximately 84 percent for the peak combined response of the system, component, or element considered. This goal is achieved by compliance with any one of the following criteria, or any alternative method that meets the intent stated above, provided that the intensity of loads or accelerations for each input are conservatively represented (approximately at the level of the 84th percentile, or the mean plus one standard deviation, of the expected input intensity).

B.2 CRITERION 1

Dynamic or transient responses of structures, components, and equipment arising from combinations of dynamic loading or motions may be combined by SRSS provided that each of the dynamic inputs or responses has characteristics similar to those of earthquake ground motions, and that the individual component inputs can be considered to be relatively uncorrelated, i.e., the individual dynamic inputs or responses considered are either from independent events or have random peak phasing. This similarity involves a limited number of peaks of force or acceleration (not more than 5 exceeding 75 percent of the maximum, or not more than 10 exceeding 60 percent of the maximum), with approximately zero mean and a total duration of strong motion (i.e., exceeding 50 percent of the maximum) of 10 seconds or less.

Explanation: Since earthquake motions in various directions produce responses which are combined conservatively by the use of SRSS, the descriptions of dynamic or transient inputs are based on those applicable to earthquake motions. The coefficient of correlation for these is less than 0.4, and the pattern of peaks is based on Table 2 of Circular 672 of the U.S. Geological Survey describing earthquake ground motions for use in the design of the Alaska oil pipeline.

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The probability distribution for the responses to earthquake motions is based on the concepts underlying U.S. NRC Regulatory Guide 1.60, where the standard deviation is 30 to 40% of the median value.

It was proven some decades ago that modal responses to earthquake motions may be conservatively combined by SRSS methods with the same degree of conservatism as that of the motions. If each of these responses is considered to be at the level of mean plus one standard deviation, the SRSS value is also at this level. For the same reasons, responses from the three component directions of earthquake motions may also be conservatively combined by SRSS methods.

B.3 CRITERION 2

When response time histories are available for all multiple dynamic loadings being combined, SRSS methods may be used for peak combined response when CDF calculations, using appropriate assumptions on the range of possible time lags between the response time histories, show the following criteria are met:

a. There is estimated to be less than approximately a 50 percent conditional probability that the actual peak combined response from these conservatively defined loadings exceeds approximately the SRSS calculated peak response, and

b. There is estimated to be less than approximately a 15 percent conditional probability that the actual peak combined response exceeds approximately 1.2 times the SRSS calculated peak response.

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APPENDIX C
ADDITIONAL STUDIES

C.1 EFFECT OF NUMBER OF MONTE CARLO TRIALS ON CDF CURVE

The Monte Carlo Method was used to simulate a random variable with a specified probability density function. The random variables in this study are time phasing and amplitude scale factor of each individual response component time history. The end product are cumulative distribution function (CDF) curves of peak combined response which give nonexceedance probability of any response amplitude. The accuracy of the resulting CDF curves directly depends on the total number of Monte Carlo trials. To adequately define a certain portion of a CDF curve a minimum number of trials are required. The relationship between a particular probability of nonexceedance which can accurately be determined and the number of trials can be conservatively approximated by Equation C-1.

$$N_T \simeq \frac{10}{1 - (NEP/100)} \tag{C-1}$$

where NEP is the nonexceedance probability which defines the upper bound of a region of interest on the CDF curve and N_T is the total number of Monte Carlo trials required in order to adequately define the CDF curve between the upper bound and the corresponding lower bound of nonexceedance probabilities. The table below shows the required number of trials corresponding to several nonexceedance probabilities of interest.

NEP	80%	85%	90%	95%
N_T	50	67	100	200

In this study, the region of particular interest on the general CDF curves (random time phasing and amplitude) are between 30 and 90 percent nonexceedance probabilities. Thus, a total number of 100 Monte Carlo trials were used in generating CDF curves which consider both random time phasing and random peak amplitude of each individual component.

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C.2 VERIFICATION

In each of the six selected cases, a set of time phasing only CDF curves (positive and negative responses) were generated using 100 trials. These CDF curves were then compared with those previously generated in Reference 3 using up to 500 trials in order to check the adequacy of using only 100 trials. As shown in Figures C-1 through C-6 the comparison is very satisfactory within the region of interest (30 percent to 90 percent).

Furthermore, two sets of general random amplitude and time phase cumulative distribution function curves were created for one case (Case 2 - Main Steam - 46I - M_c). Both 500 and 100 Monte Carlo trials were used in generating the random amplitude and time phase CDF curves, respectively. The probability density function of the amplitude scale factor of each component time history is assumed to be lognormally distributed and is defined by the 50th percentile scale factor of 1.0 and the ratio of 84th percentile to 50th percentile of 1.3 (δ = 1.3). The comparison of the resulting CDF curves are shown in Figures C-7 and C-8. Again, it demonstrates that 100 Monte Carlo trials are adequate to define the CDF curve within the region of interest.

C.3 SCALING OF THE PEAK AMPLITUDE OF INDIVIDUAL RESPONSE COMPONENT

Further investigation was necessary to determine if scaling the peak amplitude of each individual response component of one combination case to the same magnitude would bring the resulting time phasing CDF curve of the peak combined response closer to failing the Newmark-Kennedy Criterion 2. Two cases were selected for this study:

a. Main steam - 46I, OBE + SRVBDG, Negative Moment at Point C

b. LaSalle - 1, OBE (NS) + SRV (ADS) + CHUG (30 Hz), Positive Meridional Force of the Containment Wall at Drywell Floor Elevation

These two cases were chosen because of the significant difference in response component peak amplitudes as used in the Reference 3 studies. The unscaled and scaled peak amplitude and SRSS response of the two cases are summarized

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in Table C-1. Figures C-9 and C-10 show the unscaled and scaled CDF curves of the two cases. These demonstrations show that scaling the response component peak amplitude to the same magnitude raises the nonexceedance probability on the SRSS combined response and makes these cases less critical for the purpose of this demonstration study. Therefore, unscaled response components are used in the study.

