Attachment 1
ST-HL-AE-1028
11/14/83

ERRATA

Probabilistic Evaluation of Tornado Missile Hazard to the Containment Isolation Valve Compartment Equipment

Pg. 4, Paragraph B: Replace with the following

B. The potential missile model assumes

1. A missile distribution based on EPRI survey without censoring as was done for the EPRI studies.

2. A missile density upper limit increased by a factor of 2.5 over the EPRI survey to account for local variations in missile density.

3. One half of the potential missiles are distributed up to 20 ft above grade with the remainder at grade.

4. The number of unrestrained potential missiles is conservatively chosen to be 10% of all potential missiles.

Pg. D-16, Section D.10, 2nd Paragraph:

Replace the word "Twenty" in the second line with the word "Ninety".

Delete the word "elevated" in this sentence and the next.

Attachment 2
ST-HL-AE-1028
11/14/83

South Texas Project

Probabilistic Evaluation of Hurricane-Generated Missile Hazard to the Containment Isolation Valve Compartment Equipment

14926-001

Risk/Reliability Group
Los Angeles Power Division
Bechtel Power Corporation

Revision 1
November 1983

SOUTH TEXAS PROJECT HURRICANE MISSILE EVALUATION REPORT

I. Introduction

This study uses Probabilistic Risk Assessment (PRA) methodology to evaluate the probability that equipment located in the containment isolation valve cubicle (IVC) might be damaged by hurricane-generated missiles. Hurricane-generated missiles include objects on or near the plant site that could become airborne during a hurricane and be transported to the top of the IVC.

The study includes an evaluation of the likelihood of a hurricane occurrence, as well as the probability of potential missiles becoming airborne and being transported to the top of the IVC. The extent of damage is not evaluated, but is conservatively assumed to be certain and total for all missile strikes.

II. Acceptance Criteria

The NRC's acceptance criteria are contained in the "General Design Criteria (GDC) for Nuclear Plants" [1]. Specifically, GDC 2 and 4 apply to this evaluation and are summarized below:

a. GDC 2 requires that "Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as - hurricanes - without loss of capability to perform their safety functions . . ."

b. GDC 4 requires that ". . . structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles,. . . from events and conditions outside the nuclear power unit."

The Standard Review Plan (SRP) [2] Section 3.5.1.4 provides further guidance in meeting GDC 2 and 4 requirements. Specifically, SRP Section 3.5.1.4 refers to the acceptance criteria of SRP 2.2.3, which states ". . . design basis events include each postulated type of accident for which the expected rate of occurrence of potential exposures in excess of the 10 CFR Part 100 guidelines is estimated to exceed the NRC staff objective of approximately 10^{-7} per year . . . expected rate of occurrence of potential exposures in excess of the 10 CFR 100 guidelines of approximately 10^{-6} per year is acceptable if, when combined with reasonable qualitative arguments, the realistic probability can be shown to be lower. . ."

III. Summary

The probability of failure of the equipment in the IVC to perform its safety function in the event of a hurricane is evaluated using PRA methodology. The study quantifies the probability of hurricane-generated missiles hitting the top of the IVC. The results are compared to the NRC

acceptance criteria. The results indicate that hurricane-generated missiles are not a significant threat to the IVC equipment. The results further indicate that no physical barriers are required at the top of the IVC.

IV. Analysis Approach

– The probability of damage to equipment located in the IVC depends on three factors:

A. The probability distribution function for hurricane occurrence at the plant site f(w).

B. The conditional probability of one or more hurricane-generated missiles striking the top of any one of four IVC compartments, given the hurricane occurrence, $P_H(w)$.

C. The conditional probability of IVC equipment being damaged, given that the hurricane-generated missile or missiles have entered the IVC, P_D.

So:

$$P_T = \int_0^\infty f(w)P_H(w)P_D(w)dw \quad (1)$$

The hurricane occurrence rate is developed in Appendix B. The cumulative probability of exceeding a given hurricane wind speed at the plant site is shown in Table I.

The conditional probability of the missile strike, given the hurricane occurrence, depends on the following subfactors:

A. The number of potential missiles.

B. The conditional probability of the potential missiles becoming airborne (or injected), given the occurrence of a hurricane.

C. The conditional probability of missiles being transported from their origin to the target, given that they become airborne.

D. The target area.

The number of potential missiles is based on data from Electric Power Research Institute (EPRI) surveys at seven nuclear power plant sites [5]. The probability of the potential missiles becoming airborne is calculated using a missile model developed at Jet Propulsion Laboratory (JPL) [6]. The conditional probability of missiles being transported from their origin to the target is based on a statistical mechanics model [7], [8]. The area of the top of each of the four IVC compartments is 745 square feet (total target area is 2980 square feet). The IVC height is 55 feet above grade and the grade elevation does not vary significantly

within 300 feet of the IVC. The number of potential missiles and the missile density incorporated into this study are shown in Table II.

The conditional probability of IVC equipment being damaged, given that the hurricane-generated missile or missiles have entered the IVC, is conservatively taken to be certain and total. That is, the conditional probability is taken as unity.

The result of this very conservative estimate is compared with the NRC acceptance criteria of 10^{-7} and 10^{-6} per year. Because of the uncertainty of some factors, we use the median as the "best estimate" or "recommended" value [9].

