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Chet Poslusny, Senior Project Manager
Standardization Project Directorate
Associate Directorate for Advanced Reactors
and License Renewal
Office of the Nuclear Reactor Regulation

Subject: Submittal Supporting Accelerated ABWR Schedule - **Section 19D.10, Data Uncertainty Analysis for ABWR**

Dear Chet:

Attached is a final draft of Section 19D.10, Data Uncertainty Analysis for ABWR. It will be included in Amendment 30 scheduled for issuance to the NRC on July 8, 1993.

Please provide a copy of this transmittal to Glen Kelly.

Sincerely,

Jack Fox

Jack Fox
Advanced Reactor Programs

cc: Alan Beard (GE)
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19D.10 Data Uncertainty for ABWR PRA

19D.10.1 Introduction

This analysis presents the results of a quantitative data uncertainty analysis for the Advanced Boiling Water Reactor (ABWR) Level 1 Probabilistic Risk Assessment (PRA).

19D.10.2 Purpose and Summary of Conclusions

The purpose of this study was to determine and propagate data uncertainty in the internal events analysis in the ABWR Level 1 PRA, to provide the distribution of uncertainty in the calculated core damage frequency (CDF).

The uncertainty analysis results show that the ABWR CDF has the distribution shown in Figure 19D.10-1, having a mean value of 1.56E-07 per reactor-year and an error factor of 4.2, (calculated as the 95th percentile divided by the median). The 95th percentile of the distribution is 2.9 times the mean value or 4.53E-07. The 5th percentile is 3.4E-08 per reactor-year.

The top ten contributors to the uncertainty in the CDF were identified using the uncertainty importance measure. Nine of these are also in the top ten basic events ranked according to the Fussell-Vesely (F-V) importance measure. The basic event RCIMAINT (i.e., RCIC is down for test or maintenance) is the highest contributor to uncertainty in the CDF as well as to the mean value of the CDF. RCIC test and maintenance is part of the reliability assurance program (RAP), and is discussed in Subsection 19K.9. The remaining contributors are identified in Subsection 19D.10.6.1.

The uncertainty results show that the 95th percentile is only moderately sensitive to the error factors (EFs) of the basic events, and hence that lack of precise EF values has a rather small effect on the outcome. For example, doubling the EF values of each basic event simultaneously increases the 95th percentile of the CDF by only 12%. When all EFs are set equal to 15, the 95th percentile increases by only 14%. (See Note 1 in Subsection 19D.10.8).

CDF uncertainty was also analyzed according to the degree of coupling between components. When similar components were given the same failure rate value in any one simulation run, the effect of coupling was shown to be negligible. When human error events were coupled (i.e., given the same HEP value), the effect of coupling was shown to be negligible.

Possible bias uncertainty was analyzed by multiplying all mean values of basic events by two (which case is referred to as the "X2 case" in this report). It was found that seven of the top ten basic events in the nominal case, ranked by F-V importance, were in the top ten ranking in the X2 case. Similarly, five of the top six accident sequences were the same in both cases. This is an indication that insights gained from the PRA as to the relative importance of the top ten basic events, and top six accident sequences, will be correct, even if the input data is biased.

19D.10.3 Approach

The effects of uncertainty in PRA data were analyzed as follows:

(1) The sources of data were identified

(2) Error factors were assigned to the PRA data.

(3) The uncertainties were propagated across the fault trees and event trees using Monte Carlo simulation.

(4) The accuracy of the computerized mathematical modeling was established.

A sensitivity analysis was also performed on the mean values of the input data, on the truncation limits, on the EFs, and on the degree of coupling between components.

19D.10.4 Data Analysis

The data types analyzed in this report are listed in column 1 of Table 19D.10-1.

Each entry of the second column is the source reference used for the point estimate (mean) data used in the level 1 calculation. The sources for the Error Factor (EF) estimates used in this analysis are shown in column 3. Each point estimate in the analysis is treated as the mean value of a log normal distribution. All EF values used are for the 95th percentile over the 50th percentile.

19D.10.4.1 Human Error Probability (HEP) Error Factors (EFs)

An EF was assigned for each HEP from Reference 19D.10-1 (Table 7-2), which provides straightforward rules for assigning EFs based on the estimated magnitude of the HEP, and on the stress level which applies to the action. For this report, only two stress levels were used, corresponding to events prior to and events during the accident. Table 19D.10-2 shows the EFs used in both situations. A basic assumption is that the tasks are performed by experienced personnel only (licensees with at least 6 months' familiarity with the plant).

