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Common Cause Evaluations in Applied Risk Analysis of Nuclear Power Plants

T. Taniguchi
D. Ligon
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COMMON CAUSE EVALUATIONS IN APPLIED RISK ANALYSIS OF NUCLEAR POWER PLANTS

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ABSTRACT

Qualitative and quantitative approaches were developed for the evaluation of common cause failures (CCFs) in nuclear power plants and were applied to the analysis of the auxiliary feedwater systems of several pressurized water reactors (PWRs). Key CCF variables were identified through a survey of experts in the field and a review of failure experience in operating PWRs. These variables were classified into categories of high, medium, and low defense against a CCF. Based on the results, a checklist was developed for analyzing CCFs of systems.

Several known techniques for quantifying CCFs were also reviewed. The information provided valuable insights in the development of a new model for estimating CCF probabilities, which is an extension of and improvement over the Beta Factor method. As applied to the analysis of the PWR auxiliary feedwater systems, the method yielded much more realistic values than the original Beta Factor method for a one-out-of-three system.

1. INTRODUCTION AND WORK SCOPE

In recent years, probabilistic risk assessment (PRA) has gained increased applicability in both the nuclear and the nonnuclear power industries. The major purpose of performing risk assessments of nuclear power plants is to determine the risk to public health and safety associated with potential reactor accidents. Multiple failures initiated by a common cause — so-called common cause failures (CCFs) — often tend to dominate the risk from nuclear plant accidents. Hence, it is very important that common cause failures be adequately treated in plant risk assessment studies.

The technical trend for treating CCFs has been towards the use of generic or average common cause failure probabilities. For instance, given an estimated total failure rate for each redundant subsystem or component, the analyst might use a 10% conditional probability of a common cause failure for the complete system regardless of the specific design, environment, and operating procedures. However, this approach is not selective enough, since many system or component designs may have appreciably better than or less than average susceptibility to common cause failures.

The study described here has sought to determine the key factors for assigning more selective common cause failure probabilities for nuclear power plants based on engineering assessments and engineering judgments. The effort is complemented by ongoing work (FIN No. B0456) at ORNL which has the objective of developing common cause approaches based on Licensee Event Reports (LER) data. The goal of both projects has been to develop approaches to estimate order-of-probabilities to key operating and design variables.

This study has followed the guidelines set forth in the proposal GACP 02-286-REV. 2, dated April 17, 1981,[1] and has consisted of the following basic tasks:

Task 1. Identify key CCF variables and develop questionnaire to obtain input and comments on the variable ranking from experts in the field.

Task 2. Develop key variable ranking schemes and determine order of magnitude failure probability ranges for CCF categories.

Task 3. Develop alternate approaches for estimating CCF probabilities as a function of key variables.

Task 4. Apply developed approaches to a selected system.

2. SUMMARY

The objectives of the present study have been to develop a selective approach in assigning common cause failure (CCF) probabilities for nuclear power plants, to identify and rank key variables that significantly influence CCF, to develop new approaches for estimating CCF probabilities, and to test the approach by application to a specific reactor system.

The significant results of the study include the following:

- There is very good correlation between a list of key variables contributing to system defense against CCF which evolved from expert ranking and a list which was derived from actual failure data; in fact, all but one of the variables contained in the former list appear in the latter.

- The composite list of key variables describing a system's defense against CCF which was derived from both expert opinion and actual failure data is recommended as a checklist to analyze system CCFs.

- The developed checklist of variables describing system defense against CCF was successfully applied to the analysis of auxiliary feedwater systems of several PWR plants. The use of this checklist permits estimating appropriate CCF probabilities based on the range of values derived from the expert opinion survey.

- The CCF probability ranges that were estimated through expert opinion survey cannot be verified based on known compilations of failure data until a more comprehensive failure data analysis (which is beyond the scope of the present effort) has been accomplished.

- A new model for quantifying CCF was developed. This model represents an extension of and improvement over General Atomic Company's previously developed Beta Factor method, which tends to significantly overestimate CCFs for systems with more than one level of redundancy. The new model was seen to yield much more realistic values than the original Beta Factor method for a one-out-of-three unit system.

3. IDENTIFICATION OF KEY VARIABLES

3.1 APPROACH

The objective of this task has been to identify key variables that significantly influence common cause failure (CCF) probabilities. Pertinent literature was reviewed with particular attention to material describing "defense against CCF" (e.g., Refs. 2 and 3).

In order to identify and rank such variables, a questionnaire was developed and sent out to 29 risk assessment and systems experts (hereafter called experts) from 21 organizations. These experts had the option of distributing the questionnaire to other experts within their organization in order to increase the sample base.

The questionnaire listed several variables describing "defense against CCF." These variables were grouped into three major categories: low, medium, and high defense against CCF. For each category, the expert was asked to choose those variables which he considered important and to rank them in order of importance. He was also asked to estimate the percentage contribution of each variable to system failure and to estimate the overall system failure probability. Appendix A, Section A.1, contains a sample of the material sent to each expert. Two lists of experts, those who were asked to participate and those who responded, are given in Appendix A, Section A.2.

3.2 SURVEY SUMMARY

Thirty-six experts responded to the survey. A compilation of the experts' responses, including rankings of key variables, estimated percentage contribution of each variable to system CCF, estimated overall system CCF probabilities, answers to additional questions

asked in the survey, and comments, are given in Tables A-5 through A-8 in Appendix A, Section A.3.

Further discussions on the ranking schemes developed from the survey are presented in Section 4.

4. RANKING SCHEMES TO EVALUATE COMMON CAUSE FAILURE

While 36 experts have responded to the questionnaire, the analysis presented here is based on only the first 30 responses, since the last six responses were not received in time.

The information from the survey was sent to three expert mathematicians/statisticians, V.R.R. Uppuluri (ORNL), P. Slovic (Decision Research) and R.G. Easterling (SANDIA), for analysis of survey rankings and failure probability estimates. In addition, a similar analysis was also performed in-house.

The experts' ranking of key variables influencing CCF and their estimate of CCF failure probability ranges provided useful insights in the development of approaches to qualitatively and quantitatively assess CCF. In Section 6, these approaches will be used to analyze the probability of failure of the auxiliary feedwater system.

4.1 CHECKLISTS FROM EXPERT OPINION

Two ways of ranking the variables from expert opinions were developed. The results, which list the variables according to their order of importance, could be used as a checklist when analyzing whether a system has been designed to have a low, medium, or high defense against CCF.

One method for ranking the variables which was used in-house consisted of taking the percentage contribution of each variable to CCF and normalizing to unity. The variables that contribute 6% or more are shown in Table 4-1. Mr. Uppuluri also used this method, thus providing independent verification. Mr. Uppuluri's results are presented in Tables B-8, B-9 and B-10 of Appendix B. Another method of ranking used the sum of the number of times that each variable was selected by the survey respondents. The results are shown in Table 4-2. As shown, 22 of 30 respondents considered the variable "no

Table 4-1
Common Cause Variable Checklist and Order of Magnitude Probability Ranges (Method 1)

Top Ranking System Variables (by summing % s)
From Compilation of 30 Expert Opinion Survey

Σ of %s

Low Defense Against CCF		Medium Defense Against CCF		High Defense Against CCF	
Rank / %	2E-1 Upper * 2E-2 Mid-point 5E-3 Lower	Rank / %	1E-2 Upper * 7E-4 Mid-point 2E-4 Lower	Rank / %	2E-4 Upper * 1E-5 Mid-point 1.2E-6 Lower
1 / 23	Single active point failure	1 / 14	Visual inspection after maintenance	1 / 17	Minimum interface with other systems
2 / 19	No testing after maintenance	2 / 13	Partial separation or protection	2 / 15	Test - once per month or more often
3 / 14	Many interfaces with other systems	3 / 12	Moderate interface with other systems	3 / 10	Full functional test after all maintenance
4 / 13	Poor separation or protection	4 / 9	Partial diversity	4 / 10	Procedure with many backups
5 / 11	High complexity	5 / 9	Procedure with some backups	5 / 8	Design for most severe accident conditions (system)
6 / 10	No diversity	6 / 8	Single passive failure point	6 / 7	Design for most severe accident conditions (components)
7 / 9	Procedure without backup checks	7 / 8	Designed for some accident condition	7 / 7	No single failure point
		8 / 8	Medium redundancy (>½)	8 / 7	Auto start with remote manual backup
		9 / 7	Single parameter indication	9 / 7	Complete diversity
		10 / 7	Medium complexity	10 / 6	Total separation or protection
		11 / 6	Test - once per 3 to 6 months	11 / 6	Simplicity

* 2nd order least squares fit

Table 4-2
Common Cause Variable Checklist and Order of Magnitude Probability Ranges (Method 2)

Top Ranking System Variables (by Ranking)
From Compilation of 30 Expert Opinion Survey

Σ of ALL RANKINGS

Low Defense Against CCF		Medium Defense Against CCF		High Defense Against CCF	
Rank / #	2E-1 Upper * 2E-2 Mid-point 5E-3 Lower	Rank / #	1E-2 Upper * 7E-4 Mid-point 2E-4 Lower	Rank / #	2E-4 Upper * 1E-5 Mid-point 1.2E-6 Lower
1 / 22	No testing after maintenance	1 / 16	Partial separation or protection	1 / 15	Full functional test after all maintenance
2 / 9	Poor separation or protection	2 / 15	Moderate interface with other systems	2 / 13	Minimum interface with other systems
3 / 8	Single active point failure	3 / 14	Visual inspection after maintenance	3 / 13	Test - once per month or more often
4 / 17	Many interfaces with other systems	4 / 10	Partial diversity	4 / 11	Procedure with many backup checks
5 / 4	Procedure without backup checks	5 / 9	Procedure with some backup checks	5 / 10	Designed for most severe accident conditions (comp)
6 / 3	High complexity	6 / 9	Single passive failure point	6 / 9	Designed for most severe accident conditions (sys)
7 / 13	No diversity	7 / 9	Designed for some accident conditions	7 / 9	Total separation or protection
/		8 / 9	Medium redundancy (greater than 1/2)	8 / 8	Auto start with remote manual backup
/		9 / 9	Medium complexity	/	
/		/		/	
/		/		/	

* 2nd order least squares fit

testing after maintenance" as an important contributor to CCF for a system having a low defense against CCF.

The selected variables for the two methods are practically the same; the order, however, is somewhat different.

Section B.1 of Appendix B discusses the analysis in more detail and presents the complete data used.

The following are observations based on the experts' ranking of key variables:

1. No one variable was selected by all experts.

2. Variables selected by most respondents are the following:

   - "No testing after maintenance" as a a key variable for the low defense against CCF category was selected by 22 experts.
   - "Partial separation or protection" as a key variable for the medium defense against CCF category was selected by 16 experts.
   - "Full functional test after all maintenance" as a key variable for the high defense against CCF category was selected by 15 experts.

3. Variables picked most times and given high ranking (Rank 1 through 5) are as follows:

   Low defense against CCF:
   - Single action point failure - 1st
   - No testing after maintenance - 2nd
   - Poor separation or protection - 3rd

Medium defense against CCF:

- o Moderate interface with other systems - 1st
- o Partial separation or protection - 2nd
- o Visual inspection after maintenance - 3rd

High defense against CCF:

- o Minimum interface with other systems - 1st
- o Tests - once per month or more often - 2nd
- o Procedure with many backups - 3rd
- o Full functional test after all maintenance - 4th

4. In much of the published literature on CCF, "diversity" was considered as a significant contributor to high defense against common cause failure. However, as shown below, this was not apparent from the results of our survey:

Low defense against CCF:	No diversity, Rank 7
Medium defense against CCF:	Partial diversity, Rank 4
High defense against CCF:	Complete diversity, Rank 9

4.2 ESTIMATE OF PROBABILITY RANGES

Order-of-magnitude ranges of probability of failure per demand for the low, medium, and high defense against CCF were derived from expert opinion. Two methods were employed in-house. For both methods, the extreme upper and lower values were excluded. A third method was used by Mr. Uppuluri of ORNL. Results from all three methods are shown in Table 4-3.

The first method consisted of determining the arithmetic mean of the upper, midpoint, and lower estimates from the expert opinion survey.

The second method consisted of determining the median of the upper, midpoint, and lower estimates in the survey. The cumulative frequency distribution of these estimates was plotted against the probability values. The computer code SUPER*PLOT, employing a second-order least squares fit, plotted the cumulative probability curves for low, medium, and high defense against CCF as shown in Appendix B Figs. B-4, B-5 and B-6. From these curves, the median estimates were determined as shown in Table 4-3. Details on the development of the median estimates are given in Appendix B, Section B.2.

Table 4-3
Estimates of Probability Ranges

	Probability Ranges		
	Arithmetic Mean	Median	Geometric Mean
	Low Defense Against CCF		
Upper	2.5E-1	2.0E-1	6.0E-2
Midpoint	2.5E-2	2.0E-2	
Lower	4.4E-3	5.0E-3	1.3E-3
	Medium Defense Against CCF		
Upper	1.4E-2	1.0E-2	2.1E-3
Midpoint	1.6E-3	7.0E-4	
Lower	7.0E-4	2.0E-4	2.8E-5
	High Defense Against CCF		
Upper	7.4E-4	2.0E-4	6.4E-5
Midpoint	6.7E-5	1.0E-5	
Lower	7.1E-6	2.0E-6	5.0E-7

Mr. Uppuluri of ORNL calculated the geometric mean of the data for the upper and lower values only. The input data used by him, as well as his results, are presented in Tables B-17, B-18 and B-19 of Appendix B, Section B.2.

4.3 ALTERNATE CHECKLIST SCHEME

Reliance on expert opinion was only one way of developing checklists. An alternate checklist was developed from actual failure data. Given a specific system, all multiple component failures in that system were compiled and further examined to determine if such failures caused system failure. Only these types of failures were considered to be CCFs. For these events, the causes of failure were determined. Furthermore, the system configuration and plant generating conditions were examined to determine which variables contributed to the system defense against CCF. By following this approach for all CCFs that occurred in a given system, a list of system variables was developed and used to assess whether a particular system had a low, medium, or high defense against CCF. This approach was applied to the analysis of CCF in the auxiliary feedwater system, and the results are presented in Section 6.3.

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5. ALTERNATE APPROACHES

A review of published techniques for quantifying CCF and the results of Tasks 1 and 2 provided valuable insights in developing alternate approaches to estimate CCF probabilities and to relate these probabilities to key operating and design variables in a system.

The first part of this section discusses selected published techniques to model CCF. The second part introduces two alternate approaches to quantify CCF.