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Table C-1
PEAK AMPLITUDE AND SRSS (UNSCALED AND SCALED)

Case	Component	UNSCALED		SCALED	
		Peak Amplitude	SRSS	Peak Amplitude	SRSS
Main Steam-46I, M_c- Negative (in-kips)	OBE	24.51	78.84	74.93	105.97
	SRVBDG	74.93		74.93	
LASALLE-1 Positive Meridional Force (kips/in)	OBE(NS)	11.46	19.94	15.30	26.50
	SRV(ADS)	15.30		15.30	
	CHUG(30HZ)	3.52		15.30	

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CUMULATIVE DISTRIBUTION FUNCTION

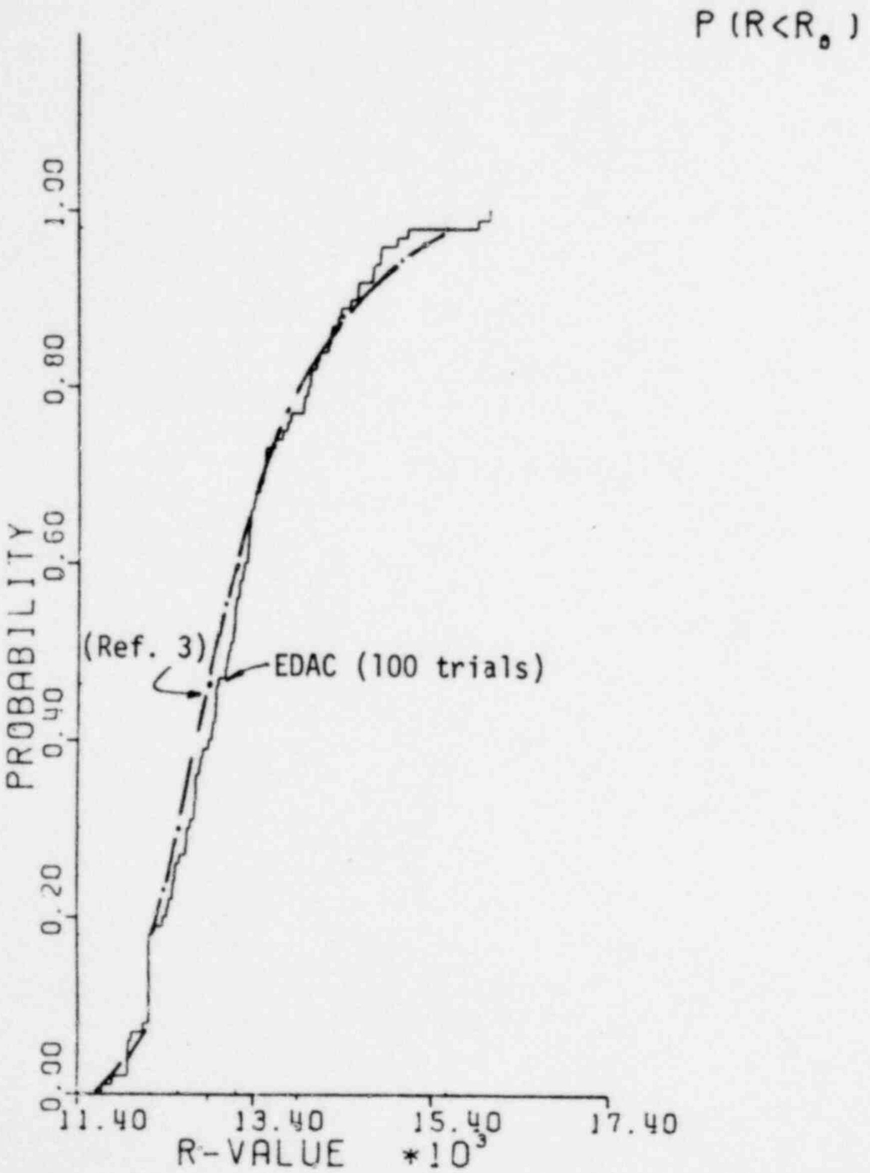

Figure C-1. Comparison of Time Phasing Only CDF Curves Main Steam 461, M_a

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COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