The HEP EFs which are used are considered conservative because Reference 19D.10-1 is based to a large extent on either (a) derived data, or (b) data from older nuclear power plants (pre-1982). Hence, refinements in training, in operations, and in Human Factors Engineering will tend to group the HEP variability between operators closer together and make the EFs smaller than the values used herein. Reference 19D.10-1 (in Table 7–2) gives EFs as step functions of the HEP. This is evidently an approximation to a smooth curve. The variability of these EFs will have some effect on the variability of the top event. The amount of effect this has is described in Subsection 19D.10.6.

19D.10.4.2 Component Failure Rate (FR) EFs

Reference 19D.10-2 was used as the main source for EF data on FRs, even though the point estimates came mainly from References 19D.10-3 and 19D.10-4.
Reference 19D.10-2 summarizes the results of a study sponsored by the Integrated Risk Assessment Data Acquisition Activity Program (IRADAP) of the Office of Analysis and Evaluation of Operational Data of the NRC. The raw data used came from the Nuclear Computerized Library for Assessing Reactor Risk (NUCLARR), which is sponsored by the NRC. Reference 19D.10-2 presents generic component failure data results obtained from data aggregation algorithms. The algorithms are based on theoretical results published in Nuclear Science and Engineering, Reference 19D.10-5.
Reference 19D.10-2 claims to offer some advantages over previous generic failure data sources, which were based largely on expert judgement.

19D.10.4.3 EFs for Special Cases

(1) Common-cause failures (CCFs) were assigned an EF of 15.

(2) An EF of 5 was assigned for each accident initiation frequency.

(3) Undeveloped events were given an EF of 15.

(4) Components which were not listed in the EF database, Reference 19D.10-5, were estimated on the basis of similarity to listed components. Table 19D.10-3 provides the similarity model used.

19D.10.4.4 Analysis of Error Factor Applicability to PRA Data

An initial hurc f the uncertainty analysis was the fact that the ABWR PRA basic event failure data for components were given in terms of probabilities of failure, whereas the EF data source (Reference 19D.10-2) gives EF values for failure rates. This issue was resolved as follows:

$$\text{when } \lambda t << 1, \text{ then } q(t) = 1\text{-}e^{-\lambda t} \approx \lambda t.$$

where

λ	=	component failure rate, and
t	=	mission time

So the 95th and 50th percentiles of q(t) are approximately given by

$$q_{0.95}^{(t)} = 1\text{-exp}\ (-\lambda_{0.95}t) \approx \lambda_{0.95}t$$

$$q_{0.5}^{(t)} = 1\text{-exp}\ (-\lambda_{0.5}t) \approx \lambda_{0.5}t$$

The error factor is defined as

$$EF = \frac{q_{0.95^{(t)}}}{q_{0.5^{(t)}}} \approx \frac{\lambda_{0.95}}{\lambda_{0.5}}$$

The percentage error in this approximation was tested and found to be less than 5% whenever the 95th percentile of the failure rate times mission time was less than or equal to 0.1. All failure rate values used in the ABWR PRA fall into this category.

19D.10.5 Analysis of Uncertainty and Sensitivity

19D.10.5.1 Analysis of Mathematical Models Used in the PRA and in this Analysis

19D.10.5.1.1 Applicability of Lognormal Distribution

An issue for the ABWR uncertainty analysis was whether the lognormal distribution was applicable to the probabilities, unavailabilities and unreliabilities (rather than failure rates). This was answered affirmatively by applying a test to doubtful cases. The method is based on the spill-over of probability mass out of the [0,1] interval, (in which all probability values must theoretically be contained). In a few cases the spill-over was not trivial. However, because such cases give worst case values, no adjustment was made to the uncertainty analysis.

19D.10.5.1.2 Sampling Uncertainties

UNCERT is a PC code, developed by Science Applications International Corporation, which is used for generating probability distributions of a top event when probability distributions of the initiating and subsequent events are specified. The *UNCERT User's Manual* (Reference 19D.10-6) shows how the fault tree description must be given to UNCERT in the form of cutsets. A Monte Carlo technique is used for calculation of the histogram of the top event probability.

19D.10.5.1.2.1 Sampling of the Tails

Sar.pling is performed using the method for generating random numbers which is described in Section 26.8 (pages 949 and 950) of Reference 19D.10-7. SAIC has checked the accuracy of the sampling for the 95th percentile of two lognormal distributions each with mean E-04, one with EF=3 and the other with EF=15. The results are within the 95th percentile confidence limits for both of these cases.