5.1 LITERATURE REVIEW

Several techniques have been either used or proposed to model and quantify common cause failure probabilities. These models range from being generally applicable to being specialized. However, the scarcity of data makes it difficult to judge whether any or all of the models are completely valid for a wide range of system applications. Some of the more recent and better known models are briefly summarized in the following subsections. Table 5-1 lists the advantages, disadvantages and limitations of each method.

5.1.1 Beta Factor Method

This model was developed at the General Atomic Company[4] for predicting the probability of multiple, concurrent, and sequential dependent failures. It assumes that the total (constant) failure rate for each unit, λ , can be separated into an independent and a common-cause failure part:

$$\lambda = \lambda_i + \lambda_c , \qquad (5\text{-}1)$$

Table 5-1
Comparative Evaluation of Known Common Cause Failure Models

CCF Model	Advantages	Disadvantages/Limitations
1. Beta Factor method	o Simple and straightforward. o Flexible - can account for dependencies between dissimilar and not necessarily redundant equipment.	o Does not distinguish between probabilities for dependent failures of two and three units in a three-unit redundant system. o Tends to produce highly conservative CCF probabilities for systems with three or more redundant units. o Limited to two- or three-unit redundancy for which experience data are available.
2. Bounding technique (geometric mean)	o None	o Procedure only provides an arbitrary allowance for potential CCFs in the system. o Method tends to be nonconservative for systems which are highly redundant, for systems which have low failure rate components and for systems with a significant portion of common cause failures.
3. Binomial Failure Rate Model	o Can distinguish among multiple unit failures in a system with greater than two redundant units. o Model is simple and has been found adequate in the estimation of common cause failure rates from Licensee Event Reports of Pumps at U.S. Commercial Nuclear Power Plants.	o Model's applicability is tied to how well observed events can be simulated by adjusting the probability of common cause shock and its rate of occurrence. o Model is not strictly applicable to redundant systems with dissimilar units. o It may be difficult to define the boundaries for the systems to which the common cause shock may be applied.
4. Shock Model	o Useful in establishing the maximum level of redundancy which is effective in reducing probability of random failures.	o Model is used mainly as a screening tool to decide on whether or not common mode failures represent a serious threat to the system. o The rate of occurrence of common mode failures, λ_{cm}, will have to be estimated based largely on engineering judgment, since no significant data exist.

Table 5-1 (Continued)

CCF Model	Advantages	Disadvantages/Limitations
5. Common-load Model	o Useful in systems with known load and resistance distributions.	o Addresses only intrinsic random errors and not engineering process errors. o Has limited application.
6. Subsystem Model	o Systematic model which allows each major class of CCF to be separately assessed in conjunction with their appropriate defenses.	o Model is more qualitative than quantitative.
7. Statistical Correlation Model	o Model improves the handling of human errors and other dependencies that are difficult to identify and model explicitly. o It allows the system model to be developed to whatever scope and level of detail is appropriate for a given problem without seriously affecting the validity of results.	o Not enough data are available to support validity of the model. o Determination of the statistical correlation coefficient, r, may be highly subjective.

where

λ_i = unit failure rate for independent failures,
λ_c = unit common cause failure rate.

The parameter β is defined as the fraction of the total failure rate that is attributable to common cause:

$$\beta = \frac{\lambda_c}{\lambda_i + \lambda_c} . \qquad (5\text{-}2)$$

Expressions for the failure probability of a multiple unit system can then be derived by modeling the common cause failures in series with the independent failures of redundant units. The Beta Factor method is limited to two or three unit redundancy for which experience data are available. As originally employed, this method does not distinguish between probabilities for dependent failures of two and three in a three-unit system.

5.1.2 Bounding Technique (Geometric Mean)

This technique was utilized in the Reactor Safety Study (WASH-1400)[5] for estimating the contribution of unidentified common cause failures to the total system unreliability. A maximum boundary for the failure probability is estimated and the sensitivity of the system unreliability to this value is determined. For a two-unit (A + B) redundant system, the upper boundary value of the probability of failure of that system is the minimum of the two values, U(A) and U(B), i.e.,

$$U(AB) \leq \min [U(A), U(B)] , \qquad (5\text{-}3)$$

where U(A) and U(B) are the upper boundary values of the failure probability for units A and B, respectively.

Assuming a log-normal distribution of component failures, the median value is at the geometric midpoint of the upper and lower bounds. Hence, the geometric mean is:

$$U_M(AB) = \sqrt{U_u(AB).U_L(AB)} \ , \qquad (5\text{-}4)$$

where

$U_u(AB)$ is the upper boundary

and

$U_L(AB)$ is the lower boundary.

Since this technique was applied to unspecified CCFs, it relied mostly on judgment to decide where the boundary lay. As such, this method is largely a screening tool for determining if more detailed analysis of the subsystem is required.

5.1.3 Binomial Failure Rate Model (BFR)

This model, developed by Vesely[6], is a specialization of the Marshall-Olkin model. It assumes that, given a system with n components, each component can fail individually and has a constant failure rate λ. In addition, a common cause shock can take place, with constant occurrence rate μ. If a shock occurs, the components fail independently, each with a probability p. The number of failed components, given that a shock occurs, is a random variable from the (n,p) binomial distribution. The BFR model distinguishes among multiple unit failures in a system with greater than two units. The applicability of the model is tied to how well observed events can be simulated by adjusting parameters p and μ. The shock rate μ is not directly available from failure data because single failures from common cause shocks cannot be distinguished from single independent failures.

5.1.4 Shock Model

This model was developed by Apostolakis[7] to determine the effects of common cause failures on the reliability of redundant systems. Failures are assumed to occur because of a shock, and the occurrence of shocks is governed by independent Poisson processes. This leads to the exponential failure distribution for the components subject to the jth risk, i.e.,

$$F_j(t) = 1-\exp(-\lambda_{jt}) \ , \qquad (5\text{-}5)$$

where

λ_j = failure rate of unit j.

When applied to a parallel system of two units, each unit has its own failure rate, λ_1 and λ_2. In addition, redundant components are subject to common mode failure rate, λ_{cm}, which is the sum of the rates of all the shocks causing such failures.

The author considers that failure data collected in the past cannot be used to estimate failure rates because even systems which are built for the same function are not truly identical. Thus, any mathematical treatment can only be used to estimate the effects of CCF from which criteria can be developed to decide whether they are significant to the system or not.

The author concludes that there is an upper bound to the degree of redundancy that can be applied to a system; otherwise, common-mode effects dominate the unreliability. This model shows that the upper bound for λ_{cm} increases by powers of λ/μ as redundancy increases; hence the value of λ_{cm} must be extremely low for the effects to be

insignificant. Thus, systems reliability analyses which consider independent failures alone are meaningless.

5.1.5 Common-load Model

The common-load model[8], like the shock model, was designed to address only intrinsic random errors and not engineering process errors. The model has been developed by Mankamo for use in the analysis of the dependency of failures when redundant structures are loaded by a common stress. It is assumed that the structures have identical resistance to stress (R) and that both stress and resistance are random variables. The model is useful in cases where load and resistance distributions are sufficiently well known.

5.1.6 Subsystem Model

Edwards and Watson[2] proposed a subsystem modeling structure for CCF. It is essentially a process model which takes into account engineering error, maintenance error, operation error, causal failures, and environmental extremes. The model incorporates in some cases other models such as the Beta Factor and the common-load models. A system model, e.g., fault tree, is required and it is related to the CCF process model. The failure process model and the system model are then combined, leading to a method of calculation based on logical network theory. This model allows each major class of CCF to be separately assessed in conjunction with its appropriate defenses.

5.1.7 Statistical Correlation Model

Hartung[9] has developed a statistical reliability model which suggests that all phenomena which cause systematic variations and/or systematic uncertainties in failure rates are potential sources of CCF. This model assumes that systematic failure rate uncertainties have the same mathematical effect as systematic variations. Hence, CCFs and uncertainties are mutually related.

In this model, the component unavailabilities are represented by random variables subject to statistical correlation. The system unavailability is given by:

$$U(A,B) = U(A) \times U(B) \mid -1 \leq r \leq 1 \ , \qquad (5\text{-}6)$$

where

$U(A,B)$ = system unavailability,
$U(A)$ = component A unavailability,
$U(B)$ = component B unavailability,
r = statistical correlation coefficient.

The extent to which the component unavailabilities may be statistically correlated depends on their diversity or replication. Replicate components tend to have highly correlated unavailabilities ($r=1$) while diverse components are likely to have less strongly correlated unavailabilities ($0<r<1$). The value of r, therefore, depends upon the similarity, or lack thereof, in the design, construction, and operation of the components.

To illustrate the use of this model, consider a two-component redundant system. The mean probability that both components are unavailable is given by:

$$\overline{P(AB)} = \overline{P(A)}.\overline{P(B)} + r\sqrt{\sigma^2_{P(A)} + \sigma^2_{P(B)}} \ , \qquad (5\text{-}7)$$

where

$\overline{P(A)}$ = the mean probability that component A is unavailable,
$\overline{P(B)}$ = mean probability that component B is unavailable,
$\sigma^2_{P(A)}$ = variance in unavailability of component A,
$\sigma^2_{P(B)}$ = variance in unavailability of component B,
r = statistical correlation coefficient.

The square root term on the right-hand side of the equation is defined as the coupled failure probability and it is assumed to represent the common cause failure probability.

Statistical correlations can also be done with the Bayesian approach. Here, the diversity (or statistical correlation between two failure rates) is reflected in the weight to be given to a piece of new evidence in updating a prior belief.

5.2 SPECIALIZED BETA FACTOR METHOD

A major concern with the original Beta Factor method is the assumption that the same β could be used regardless of the number of redundancies present in the system. While applicable to some CCF types, this assumption is not generally true. The method works well when applied to a two-unit redundant system, but it yields high failure values for a three-unit redundant system. Most of the available failure data, from which the β factor is calculated, are primarily from relatively high failure rate components in simple two-unit redundant systems. Failure rate data are scarce for higher orders of redundancy. Hence, the generic β factor is weighted more towards two-unit redundant systems. This leads to highly conservative CCF probabilities for systems with three or more redundant units. Indeed, this suggests that β for a two-unit system could generally be different from that for systems with three or more redundant units.

In an effort to derive a more realistic β factor, an approach is introduced here which applies the β factor method to different levels of system redundancy. Moreover, this approach is useful for handling CCFs for specific (rather than generic) system application.

First, consider a generic system, S, containing K components which contribute to CCF.

The CCF rate for the system is defined as:

$$\lambda_{c,s} = \sum_{k=1}^{K} f_{k,s} \lambda_{c,k} , \tag{5-8}$$

where

$\lambda_{c,k}$ = generic CCF rate for component k,

$f_{k,s}$ = fractional CCF contribution to the failure of system S due to component k $\left(\sum_{k=1}^{K} f_{k,s} = 1\right)$,

K = total number of CCF contributors (components) in system S.

Similarly, for independent failures (IF), one can define:

$$\lambda_{i,s} = \sum_{\ell=1}^{L} g_{\ell,s} \lambda_{i,\ell} = 1 , \tag{5-9}$$

where

$\lambda_{i,\ell}$ = generic IF rate of component,

$g_{\ell,s}$ = fractional IF contribution to the failure of system due to component ℓ $\left(\sum_{\ell=1}^{L} g_{\ell,s} = 1\right)$,

L = total number of IF contributors (components) in system S.

In general, sets K and L are not the same, K being a subset of L. From Eqs. (5-8) and (5-9), one can derive a generic system β factor:

$$\beta_s = \frac{\lambda_{c,s}}{\lambda_s} = \frac{\lambda_{c,s}}{\lambda_{c,s} + \lambda_{i,s}} \quad . \tag{5-10}$$

This β factor is generic, since it applies to many reactors that have a system of type S.

Eq. (5-10) can also be defined in terms of the number of failures, n, instead of in terms of failure rates:

$$\beta_s = \frac{n_{c,s}}{n_{c,s} + n_{i,s}} \quad . \tag{5-11}$$

Consider now a specific system with different levels of redundancy, r (e.g., an AFS with two or three redundant pumps). Let us define a set of specific failure rates for system S as follows:

$$\lambda_{c,s,r} = \gamma_{c,r}\lambda_{c,s} \ , \tag{5-12}$$

$$\lambda_{i,s,r} = \gamma_{i,r}\lambda_{i,s} \ , \tag{5-13}$$

where

$\lambda_{c,s,r}$ = specific CCF rate for system S with r redundant units,

$\lambda_{i,s,r}$ = specific IF rate for system S with r redundant units,

$$\gamma_{c,r} = \frac{\text{number of CCFs for r redundant unit system}}{\text{number of all CCFs in the selected system}},$$

$$\gamma_{i,r} = \frac{\text{number of IFs for r redundant unit system}}{\text{number of all IF}_s \text{ in the selected system}}.$$

Then one can define a specific β factor for S, according to the order of redundancy:

$$\beta_{s,r} = \frac{\lambda_{c,s,r}}{\lambda_{c,s,r} + \lambda_{i,s,r}} = \frac{\gamma_{c,r}\lambda_{c,s}}{\gamma_{c,r}\lambda_{c,s} + \gamma_{i,r}\lambda_{i,s}}. \qquad (5\text{-}14)$$

The gammas (γ) can be interpreted as measures of the deviation in failure behavior of the r redundant units from the average (generic) case.

The β factors for use in this method were derived according to the model described in Section 5.3 following.