V. Assumptions and Conservatisms

The following assumptions are used in this study:

A. A hurricane missile strike on the top of any one IVC represents failure (see conservatisms A and C, below).

B. The distribution of potential missiles by number and length is based on an EPRI survey of seven nuclear plants [5].

C. The conditional probability of a missile striking the target, given the hurricane occurrence, is adopted from the tornado missile model [7, 8, 11].

D. The frequency of hurricane wind speed is fitted with a Weibull distribution.

Conservatisms incorporated in this study are:

A. The strike probability, in comparison to the NRC's activity release frequency acceptance criteria, assumes:

   1. Missile-inflicted damage is certain and total.
   2. For purposes of this study damage was not evaluated. It is assumed that damage could lead directly to "potential exposures in excess of the 10CFR100 guidelines..." (SRP 2.2.3 acceptance criteria).

B. The potential missile model assumes:

   1. A missile distribution based on EPRI survey without censoring as was done for the EPRI studies.

   2. A missile density upper limit increased by a factor of 2.5 over the EPRI survey to account for local variations in missile density.

   3. All the missiles are distributed up to 20 feet above grade.

   4. The number of unrestrained missiles was conservatively chosen to be 10% of all missiles.

C. Geometric factors that result in further conservatisms are:

1. Sheltering by other structures is neglected.

2. A missile strike in any IVC opening results in failure.

3. The area of safety-related equipment inside the IVC is less than the IVC top area.

VI. Results and Conclusions

The result of the analysis is the probability of hurricane missile damage to the IVC equipment. The median (50th percentile) value is reported in Table III. The median or "best estimate" value of strike probability is approximately 1.2×10^{-10} per year. This is very small compared to the NRC activity release acceptance criteria value of 10^{-7} to 10^{-6} per year.

The above results indicate that hurricane-generated missiles are not a significant threat to the IVC equipment. These results further indicate that no physical barriers are required at the top of the IVC to protect IVC equipment from potential hurricane-generated missiles.

VII. REFERENCES

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TABLE I

THE PROBABILITY OF EXCEEDING A GIVEN WIND SPEED, w, AT THE STP PLANT SITE PER YEAR

w (m/s)	w (mph)	Weibull Distribution Based Upon Table B.2
50	112	5.4×10^{-3}
55	123	2.0×10^{-3}
60	134	6.1×10^{-4}
65	145	1.6×10^{-4}
70	157	2.9×10^{-5}
75	168	4.0×10^{-6}
80	179	6.0×10^{-7}

TABLE II

DISTRIBUTION OF POTENTIAL MISSILES

	Median (50th Percentile)
Number of Potential Missiles on Site and Vicinity (2.5×10^7 ft^2), N_p	6,000
Local Surface Density of Potential Missiles Near the IVC (ft^{-2}), n_p	2.40×10^{-4}

Table III

MEDIAN VALUE FOR THE PROBABILITY OF DAMAGE TO IVC FROM HURRICANE-GENERATED MISSILES

Weibull wind speed distribution at the plant site, 90% restrained, 10% unrestrained potential missiles up to 20-foot above grade For uncorrelated sampling errors (see Table B.8)	1.2×10^{-10} per year

APPENDIX A

GENERAL METHOD

A.1 Introduction

Probabilistic evaluation of hurricane-generated missile hazard to the containment isolation valve cubicle equipment is based on historical data of hurricane occurrences along the Gulf of Mexico and on a theoretical model for the conditional probability of hitting a target given the hurricane occurrence.

A.2 Hurricane Frequency of Striking the STP Nuclear Power Plant Site

According to [10], the cumulative distribution of extreme wind occurrence can be described in two ways:

$$F_1 (w) = \exp \left\{- \exp \left[- \frac{(w - \alpha)}{\sigma}\right]\right\} \quad (A.1)$$

$$F_2 (w) = \exp \left[- \left(\frac{(w - \alpha)}{\sigma}\right)^{-\gamma}\right] \quad (A.2)$$

where $F_1(w)$ and $F_2(w)$ are cumulative functions of Type I and Type II distributions, w is an extreme wind speed in mph, and α, σ, and γ are distribution parameters.

Because the wind speed, w, in the formula for conditional probability of hitting is given in m/s, we introduce conversion coefficient $\beta = 2.2374145$, which converts m/s into mph.

We will use formulae (A.1) and (A.2) in the asymptotic area where $F_1(w)$ and $F_2(w)$ differ from unity by a small number (10^{-3} or less). In this area, formulae A.1 and A.2 can be simplified:

$$F_1 (w) = 1 - \exp \left[- \left(\frac{\beta w - \alpha}{\sigma}\right)\right] \quad (A.3)$$

$$F_2 (w) = 1 - \left(\frac{\beta w - \alpha}{\sigma}\right)^{-\gamma} \quad (A.4)$$

Batts [4] proposed the use of a Weibull distribution, which gives the best fit for a tail:

$$F_w (w) = 1 - \exp \left[- \left(\frac{\beta w - \alpha}{\sigma}\right)^{\gamma}\right] \quad (A.5)$$