19D.10.5.1.3 Coupling Uncertainties

19D.10.5.1.3.1 Coupling of Hardware Failure Rates

When using simulation runs to study uncertainty of a top event, the following issue about similar components arises:

How are the failure probabilities to be sampled when a group of components are made by the same manufacturer and used in the same manner? Evidently, the same probability is to apply to each member of the group. Reference 19D.10-6 refers to this as coupling of basic events, and describes a methodology for coupling events whenever appropriate. This is done by using UNCERT in conjunction with CAFTA. (CAFTA is the PC code used to calculate top event probabilities for the level 1 calculation.) Basic events were coupled in this sense whenever coupling was appropriate.

19D.10.5.1.3.2 Model for the Coupling of Human Errors

Since no previously studied model of human error coupling was found, the human events were initially coupled by splitting the human actions into pre-event and post-event actions and coupling events within each group. The coupling capability of UNCERT is such that only events which have the same error factors can be coupled. This was a constraint on the coupling model used. However, further analysis showed that this was not a serious limitation.

19D.10.5.1.3.3 Cutset Truncation Uncertainties

The CAFTA code was used for generating the cutsets in the level 1 calculation. [CAFTA was developed by SAIC for the Electrical Power Research Institute (EPRI) in 1986.]

CAFTA was used in the uncertainty analysis to generate cutsets upon which to do the Monte Carlo simulation. The cutsets obtained are all cutsets having a probability of occurrence greater than a chosen truncation limit. The following sensitivity analyses were performed to investigate the adequacy of the truncations used to obtain the main CDF result.

(1) A computer run was made with all basic events multiplied by a factor of 2, and the truncation limit set equal to that used during the point estimate run (nominal case).

(2) The total probability of the additional cutsets picked up for the worst case (the X2 case) run, was compared to the probability of the top event in the nominal case. If this is small, than it is clear that the truncated cutsets do not contribute much to the uncertainty of the result. This is so, because multiplying all mean values by a factor of 2 is an extreme worst case which would essentially never be obtained if a Monte Carlo analysis were run with any value of EF applied across all basic events appearing in the cutsets.

19D.10.5.2 Sensitivity Analysis on the Mean Values of the Basic Events

Bias error uncertainty was first investigated by multiplying the probability of each basic event by 2. The effect of multiplying all basic event probabilities by 2.0 (the X2 case), and running a PRA quantification with point estimates is equivalent to choosing a value above the 85th percentile for each basic event (See Note 2 in Subsection 19D.10.5.1.3.3). This case is rather conservative and would almost never be obtained by random sampling. The results of the X2 case are discussed in Subsection 19D.10.6.3.

The combined effect of bias error uncertainty and EF was investigated by increasing the probability of each basic event by 40%, keeping the same EFs, and using Monte Carlo simulation. The mean value CDF thus obtained is 3.92E-07/year, or 2.5 times the base case CDF. The 95th percentile is 1.14E-06/year. This shows the effect of possible systematic bias error in the PRA.

19D.10.5.3 Sensitivity Analysis on the EFs

To calculate the sensitivity of the 95th percentile to the value of EF, a curve of the 95th percentile divided by the mean value is plotted. This curve is shown in Figure 19D.10-2. The most sensitive region of interest is for the smaller values of EF, and the least sensitive region is between 9 and 18. The sensitivity is judged excellent between 9 and 18 because the variation in the 95th percentile will be less than 3% in that region whenever EF is changed by one unit.

19D.10.5.4 Sensitivity Analysis on Coupling of Basic Events

19D.10.5.4.1 Hardware Coupling Sensitivity Analysis

Two degrees of coupling of basic events were investigated:

(1) Uncoupled Case

In this case, components even with the same type, manufacturer and application were assumed to be different when sampling the failure probabilities.

(2) Coupled Case

In this case, components of the same type and application where assumed to have the same failure probability.

The X2 case, which is discussed in Subsections 19D.10.5.1.3 and in 19D.10.5.2, is also a tightly coupled case wherein all basic event values are simultaneously taken above the 85th percentile of the nominal case (See Note 2 in Subsection 19D.10.8).

A Monte Carlo simulation was run to determine the degree of spreading which occurs as a function of coupling. The results are discussed in Subsection 19D.10.6.

19D.10.5.4.2 Coupling of Human Errors, Sensitivity Analysis

Human error events were coupled, and it was found that, in general, the coupling of human error probabilities (HEPS) does not contribute significantly to the mean value of the CDF. All operator (post-event) actions and all the maintenance (pre-event) actions were coupled separately because the actions are basically different, and control room operator crews are manned by different people than the maintenance crews. HEPs whose error factors were equal were coupled together.