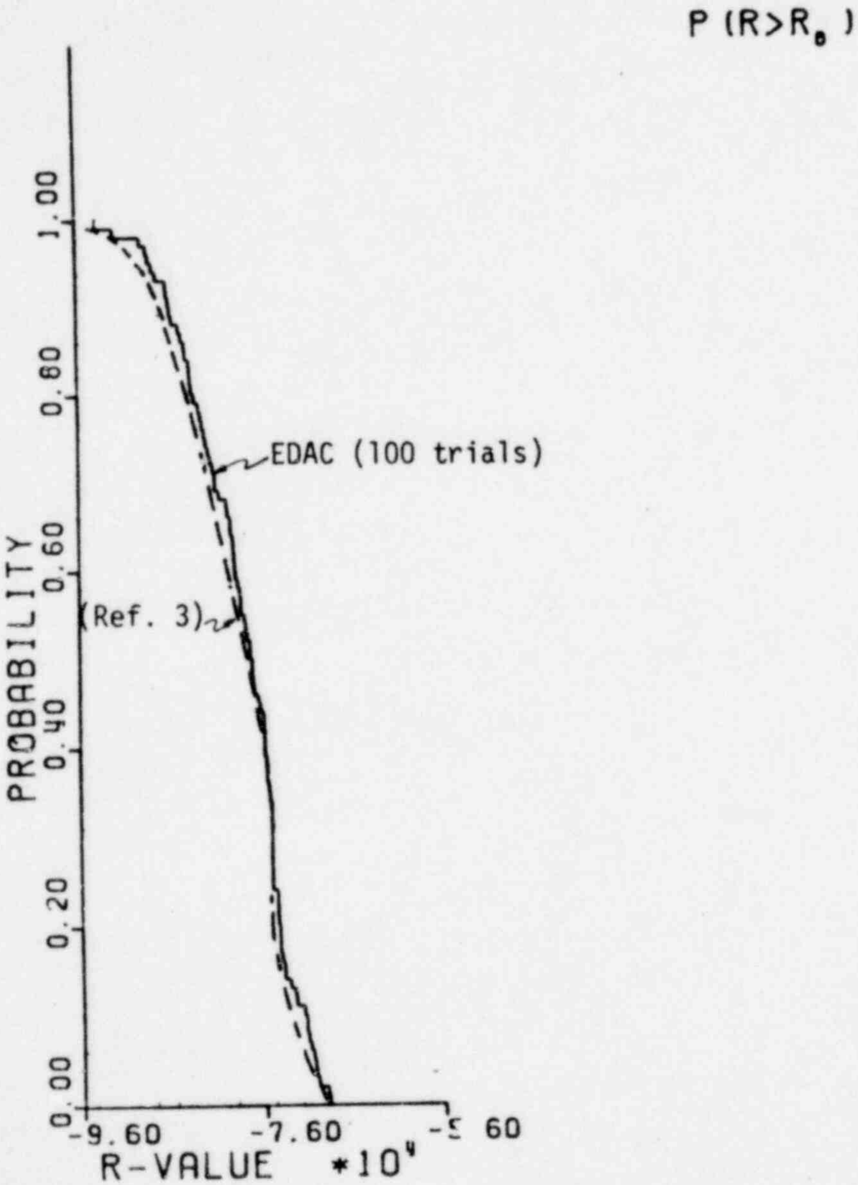

Figure C-2. Comparison of Time Phasing Only CDF Curves Main Steam 461, M_c

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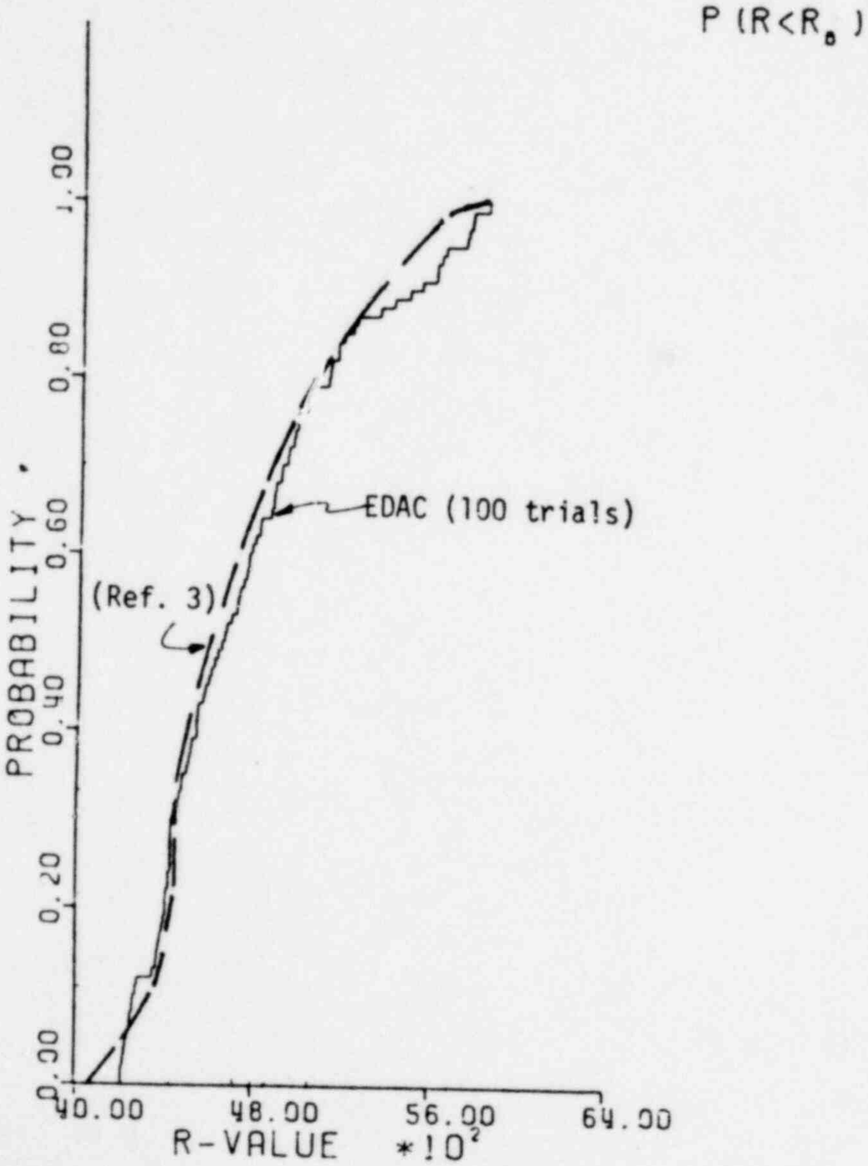