5.3 MODEL FOR A ONE-OUT-OF-THREE SYSTEM

The original Beta Factor method made no distinction among β factors for two, three, or more parallel redundant units. A new model which permits such a distinction is introduced here. This model will be derived for a one-out-of-three system where the original Beta Factor method was seen to be too conservative in predicting failure rates due to CCF. The comparison between this method and the original Beta Factor method will be shown in Section 6 of this report as applied to auxiliary feedwater systems. Let us consider a system with three 100% parallel redundant units (a one-out-of-three unit system) and let us develop a Markov model for transitions among all states of this system that are possible with CCF. The possible states of the system, 0 through 3 (see Fig. 5-1), indicate the exact number of units in the system that are failed at one time. Let P_i be the probability that the system has exactly i failed units (here i = 0,1,2,3) and let Z_{ij} be the transition rate from initial state i to final state j. Then one can write a set of differential equations describing the states of the system as follows:

$$\frac{dP_i(t)}{dt} = -Z_i P_i(t) + \sum_{\substack{j=0 \\ j \neq i}}^{3} Z_{ji} P_j(t) \ ,$$

where $\quad i = 0, 1, 2, 3 \ ,$ (5-15)

or more explicitly, if it is assumed that there is no repair (i.e., $Z_{10} = Z_{21} = Z_{32} = 0$),

$$\frac{dP_0}{dt} = -(Z_{01} + Z_{02} + Z_{03})P_0 \ , \qquad (5\text{-}16)$$

$$\frac{dP_1}{dt} = Z_{01} P_0 - (Z_{12} + Z_{13})P_1 \ , \qquad (5\text{-}17)$$

$$\frac{dP_2}{dt} = Z_{02} P_0 + Z_{12}P_1 - Z_{23}P_2 \ , \qquad (5\text{-}18)$$

$$\frac{dP_3}{dt} = Z_{03} P_0 + Z_{13}P_1 + Z_{23}P_2 \ , \qquad (5\text{-}19)$$

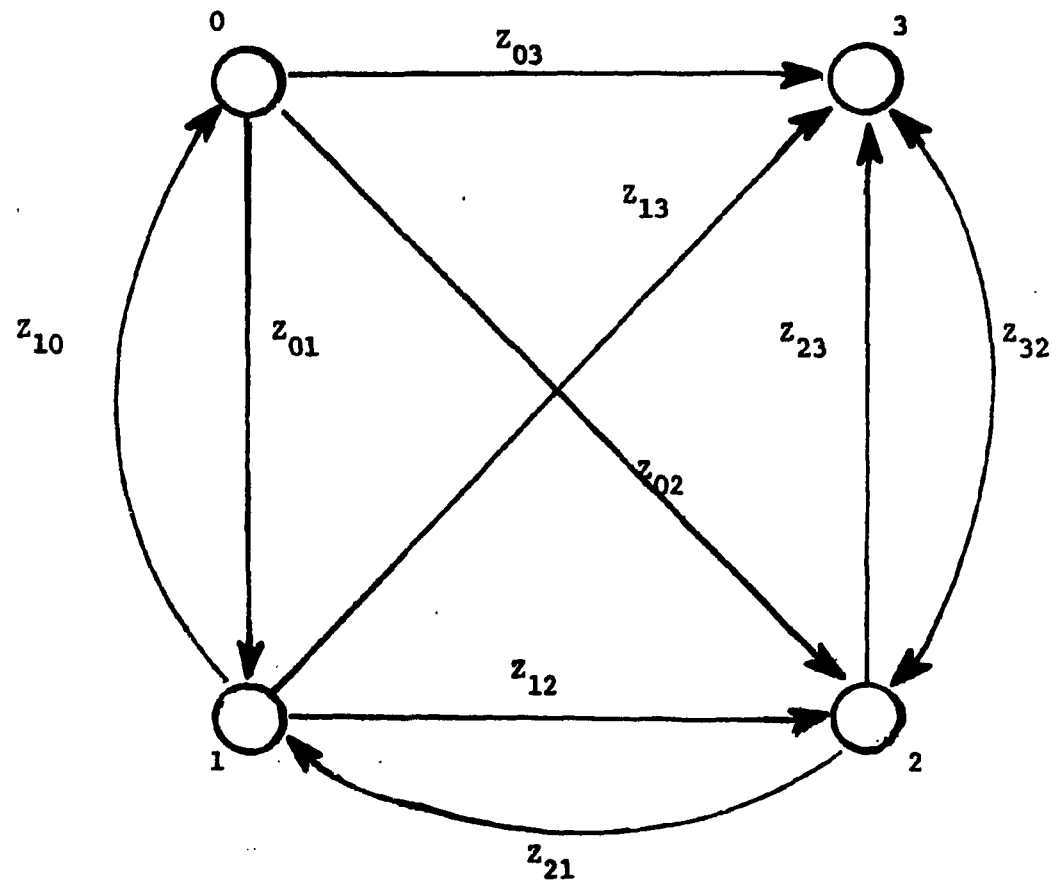

Fig. 5-1 State Transition Diagram for a One-Out-of-Three Parallel Unit System

where, according to Eq (5-15),

$$z_0 = z_{01} + z_{02} + z_{03} , \tag{5-20}$$

$$z_1 = z_{12} + z_{13} , \tag{5-21}$$

$$z_2 = z_{23} . \tag{5-22}$$

The fact that all states of the system are included is expressed through the following equation:

$$\sum_{i=0}^{3} P_i = 1 \ . \tag{5-23}$$

Also, note that:

$$\sum_{i=0}^{3} \frac{dP_i}{dt} = 0 \ . \tag{5-24}$$

The failure probability, Q, for the one-out-of-three system is simply equal to P_3, the probability that exactly three units are in the failed state.

Using Eq. (5-23), Q can be written as

$$Q = 1 - (P_0 + P_1 + P_2) \ . \tag{5-25}$$

Eqs. (5-16) through (5-18) can be integrated using the following initial conditions:

$$P_0(t=0) = 1 \tag{5-26}$$

and

$$P_1(t=0) = P_2(t=0) = P_3(t=0) = 0 \ . \tag{5-27}$$

The solutions are:

$$P_0 = e^{-\tau_0 t} \ , \tag{5-28}$$

$$P_1 = \frac{Z_{01}}{Z_1 - Z_0} \left(e^{-Z_0 t} - e^{-Z_1 t}\right) , \qquad (5\text{-}29)$$

and

$$P_2 = \frac{1}{(Z_2 - Z_0)} \left[Z_{02} + \frac{Z_{01} Z_{12}}{Z_1 - Z_0}\right] e^{-Z_0 t} - \left[\frac{Z_{01} Z_{12}}{(Z_2 - Z_1)(Z_1 - Z_0)}\right] e^{-Z_1 t}$$

$$- \left[\frac{1}{(Z_2 - Z_0)} \left(Z_{02} + \frac{Z_{01} Z_{12}}{Z_1 - Z_0}\right) - \frac{Z_{01} Z_{12}}{(Z_2 - Z_1)(Z_1 - Z_0)}\right] e^{-Z_2 t} . \qquad (5\text{-}30)$$

As in the original Beta Factor method, let us subdivide failure rates, λ, into independent and dependent (common cause) components, i.e.:

$$\lambda = \lambda_i + \lambda_c . \qquad (5\text{-}31)$$

Let us further subdivide dependent failures into double and triple failures, i.e.,

$$\lambda_c = \lambda_2 + \lambda_3 , \qquad (5\text{-}32)$$

and let us define two new β factors,

$$\beta_2 = \frac{\lambda_2}{\lambda} \qquad (5\text{-}33)$$

and

$$\beta_3 = \frac{\lambda_3}{\lambda} , \tag{5-34}$$

whence

$$\beta = \frac{\lambda_c}{\lambda} = \beta_2 + \beta_3 . \tag{5-35}$$

In terms of these quantities, the transition rates of Eqs. (5-16) through (5-22) become:

$$Z_{01} = 3\lambda_1 = 3(1-\beta)\lambda , \tag{5-36}$$

$$Z_{02} = 3\lambda_2 = 3\beta_2\lambda , \tag{5-37}$$

$$Z_{03} = \lambda_3 = \beta_3\lambda , \tag{5-38}$$

$$Z_{12} = 2\lambda_1 = 2(1-\beta)\lambda , \tag{5-39}$$

$$Z_{13} = \lambda_2 = \beta_2\lambda , \tag{5-40}$$

$$Z_{23} = \lambda \ , \tag{5-41}$$

$$Z_0 = 3(1-\beta)\lambda + 3\beta_2\lambda + \beta_3\lambda \ , \tag{5-42}$$

$$Z_1 = 2(1-\beta)\lambda + \beta_2\lambda \ , \tag{5-43}$$

$$Z_2 = \lambda \ . \tag{5-44}$$

Using Eqs. (5-25), (5-28), (5-29), (5-30) and (5-36) to (5-44), the system failure probability becomes:

$$Q = 1 - Ae^{-(3-2\beta_3)\lambda t} - Be^{-(2-\beta_2-2\beta_3)\lambda t} - Ce^{-\lambda t} \ , \tag{5-45}$$

$$A = 1 - \frac{3\beta_2 \ (3-\beta-\beta_3)}{2(1-\beta_3)(1+\beta_2)} \ , \tag{5-46}$$

$$B = - \frac{3(1-\beta)(1-\beta_2)}{(1+\beta_2)(1-\beta-\beta_3)} \ , \tag{5-47}$$

and

$$C = \frac{3}{2(1-\beta_3)}\left[\beta_2 + \frac{2(1-\beta)^2}{(1-\beta-\beta_3)}\right] . \qquad (5\text{-}48)$$

By comparison with Eqs. (5-45) through (5-48), the one-out-of-three system failure probability (unreliability) given by the original Beta Factor method is:

$$Q = 1 - e^{-(3-2\beta)\lambda t} + 3e^{-(2-\beta)\lambda t} - 3e^{-\lambda t} . \qquad (5\text{-}49)$$

In Section 6, numerical values predicted by both models will be compared with actual failure data for auxiliary feedwater systems. The new method will be seen to yield better results than the original Beta Factor method.

5.4 DATA-BASED APPROACH TO QUANTIFY COMMON CAUSE FAILURE

In the Beta Factor method, β can be estimated from the number of failures only. We also introduce here another approach, which uses experience data estimates of system failures and divides them by system trials. The CCF probability (Q_{cc}) is quantified as follows:

1. Collect system trials.

2. Collect system failures.

3. Divide above (1&2) into subsets by:
   - o System type (2 out of 3, 1 out of 2, 2 out of 4, 1 out of 3, ...),
   - o Component type,
   - o Operational mode.

4. Determine current estimates of Q_{cc}:

$$Q_{cc} = \frac{\text{CC system failure(s)}}{\text{system trials}} .$$

5. List values of Q_{cc}.

6. Determine if "assessed" system has features that will eliminate or add to the list.

7. Determine value of Q_{cc} for "assessed" system:

$$Q_{cc} = \frac{\text{current CCF} \pm \text{"assessed" CCFs}}{\text{system trials}} .$$

The advantage of this approach is that it is realistic. The disadvantage is that system trials are not recorded like failures; thus they are very difficult to collect. This can be accomplished either by minute examination of operational data or by correlating with the occurrence of certain events.

6. SYSTEM APPLICATIONS

The auxiliary feedwater system (AFS) was selected for applying the developed approaches to the evaluation of CCF. This system has been extensively studied over the last few years and a significant amount of data on AFS failure are available.

6.1 MAJOR FINDINGS

A review of the failure data on the AFS for 42 PWRs operating from January 1, 1972, to June 30, 1981, identified 12 key variables which could have prevented the common cause failures of the system. In comparison, 11 of these variables were selected by experts following the survey (Section 4).

Out of the 326 failures reported on the AFS, 50 failed two or three redundant units, but only eight of these caused the system to fail - five CCFs for a two redundant train system and three CCFs for a three redundant train system.

A checklist was developed using these variables as guidelines for estimating the failure probability range of the AFS of several PWR plants.

The failure data were also used to analyze the failure probabilities of two- and three-redundant unit AFSs using the specialized Beta Factor method discussed in Section 5. We found that the original Beta Factor method worked well for a one-out-of-two unit system but yielded a very high value for a one-out-of-three unit system. The new method produced significantly better results for the one-out-of-three unit system.

Another approach for quantifying CCF has been developed based on the number of system failures and system trials. However, following extensive search of data, it was established that data on the number of system trials were not readily available. Hence, quantitative estimates using this method could not be obtained. This would have been useful for verifying the probability ranges determined from the survey of experts.

6.2 DATA SEARCH

Several sources (Refs. 10 through 15) were reviewed to collect failure data on the AFS of 42 PWRs from January 1972 to June 30, 1981. As shown in Table 6-1, six AFS component categories that can be affected by CCF are identified. Failure data are classified into single, double, and triple failures. Of the 326 failures reported, 50 were common cause failures (CCF) which failed two or three redundant units simultaneously. More details on the data are given in Appendix C.

Following the development of the checklists as discussed in Section 4, the AFS design of each plant which experienced CCF was examined in more detail and ranked according to its defenses against CCF (Section 6.3). The data presented in Table 6-1 also served as the basis for the quantification of CCF probabilities using the modified Beta Factor approach discussed in Sections 5.2 and 5.3.

6.3 CHECKLIST FROM EXPERIENCE DATA

Multiple component failures given in Table C-2 in Appendix C were investigated to determine if these failures led to system failures. The results are summarized in Table 6-2. Five CCFs were found for the two redundant train system and three CCFs were found for the three redundant train system. In addition there were two related events,

Table 6-1
Single and Multiple Component Failures in the AFS

Component Category	One-Loop Single	Two-Loop		Three-Loop			Total Failure		
		1 out of 2	2 out of 2	1 out of 3	2 out of 3	3 out of 3	Single	Double	Triple
1. Pumps	2	59	8**	81	16	3	142	24	3
2. Valves	4	37	4	71	10	2	112	14	2
3. Controls		9					9		
4. Condensate Stor./ Service Water		2		4			6		
5. Diesel Generators/ Others	1	2		3			6		
6. Strainers				3	2	3	3	2	3
TOTAL	7	109	12	162	28	8	278	40	8
System-calendar months	270.6	919.9		2183.6			3374.1		
Unit-calendar months	270.6	1839.8		6551.3			8661.7		

*Note: Failure of two valves to open resulted in total system failure.

**Two failures may not be CCF as discussed in Section 6.3 but are included in the list pending more detailed evaluation of the events.

Table 6-2
Common Cause Failure (CCF) — AFS

Plant	Initial Criticality + Commercial	No. AFS Loops	Event Date	Failure Mode	Cause	Defense Against CCF	Plant Condition	Remarks
Arkansas 2 (CE/Bechtel) 50368	12/5/78 3/26/80	2 (T/M)	4/7/80	EFW Pumps — Loss of suction for about 1 min during running	Flashing in main FW train forcing, hot water thru startup and blowdown deminerlizer to the EFW pump, where it flashed to steam.	• Minimize interfaces with other systems	15 min after trip from 98% due to LOSP hot SD	Operator isolated EFW suction from startup & blowdown demineralizer and vented pumps.
Davis Besse 1 (B&W/Bechtel) 50346	8/12/77 7/31/78	2 (2T's)	1/2/79	Turbine AFP's fail to start	Main steam valves 106 & 106a (? 107) fail to open due to dirt buildup on valve stems caused by recent const. activities	• Diversity • Testing more often • Separation	83% no SD	From Graybook no SD's occurred on 1/2/79; thus this must have occurred during a test. With both AFPs failed, the plant should have been SD.
TMI-2 (B&W/UE&C) 50320	3/28/78 12/30/78	3 (2M, 1T)	3/28/79	No flow to SG's at start	Not re-opening discharge valves after pump recirc test	• Full functional flow test to SG-recirc test inadequate	100% BFP trip	Recirc pump test requires closure of discharge valves.
Haddem Neck (W/S&W) 50213-561	7/24/67 1/1/68	2 (2T)	7/5/76 LER 76-16	Both AFP's would not develop proper discharge pressure at start	Both pumps vapor bound-faulty check valve caused back leakage. Cause unknown.	• Unknown	SD. Hot Standby	Plant in startup mode.
Kiwaunee W/Pioneer Services & Eng Co 50305-354	3/7/74 6/74	3 (2M, 1T)	11/5/75	AFW pumps (3) fail to provide adequate flow. Main BFP's started	Clogged inlet strainers with demineralizer resin beads.	• Simplicity-strainers are added complexity	Plant startup	#40 mesh screens installed with 1/8" perforations. #40 mesh screens removed 11/17/75.