It was found that although coupling of these human error events gives an increase of about 20% in the CDF, almost all of the increase comes from the coupling of just two human actions: "Q" or "Q2", "and HOOBOPHL", which are post-event operator actions relating to high pressure injection. Coupling of maintenance events had very little effect on CDF. For the case of operating crews, it is felt that different crews, at different plants, and in different locations within the total population of plants, will result in differences between the HEP performance of "Q" or "Q2", "and HOOBOPHL". The conclusion is that HEPs need not be coupled to estimate the CDF distribution.

The sensitivity analysis was pursued further, by setting all HEP EFs equal to 5 with all HEPs coupled. This resulted in a 33% increase in mean CDF. However, when "Q" and "Q2" were decoupled from the rest of the HEPs, then the CDF dropped back down to 1.57E-07/year (almost the base case). When "HOOBOPHL" was decoupled from the rest of the HEPs, a similar result was observed.

19D.10.6 Discussion of Results

The uncertainty analysis was run several times with sample sizes of 5000 for each run. Table 19D.10-4 presents typical runs for the uncoupled and coupled fault tree models. Also included in Table 19D.10-4 are the ratios of 95th percentile to the mean, and to the median.

The mean and the 95th percentiles are fairly insensitive to the degree of coupling. This is the case because there are no coupled components in the top cutsets which contribute the largest percentage to the top event. The uncertainty analysis was carried out on the top 300 cutsets, which contribute 1.53E-07/year, or 98.09% of the top event point estimate of 1.56E-07/year. This procedure is justified by the fact that the cutset probabilities become negligible below the top one hundred or so cutsets. Any cut-off cutset has a probability of less than 1.1E-11. The 95th percentile of the top 300 cutsets is within 3% of the 95th percentile of total cutsets generated (See Note 3 in Subsection 19D.10.8).

19D.10.6.1 The Top Ten Contributors to Uncertainty in the CDF

The top 22 events (as ranked by the Fussell-Vesely (F-V) importance measure) were chosen for the calculation of their uncertainty importance. This was obtained by calculating the standard deviation of the top event probability (i.e., the CDF) when only the selected event's probability is allowed to vary. (All other basic event probabilities are held constant at their point estimates.) Runs of 5,000 samples each were made for each of the selected events. The results are given in Table 19D.10-5.

Table 19D.10-5 shows the 10 top contributors to uncertainty in the CDF. The basic events listed in Table 19D.10-5 are defined in Subsections 19D.4 and 19D.6. Nine of the contributors are also in the top ten list when ranked by the Fussell-Vesely (F-V) importance measure. Event EBY1CCF moved from 12th to 10th place, while RLU001DW dropped from 10th to 11th place. Thus, the ranks in Table 19D.10-5 are mostly a permutation of the ranking by F-V importance measure. The permutation has the following pattern. Events with higher EFs move up a notch or two, and events with lower EFs move down a notch or two. It is interesting to note that event RCIMAINT has kept the number 1 rank even though it has an EF of 10. This is because its F-V importance is much higher than that of any other event.

19D.10.6.2 The Effect of Error Factors on the Top Event Distribution

The coupled case was run several times (5000 samples per run) with a variety of EFs to determine the effect of the adequacy of the EF treatment used in the uncertainty analysis. Table 19D.10-6 summarizes the results.

19D.10.6.3 Uncertainty Due to the Truncation Limits Used in Generating the Cutsets

The uncertainty from the truncation by the CAFTA software was studied in two ways:

(1) Case 1—Lower Truncation Limits

The truncation limit used in the basic PRA run was E-13. Additional runs were made with all sequences truncated at E-14. The difference in CDF was about 0.7%.

(2) Case 2—Multiplying The Point Estimates By Two

This case was considered for several reasons:

(a) It provides an additional indication of the sensitivity of importance measures to point-estimate bias.

(b) It brings up a different group of cutsets than those brought up in case 1 above.

For case 2, some of the truncation limits had to be increased. With the higher truncation limits, the top 400 cutsets (for the X2 case) were generated. Then, the additional cutsets (below the top 400) were generated and the CDF probability was determined to be 1.4E-06/year for all the cutsets. This number was adjusted to estimate what these cutsets would contribute when their mean values were reduced back to the nominal case. The resulting estimate is 1.58E-07/year, which is only 1.3% larger than the point-estimate case.