The density functions for hurricane occurrence for all three types of cumulative distribution given by formulae (A.3), (A.4), and (A.5) are:

$$f_1 (w) = \frac{\beta}{\sigma} \exp\left[- \left(\frac{\beta w - \alpha}{\sigma}\right)\right] \quad (A.6)$$

$$f_2 (w) = \frac{\gamma\beta}{\sigma} \left(\frac{\beta w - \alpha}{\sigma}\right)^{-\gamma-1} \quad (A.7)$$

$$fw (w) = \frac{\gamma\beta}{\sigma} \left(\frac{\beta w - \alpha}{\sigma}\right)^{\gamma-1} \exp\left[- \left(\frac{\beta w - \alpha}{\sigma}\right)^{\gamma}\right] \quad (A.8)$$

Therefore, the probability, dP_o, that a hurricane with maximum wind speed in the range (w, w + dw) will strike the plant site is:

$$dP_o = f (w) dw \quad (A.9)$$

where f(w) is one of density functions (A.6), (A.7), or (A.8).

Now we have to choose between these three distributions. The Type II distribution was designed for nontropical storms. According to [12], the application of Type II distribution to hurricanes leads to a ridiculous result. For example, for the estimated 1000-year wind (i.e., the probability of occurrence 10^{-3} per year), a value of 1250 mph is predicted by (A.7). It is much higher than a maximum possible wind speed for hurricanes

According to [12], the gradient wind, w, can be evaluated according to the formula:

$$w = \frac{\xi}{\rho f} \frac{dp}{dn} \quad (A.10)$$

where:

$\frac{dp}{dn}$ = gradient of pressure

ρ = air density

f = Coriolis parameter

ξ = coefficient depending on ratio of geostrophic wind velocity and Coriolis velocity. The range for cyclonic winds is:

$$0.5 < \xi < 1 \quad (A.11)$$

Assuming the maximum pressure drop of 1 atm and minimum distance of this pressure drop of 1 km, we obtain the maximum value for the pressure gradient:

$$\frac{dp}{dn} = 101.3 \frac{Kg}{m^2 s^2} \qquad (A.12)$$

Maximum hurricane wind speed, w_m, corresponding to this gradient of pressure at the site latitude is in the range:

$$120 \text{ mph} < w_m < 240 \text{ mph} \qquad (A.13)$$

Analysis performed in [12, 15] indicates that Weibull distribution is more appropriate for high wind prediction than Type I distribution. Therefore, the Weibull distribution was incorporated in this study.

The STP site location is shown on Figure A-1. It is located between mileposts 300 and 350. Cumulative distributions are shown in Table I.

A.3 Conditional Probability of Hitting a Target, Given the Hurricane Occurrence at Plant Site

The conditional probability, P_H, of a missile hitting a target given a hurricane occurrence at the plant site was adopted from the tornado missile study [7, 8]:

$$P_H (w) = n_p A \eta (w) \psi (w, z) \qquad (A.14)$$

where:

n_p = local density of potential missiles
A = area of target
z = target elevation over the ground
$\eta(w)$ = probability of injection of potential missiles
$\psi (w, z)$ = height distribution of airborne missiles

The probability of injection, $\eta(w)$, was calculated according to the method described in [8]. The parameters of height distribution, $\psi (w, z)$, were calculated according to the formulae given in [11].

An example of these calculations is shown in Table A.1a and b. This is based upon the Weibull distribution of hurricane wind speeds which corresponds to the best estimate speeds given in Table B.5. The results for restrained and unrestrained missiles are given in Table A.1a and Table A.1b, respectively.

As mentioned above, the transport model used was developed specifically for winds characteristic of tornados. This implies a high degree of randomness in wind direction at a particular location during a single storm. The model thus assumes that the direction of missile transport is isotropic. The applicability to the straight line hurricane winds depends upon a consideration of the different wind directions that can occur at a particular site for a large number of storms rather than for a single storm as for tornados. The data [10] indicate a fair degree of randomness in wind direction at the site over the period

of data collection. Since our analysis is based on a large sample of hurricanes with long recurrence intervals the transport model developed assuming a random wind direction can be used here with a high degree of confidence.

A.4 Damage Probability to IVC Per Year

The annual damage probability, P_T, to the IVC can be calculated by formula:

$$P_T = \int_{w_o}^{\infty} f(w)\, P_H(w)\, dw \qquad (A.15)$$

since $P_D = 1$ for all strikes.

where $P_H(w)$ is given by formula (A.14) and $f(w)$ by formula (A.8).

w m/s	w mph	η(w)	ψ(z,w) (z=55 ft)	$P_{H(w)}$
88.0000	197	.00000	.23934+00	.00000
89.0000	199	.20000-02	.24581+00	.35160-03
90.0000	201	.16000-01	.25227+00	.28868-02
91.0000	204	.27000-01	.25871+00	.49959-02
92.0000	206	.35000-01	.26514+00	.66370-02
93.0000	208	.55000-01	.27155+00	.10682-01
94.0000	210	.77000-01	.27793+00	.15306-01
95.0000	213	.10100+00	.28429+00	.20536-01
96.0000	215	.12200+00	.29063+00	.25359-01
97.0000	217	.12200+00	.29693+00	.25909-01
98.0000	219	.11700+00	.30321+00	.25372-01
103.0000	230	.17300+00	.33407+00	.41334-01
108.0000	242	.23500+00	.36395+00	.61170-01
113.0000	253	.26100+00	.39273+00	.73309-01
118.0000	264	.34000+00	.42033+00	.10221+00
123.0000	275	.35500+00	.44671+00	.11342+00
128.0000	286	.38500+00	.47186+00	.12993+00
133.0000	298	.39000+00	.49577+00	.13829+00
138.0000	309	.43800+00	.51849+00	.16242+00
143.0000	320	.46800+00	.54003+00	.18076+00
148.0000	331	.46200+00	.56044+00	.18518+00