Table 6-2 (Continued)

Plant	Initial Criticality + Commercial	No AFS Loops	Event Date	Failure Mode	Cause	Defense Against CCF	Plant Condition	Remarks
Trojan W/Bechtel 50344	12/15/75 5/20/76	2 (1T, 1D)	1/16/76 76-06 50344/233	AFW pumps (2) fail to autostart	Mislogged lifted lead to auto-start circuitry	• Testing after maintenance • Manual backup	24% Hi Hi SG level trip	
*This event may not be a CCF. One train was declared inoperable.			*2/29/76 76/17 50344-436 pg. 128	*Diesel FW pump auto start, fail to remote manual start, started from local manual after re-setting overspeed trip about 2 min following trip	*Long cranking time on cold engine	*Design/proto-typical. DDAFP: Water jacket heater control circulating mod.TDAFP: quick starting oil reservoir • Minimum redundancy	58% LoLo level trip	Turbine AF pump declared inoperable 2 days before
			10/3/80	Both AFW pumps fail to auto start, assumed manual start o.k.	Wiring error-leads to slave relay connected to wrong terminal	• Testing after maintenance	98% LoLo SG level trip	
Turkey Pt 3 W/Bechtel 50250-230	10/20/72 12/14/72	3 (3T)	5/8/74 74-7	3 pumps fail to start on test	2 pumps-packing too tight. 1 pump-govenor linkage sticking	• Test after maintenance	100%	Tested on 5/7/84 & packing ad-justed. Common mode, but not common cause
Turkey Pt 4 W/Bechtel 50251-136	6/11/73 9/7/73	3 (3T)	6/18/73 4-73-7	3 pumps fail to auto start. 3 pumps manually started.	Fuses for auto start logic not installed	• Testing before rise to power	Lo power physics testing. SI occurs	7 days after initial criticality

one in the two-train system (2/29/76 Trojan) and another in the three-train system (10/20/72 Turkey Pt. 3).

Table 6-2 also gives the possible "defenses" which could have prevented the common cause failure. These variables were determined mainly by reviewing the specific AFS design configuration, operation, interfaces, etc., using the NUREG documents on AFS as guidelines[16, 17, 18]. Since there were very few AFS common cause failures, all events (i.e., CCFs and related events) were used to develop a list of key variables which describe a system's defense against CCF. Twelve variables were determined from the data and these are shown in Table 6-3. Only two variables were found to occur more than once. They are (1) test after maintenance and (2) auto start with remote manual backup. These were considered to be the dominant defense mechanisms against CCF.

6.4 COMPARISON OF CHECKLIST FROM EXPERT OPINION WITH EXPERIENCE DATA

Table 6-4 shows the comparison of system variables describing defenses against CCF derived from experience data with those derived from the expert opinion survey. All but one of the variables ranked by experts were contained in the list of variables derived from actual failure data. Eight of these variables were among the top-ranked variables as shown from the results of the survey (see Tables 4-1 and 4-2).

Indeed the results indicate that, for the small sample size of AFS CCFs that were found, the expert opinion survey covered more than 90% of the key variables in the system defense against CCF.

6.5 APPLICATION OF THE CHECKLIST TO EVALUATE COMMON CAUSE FAILURE

Figure 6-1 shows a work sheet that was developed to estimate the CCF probability for the various systems and to show how the checklists

Table 6-3

System Variables Describing Defense Against CCF

Derived from Experience Data

Frequency	System Variables	(a)
3	Testing after maintenance	1
3	Autostart with remote manual backup	
1	Design adequacy/prototypical	1
1	Minimum interface with other systems	
1	Diversity	
1	Testing more often	
1	Separation	
1	Full flow tests to SGs (inadequate testing)	
1	Simplicity - remove strainers	
1	Testing before rise-to-power	
1	Medium redundancy (>1/2)	1
1	Outage time limitation - train	1
1	Unknown	

(a)From related events.

and experience data were used in rating the AFS. We recommend that, when this approach is used, the most current drawings, technical specifications, procedures, etc. should be used for the analysis. Section C.2 of Appendix C discusses the use of this approach in more detail as applied to the analysis of various AFSs.

Table 6-4

Comparison of Expert Opinion Checklist Variables with Experience Data Variables

Summary of "Defense Against CCF" Variables Determined from Experience Data		Compilation of 30 Expert Opinion Surveys			
Frequency		(a)	(b)	(c)	(d)
3	Testing after maintenance	1	X	X	X
3	Auto start with remote manual backup		X	X	X
1	Design adequacy/prototypical	1		X	X
1	Minimum interface with other systems		X	X	X
1	Diversity		X	X	X
1	Testing more often		X	X	X
1	Separation		X	X	X
1	Full flow tests to SGs (inadequate testing)				X
1	Simplicity - remove strainers		X	X	X
1	Testing before rise-to-power				
1	Medium redundancy (>1/2)	1	X	X	X
1	Outage time limitation - train	1		X	X
1	Unknown				

(a) From related events.
(b) Among top ranked variables - Tables 4-1 and 4-2.
(c) On original listing - Appendix A, Table A-1.
(d) On listing after survey - Appendix B, Tables B-1, B-2, B-3 or Tables B-8, B-9, B-10.

6.6 QUANTIFICATION OF COMMON CAUSE FAILURE PROBABILITIES

6.6.1 Specialized Beta Factor Method

The methodology discussed in Sections 5.2 and 5.3 is applied here to analyze the failure probabilities of two and three redundant unit AFSs. From the data in Table 6-1, the probability of failure to start for multiple unit systems (assuming one demand per month) is:

$$Q_D = \frac{319}{8391.2} = .0380 \ .$$

Figure 6-1

SAMPLE APPLICATION OF VARIABLE CHECK LIST TO ESTIMATE FAILURE PROBABILITY
AUXILIARY FEEDWATER SYSTEM(AFS)

PLANT: _____ NSS: _____ SOURCE: _____

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor No info.	SYSTEM VARIABLE
LO	MED	HI	N	
				RATING

Evaluator: _____

Date: _____

Table 6-5 gives the total number of independent ($N_{i,k}$) and common cause failures ($N_{c,k}$) for each component k. The fractional independent (g_k) and CCF (f_k) contributions to system failure due to component k are also given. With these values we can calculate the number of common cause failures (n_c) and independent failures (n_i) for a generic system, using Eqs. (5-8) and (5-9) of Section 5.2. Thus, we have:

$$n_c = 21 \ ,$$
$$n_i = 116 \ .$$

Table 6-5

Independent and Common Cause Contributions to System Failures

Category (k)	$N_{I,k}$	$N_{c,k}$	g_k*	f_k**
Pumps	140	27	0.52	0.56
Valves	108	16	0.40	0.33
Controls	9	-	0.03	-
Service water	6	-	0.02	-
DGs, others	5	-	0.02	-
Strainers	3	5	0.01	0.11
	271	48	1.00	1.00

$$*g_k = \frac{N_{I,k}}{\sum_k N_{I,k}}$$

$$**f_k = \frac{N_{c,k}}{\sum_k N_{c,k}}$$

Next, we calculate the specific beta factors for two-unit and three-unit systems, using Eqs. (5-12), (5-13), and (5-14) of Section 5.2.

6.6.1.1 Failure Probability of One-out-of-Two Unit System. For two-unit failures, the data consist of two-out-of-two and two-out-of-three failures. Hence,

a) $\lambda_{c,2/2} = \dfrac{\text{Number of 2-out-of-2 unit failures}}{\text{Total number of CCFs in all plants}}$

$= \dfrac{12}{48} = 0.25$.

b) $\lambda_{i,2/2} = \dfrac{\text{Number of independent failures in 2-unit systems}}{\text{Total number of independent failures in all plants}}$

$= \dfrac{109}{271} = 0.40$.

c) $\lambda_{c,2/3} = \dfrac{\text{Number of 2-out-of-3 unit failures}}{\text{Total number of CCFs in all plants}}$

$= \dfrac{28}{48} = 0.58$.

d) $\lambda_{i,2/3} = \dfrac{\text{Number of independent failures in 3-unit systems}}{\text{Total number of independent failures in all plants}}$

$= \dfrac{162}{271} = 0.60$.

e) $n_{c,2/2} = 21(.25) = 5.25$.

f) $n_{i,2/2} = 116(.40) = 46.4$.

g) $n_{c,2/3} = 21(.58) = 12.18$.

h) $n_{i,2/3} = 116(.60) = 69.6$.

Therefore:

$$\beta = \frac{5.25 + 12.18}{46.4 + 69.6 + 5.25 + 12.18} = .13 \ .$$

The reliability expression for a one-out-of-two unit system, considering both independent and common cause failure, is given by the original Beta Factor method as:

$$R = 2e^{-\lambda t} - e^{-(2-\beta)\lambda t} \ .$$

The failure probability, $Q_{1/2}$, for a one-out-of-two unit system is:

$$Q_{1/2} = 1-R \ .$$

Since $\lambda t \cong .038$ and $\beta_2 = 0.13$, we have:

$$Q_{1/2} = 1-2e^{-0.038} + e^{-(2-0.13)0.038} = 6.0 \times 10^{-3} \ .$$

From data (six multiple failures resulted in total system failure) the failure probability is:

$$Q_{1/2} = \frac{6}{919.9} = 6.5 \times 10^{-3} \ .$$

Hence, the probability value using the Specialized Beta Factor method is only 8% lower than that obtained from actual data.

6.6.1.2 <u>Failure Probability for One-Out-of-Three Unit System</u>. For three-out-of-three unit failures,

a) $\gamma_{c,3/3} = 8 = 0.17$,

b) $\gamma_{i,3/3} = 162 = 0.60$,

c) $n_{c,3/3} = 0.17(21) = 3.57$,

d) $n_{i,3/3} = 0.60(116) = 69.6$,

e) $\beta_3 = \frac{3.57}{69.6 + 3.57} = 0.05$.

Using the equations developed in Section 5.3:

$$Q_{1/3} = 1 - (Ae^{-Z_0 t} + Be^{-Z_1 t} + Ce^{-Z_2 t})$$

$$= 1-0.4980e^{-(3-.1)0.038} + 2.4597e^{-(2-0.23)0.038} - 2.9617e^{-0.038}$$

$$= 2.3 \times 10^{-3} .$$

Based on data alone (three multiple failures led to total system failure):

$$Q_{1/3} = \frac{3}{2183.6} = 1.4 \times 10^{-3} .$$

6.6.1.3 <u>Failure Probability Using the Original Beta Factor Method</u>. Using the original Beta Factor method, where a generic beta factor is used for both two and three redundant units, we obtained:

$$\beta = \frac{21}{121+21} = 0.15 ,$$

$$Q_{1/2} = 1-2e^{-0.038} + e^{-(2.015)0.038} = 6.7 \times 10^{-3}$$

$$Q_{1/3} = 1-e^{-(3-2\beta)t} + 3e^{-(2-\beta)\lambda t} - 3e^{-\lambda t} = 5.7 \times 10^{-3} .$$

Thus, we found that the original Beta Factor method worked well for a one-out-of-two unit system but yielded a very high value for a one-out-of-three unit system. The new method produced significantly better results for the one-out-of-three unit system.

6.6.2 Systems Common Cause Failure Probability

Another approach to quantifying CCF for a given system configuration is discussed in Section 5.4. Two basic parameters, the system failures and system trials are involved here.

The system failures are relatively easy to retrieve. For the AFS, in Section 6.3, five CCFs in a two pump system and three CCFs in a three pump system were found.

The system trials, or demands, are considerably more difficult to obtain. In NUREG-0611 and NUREG-0635, Annex 1 to Appendix X requested that each plant provide AFS information such as operating experience, including:

- Number of main feedwater interruptions per year experience to date for each unit.
- Number of demands on AFS per year to date (test and actual) for each unit.
- Summary of AFS malfunctions, problems and failures.

Following extensive search, it was established that trial data associated with CCFs were not available and must be collected.

The number of trials, test and actual, can be estimated from the plant operational reports, monthly data tables, or the Graybooks (NUREG-0200). This, however, is a very time consuming task that is beyond the scope of this project.

Thus, quantitative estimates using this method could not be obtained to verify the probability ranges from the expert survey.

7. CONCLUSIONS

- The top ranking variables describing defense against CCF that were derived from expert opinion surveys and from experience data could be used as a checklist in searching for system CCFs.

- The CCF probability ranges derived from expert survey may be used in the absence of more refined and accurate data.

- System success data as well as system failure data are required to realistically or practically determine CCF probabilities. System success data are more difficult to obtain because they are not explicitly stated. They can, however, be derived implicitly from given information and the operational characteristics of each plant.

- The checklist approach was applied qualitatively and semi-quantitatively to evaluate common cause failures for the PWR auxiliary feedwater system. It is expected that such an approach could be used on other systems.

- The original Beta Factor method has been modified to permit the calculation of specific beta factors for systems with more than one level of redundancy. This new approach yielded a significantly better value for a one-out-of-three unit system than was obtained using the original Beta Factor method.

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A1. Material Sent to Experts for "Defense Against CCF" Evaluation

Introduction
Instructions for Filling Out Evaluation Sheet (Part 1)
Questions (Part 2)
Guide for System Common Cause Evaluation (Table A-1)
Guide for System Common Cause Evaluation — Sample (Table A-2)

A2. List of Experts

Experts Who Were Asked to Participate in the Survey (Table A-3)
Experts Who Responded (Table A-4)

A3. Compilation of Expert Opinions and Answers to Questions

Thirty-six expert opinions, or evaluations, have been compiled in Tables A-5 thru A-7. When the evaluator did not respond, input spaces (i.e., probability range, ranking, etc.) were left blank.

Table A-8 presents the answers received to the questions asked in the CCF survey questionnaire.

* * * * *

Introduction

A DELPHI-type method is used to assess experts' opinions on the effects of common cause failures on nuclear power plant safety systems. A questionnaire is the first of a sequence of information exchanges with experts for the purpose of identifying key variables which influence common cause failures. Responses to the questionnaire will be analyzed and areas of agreement and disagreement will be identified. Respondents will be sent the summarized analysis of all responses and may be asked to fill out the questionnaire again should there be any widely divergent opinions.