In conclusion, it is felt that the truncation limits of the PRA are adequate, and that the calculated top event probabilities are representative of the true CDF.

19D.10.6.4 Robustness of the Top Events Cutsets, and Sequences

Case 2 above (i.e., with all event and sequence frequencies multiplied by two) was used to analyze the robustness of the PRA in several ways discussed below.

19D.10.6.4.1 Robustness of the Fussell-Vesely (F-V) Importance Measure

Table 19D.10-7 shows how the top 10 events with the highest F-V importance are changed in the X2 case. The events are defined in Subsections 19D.4 and 19D.6.

Table 19D.10-7 shows that 7 of the same events are in the top ten in both cases. This shows that the F-V importance measure ranking is very robust with respect to bias increase in the point estimates. Table 19D.10-8 shows the top ten events in the X2 case.

19D.10.6.4.2 Robustness of the Six Top Accident Sequences

Table 19D.10-9 shows how the six top accident sequences transpose when all of the basic event unavailabilities are multiplied by two (i.e., in the X2 case). The accident event sequences are illustrated in the event trees of Subsection 19D.4. Five of the same sequences are in the top six in both the base case and in the X2 case. It is very interesting that in the base case, the top six sequences contribute 90% of the probability mass of the CDF.

19D.10.7 Conclusion

The ABWR PRA is robust with respect to uncertainty in the basic event probability data. As a result, the 95th percentile of top event frequency does not change much with reasonable increases in the mean values, and in the EFs of the basic events.

19D.10.8 Notes

Note 1—Setting All EFs to 15.

The EFs were set equal to 15 in order to determine how sensitive the ABWR uncertainty analysis results were to the EFs used in the ABWR fault trees. The results showed that when all EFs were set to 15, the 95th percentile of the CDF increased by only 14%. This result is not surprising when considered in terms of the information presented in Table 19D.10-5 and Figure 19D.10-2. Table 19D.10-5 presents the top ten contributing basic events (BEs) to the CDF uncertainty. Figure 19D.10-2 is a sensitivity curve for $x_{0.95}$/mean (where $x_{0.95}$ is the 95th percentile of the BE probability (BEP) as a function of the uncertainty (EF) of the estimate of that BEP. Since the mean is a constant, Figure 19D.10-2 is also a sensitivity curve for the 95th percentile. Table 19D.10-5 and Figure 19D.10-2 provide the following pertinent information:

(1) Table 19D.10-5 shows that four of the top ten contributors to uncertainty already have EF = 15 in the base case, and the change will not affect the BEP distributions in these cases. Two were raised from EF = 10 to EF = 15, and only four were raised from EF = 5 to EF= 15 in the EF sensitivity study.

(2) Figure 19D.10-2 shows that the difference in the values of the 95th percentile is less than 3% when a base case EF=10 is raised to EF = 15. (I.e., $x_{0.95}$/mean changes from about 3.7 to about 3.8). Similarly, when a base case EF=5 is raised to EF = 15, the difference is about 27%. (I.e., $x_{0.95}$/mean changes from about 3.0 to about 3.8).

Combining this information from Table 19D.10-5 and Figure 19D.10-2, we see that the 95th percentile of the top ten contributors to CDF uncertainty changed a small amount, on the average, when the EFs of the top ten BEs are raised to an EF = 15.

Note 2—Multiplying the Mean Values by Two

The effect of multiplying all basic event probabilities by 2.0 results in all probabilities being above the 85th percentile for all basic events, irrespective of whether the error factor is small or not. It is shown below that the maximum value of the 85th percentile ($x_{0.85}$) divided by the mean (x)can be calculated as follows:

$$(x_{0.85}/\bar{x})_{max} = \exp\left(0.5(Z_{0.85}^2)\right)$$

where

$Z_{0.85}$ = the 85th percentile of the standard normal distribution (which is equal to 1.04).

The value of this ratio is approximately 1.72. This shows that the 85th percentile of any lognormal distribution is always less than two times its mean value.

Derivation Of The Value For $(x_{0.85}/\bar{x})_{max}$—First, the EF can be written in terms of the median and the 95th percentile as

$$EF = x_{0.95}/x_{0.5}$$

where

$x_{0.95}$ = 95th percentile

$x_{0.5}$ = 50th percentile

From this definition it follows that

$$EF = \exp(1.645\sigma)$$

and that

$$\sigma = (\ln EF)/1.645$$

where

σ = the standard deviation of the standard normal distribution.