Figure C-3. Comparison of Time Phasing Only CDF Curves RHR Wetwell, M_a

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CUMULATIVE DISTRIBUTION FUNCTION

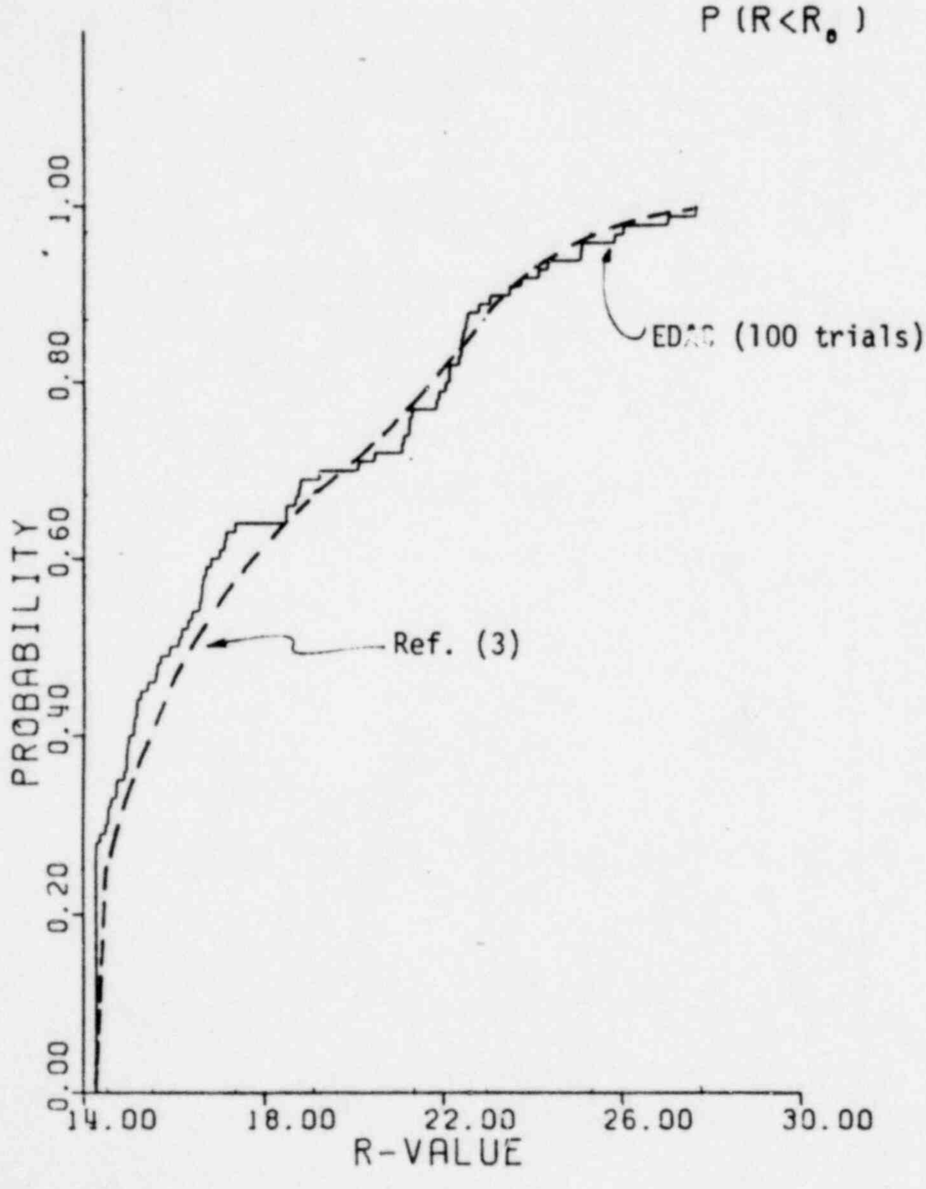

Figure C-4. Comparison of Time Phasing Only CDF Curves Zimmer, OBE(NS)

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CUMULATIVE DISTRIBUTION FUNCTION