Table A.1a: Height distribution, ψ(z,w), Injection Probability η(w) and conditional probability of hitting, $P_H(w)$, as functions of wind speed, w; based upon Weibull parameters corresponding to Table B.2; restrained missiles.

w m/s	w mph	$\eta(w)$	$\psi(z,w)$ (z=55 ft)	$P_{H(w)}$
81.0000	181	.00000	.19396+00	.00000
82.0000	183	.11000-01	.20042+00	.15768-02
83.0000	186	.30000-01	.20690+00	.44393-02
84.0000	188	.36000-01	.21339+00	.54941-02
85.0000	190	.48000-01	.21988+00	.75482-02
86.0000	192	.68000-01	.22637+00	.11009-01
87.0000	195	.10900+00	.23285+00	.18153-01
88.0000	197	.11900+00	.23934+00	.20370-01
89.0000	199	.14400+00	.24581+00	.25315-01
90.0000	201	.13600+00	.25227+00	.24537-01
91.0000	204	.14300+00	.25871+00	.26460-01
96.0000	215	.19600+00	.29063+00	.40740-01
101.0000	226	.25900+00	.32183+00	59615-01
106.0000	237	.28500+00	.35212+00	.71774-01
111.0000	248	.36900+00	.38135+00	.10064+00
116.0000	260	.38100+00	.40943+00	.11157+00
121.0000	271	.41900+00	.43630+00	.13075+00
126.0000	282	.42000+00	.46194+00	.13876+00
131.0000	293	.46600+00	.48635+00	.16209+00
136.0000	304	.49900+00	.50955+00	.18185+00
141.0000	315	.48800+00	.53155+00	.18552+00
146.0000	327	.53800+00	.55241+00	.21255+00
151.0000	338	.57200+00	.57216+00	.23407+00

Table A.1b: Height distribution, $\psi(z,w)$, Injection Probability, $\eta(w)$, and conditional probability of hitting, $P_H(w)$, as functions of wind speed, w; based upon Weibull parameters corresponding to Table B.2; for unrestrained missiles.

APPENDIX B

SENSITIVITY OF RESULTS TO ERRORS IN THE HURRICANE WIND SPEED DATA

B.1 Background

Although historical data does exist for extreme wind speeds along the Gulf of Mexico coastline [10] it has been shown that predictions of extreme wind speeds in hurricane-prone regions cannot in general be based solely upon a statistical analysis of these data [12]. Indirect methods are therefore commonly employed. Historical data are used to make statistical inferences concerning the various climatological characteristics of hurricanes in the region of interest and probabilistic models for each of these characteristics are developed. In addition, a physical model of the hurricane wind structure is developed. Using this information a large number of hurricanes are simulated by Monte Carlo techniques. From these simulated hurricanes, the largest wind speeds are used to estimate the cumulative distribution function of hurricane wind speeds at the site of interest.

This technique is susceptible to several errors which can generally be classified into four categories [12]: (1) sampling errors due to the limited amount of historical data used to develop the statistical model of the hurricane, and the limited number of hurricanes generated by Monte Carlo simulation; (2) probabilistic modeling errors due to the imperfect choice of distribution functions to which the climatological data are fitted; (3) observational errors in the measurement of actual wind speeds; and (4) physical modeling errors due to the imperfect representation of the dependence of wind speeds on various parameters.

The purpose of this appendix is to evaluate the impact that these errors may have on the results of this study. The procedure will be to examine the fastest-mile wind speed predictions for various recurrence intervals given by different authors using somewhat different models. From this, a best-estimate will be predicted for each recurrence interval along with a distribution of wind speeds around each recurrence interval which accounts for the possible errors. A Monte Carlo technique will be used to select a wind speed value for each recurrence interval. These wind speeds will be used to fit a Weibull distribution for hurricane wind speeds which can then be used to predict the damage probability as indicated in the main body of the report (See figure B.1a). Repeating this Monte Carlo simulation numerous times will provide an indication of the sensitivity of the final results to the choice of best fit for the Weibull distribution of hurricane wind speeds.

Since various selection effects could result in the errors associated with fastest-mile wind speed predictions at the different recurrence intervals not being entirely independent, this sensitivity study was performed twice. The first study was done assuming the errors in the selection of fastest-mile wind speeds at each recurrence interval were completely uncorrelated. The second study assumed these errors to be 100% correlated. (See figure B.1b)

B.2 Data

The first task is to determine best-estimate fastest-mile wind speeds for several different recurrence intervals. Intervals of 25, 50, 100 and 2000 years were chosen. Although mentioned earlier that a wind speed distribution based solely upon historical data is not acceptable, the results from that data are presented here for comparison with that generated by the hurricane simulation studies.