The 85th percentile, $x_{0.85}$, can also be written as

$$x_{0.85} = x_{0.5} \exp(Z_{0.85}\ (\ln EF)/1.645) \qquad (19D.10\text{-}1)$$

Substituting Equation 19D.10-1 into the equation for the mean, $\bar{x}$, of a lognormal distribution gives:

$$\bar{x} = x_{0.5} \exp\ ((\ln EF)^2/2(1.645)^2) \qquad (19D.10\text{-}2)$$

Dividing Equation 19D.10-1 by Equation 19D.10-2 gives

$$x_{0.85}/\ \bar{x} = \exp(1.04(\ln EF)/\ 1.645 - 0.5\ ((\ln EF)/1.645)^2)$$

This equation is a maximum when

$$\ln EF = (1.04)\ (1.645) = 1.711$$

This value of EF gives the maximum value of the ratio $x_{0.85}/\ \bar{x}$:

$$(x_{0.85}/\ \bar{x})_{max} = \exp(0.5(1.04)\ ^2) = 1.72.$$

Note 3—Effect of Including More Cutsets

The coupling which was performed for the uncertainty analysis is such that the coupled events very rarely appear together in the same cutsets, and thus the mean values of the cutsets are affected very little by the coupling. Since the top 300 cutsets contribute 98% of the CDF, coupling the cutsets below the top 300 should add no more than a few percent to the total, even if almost all the basic events appearing in many of the cutsets were coupled.

19D.10.9 References

19D.10-1 A.D. Swain and H.E. Guttman, *Handbook of Human Reliability Analysis With Emphasis on Nuclear Power Plant Applications*, NUREG/CR-1278, August 1983.

19D.10-2 C.D. Gentillon, *Component Failure Data Handbook*, EGG-EAST-8563, April 1991.

19D.10-3 *GESSAR II PRA, 238 Nuclear Island, BWR/6 Standard Plant Probabilistic Risk Assessment*, 19, 22A7007, General Electric Co., March 1982.

19D.10-4 *Failure Rate Data Manual for GE BWR Components*, NEDE-22056, Rev. 2, Class III, General Electric Co, January 17, 1986.

19D.10-5 H.F. Martz and M.C. Bryson, *On Combining Data for Estimating the Frequency of Low-Probability Events with Application to Sodium Valve Failure Rates*, Nuclear Science and Engineering, 83, 1983, pp 267-280.

19D.10-6 *UNCERT User's Manual*, Science Applications Corporation, Los Altos, CA, 1991.

19D.10-7 M. Aboramowitz and I. A. Stegun, Editors, *Handbook of Mathematical Functions With Formulas, Graphs, and Mathematical Tables*, NBS Applied Mathematical Series 55, December 1972 printing.

19D.10-8 A.D. Swain, *Accident Sequence Evaluation Program Human Reliability Analysis Procedure*, NUREG/CR-4772, February 1987.

Table 19D.10-1 Data Sources

Type of Data	Point Estimate Sources*	EF Sources*
(1) Accident initiator frequency data	19D.10-3	Judgement
(2) Component failure data	19D.10-3 19D.10-4	19D.10-2 19D.10-5
(3) Human error prediction (HEP) data	19D.10-1 19D.10-3 19D.10-4	19D.10-1 19D.10-8

* The numbers in the columns refer to references cited in Subsection 19D.10.9

Table 19D.10-2 EF Values for HEPs

Circumstances Under Which Error Occurs	Mean HEP Estimate	EF
Before the accident Initiator (Type A)	<0.001	10
	0.001 to 0.01	3
	>0.01	5
After occurrence of accident initiator (Type C)	<0.001	10
	≥0.001	5

Table 19D.10-3 EF Values Assigned by Similarity

Component	Rationale/Similar Item
Cable	Conductor
Suction Strainer	Filter
Instrument Line	Conductor
Spargers	Weighted average of Pipe and Filters
Refrigerators and Coolers	Air Conditioning Unit and Chillers
Pool	Pipe
Tank	Pipe
Transmission Line	Conductor

Table 19D.10-4 Top Event Uncertainty Results (Top 300 Cutsets Only)

	Mean (xE07)	5th Percentile (xE07	95th Percentile (xE07)	Ratios, i.e., $x_{0.95}$ /Mean	$x_{0.95}$/ Median
Uncoupled	1.51	0.32	4.09	2.71	4.05
Coupled	1.53	0.32	4.42	2.89	4.45