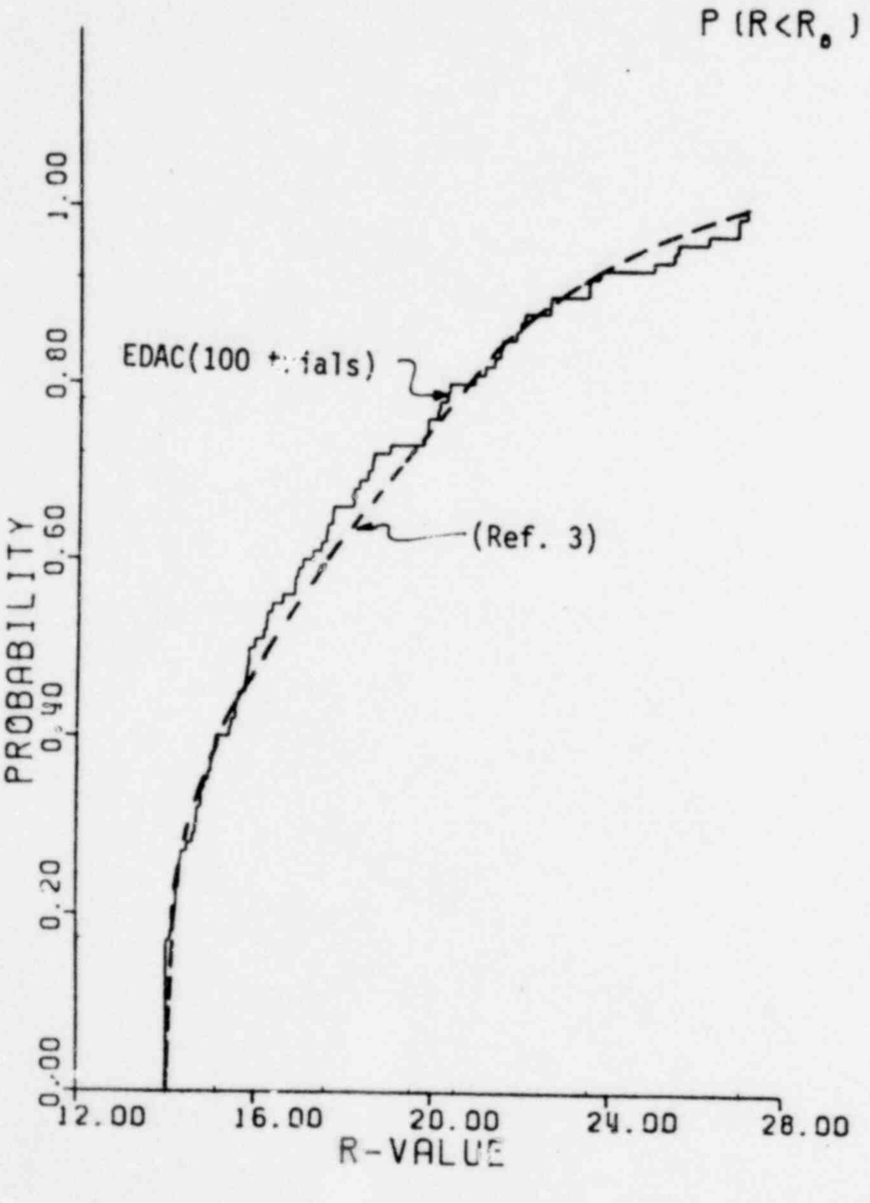

Figure C-5. Comparison of Time Phasing Only CDF Curves Zimmer, OBE(EW)

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CUMULATIVE DISTRIBUTION FUNCTION