Historical data are presented in [10]. Data for the South Texas Project Site is determined by linear interpolation of the data presented for Corpus Christi and Galveston. The applicability of linear interpolation is discussed in [13]. The data for Corpus Christi are for winds at a height of 10m; those for Galveston are for winds at 30m. Because the potential missiles are distributed up to 20 ft(~6m) the 10m data are considered more appropriate. The data for Galveston were converted to 10m winds according to equation 3.1.1 of reference [12]:

$$\frac{U(Z_1)}{U(Z_2)} = \frac{\ln[(Z_1-Z_d)/Z_o]}{\ln[(Z_2-Z_d)/Z_o]} \tag{B.1}$$

where

$U(Z_i)$ = wind speed at height Z_i
Z_o = 0.7 for STP
Z_d = 0.0 for STP

then

$$\frac{U(10)}{U(30)} = 0.708$$

Table B.1 shows the results for the four recurrence intervals.

Two independent simulation studies were considered, each using slightly different physical models [13], [15]. Table B.2 shows the appropriate data for the plant site for the simulation study [13].

Data in [15] are presented in terms of mean hourly extremes in m/s. Conversion to mph is straightforward. Conversion of the data to fastest-mile wind speeds is accomplished by multiplying the mean hourly extremes by an appropriate coefficient as discussed in [12]. The results are presented in Table B.3.

B.3 Discussion of Errors

The four types of errors mentioned previously imply some uncertainty in the specification of the fastest-mile wind speeds at various recurrence intervals. A consideration of those errors will help in the choice of a best estimate for each wind speed and a measure of the error inherent in each number. For each recurrence interval the wind speed is assumed to be distributed normally about the best estimate value. Observational errors are accounted for by resorting

to the Monte Carlo hurricane simulation studies and are responsible for the differences between Table B.1 and Tables B.2 and B.3. The two simulation studies, [13] and [15], represent the use of different physical and probabilistic models. Therefore, allowance can be made for the effects of modeling errors by choosing the most conservative of the results. For these reasons the results in Table B.2 have been selected as the best-estimate values for the given recurrence intervals.

Sampling errors can be evaluated to provide an estimate of the spread of the distribution of errors around the best-estimate value. The sampling error due to the limited amount of historical data is discussed in [16] and is estimated to be about 6-10% [13]. Data reported in [13] reduces this type of error by using a smoothing technique where the fastest-mile wind speed at each milepost is calculated by finding the average of the reported speed at that milepost and those for the two nearest neighbor mileposts. This increases the data set by a factor of three and, hence, reduces the error by a factor of $\sqrt{3}$. The relative error due to this type of sampling error is, therefore, 0.035 to 0.058. A value of 0.045, which shall be denoted as δ_1, was chosen for this study.

The second type of sampling error, that due to the limited number of hurricanes in the simulations, is determined by the inherent accuracy of the Monte Carlo method. This type of error is discussed in [17]. For an N-year recurrence interval wind speed, w, the standard deviation of the distribution of speeds about the best estimate is given by:

$$\Delta w = \frac{\sqrt{\frac{1}{N}\left(1-\frac{1}{N}\right)}}{f(w)} \cdot \frac{1}{\sqrt{n}} \qquad \text{(B.2)}$$

where

n = number of simulations
f(w) = density function for the Weibull distribution

Table B.4 shows the results of the calculation for n = 1000 (the number of simulations used in [13]).

For the purpose of comparison, the value of δ_2 for N=50, n=1000, and a Type I distribution, is given by [16] as δ_2 = 0.018. Thus, the relative error used here is generally at least twice this value.

The two types of sampling errors can be combined by the following equation:

$$\delta = \sqrt{\delta_1^2 + \delta_2^2} \qquad \text{(B.3)}$$

The final results are shown in Table B.5

B.4 Best-Fit Weibull Distribution

Now that the errors are quantified, Monte Carlo techniques can be employed to select a set of wind speeds, one for each recurrence interval, for each simulation used in the study. Each set of four wind speeds must be fit to a Weibull distribution for use ultimately in calculating the damage probability.

The fitting procedure is basically a least-squares method. Denote the four wind speeds to be fitted by w_i where i = 1, 2, 3, 4 correspond to recurrence intervals of 25, 50, 100 and 2000 years respectively. A value for the Weibull tail-length parameter, γ, is chosen and the location parameter, $\alpha(\gamma)$, and the scale parameter, $\sigma(\gamma)$ (see equation A.8), are calculated from:

$$\sigma(\gamma) = \frac{w_2 - w_1}{(\ln N_2)^{1/\gamma} - (\ln N_1)^{1/\gamma}} \qquad \text{(B.4)}$$

$$\alpha(\gamma) = w_2 - \sigma (\ln N_2)^{1/\gamma} \qquad \text{(B.5)}$$

An error function is then evaluated:

$$E = \sum_{i=1}^{4} \left(\frac{w_i(\gamma) - w_i}{w_i} \right)^2 \qquad \text{(B.6)}$$

where $w_i(\gamma)$ is the fitted wind speed value according to the current choice of γ

An iteration is performed on γ in order to minimize the value of E.