The variables shown in the evaluation sheet are selected for a fluid-mechanical system and are given for three categories: system design, component design and man-machine interfaces. Nevertheless, these variables were intended to be generic in nature and to apply to any system. They represent those causes which provide either low, medium or high defense against common cause failures. For example, a fully diversified system results in a much lower failure probability due to common cause (high defense) than a system with no diversity (low defense).

The questionnaire is in two parts. The first part involves the completion of the evaluation sheet according to the instructions provided. The second part involves additional questions designed to determine the completeness of the evaluation sheet and the respondent's view of how it could be improved.

Instructions for Filling Out Evaluation Sheet (Part 1)

1. Give an estimate of the overall failure probability, Q, range for the low, medium and high defense against common cause failures.

2. Select at least four but not more than ten variables from the listed 23 variables which you feel are the most important contributors to common cause failures for the three defense classifications. Please include other variables which you feel that should be included (in the blank spaces provided).

3. Rank these variables in the order of importance (i.e., 1 is the highest) and estimate the percent contribution of each.

A "sample" completed sheet is provided for illustration in Attachment 1.

Questions (Part 2)

The variables listed were developed for three major categories, namely, system design, component design and man-machine interfaces.

1. Are any other major categories needed?

yes no

2. Can/should any of the three major categories be subdivided?

yes no

a. If so, why?

b. How would such subdivision improve the analysis?

3. Would your ranking of the variables change if applied to another system, e.g., an electronic system?

yes no

a. If yes, how?

b. Would the failure probability range for the three defense classifications change when applied to an electronic system (instead of fluid-mechanical)?

yes no

c. If yes, please elaborate.

Table A-1
Guide for System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM EVALUATOR:_____ AFFILIATION:_____ DATE:_____

	Low Defense Against CC Overall Failure Probability Q, range : 10^{-} - 10^{-}		Medium Defense Against CC Overall Failure Probability Q, range : 10^{-} - 10^{-}		High Defense Against CC Overall Failure Probability Q, range : 10^{-} - 10^{-}	
	Rank %	Variable	Rank %	Variable	Rank %	Variable
SYSTEM DESIGN		Single active point failure		Single passive failure point		No single failure point
		Poor separation or protection		Partial separation or protection		Total separation or protection
		No diversity		Partial diversity		Complete diversity
		Designed for normal operating conditions.		Designed for some accident conditions		Designed for most severe accident conditions
		High complexity		Medium complexity		Simplicity
		Minimum redundancy (2/3 or 1/2 of system)		Medium redundancy (greater than 1/2)		High redundancy (much greater than 1/2)
		No testing before initial reactor criticality.		Some testing before initial criticality		Complete testing before criticality
		Many interfaces with other systems		Moderate interfaces with other systems		Minimum interfaces with other systems
COMPONENT DESIGN		No derating (minimum capacity)		Some derating (some added capacity)		Adequate derating (more than adequate capacity)
		No fail-safe		Some fail-safe		Fail-safe
		Designed for normal operating conditions.		Designed for moderate accident conditions		Designed for most severe accident conditions
		Minimum codes and standards		Moderate codes and standards		Stringent codes and standards
		No diversity		Partial diversity		Complete diversity
		Prototypical		Some prototypical and proven		All components proven
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test once per year		Test-once per 3 to 6 months		Test-once per month or more frequently
		Test-all trains together		Test-one train at a time		Test-automatic recovery from test
		No outage time limitation		Long outage time limitation		Short outage time limitations
		Local manual standby		Remote manual standby		Automatic standby
		Manual start, only		Auto start, only		Auto start with remote manual backup
		Test same personnel and shift		Test-different personnel and shift		Test - automatic recovery from test
		No testing after maintenance		Visual inspection after maintenance		Full functional test after all maintenance
		Procedure without backup checks		Procedure with some backup checks		Procedure with many backup checks
		Few control room indications		Single parameter indication		Diverse parameter indications

Table A-2
Guide for System Common Cause Evaluation — Sample

SYSTEM: FLUID-MECHANICAL SYSTEM EVALUATOR: _____ AFFILIATION: _____ DATE: _____

	Low Defense Against CC Overall Failure Probability Q, range : 10^{-1} - 10^{-3}		Medium Defense Against CC Overall Failure Probability Q, range : 10^{-2} - 10^{-4}		High Defense Against CC Overall Failure Probability Q, range : 10^{-3} - 10^{-5}	
	Rank / %	Variable	Rank / %	Variable	Rank / %	Variable
SYSTEM DESIGN	1 / 30	Single active point failure	2 / 30	Single passive failure point		No single failure point
		Poor separation or protection		Partial separation or protection	4 / 10	Total separation or protection
	6 / 5	No diversity	1 / 30	Partial diversity	2 / 20	Complete diversity
		Designed for normal operating conditions.		Designed for some accident conditions		Designed for most severe accident conditions
	7 / 5	High complexity	3 / 20	Medium complexity		Simplicity
		Minimum redundancy (2/3 or 1/2 of system)		Medium redundancy (greater than 1/2)		High redundancy (much greater than 1/2)
		No testing before initial reactor criticality.		Some testing before initial criticality		Complete testing before criticality
		Many interfaces with other systems		Moderate interfaces with other systems		Minimum interfaces with other systems
COMPONENT DESIGN		No derating (minimum capacity)		Some derating (some added capacity)		Adequate derating (more than adequate capacity)
		No fail-safe		Some fail-safe		Fail-safe
		Designed for normal operating conditions.		Designed for moderate accident conditions		Designed for most severe accident conditions
		Minimum codes and standards		Moderate codes and standards		Stringent codes and standards
		No diversity		Partial diversity		Complete diversity
		Prototypical		Some prototypical and proven	3 / 15	All components proven
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test once per year		Test-once per 3 to 6 months	5 / 5	Test-once per month or more frequently
		Test-all trains together		Test-one train at a time		Test-automatic recovery from test
	3 / 10	No outage time limitation		Long outage time limitation	7 / 5	Short outage time limitations
		Local manual standby		Remote manual standby		Automatic standby
	4 / 10	Manual start, only	5 / 10	Auto start, only	1 / 40	Auto start with remote manual backup
	5 / 10	Test-same personnel and shift		Test-different personnel and shift		Test - automatic recovery from test
	2 / 30	No testing after maintenance	4 / 10	Visual inspection after maintenance	6 / 5	Full functional test after all maintenance
		Procedure without backup checks		Procedure with some backup checks		Procedure with many backup checks
		Few control room indications		Single parameter indication		Diverse parameter indications

Table A-3
Survey Sent to Following Experts

Name	Affiliation
G. E. APOSTOLAKIS	UCLA
C. L. ATWOOD	EG&G
R. BARI	BNL
J. BUCHANNON	ORNL
K. CANADAY	DUKE
D. D. CARLSON	SNL
R. C. ERDMANN	SAI, PALO ALTO, CA
G. F. FLANAGAN	ORNL
K. N. FLEMING	PLG, INC.
J. FRAGOLA	SAI, NY
J. B. FUSSELL	JBF ASSOCIATES
W. C. GANGLOFF	WESTINGHOUSE (PWR)
J. A. HARTUNG	AI
J. HERBST	CE
J. JACKSON	LANL
I. M. JACOBS	GE
B. KLOPP	COMM ED.
H. E. KNEE	ORNL
H. LEWIS	UCBS
J. MURPHY	NRC
J. PENLAND	SAI, TENN
N. RASMUSSEN	MIT
F. RAWSOME	NRC
R. SIMONELLI	WESTINGHOUSE(CLINCH RIVER)
K. R. SOLOMON	RAND
W. W. STROM	SCE
M. TAYLOR	NRC
W. E. VESELY	NRC
D. WORLEDGE	EPRI

Table A-4
List of Respondents

Name	Affiliation
G. APOSTOLAKIS	UCLA
C. ATWOOD	EG&G, Idaho
F. BALOH	Westinghouse (ARD)
R. J. BARTHOLOMEW	LASL
H. W. BRANDT	Westinghouse (ARD)
T. BRYAN	Westinghouse (ARD)
K. S. CANADY	Duke Power Co.
D. CARLSON	Sandia
K. DEUTCH	Westinghouse (ARD)
D. GILES	Westinghouse (ARD)
R. C. ERDMAN	SAI, Palo Alto
D. FINNICUM	Combustion Engineering
K. FLEMING	PLG, Inc.
J. FRAGOLA	SAI, New York
W. C. GANGLOFF	Westinghouse (PWR)
J. GRAHAM	Westinghouse
N. P. GRIMM	Westinghouse (ARD)
E. W. HAGEN	ORNL-NSIC
J. HARTUNG	Atomics International
I. M. JACOBS	General Electric
B. KESSINGER	Westinghouse (ARD)
G. T. KLOPP	Commonwealth Edison
H. E. KNEE	ORNL
R. E. KOSKY	Westinghouse (ARD)
F. A. LIJEWSKI	Westinghouse (ARD)
J. LOCANTE	Westinghouse (ARD)
I.A. PAPAZOGLOU	Brookhaven National Lab.

Table A-4 (Continued)

Name	Affiliation
C. N. PENDLETON	So. Cal. Edison
J. R. PENLAND	SAI
N. RASMUSSEN	MIT
E. SCHMIDT	Westinghouse (ARD)
W. SEVERSON	Westinghouse (ARD)
R. SIMONELLI	Westinghouse (ARD)
K. A. SOLOMON	RAND
N. C. WAMPOLE	Westinghouse (ARD)
P. P. ZEMANICK	Westinghouse (ARD)

Table A-5
System Common Cause Evaluation (Low Defense)

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF Sheet 1 of 4

	Low Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)	1E-0 - 1E-3 (3E-2)	1E-4 - 1E-6 (1E-5)	3E-1 - 1E-3 (6E-3)	1E-1 - 1E-3 (1E-2)	1E-2 - 1E-3 (3E-3)	1E-1 - 1E-2 (3E-2)	1E-1 - 1E-2 (3E-2)	1E-1 - 1E-2 (3E-2)	1E-1 - 1E-2 (3E-2)	1E-2 - 1E-4 (1E-3)
	Rank / % — Variable / Evaluator	1	2	3	4	5	6	7	8	9	10
SYSTEM DESIGN	Single active point failure	1 .30			1 .25		1 .40		3 .15	1 .20	
	Poor separation or protection		2 .26	3 .15	7 .05	2 .20	6 .05	1	2 .25		6 .05
	No diversity				4 .15	1 .30					2 .20
	Designed for normal operating conditions.						2 .20				5 .15
	High complexity			6 .10		7 .05				2 .20	
	Minimum redundancy (2/3 or 1/2 of system)	2 .30			6 .05	10 .05		3			
	No testing before initial reactor criticality.										
	Many interfaces with other systems			2 .20	3 .20	8 .03	3 .15		1 .35	5 .20	
	Procedure not checked before publication		4 .10								
	No dependency check										
COMPONENT DESIGN	No derating (minimum capacity)										
	No fail-safe			5 .10				4			
	Designed for normal operating conditions.		5 .10	1 .30		5 .10					4 .15
	Minimum codes and standards					6 .05					
	No diversity										3 .20
	Prototypical	7 .02									1 .25
MAN-MACHINE INTERFACE HUMAN FACTOR & OTHERS	Test once per year								4 .15		
	Test-all trains together				5 .05	9 .02					
	No outage time limitation						4 .10				
	Local manual standby										
	Manual start, only	6 .05								3 .20	
	Test-same personnel and shift		6 .07								
	No testing after maintenance	3 .20	1 .27	4 .15	2 25	4 .10				4 .20	
	Procedure without backup checks	5 .05	3 .20			3 .	5 .10	2			
	Few control room indications	4 .08							5 .10		
	Poor training procedures										
	Manufactured quality - poor										
	Inadequate functional testing										
	Minimal operator training										
	Poor supervision										

Table A-5 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF — Sheet 2 of 4

	Low Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)			1E-1 - 1E-3 (1E-2)	1E-2 - 1E-4 (1E-3)	1E-2 - 3E-4 (1.5E-3)	1E-0 - 1E-1 (3E-1)		1E-1 - 1E-2 (3E-2)	1E-1 - 1E-3 (1E-2)	1E-0 - 1E-2 (1E-1)
	Rank / Variable \ Evaluator	11	12	13	14	15	16	17	18	19	20
SYSTEM DESIGN	Single active point failure	2 .25		1 .20	2 .12	5 .10	1 .40	3 .13	1 .25	1 .30	
	Poor separation or protection			2 .20	2 .12	1 .30			3 .15	6 .05	5 .05
	No diversity			5 .10		8 .05		9 .05		3 .20	7 .05
	Designed for normal operating conditions.							4 .10	8 .05		
	High complexity	1 .25	1 .40			4 .10				2 .25	2 .10
	Minimum redundancy (2/3 or 1/2 of system)								2 .15		
	No testing before initial reactor criticality.		4 .05		3 .25						
	Many interfaces with other systems	3 .10	3 .05	6 .10			3 .20				1 .40
	Procedure not checked before publication										
	No dependency check										10 .05
COMPONENT DESIGN	No derating (minimum capacity)		8 .04		4 .10				6 .05		6 .05
	No fail-safe		2 .30	7 .05				5 .10	4 .10		
	Designed for normal operating conditions.							6 .10		4 .10	
	Minimum codes and standards		9 .04			3 .10			9 .05		
	No diversity						2 .30	8 .10			3 .10
	Prototypical	4 .20				7 .05					
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test once per year										9 .05
	Test-all trains together		6 .04								
	No outage time limitation	5 .10	5 .04								
	Local manual standby										
	Manual start, only										
	Test-same personnel and shift	6 .10					4 .05				
	No testing after maintenance		7 .04	3 .20	5 10	2 20	5 .03	7 .10	5 .10	5 .10	4 .10
	Procedure without backup checks			4 .15			6 .02	2 .15	7 .05		
	Few control room indications					6 .10		1 .15			8 .05
	Poor training procedure										
	Manufactured quality - poor				1 .30						
	Inadequate functional testing							10 .05			
	Minimal operator training										
	Poor supervision										