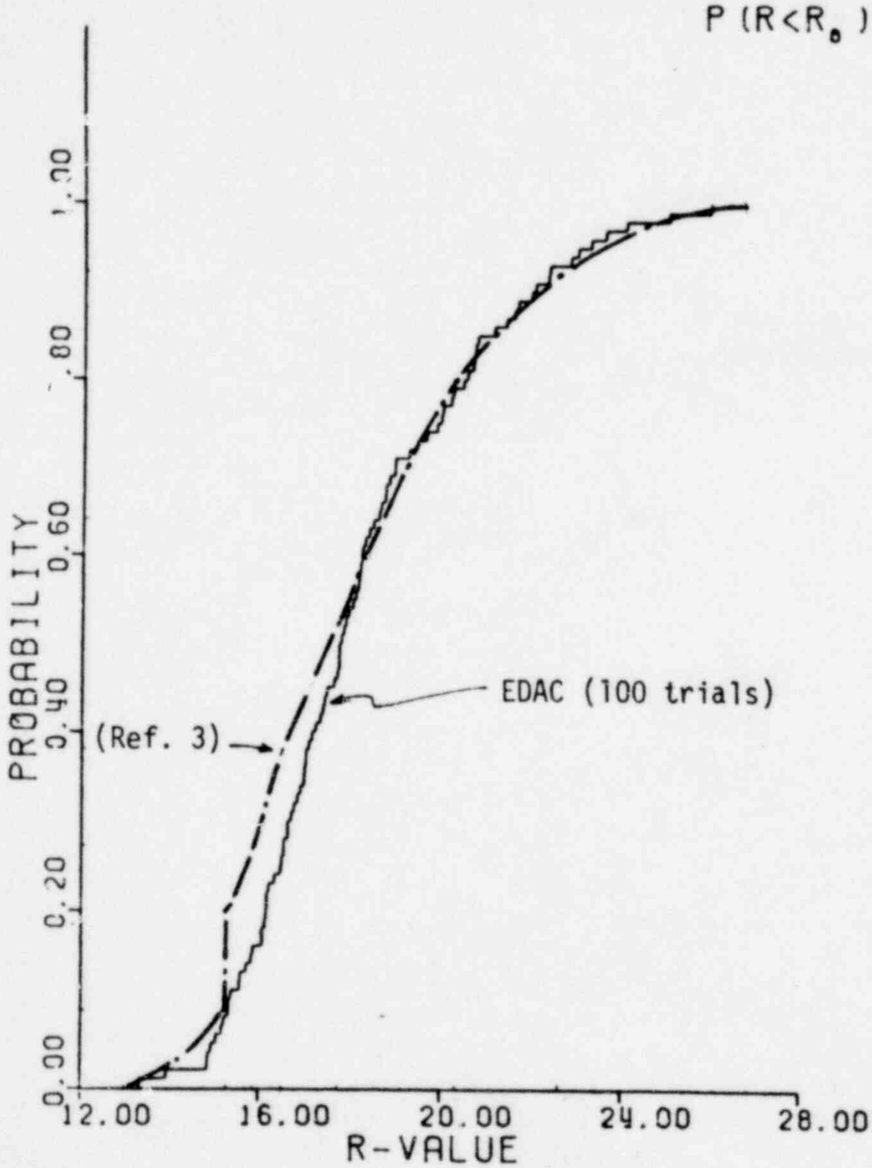

Figure C-6. Comparison of Time Phasing Only CDF Curves LaSalle-1

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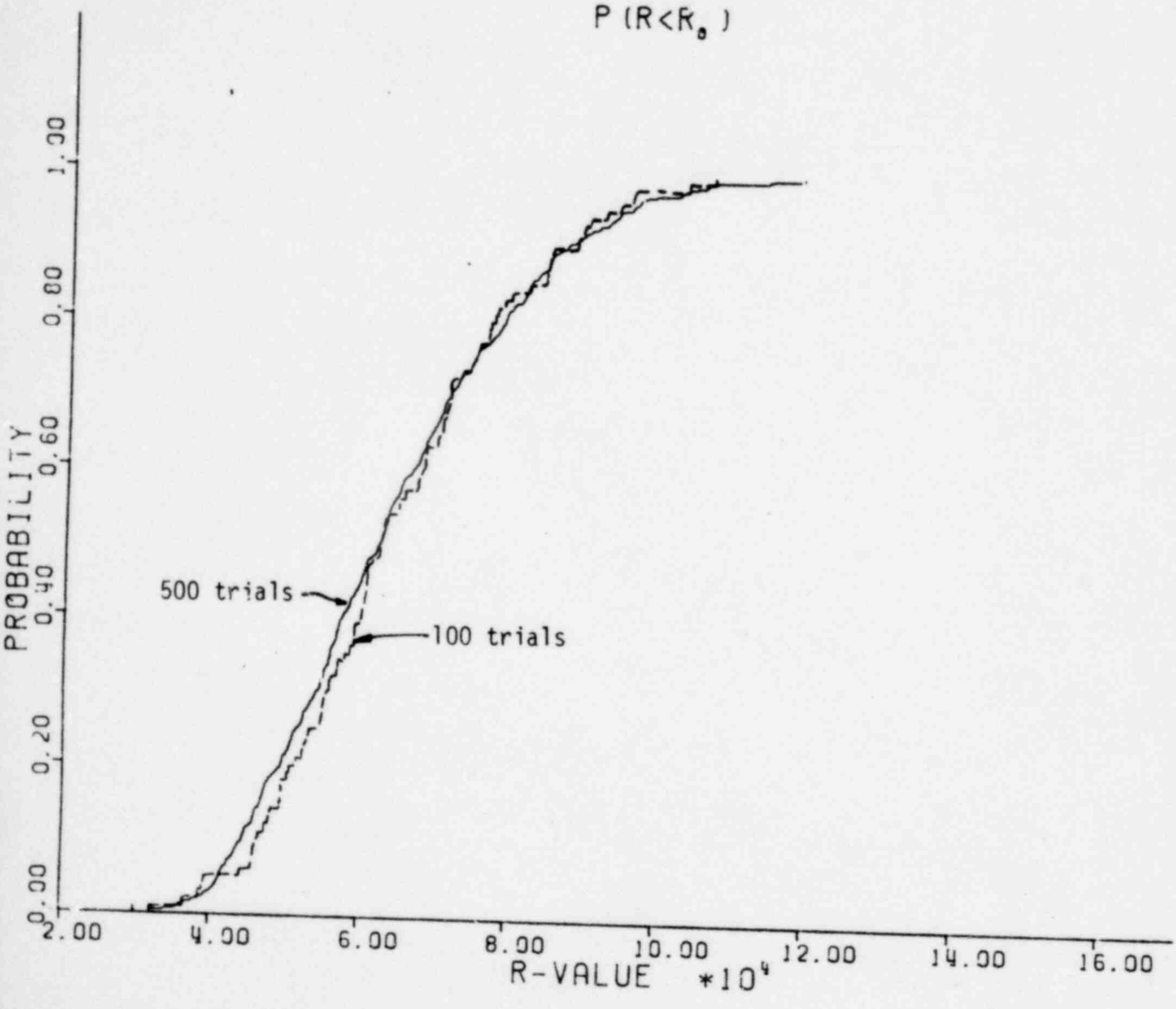

Figure C-7. Comparison of General Random Amplitude and Time Phasing CDF Curves Main Steam 461, M_C (Positive)