Table 19D.10-5 Top Ten Contributors to Uncertainty in the CDF

Basic Event	EF	Rank by F-V Importance	Standard Deviation (xE08)
RCMAINT	10	1	7.51
CCFMUX	15	4	4.99
RTU001DH	15	5	4.68
HOOBOPHL	5	2	3.01
CCFTLU	15	8	2.74
ILCCFH	15	9	2.48
Q	5	3	2.22
Q2	5	6	1.94
RPM001DW	4.5	7	1.28
EBY1CCF	10	12	1.02

Table 19D.10-6 Sensitivity of 95th Percentile to EF Values (Top 300 Cutsets Only)

EF Modification	Mean (xE07)/Year	95th Percentile (xE07)/Year
All EFs = half the base case	1.54	3.19
Base Case	1.53	4.42
All EFs = twice the base case	1.54	4.82
All EFs = 5	1.56	3.84
All EFs = 15	1.56	4.99

Table 19D.10-7 Fussell-Vesely (F-V) Importance Comparison 1

Component/Rank in Base Case		F-V Importance Measure-Base Case	F-V Rank in X2 Case
1	RCIMAINT	0.219	8
2	HOOBOPHL	0.160	4
3	Q	0.124	1
4	CCFMUX	0.121	6
5	RTUC01DH	0.121	15
6	Q2	0.109	2
7	RPM001DW	0.0745	21
8	CCFTLU	0.0604	10
9	ILCCCFH	0.0604	9
10	RLU001DW	0.0460	28

Table 19D.10-8 F-V Importance Ccmparison 2

Component/Rank in X2 Case		F-V Importance in X2 Case	F-V Rank in Base Case
1	Q	0.318	3
2	Q2	0.279	6
3	COND	0.2580	18
4	HOOBOPHL	0.2550	2
5	GTURBINE	0.2280	20
6	CCFMUX	0.1910	4
7	ELOOP12	0.1560	22
8	RCIMAINT	0.1230	1
9	ILCCCFH	0.00956	9
10	CCFTLU	0.00956	8

Table 19D.10-9 Top Six Sequences Comparison and Frequency

Base Case (xE08)		X2 Case (xE07)	
Sequence	CDF	Sequence	CDF
BE2-02	6.68	TIS-06	2.60
BE8-05	2.44	BE2-02	2.55
BE0-01	1.62	TM-06	1.78
TIS-06	1.61	TIS-05	1.71
TM-06	1.10	TT-06	1.04
TT-06	0.643	BE8-05	0.93