B.5 Results of Sensitivity Study

The procedure described in section B.4 is repeated for each simulation. This results in a different Weibull distribution and, hence, a different damage probability for each simulation. One hundred simulations were carried out for the case where the errors were considered to be completely uncorrelated and twenty were done for the case where the errors were 100% correlated.

The absolute range of fitted wind speeds obtained for various recurrence intervals are given in tables B.6 and B.7. Considering the number of simulations done for each case, the ranges can be assumed to be essentially the same.

Damage probabilities can be calculated for each simulation using the methods outlined in Appendix A. A summary of the results from all of the simulations is given in Table B.8. The apparent differences in the results between the cases for correlated and uncorrelated errors are slight enough to be considered as an artifact of the Monte Carlo simulation technique rather than any real difference.

Recurrence Interval	Corpus Christi (10m)	Galveston (30m)	Galveston (10m)	Interpolation for plant site (10m)
25 yr	105	88	62.3	83.65
50 yr	116	94	66.6	91.30
100 yr	124	98	69.4	96.70
1000 yr	145	111	78.6	111.8

Table B.1: Fastest mile wind speed data based upon historical records [10]. All wind speeds are in miles per hour.

Recurrence Interval	Fastest-Mile Wind Speed in mph at 10m
25	83.1
50	94.5
100	104.7
2000	135.9

Table B.2: Fastest-mile wind speed data for plant site based upon Monte Carlo hurricane simulation study [13].

Recurrence Interval	Mean Hourly Extreme (m/s)	Mean Hourly Extreme (mph)	Correction to Fastest-Mile	Fastest-Mile Wind Speed (mph)
25	28	62.7	1.28	80.2
50	31	69.4	1.29	89.5
100	35	78.3	1.30	101.8
2000	47	105.2	1.32	138.8

Table B.3: Fastest-mile wind speed data for plant site based upon Monte Carlo hurricane simulation study [15].

Recurrence Interval (yr)	Δw (mph)	Relative Error $\delta_2 = \Delta w/w$
25	2.774	0.0334
50	3.354	0.0355
100	4.254	0.0406
2000	12.252	0.0902

Table B.4: Sampling errors due to a limited number of hurricane simulation.

Recurrence Interval (yr)	Relative Sampling error, δ	Best-Estimate Fastest-Mile Wind Speed, (mph) (From Table B.2)	Standard Deviation (mph)
25	0.0560	83.1	4.65
50	0.0573	94.5	5.41
100	0.0606	104.7	6.34
2000	0.1008	135.9	13.70

Table B.5: Best-estimate and standard derivation for fastest-mile wind speeds of various recurrence intervals.

Recurrence Interval (yrs)	Range of Fitted Fastest-Mile Wind Speeds (mph)
25	75.1 - 91.3
50	87.0 - 103.8
100	91.2 - 116.9
2,000	109.2 - 160.5
10,000	119.0 - 177.3
100,000	132.0 - 211.0
1,000,000	142.3 - 247.0

Table B.6: Range of fitted fastest-mile wind speeds for various recurrence intervals for completely uncorrelated errors.

Recurrence Interval (yrs)	Range of Fitted Fastest-Mile Wind Speeds (mph)
25	75.4 - 91.1
50	85.6 - 103.8
100	94.0 - 115.5
2,000	120.2 - 157.7
10,000	130.3 - 177.0
100,000	142.2 - 201.7
1,000,000	151.5 - 224.1

Table B.7: Range of fitted fastest-mile wind speeds for various recurrence intervals for 100% correlated errors.

	5th Percentile	Median	95th Percentile
Completely uncorrelated errors	4.43×10^{-14}	1.20×10^{-10}	3.26×10^{-7}
100% correlated errors	6.57×10^{-15}	7.49×10^{-11}	8.53×10^{-7}

Table B.8: Damage probability estimates assuming 10% unrestrained and 90% restrained potential missiles.