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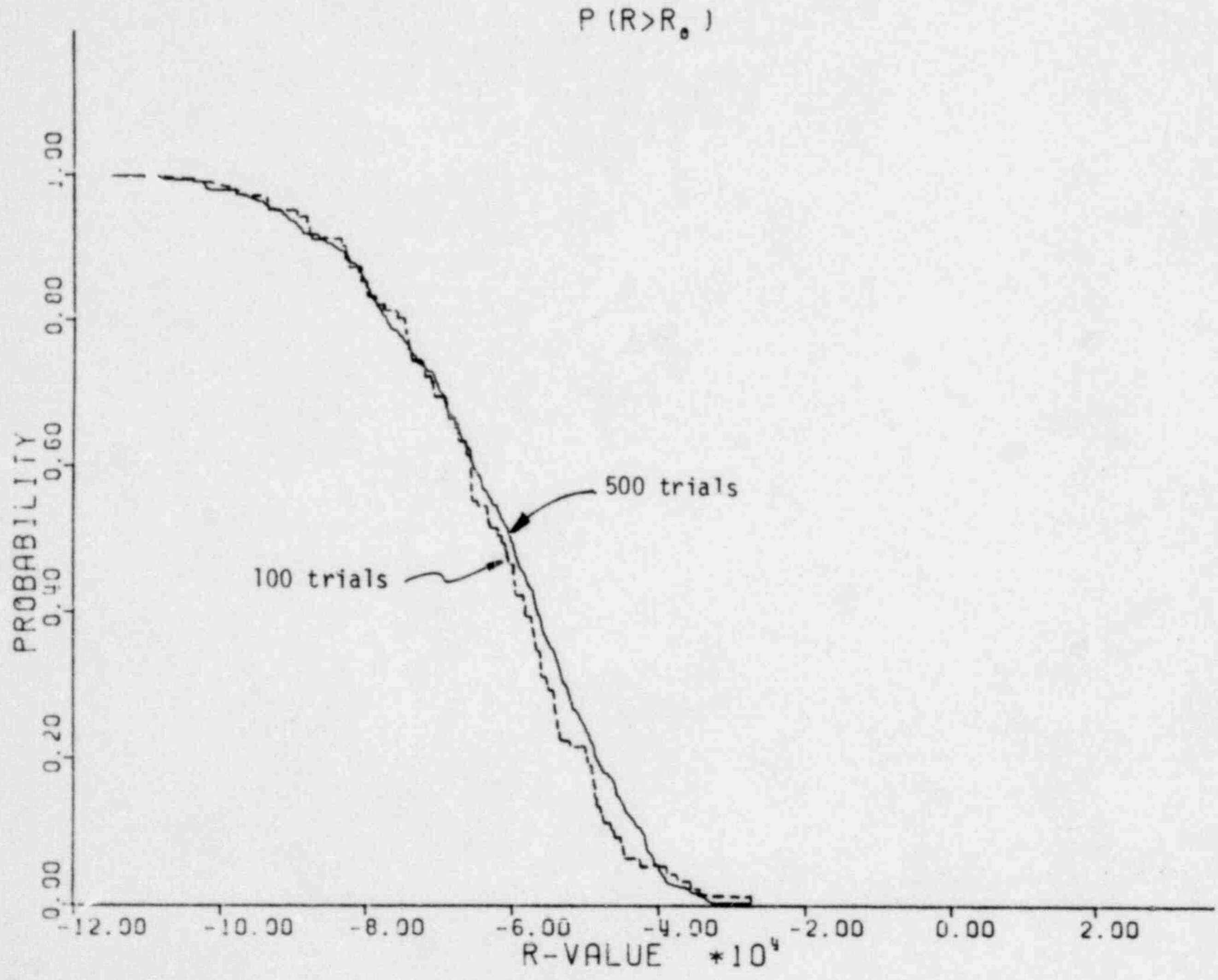

Figure C-8. Comparison of General Random Amplitude and Time Phasing CDF Curves Main Steam 461, M_c (Negative)

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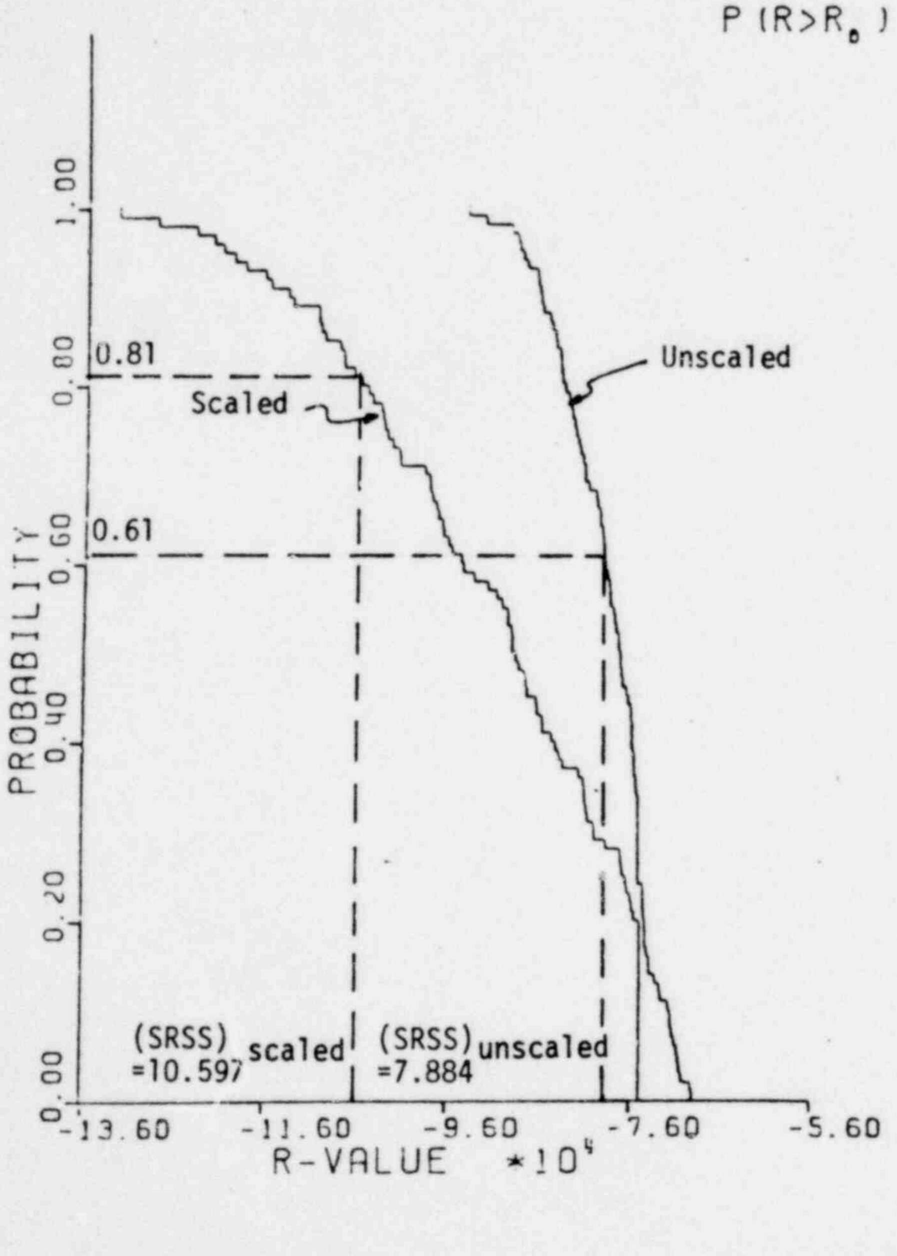