Figure 19D.10-1 Core Damage Frequency Distribution

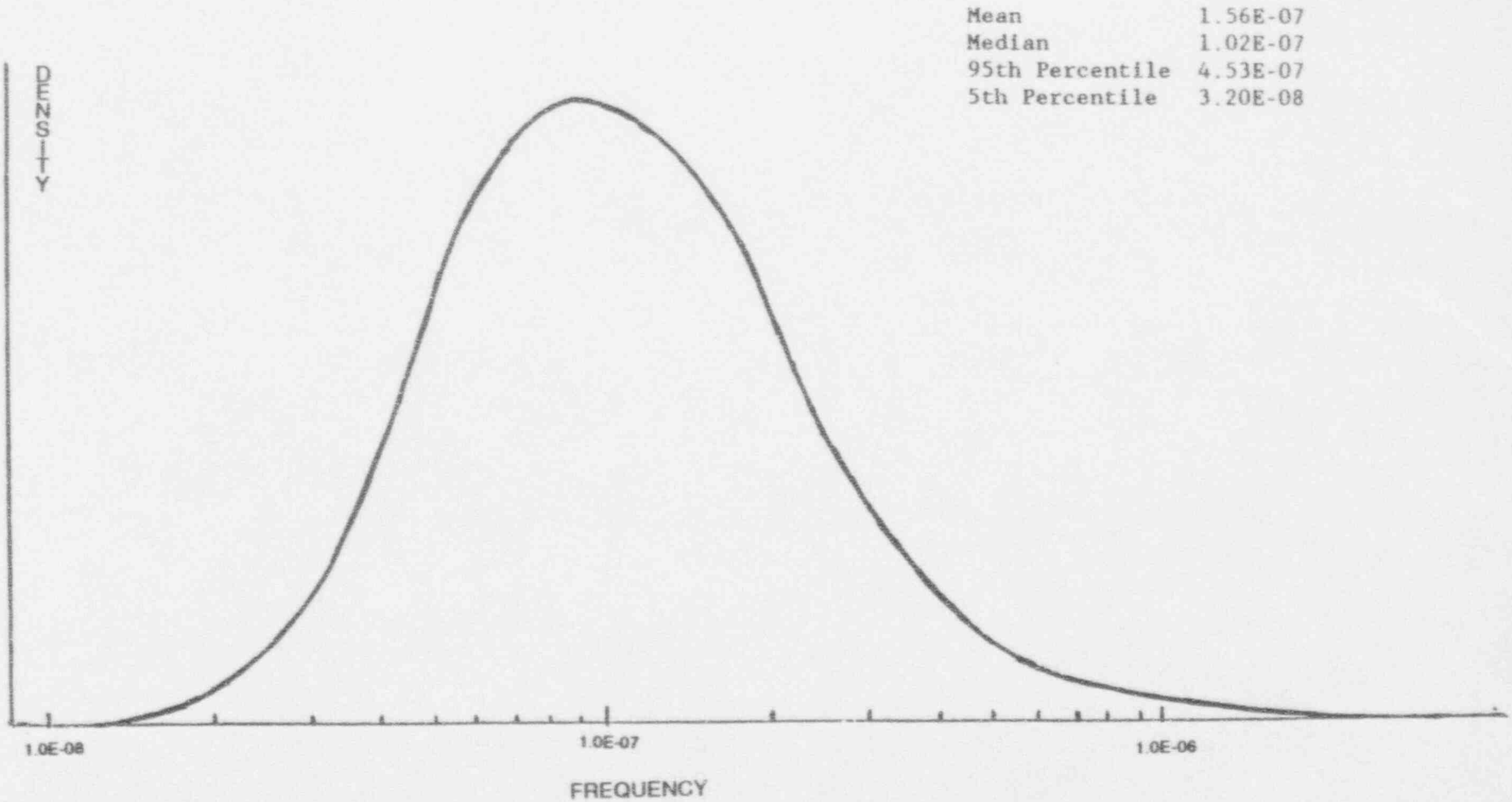

Figure 19D.10-1 CORE DAMAGE FREQUENCY DISTRIBUTION

Figure 19D.10-2 Values of 95th Percentile Divided by the Mean Versus Error Factor

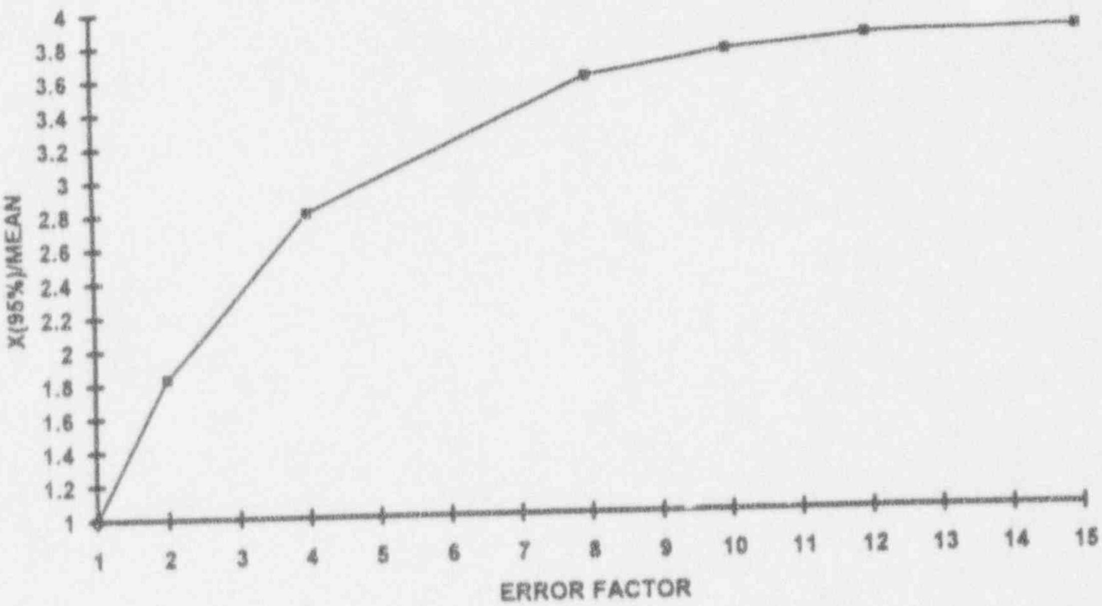

Figure 19D.10-2 VALUES OF 95TH PERCENTILE DIVIDED BY THE MEAN VERSUS ERROR FACTOR