Table A-5 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF Sheet 3 of 4

	Low Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)		1E-1 - 1E-2 (3E-2)	1E-0 - 1E-1 (3E-1)	1E-1 - 1E-3 (1E-2)	1E-0 - 1E-2 (1E-1)		1E-2 - 1E-4 (1E-3)	1E-3 - 1E-4 (3E-4)	1E-2 - 1E-4 (1E-3)	1E-1 - 1E-4 (3E-3)
	Rank % / Variable \ Evaluator	21	22	23	24	25	26	27	28	29	30
SYSTEM DESIGN	Single active point failure	1 .25	1 .20		6 .10		1 .30				3 .15
	Poor separation or protection			6 .10	2 .15	6 .08	7 .05	9 .05			
	No diversity	4 .15		1 .20		7 .08		5 .10	5 .10		
	Designed for normal operating conditions.					9 .16					
	High complexity	6 .10		3 .20	5 .10	10 .04					5 .10
	Minimum redundancy (2/3 or 1/2 of system)					11 .04			8 .05		
	No testing before initial reactor criticality.	7 .05						2 .20			
	Many interfaces with-other systems		7 .05	4 .10	7 .05		3 .15		9 .05		7 .05
	Procedure not checked before publication										
	No dependency check										
COMPONENT DESIGN	No derating (minimum capacity)								7 .05		8 .05
	No fail-safe			5 .10							4 .10
	Designed for normal operating conditions.	3 .10			8 .05						
	Minimum codes and standards										
	No diversity								6 .05		
	Prototypical					2 .12					
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test once per year					3 .12					6 .10
	Test-all trains together		6 .10				2 .20	4 .10	4 .10		
	No outage time limitation		4 .15					8 .05			
	Local manual standby										
	Manual start, only	5 10	2 .20								
	Test-same personnel and shift		5 .15		3 .15	5 12	4 10				
	No testing after maintenance		3 15	2 30	1 .30		5 10	6 05	1 .20		9 .05
	Procedure without backup checks	2 25			4 10		6 10	3 15	3 .20		
	Few control room indications							7 05			
	Poor training procedures								2 .20		
	Manufactured quality - poor										
	Inadequate function tests					1 24					
	Minimal operator training							1 25			1 .25
	Poor supervision										2 .15

Table A-5 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF Sheet 4 of 4

	Low Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)	1E-1 - 1E-3 (3E-2)	1E-2 - 1E-3 (3E-3)	1E-1 - 1E-2 (3E-2)	1E-0 - 1E-2 (1E-1)						
	Rank / Variable \ Evaluator	31	32	33	34	35	36				
SYSTEM DESIGN	Single active point failure	1 .20			1 .40		1 .30				
	Poor separation or protection			5 .10			3 .20				
	No diversity	6 .10		4 .10	5 .05						
	Designed for normal operating conditions.	5 .10					4 .20				
	High complexity	3 .15		6 .10		1 .30					
	Minimum redundancy (2/3 or 1/2 of system)			7 .10							
	No testing before initial reactor criticality.	4 .10									
	Many interfaces with-other systems	2 .15		3 .10	3 .15	2 .30					
	Procedure not checked before publication										
	No dependency check										
COMPONENT DESIGN	No derating (minimum capacity)					3 .20					
	No fail-safe										
	Designed for normal operating conditions.										
	Minimum codes and standards			2 .20							
	No diversity			1 .20							
	Prototypical										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test once per year										
	Test-all trains together				4 .05						
	No outage time limitation						2 .30				
	Local manual standby										
	Manual start, only										
	Test-same personnel and shift										
	No testing after maintenance	8 .10		8 .04	2 .30	4 .15					
	Procedure without backup checks			9 .03		5 .05					
	Few control room indications	7 .10		10 .03	6 05						
	Poor training procedure										
	Manufacured quality - poor										
	Inadequate functional testing										
	Minimal operator training										
	Poor supervision										

Table A-6
System Common Cause Evaluation (Medium Defense)

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF Sheet 1 of 4

	Medium Defense Against CC Overall Failure Probability (per demand) Q, range (Midpoint)	1E-3 - 1E-4 (3E-4)	1E-5 - 1E-7 (1E-6)	3E-3 - 1E-4 (5E-6)	1E-2 - 1E-4 (1E-3)	1E-3 - 1E-4 (3E-4)	1E-2 - 1E-4 (1E-3)	1E-2 - 1E-3 (3E-3)	1E-2 - 1E-4 (1E-3)	1E-3 - 1E-4 (3E-4)	1E-3 - 1E-6 (3E-5)
	Rank % / Variable / Evaluator	1	2	3	4	5	6	7	8	9	10
SYSTEM DESIGN	Single passive failure point						3 .20		3 .20	1 .30	
	Partial separation or protection	4 .08	1 .33	4 .15	6 .10	2 .20	1 .30	1	4 .10		
	Partial diversity				3 .15	1 .30					2 .20
	Designed for some accident condition				1 .25		4 .15				6 .10
	Medium complexity			5 .10						2 .15	
	Medium redundancy (greater than 1/2)				2 .20	6 .05		3	2 .25		
	Some testing before initial criticality					4 .10					
	Moderate interfaces with other syste			1 .30			2 .25	4	1 .30	3 .15	4 .15
	Procedure checked informally before publication		5 .07								
	System dependency review										
COMPONENT DESIGN	Some derating (some added capacity)									4 .15	
	Some fail-safe			6 .10							
	Designed for moderate accident conditions		4 .10	2 .20	4 .15						
	Moderate codes and standards					7 .05					
	Partial diversity										3 .20
	Some prototypical and proven	5 .02									1 .25
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per 3 to 6 months	1 .35							5 .10	6 .15	
	Test-one train at a time										
	Long outage time limitation						5 .10				
	Remote manual standby										
	Auto start, only										5 .10
	Test-different personnel and shift										
	Visual inspection after maintenance	3 .20	2 .25	3 .15		5 .10					
	Procedure with some backup checks	2 .35	3 .25		5 .15	3 .20		2		5 .10	
	Single parameter indication								6 .05		
	Moderate training & intermediate skill level										
	Manufactured quality - good										
	Inadequate functional testing										
	Adequate supervision										

Table A-6 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION – MEDIUM DEFENSE AGAINST CCF — Sheet 2 of 4

	Medium Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)			1E-3 – 1E-5 (1E-4)	1E-4 – 1E-6 (1E-5)	5E-4 – 3E-5 (1.2E-4)	1E-1 – 1E-2 (3E-2)		1E-2 – 1E-3 (3E-3)	1E-2 – 1E-4 (1E-3)	1E-3 – 1E-6 (1E-4)
	Rank / Variable \ Evaluator	11	12	13	14	15	16	17	18	19	20
SYSTEM DESIGN	Single passive failure point	3 .10		1 .20				2 .30		7 .05	
	Partial separation or protection			5 .15	4 .15	2 .20			2 .20	2 .20	4 .10
	Partial diversity			2 .15	3 .15					1 .20	5 .05
	Designed for some accident condition							3 .20	5 .10		
	Medium complexity	1 .25	5 .10			4 .15	3 .10				2 .20
	Medium redundancy (greater than 1/2)	2 .25							1 .25	6 .10	
	Some testing before initial criticality		4 .10							5 .10	
	Moderate interfaces with other syste		3 .10	4 .15			2 .20				1 .40
	Procedure not checked before publication										
	System dependency review										9 .02
COMPONENT DESIGN	Some derating (some added capacity)	4 .10			5 .15						6 .05
	Some fail-safe				6 .10	5 .10			3 .15		
	Designed for moderate accident conditions		9 .05						4 .15		
	Moderate codes and standards										
	Partial diversity	6 .10			2 .20						3 .10
	Some prototypical and proven	7 .10	2 .10			7 .05				4 .10	
	No diversity						1 .60				
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per 3 to 6 months										7 .05
	Test-one train at a time		8 .05								
	Long outage time limitation		1 .20								
	Remote manual standby										
	Auto start, only					3 .20		5 .10	6 .10	8 .05	
	Test-different personnel and shift		6 .10	7 .10		6 .05	4 .10				
	Visual inspection after maintenance	5 .10	7 .10	6 .10				4 .10			
	Procedure with some backup checks			3 .15							
	Single parameter indication					1 .25		1 .30		3 .20	8 .03
	Moderate training & intermediate skill level				1 .25						
	Manufactured quality – good								7 .05		
	Inadequate fuctional testing										
	Adequate supervision										

Table A-6 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF — Sheet 3 of 4

	Medium Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)		1E-3 - 1E-4 (3E-4)	1E-1 - 1E-3 (1E-2)	1E-2 - 1E-4 (1E-3)	1E-2 - 1E-4 (1E-3)		1E-4 - 1E-6 (1E-5)	1E-4 - 1E-5 (3E-5)	1E-3 - 1E-5 (1E-4)	1E-3 - 1E-5 (1E-4)
	Rank % / Variable \ Evaluator	21	22	23	24	25	26	27	28	29	30
SYSTEM DESIGN	Single passive failure point		5 .07				5 .10				
	Partial separation or protection			6 .10					7 .05		
	Partial diversity			2 .20				6 .10	1 .25		
	Designed for some accident condition	1 .30			5 .10	4 .10			6 .10		
	Medium complexity			4 .20		9 .02					
	Medium redundancy (greater than 1/2)					8 .03		1 .25			
	Some testing before initial criticality	2 .20		5 .10			1 .20				
	Moderate interfaces with other syste								5 .10		4 .10
	Procedure not checked before publication										
	System dependency review										
COMPONENT DESIGN	Some derating (some added capacity)										5 .10
	Some fail-safe		4 .18	3 .10							
	Designed for moderate accident conditions	6 .10			4 .10						
	Moderate codes and standards										
	Partial diversity								4 .10		
	Some prototypical and proven	5 .10				1 .20					
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per 3 to 6 months		2 .25			7 .10	4 .20				
	Test-one train at a time										
	Long outage time limitation				2 .25		3 .20	4 .10			
	Remote manual standby										
	Auto start, only		1 25								
	Test-different personnel and shift					1 .20					
	Visual inspection after maintenance		3 25	1 .30	1 35		2 .30	3 15			3 .20
	Procedure with some backup checks	3 15						7 10	2 .20		
	Single parameter indication	4 15			3 20			5 .10			
	Moderate training & intermediate skill level							2 20	3 .20		1 .40
	Manufactured quality - good										
	Inadequate functional testing					2&5 &6 40					
	Adequate supervision										2 20

Table A-6 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF Sheet 4 of 4

	Medium Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)	3E-2 - 3E-4 (1E-3)	1E-3 - 1E-4 (3E-4)	1E-2 - 1E-4 (1E-3)	1E-2 - 1E-4 (1E-3)						
	Rank / Variable \ Evaluator	31	32	33	34	35	36				
SYSTEM DESIGN	Single passive failure point										
	Partial separation or protection			3 .10							
	Partial diversity										
	Designed for some accident condition										
	Medium complexity			4 .10		1 .30					
	Medium redundancy (greater than 1/2)			5 .10							
	Some testing before initial criticality			1 .15							
	Moderate interfaces with other syste			2 .15	3 .20	3 .20	3 .20				
	Procedure not checked before publication										
	System dependency review										
COMPONENT DESIGN	Some derating (some added capacity)					2 .30					
	Some fail-safe				1 .40						
	Designed for moderate accident conditions			6 .10							
	Moderate codes and standards										
	Partial diversity										
	Some prototypical and proven										
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per 3 to 6 months						4 .20				
	Test-one train at a time										
	Long outage time limitation						1 .30				
	Remote manual standby			7 .10							
	Auto start, only				5 .05	4 .10					
	Test-different personnel and shift				4 .10						
	Visual inspection after maintenance			8 .10	2 .25		2 .30				
	Procedure with some backup checks			9 .05		5 .10					
	Single parameter indication			10 .05							
	Moderate training 7 intermediate skill level										
	Manufacured quality - good										
	Inadequate functional testings										
	Adequate supervision										

Table A-7
System Common Cause Evaluation (High Defense)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF — Sheet 1 of 4

	High Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)	1E-4 - 1E-8 (1E-6)	1E-6 - 1E-8 (1E-7)	3E-3 - 3E-6 (1E-4)	1E-4 - 1E-6 (1E-5)	1E-4 - 1E-6 (1E-5)	[illegible] 1E-6 (1E-5)	1E-3 - 1E-5 (1E-4)	1E-4 - 1E-6 (1E-5)	1E-5 - 1E-7 (1E-6)	1E-5 - 1E-7 (1E-6)
Rank / Variable \ Evaluator		1	2	3	4	5	6	7	8	9	10
SYSTEM DESIGN	No single failure point						2 .25		3 .20		
	Total separation or protection		1 .40	5 .10		2 .20		1			
	Complete diversity				3 .15	1 .30				5 .20	
	Designed for most severe accident conditions						5 .10				2 .25
	Simplicity			4 .15					2 .25		
	High redundancy (much greater than 1/2)					3 .10		3			
	Complete testing before criticality								4 .10		
	Minimum interfaces with other systems			1 .30	1 .30		4 .15		1 .30	1 .20	1 .55
	Design review						1 .30				
COMPONENT DESIGN	Adequate derating (more than adequate capacity)										
	Fail-safe			6 .10				4			
	Designed for most severe accident conditions		4 .08	2 .20		5 .10				4 .20	3 .20
	Stringent codes and standards				5 .10						
	Complete diversity	3 .05									
	All components proven					8 .05			6 .05		
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per month or more frequently	1 .60							5 .10		
	Test-automatic recovery from test										
	Short outage time limitations	4 .05					3 .20				
	Automatic standby									3 .20	
	Auto start with remote manual backup				6 .05						
	Test - automatic recovery from test										
	Full functional test after all maintenance		3 17	3 .15	2 .25	6 .05					
	Procedure with many backup checks	2 .30	2 .35		4 10	4 10		2			
	Diverse parameter indications				7 .05	9 .05				2 .20	
	Staggerered testing					7 .05					
	High training & high skill, simulator(military type)										
	Manufactured quality - excellent										
	Knowledgable & involved supervisor with solid management backing										

Table A-7 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CC/ — Sheet 2 of 4

	High Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)			1E-3 - 1E-6 (3E-6)	1E-5 - 1E-7 (1E-6)	5E-5 - 1E-6 (7E-6)	1E-2 - 1E-3 (3E-3)		1E-3 - 1E-5 (1E-4)	1E-4 - 1E-6 (1E-5)	1E-6 - 1E-12 (1E-9)
	Rank / % — Variable / Evaluator	11	12	13	14	15	16	17	18	19	20
SYSTEM DESIGN	No single failure point	3 .25			6 .05				1 .25		
	Total separation or protection				6 .05				3 .15		5 .10
	Complete diversity					6 .05					
	Designed for most severe accident conditions				5 .15			3 .20		4 .15	
	Simplicity	1 .25					3 .10				2 .20
	High redundancy (much greater than 1/2)					3 .15			2 .15		
	Complete testing before criticality				4 .15			4 .15	4 .10		
	Minimum interfaces with other systems			4 .20	3 .20		2 .20			5 .15	1 .30
	Design review										
COMPONENT DESIGN	Adequate derating (more than adequate capacity)										
	Fail-safe					5 .10					
	Designed for most severe accident conditions					4 .10				3 .20	
	Stringent codes and standards	4 .15									
	Complete diversity										
	All components proven	2 .25							5 .10		
	No diversity						1 .60				
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per month or more frequently	5 .05				1 .40				1 .20	3 .20
	Test-automatic recovery from test										
	Short outage time limitations			3 .20							
	Automatic standby							1 .20			
	Auto start with remote manual backup		2 10			2 20			6 10	6 10	
	Test - automatic recovery from test		1 10	5 20			4 10	5 15			
	Full functional test after all maintenance	6 05		2 20				6 10	7 10	2 15	
	Procedure with many backup checks			1 20	2 20						
	Diverse parameter indications							2 20		7 .05	4 .20
	Staggered testing										
	High training & high skill, simulator(military type)				1 20						
	Manufactured quality - excellent								8 .05		
	Knowledgable &involved supervisor with solid management backing										