Figure C-9. Main Steam 461, M_c, Unscaled and Scaled Time Phasing Only CDF Curves

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CUMULATIVE DISTRIBUTION FUNCTION

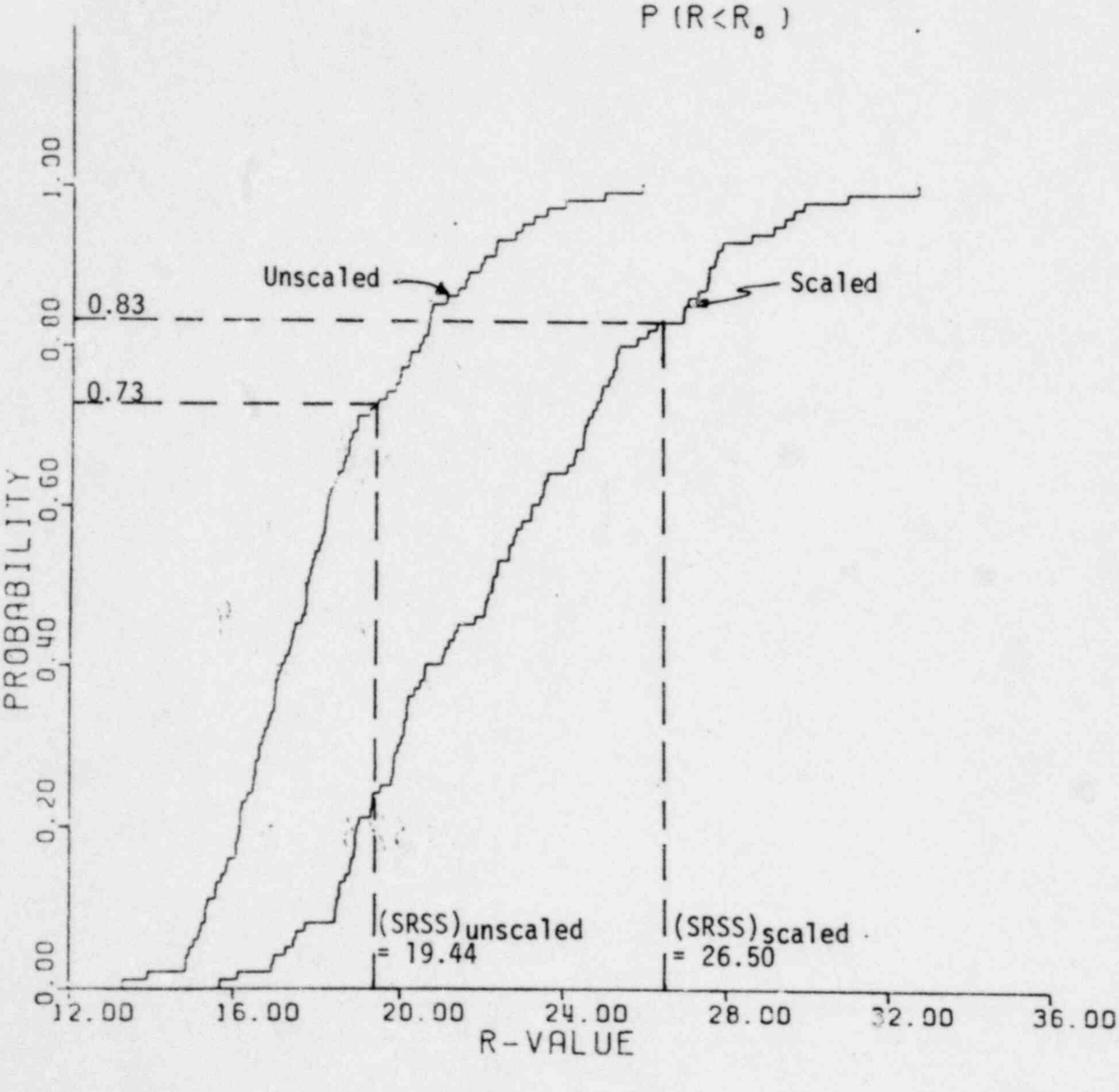

Figure C-10. LaSalle-1, Unscaled and Scaled Time Phasing Only CDF Curves

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