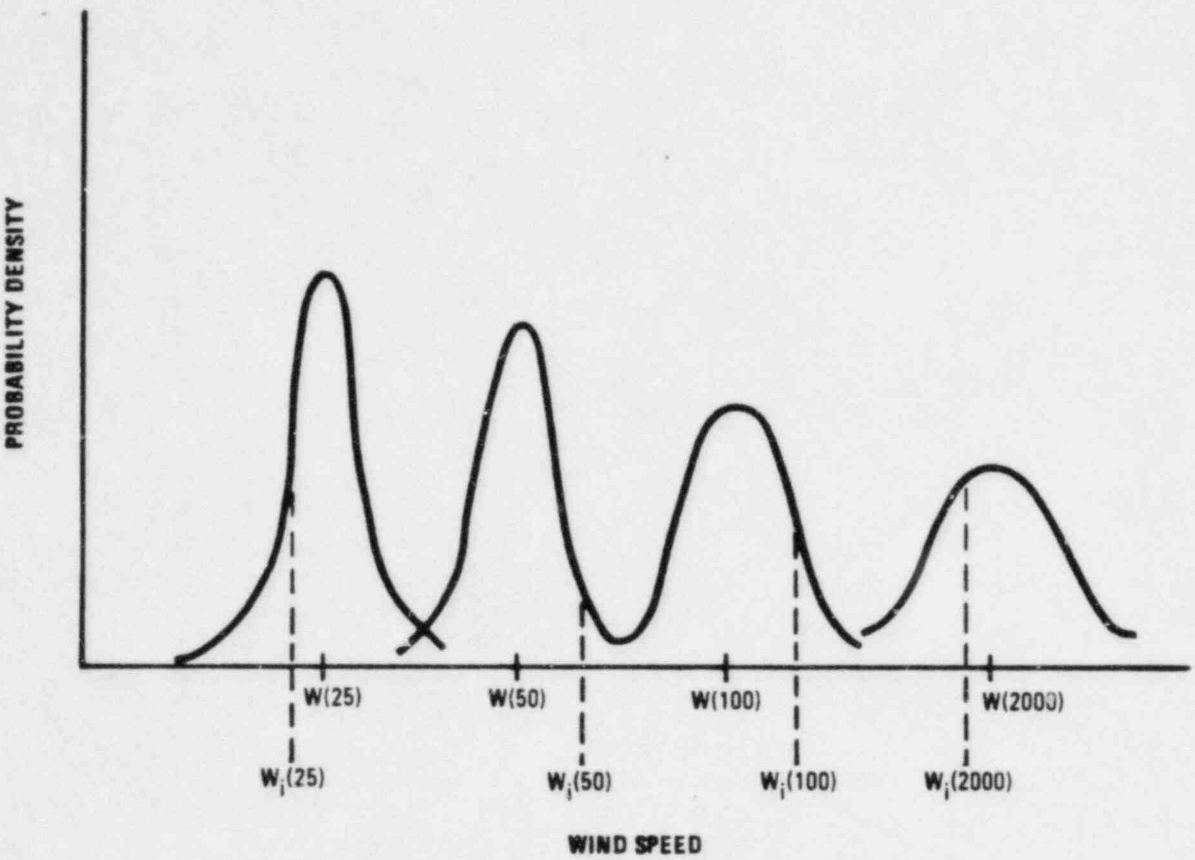

Figure B.1a: Representation of Monte Carlo simulation procedure for uncorrelated errors. w(25), w(50), w(100) and w(2000) represent best estimate wind speeds for recurrence intervals of 25, 50, 100 and 2000 years respectively. The estimated probability distribution functions are shown in each case. The i^{th} Monte Carlo trial selects at random the four wind speeds $w_i(25)$, $w_i(50)$, $w_i(100)$ and $w_i(2000)$. These four values are used to fit a Weibull distribution. Note: The distributions shown are not intended to be accurate representatives of the actual wind speed distribution, but are for illustration purposes only. This fitted Weibull distribution is then used to calculate a damage probability for the i^{th} trial.