Table A-7 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF — Sheet 3 of 4

	High Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)		1E-5 - 1E-6 (3E-6)	1E-3 - 1E-5 (1E-4)	1E-4 - 1E-5 (3E-5)	1E-4 - 1E-5 (3E-5)		1E-5 - 1E-7 (1E-6)	1E-5 - 1E-6 (3E-6)	1E-4 - 1E-6 (1E-5)	1E-4 - 1E-8 (1E-6)
	Rank % / Variable \ Evaluator	21	22	23	24	25	26	27	28	29	30
SYSTEM DESIGN	No single failure point		2 .22					6 .10			
	Total separation or protection	4 .10									3 .10
	Complete diversity	3 .15			5 .10				1 .30		
	Designed for most severe accident conditions					4 .15		7 .10	6 .15		1 .20
	Simplicity					2 .20					
	High redundancy (much greater than 1/2)			4 .25	3 .20		4 .20				
	Complete testing before criticality										
	Minimum interfaces with other systems		7 .06						5 .15		
	Design review										
COMPONENT DESIGN	Adequate derating (more than adequate capacity)						1 .20				
	Fail-safe		4 .16								9 .05
	Designed for most severe accident conditions	6 .05					2 .20				8 .05
	Stringent codes and standards										
	Complete diversity								4 .05		2 .15
	All components proven	2 .30				3 .15					
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per month or more frequently	5 .10		1 .25	4 .15	5 .15	3 .20	1 .25			10 .05
	Test-automatic recovery from test										4 .10
	Short outage time limitations		3 .18				5 .20				
	Automatic standby			2 .25	6 .05						
	Auto start with remote manual backup	1 .30	1 .27		2 .20						
	Test - automatic recovery from test		5 .10		1 .25			2 .20			
	Full functional test after all maintenance		6 .06			1,6 7 .35		3 .15			5 .10
	Procedure with many backup checks			3 .25	7 .05			5 .10	2 .20		
	Diverse parameter indications							4 .10			
	Staggered testing										
	High training & high skill, simulator (military type)								3 .15		6 .10
	Manufactured quality - excellent										
	Knowledgable & involved supervisor with solid management backing										7 .10

Table A-7 (Continued)

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF — Sheet 4 of 4

	High Defense Against CC Overall Failure Probability (per demand) Q, range (Mid-point)	1E-2 - 1E-5 (3E-4)	1E-4 - 1E-6 (1E-5)	1E-5 - 1E-6 (3E-6)	1E-4 - 1E-6 (1E-5)						
	Rank / % — Variable / Evaluator	31	32	33	34	35	36				
SYSTEM DESIGN	No single failure point	1 .20									
	Total separation or protection										
	Complete diversity	6 .10		6 .10							
	Designed for most severe accident conditions	5 .10					4 .20				
	Simplicity	3 .15									
	High redundancy (much greater than 1/2)			7 .10	2 .35						
	Complete testing before criticality	.10									
	Minimum interfaces with other systems	2 .15		4 .10	3 .10		2 .30				
	Design review										
COMPONENT DESIGN	Adequate derating (more than adequate capacity)										
	Fail-safe										
	Designed for most severe accident conditions				1 .45		3 .20				
	Stringent codes and standards			5 .10		4 .20					
	Complete diversity										
	All components proven										
	No diversity										
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS	Test-once per month or more frequently						1 .30				
	Test-automatic recovery from test					.20					
	Short outage time limitations			3 .10							
	Automatic standby										
	Auto start with remote manual backup			2 .15							
	Test - automatic recovery from test			8 .10		2 .20					
	Full functional test after all maintenance	8 .10		9 .05							
	Procedure with many backup checks			10 .05		1 .40					
	Diverse parameter indications	7 .10		1 .15	4 .10						
	Staggerered testing										
	High training & high skill, simulator (military type)										
	Manufactured quality - high										
	Knowledgable & involved supervisor with solid management backing										

Table A-8
System Common Cause Evaluation — Summary of Answers to Questions

1. Are any other major categories needed?

Evaluator	Yes	No	Comment
1	✓		Plant structure & layout be considered in terms of external events such as tornadoes, etc.
2		✓	
3	✓		Component & machine interface.
4		✓	
5	✓		There should be some way to index management commitment and operator motivation to provide a safe system.
6		✓	
7	✓		Most, >2/3, can be attributed to the human element as designer, operator, maintainer, supervisor, administrator. However, this element does not yield to a quantitative resolution such as to failure rate or MTTF.* Thus, the problem is a real challenge to predict the unpredictable, while the minor part, equip. oriented, is to factor the dependencies into the system fault tree.
8	✓		Operations/Maintenance.
9		✓	
10		✓	
11	✓		Maintainability, accessibility, inspectability, replacement parts, monitoring, etc.
12	—	—	
13	—	—	
14	✓		Man-machine section needs clarification, more human error categories-operations, maintenance, running procedures.
15	✓		Training (experience, simulators, etc clarify "others" section for the intended testing and au o operations.
16		✓	
17		✓	
18	✓		Manufactured quality.

*Mean time to failure.

Table A-8 (Continued)

Evaluator	Yes	No	Comment
19		✓	
20	✓		The standards category should be broken out for separate consideration - possibly.
21		✓	
22		✓	
23	✓		A separation should be made for external common cause and internal.
24		✓	
25		✓	
26		✓	
27	✓		Such as environmental effects (fire, flooding, seismic, etc.)
28	—	—	
29		✓	
30		✓	
31			I am uncomfortable with your categorization scheme but am not sure how to change it. A great deal of effort probably needs to be put into this area to get good results.
32		✓	
33		✓	
34		✓	
35		✓	
36		✓	

— Did not answer the question

Table A-8 (Continued)

2. Can/should any of the three major categories be subdivided?

Evaluator	Yes	No	Comment
1		✓	
2		✓	
3		✓	
4		✓	Not initially, perhaps later in this study.
5		✓	
6		✓	
7		✓	
8		✓	
9		✓	
10		✓	
11	✓		Maintainability, accessibility, inspectability, replacement parts, monitoring, etc. Help pinpoint the problem.
12	—	—	
13	—	—	
14	✓		Man-machine section needs clarification - more human error categories - operations, maintenance, running procedures.
15		✓	
16		✓	
17		✓	
18		✓	
19	✓		Man-machine interface is too broad. Operations, testing and maintenance could be separated into sub-divisions. Thought process might be clearer.
20	✓		The final category is a little broad dealing as it does with design, operation and test - separate out design. More focus on design issues - bad design and its influence on operation is not really focused here, and it is important.
21		✓	

Table A-8 (Continued)

Evaluator	Yes	No	Comment
22		✓	
23	✓		A separation should be made for external common cause and internal. The defense for seismic, or flood, etc. caused events will differ from defense of cascading events.
24		✓	
25		✓	
26		✓	
27	—	—	
28	—	—	
29		✓	
30	✓		MMI/Human Factors should be divided into design factors and operational factors. Broad personnel selection, management attitude, training, etc. are operational human factors which can make orders of magnitude difference in system failure probability and can compensate for many design problems. Also, such factors as design control (QA) can catch things before operations or during.
31			Same answer as question 1.
32	✓		It depends very much on the probabilistic model to be used.
33	✓		One needs to have intermediate subsystems with emphasis on component interfaces, rather than a jump from components to total system design. More attention needs to be given to interfaces to reduce CC. The failure mode assessment would be more complete. Minimization of interfaces (or isolation of subsytems) would help in the function of fault trees.
34		✓	
35		✓	
36		✓	

— Did not answer the question

Table A-8 (Continued)

3a. Would your ranking of the variables change if applied to another system, e.g., an electronic system?

Evaluator	Yes	No	Comment
1	✓		Greater potential benefit in diversity due to reduced chances of human error in calibration and testing.
2	✓		For signal conditioning systems, human errors & defective procedure would dominate everything. Separation would be minor contributor. For other systems, I don't know.
3			Unsure?
4	✓		Maintenance to mechanical systems requires much man-machine interface while maintenance to electronic systems often times entails merely swapping components.
5		✓	The concepts are too abstract without a specific system under analysis. At this level of definition, I can't distinguish between an electronic system and a fluid-mechanical system.
6		✓	
7		✓	
8		✓	Not appreciably.
9	✓		Usually, electronic systems can be subjected to burn ins.
10		✓	
11			?
12	—	—	
13	—	—	
14	✓		There are more cascade failures, and electronic base line is different in preparing components for use - easier to prove out prior to use.
15			Probably not.
16		✓	
17	✓		Separation, protection becomes a factor, redundancy becomes a factor, etc.
18		✓	

Table A-8 (Continued)

Evaluator	Yes	No	Comment
19	✓		More data available, so major contributors are probably known, not guesses.
20	✓		They are very general variables - the % contributions might change a little.
21	✓		Design transients and failure modes are not similar for electronic systems.
22	✓		Parameter having to do with signal separation and isolation would contribute more significantly.
23		✓	
24	✓		Complexity has a strong influence on an electronic system.
25		✓	
26	✓		Included a ranking for electronic system.
27		✓	
28	—	—	
29	✓		Electrical systems tend to fail for different causes, e.g., very susceptible to fire and high moisture, mechanical systems not.
30	✓		I would find control room indications, testing and use of prototype hardware much larger contributors and maintenance much smaller.
31	✓		Design margin would become more important.
32		✓	
33		✓	
34	✓		Ranking would be much different, because electrical failures are generally different than in fluid mechanical systems. Also variables would change.
35	✓		Believe electronic circuits (sneak circuits) should have more testing.
36		✓	

— Did not answe the question

Table A-8 (Continued)

3b. Would the failure probability range for the three defense classifications change when applied to an electronic system (instead of fluid-mechanical)?

Evaluator	Yes	No	Comment
1	✓	✓	Distinction between relay logic and solid state logic systems must be taken. The solid state logic systems will substantially reduce the probability range.
2	✓		The average would decrease. The range would increase (to more than a factor of 100) because there seems to be more variability in the data with electronic (inst. & control) than with hydraulic (pumps).
3	Likely		Unsure
4	✓		Electronic systems have proved to be inherently more reliable than mechanical systems. Categories may shift by an order of magnitude or more.
5	✓		It would probably change. In general, all electronic systems can probably achieve lower failure probabilities than fluid-mechanical because it is easier to isolate the channels and we can usually afford more redundancy.
6		✓	
7		✓	Electronics have fewer moving parts but the interdependencies between them are much less obvious.
8		✓	
9	✓		Usually electronic systems can be subjected to burn ins.
10	✓		Typical electronic system is more reliable.
11			?
12	—	—	
13	—	—	
14	✓		
15			Probably not.
16		✓	
17	✓		I would expect there would be change because variables associated with the electronic system could be considered differently and weights would change.

Table A-8 (Continued)

Evaluator	Yes	No	Comment
18		✓	
19	✓		The number would be larger.
20	✓		They are simply judgements of what low, medium and high defenses mean to me.
21	✓		Failure probability much less to electronic system design with appropriate redundancy and separation.
22		✓	
23		✓	
24	✓		Lower probability for each classification would be approx. half an order of magnitude lower; range for low defense would be $5x10^{-2}$ to $5x10^{-4}$.
25		✓	
26	✓		I have not supplied quantitative estimate for the "overall failure probability" because I think such an estimate will depend on the actual definition of this quantity. Is it probability of failure on demand? Is it an average unavailability (combined with a frequency of demands)? If the latter is the case, what is the value of the time horizon? A definition of what it meant by "overall failure probability" would help.
27		✓	
28	—	—	
29	✓		If well designed, would usually be more reliable.
30		✓	Junk is junk and quality is quality.
31			I have not evaluated enough electrical systems to make an intelligent response to this question.
32	✓		More reliable components and design.
33	✓		The electronic system would have failure probabilities (or failure rates) two or three orders of magnitude less than fluid mechanical system.
34	✓		Medium 10^{-2} - 10^{-3}, High 10^{-3} - 10^{-5}
35	✓		Testing of system and components does not always guarantee satisfactory performance when next needed. Only the level of confidence is improved.
36		✓	

— Did not answer the question

Table A-8 (Continued)

Evaluator	Yes	No	Comment
18		✓	
19	✓		The number would be larger.
20	✓		They are simply judgements of what low, medium and high defenses mean to me.
21	✓		Failure probability much less to electronic system design with appropriate redundancy and separation.
22		✓	
23		✓	
24	✓		Lower probability for each classification would be approx. half an order of magnitude lower; range for low defense would be $5x10^{-2}$ to $5x10^{-4}$.
25		✓	
26	✓		I have not supplied quantitative estimate for the "overall failure probability" because I think such an estimate will depend on the actual definition of this quantity. Is it probability of failure on demand? Is it an average unavailability (combined with a frequency of demands)? If the latter is the case, what is the value of the time horizon? A definition of what it meant by "overall failure probability" would help.
27		✓	
28	—	—	
29	✓		If well designed, would usually be more reliable.
30		✓	Junk is junk and quality is quality.
31			I have not evaluated enough electrical systems to make an intelligent response to this question.
32	✓		More reliable components and design.
33	✓		The electronic system would have failure probabilities (or failure rates) two or three orders of magnitude less than fluid mechanical system.
34	✓		Medium 10^{-2} - 10^{-3}, High 10^{-3} - 10^{-5}
35	✓		Testing of system and components does not always guarantee satisfactory performance when next needed. Only the level of confidence is improved.
36		✓	

— Did not answer the question

APPENDIX B

ANALYSIS OF SURVEY INFORMATION

Appendix B summarizes the following activities based on expert opinion and CCF experience data:

- o Development of the checklist schemes.
- o Determination of the order of magnitude probability ranges.