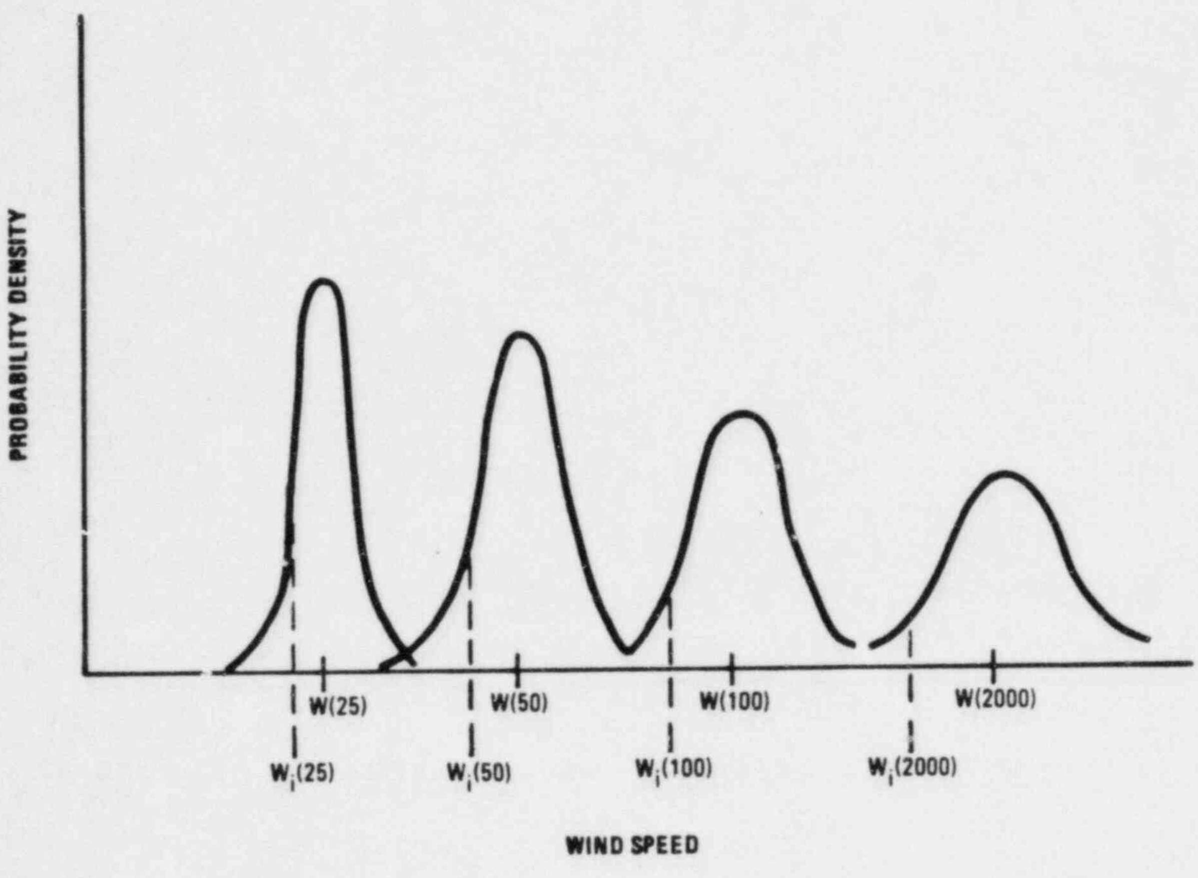

Figure B.1b: Representation of Monte Carlo simulation for 100% correlation of errors. Note that each sample wind speed, $w_i(x)$, has the same relative error (for example, 1σ) although the absolute magnitude of the error may differ due to the different distributions at each recurrence interval.

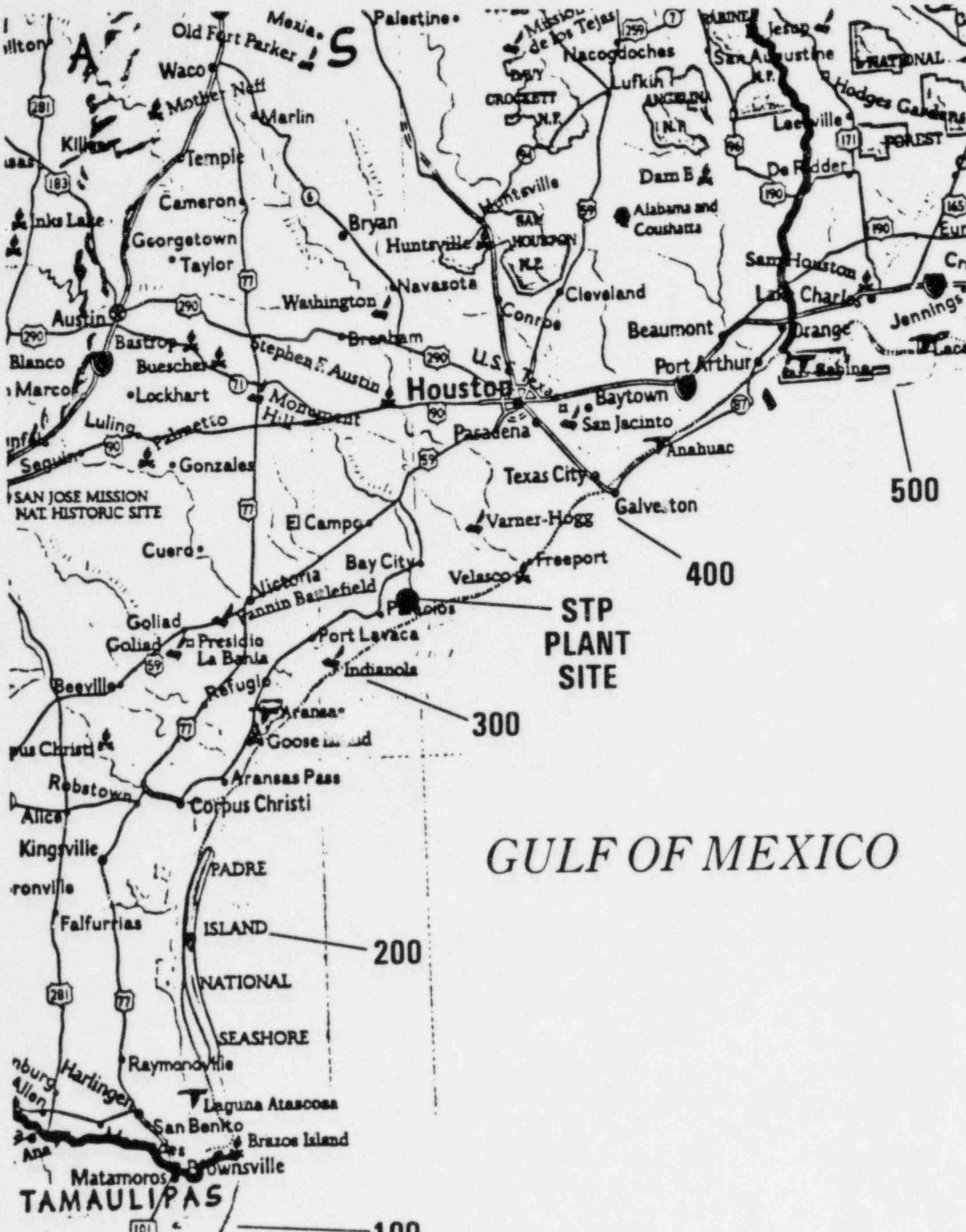

FIGURE A-1
STP SITE AND COASTAL REGION