B1. Development of Checklist Schemes

For the preliminary development of checklist schemes, the first 30 returns were used. The six additional inputs were received too late to permit incorporation into the final results.

B1.1 Summation of Percentages (Σ of %s)

One checklist was developed by summing the percentage contribution of each variable selected. The overall results are shown in Tables B-1, B-2, and B-3. The extreme values, both upper and lower, were eliminated from these results.

Mr. Uppuluri of ORNL also ranked the variables by summing the percentage contribution and taking the average. His results are shown in Tables B-4, B-5 and B-6. His rankings are identical with the authors' results although his average values differed slightly because he used all the data and did not eliminate the extreme values.

The dominant variables for "defense against CCF" from Σ of % are summarized on Table B-7.

B1.2 Summation of Ranking (Σ of rankings)

Another checklist was developed by summing the number of times each variable was ranked. The overall results are shown in Tables B-8, B-9, and B-10.

Table B-1
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM

COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF
(30 Experts)

	Low Defense Against CC		2E-1 Upper 2E-2 Mid-point 5E-3 Lower		2nd order least squares fit						
	Rank	Variable	Σ all %'s / % of all	Rank-TRV	Σ all %'s / % of all	% TRV's	TRV -Top Ranking Variables				
SYSTEM DESIGN		Single active point failure	4.07 / .145	1	4.07 / .145	.233					
		Poor separation or protection	2.31 / .083	4	2.31 / .083	.132					
		No diversity	1.73 / .062	6	1.73 / .062	.099					
		Designed for normal operating conditions.	.66 / .024								
		High complexity	1.99 / .071	5	1.99 / .071	.114					
		Minimum redundancy (2/3 or 1/2 of system)	.64 / .023								
		No testing before initial reactor criticality.	.55 / .020								
		Many interfaces with-other systems	2.43 / .086	3	2.43 / .086	.139					
		Procedure not checked before publication	.10 / .004								
		No dependency check	.05 / .002								
COMPONENT DESIGN		No derating (minimum capacity)	.34 / .012								
		No fail-safe	.85 / .030								
		Designed for normal operating conditions.	1.00 / .036								
		Minimum codes and standards	.24 / .009								
		No diversity	.75 / .027								
		Prototypical	.64 / .023								
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test once per year	.42 / .015								
		Test-all trains together	.61 / .022								
		No outage time limitation	.44 / 016								
		Local manual standby									
		Manual start, only	55 / .020								
		Test-same personnel and shift	74 / .026								
		No testing after maintenance	3.29 / .118	2	3.29 / .118	.189					
		Procedure without backup checks	1.62 / .058	7	1.62 / .058	.093					
		Few control room indications	.53 / .019	8							
		Poor training procedure	.20 / .007								
		Manufactured quality - poor	30 / 011								
		Inadequate functional testing	.29 / .010								
		Minimal operator training	.50 / .018								
		Poor supervision	.15 / .005								
		Σ	27.99 / 1.002		17.44 / .623	.999					

Table B-2
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM

COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF
(30 Experts)

	Medium Defense Against CC		1E-2 Upper 7E-4 Mid-point 2E-4 Lower		2nd order least squares fit						
	Rank	Variable	Σ all Σ's / % of all	Rank-TRV	Σ all Σ's / % of all	Σ TRV's	TRV - Top Ranking Variables				
SYSTEM DESIGN		Single passive failure point	1.52 / .054	6	1.52 / .054	.081					
		Partial separation or protection	2.41 / .086	2	2.41 / .086	.129					
		Partial diversity	1.75 / .063	4	1.75 / .063	.094					
		Designed for some accident condition	1.40 / .050	7	1.40 / .050	.075					
		Medium complexity	1.27 / .045	10	1.27 / .045	.068					
		Medium redundancy (greater than 1/2)	1.38 / .049	8	1.38 / .049	.074					
		Some testing before initial criticality	.80 / .029								
		Moderate interfaces with other syste	2.20 / .088	3	2.20 / .088	.118					
		Procedure not checked before publication	.07 / .003								
		System dependency review	.02 / .001								
COMPONENT DESIGN		Some derating (some added capacity)	.55 / .020								
		Some fail-safe	.73 / .026								
		Designed for moderate accident conditions	.85 / .030								
		Moderate codes and standards	.05 / .002								
		Partial diversity	.70 / .025								
		Some prototypical and proven	.92 / .033								
		No diversity	.60 / .021								
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per 3 to 6 months	1.20 / .043	11	1.20 / .043	.064					
		Test-one train at a time	.05 / .002								
		Long outage time limitation	.85 / .030								
		Remote manual standby									
		Auto start, only	.80 / .029								
		Test-different personnel and shift	.55 / .020								
		Visual inspection after maintenance	2.65 / .095	1	2.65 / .095	.142					
		Procedure with some backup checks	1.65 / .059	5	1.65 / .059	.088					
		Single parameter indication	1.28 / .046	9	1.28 / .046	.068					
		Moderate training & intermediate skill level	1.05 / .036								
		Manufactured quality - good	.05 / .002								
		Inadequate functional testing	.40 / .014								
		Adequate supervision	.20 / .007								
		Σ	27.95 / 1.009		18.71 / .669	1.001					

Table B-3
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM

COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF
(30 Experts)

	High Defense Against CC		2E-4 Upper 1E-5 Mid-point 1.2E-6 Lower		2nd order least squares fit						
	Rank	Variable	Σ all Z's	Rank-TRV	Σ all Z's	% TRV's	TRV - Top Ranking Variables				
SYSTEM DESIGN		No single failure point	1.32 .049	7	1.32 .049	.071					
		Total separation or protection	1.20 .044	10	1.20 .044	.064					
		Complete diversity	1.25 .046	9	1.25 .046	.068					
		Designed for most severe accident conditions	1.45 .053	5	1.45 .053	.078					
		Simplicity	1.15 .042		1.15 .042	.062					
		High redundancy (much greater than 1/2)	1.05 .039								
		Complete testing before criticality	.50 .018								
		Minimum interfaces with other systems	3.06 .113	1	3.06 .113	.165					
		Design review	.30 .011								
COMPONENT DESIGN		Adequate derating (more than adequate capacity)	.20 .007								
		Fail-safe	.41 .015								
		Designed for most severe accident conditions	1.38 .051	6	1.38 .051	.074					
		Stringent codes and standards	.25 .009								
		Complete diversity	.25 .009								
		All components proven	.90 .033								
		No diversity	.60 .022								
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per month or more frequently	2.70 .099	2	2.70 .099	.146					
		Test-automatic recovery from test	.10 .004								
		Short outage time limitations	.83 .031								
		Automatic standby	.70 .026								
		Auto start with remote manual backup	1.27 .047	8	1.27 .047	.069					
		Test - automatic recovery from test	1.10 .040								
		Full functional test after all maintenance	1.88 .069	3	1.88 .069	.102					
		Procedure with many backup checks	1.85 .068	4	1.85 .068	.100					
		Diverse parameter indications	.85 .031								
		Staggerered testing	.05 .002								
		High training & high skill, simulator(military type)	.45 .017								
		Manufactured quality - high	.05 .002								
		Knowledgable & involved supervisor with solid management backing	.10 .004								
		Σ	27.20 1.001		18.51 .680	.999					

Table B-4

System Common Cause Evaluation - Low Defense Against CCF

IDENTIFICATION	SUM	AVERAGE	EXP(AVERAGE)	RANK
SYSTEM DESIGN				
SINGLE ACTIVE POINT FAILURE	4.0700	0.1403	1.150670	1
POOR SEPARATION OR PROTECTION	2.3100	0.0797	1.082914	4
NO DIVERSITY	1.7300	0.0597	1.061470	6
DESIGNED FOR NORMAL OPER. COND.	0.6600	0.0228	1.023020	12
HIGH COMPLEXITY	1.9900	0.0686	1.071030	5
MIN. REDUND.(2/3 OR 1/2 SYS)	0.6400	0.0221	1.022314	13
NO TEST DEF. INITIAL CRIT.	0.5500	0.0190	1.019145	16
MANY INTERFACES W/OTHER SYSTEM	2.4300	0.0832	1.087404	3
PROC. NOT CHECKED BEFORE PUBL.	0.1000	0.0034	1.003454	28
NO DEPENDENCY CHECK	0.0500	0.0017	1.001726	29
COMPONENT DESIGN				
NO DERATING (MIN. CAPACITY)	0.3400	0.0117	1.011793	22
NO FAIL-SAFE	0.8500	0.0293	1.029744	9
DESIGN FOR NORMAL OPER.COND.	1.0000	0.0345	1.035084	8
MINIMUM CODES AND STDS.	0.2400	0.0083	1.008310	25
NO DIVERSITY	0.7500	0.0259	1.026199	10
PROTOTYPICAL	0.6400	0.0221	1.022314	13
MAN-MACHINE INTERFACE				
TEST ONCE PER YEAR	0.4200	0.0145	1.014588	21
TEST - ALL TRAINS TOGETHER	0.6100	0.0210	1.021257	15
NO OUTAGE TIME LIMITATION	0.4400	0.0152	1.015288	20
MANUAL START ONLY	0.5500	0.0190	1.019146	16
TEST- SAME PERSONNEL AND SHIFT	0.7400	0.0255	1.025846	11
NO TESTING AFTER MAINTEMANCE	3.2900	0.1134	1.120134	2
PROCEDURE WITHOUT BACKUP CHECK	1.6200	0.0559	1.057452	7
FEW CONTROL ROOM INDICATIONS	0.5300	0.0183	1.018444	18
POOR TRAINING PROCEDURES	0.2000	0.0069	1.006920	26
MANUFACTURED QUALITY - POOR	0.3000	0.0103	1.010399	23
INADEQUATE FUNCTIONAL TESTING	0.2900	0.0100	1.010050	24
MINIMAL OPERATOR TRAINING	0.5000	0.0172	1.017391	19
POOR SUPERVISION	0.1500	0.0052	1.005186	27

Table B-5

System Common Cause Evaluat[illegible] - Medium Defense Against CCF

IDENTIFICATION	SUM	AVERAGE	EXP(AVERAGE)	RANK
SYSTEM DESIGN				
SINGLE PASSIVE POINT FAILURE	1.5200	0.0524	1.053212	6
PARTIAL SEPARATION OR PROTECTN	2.4100	0.0931	1.036654	2
PARTIAL DIVERSITY	1.7500	0.0603	1.062203	4
DESIGNED FOR SOME ACCID. COND.	1.4000	0.0483	1.049460	7
MEDIUM COMPLEXITY	1.2700	0.0438	1.044766	10
MEDIUM REDUNDANCY (> 1/2)	1.3800	0.0476	1.048737	8
COMPONENT DESIGN				
SOME TEST BEF. INITIAL CRIT.	0.8000	0.0276	1.027970	16
MOD. INTERFACES W/OTHER SYSTEM	2.2000	0.0759	1.078814	3
PROC. NOT CHECKED BEFORE PUBL.	0.0700	0.0024	1.002417	25
SYSTEM DEPENDENCY REVIEW	0.0200	0.0007	1.000690	29
SOME DERATING (ADDED CAPACITY)	0.5500	0.0190	1.019146	21
SOME FAIL-SAFE	0.7300	0.0252	1.025492	18
DESIGN FOR MOD. ACCID. COND.	0.8500	0.0293	1.029744	15
MODERATE CODES AND STDS.	0.0500	0.0017	1.001726	26
PARTIAL DIVERSITY	0.7000	0.0241	1.024432	19
SOME PROTOTYPICAL AND PROVEN	0.9200	0.0317	1.032233	13
NO DIVERSITY	0.6000	0.0207	1.020905	20
MAN-MACHINE INTERFACE				
TEST ONCE PER 3 TO 6 MONTHS	1.2000	0.0414	[illegible]	11
TEST- ONE TRAIN AT A TIME	0.0500	0.0017	[illegible]	26
LONG OUTAGE TIME LIMITATON	0.8500	0.0293	[illegible]	14
AUTO START ONLY	0.8000	0.0276	1.027970	16
TEST- DIFF. PERSONNEL & SHIFT	0.5500	0.0190	1.019146	21
VISUAL INSPECTION AFTER MAINT.	2.8500	0.0914	1.095685	1
PROCEDURE W/SOME BACKUP CHECKS	1.6500	0.0569	1.058546	5
SINGLE PARAMETER INDICATION	1.2800	0.0441	1.045126	9
MOD. TRAINING & INTERM. SKILL	1.0500	0.0362	1.036870	12
MANUFACTURED QUALITY - GOOD	0.0500	0.0017	1.001728	26
INADEQUATE FUNCTIONAL TESTING	0.4000	0.0138	1.013889	23
ADEQUATE SUPERVISION	0.2000	0.0069	1.006920	24

Table B-6

System Common Cause Evaluation - High Defense Against CCF

IDENTIFICATION	SUM	AVERAGE	EXP(AVERAGE)	RANK
SYSTEM DESIGN				
NO SINGLE FAILURE POINT	1.3200	0.0455	1.046569	7
TOTAL SEPARATION OR PROTECTION	1.2000	0.0414	1.042247	10
COMPLETE DIVERSITY	1.2500	0.0431	1.044046	9
DESIGNED FOR MOST SEVERE ACCID.	1.4500	0.0500	1.051271	5
SIMPLICITY	1.1500	0.0397	1.040452	12
HIGH REDUNDANCY (MUCH > 1/2)	1.0500	0.0362	1.036870	13
COMPLETE TEST. BEFORE CRIT.	0.5000	0.0172	1.017391	19
MIN. INTERFACES W/OTHER SYSTEM	3.0600	0.1055	1.111285	1
DESIGN REVIEW	0.3000	0.0103	1.010399	22
COMPONENT DESIGN				
ADEQUATE DERATING	0.2000	0.0069	1.006920	25
FAIL-SAFE	0.4100	0.0141	1.014238	21
DESIGNED FOR MOST SEVERE ACCID.	1.3800	0.0476	1.048737	6
STRINGENT CODES AND STDS.	0.2500	0.0086	1.008658	23
COMPLETE DIVERSITY	0.2500	0.0086	1.002659	23
ALL COMPONENTS PROVEN	0.9000	0.0310	1.031521	14
NO DIVERSITY	0.6000	0.0207	1.020905	18
MAN-MACHINE INTERFACE				
TEST ONCE PER MONTH	2.7000	0.0931	1.097575	2
SHORT OUTAGE TIME LIMITATIONS	0.8300	0.0286	1.029024	16
AUTOMATIC STANDBY	0.7000	0.0241	1.024432	17
AUTO START W/ REMOTE BACKUP	1.2700	0.0438	1.044766	8
TEST- AUTOMATIC RECOVERY	1.2000	0.0414	1.042247	10
FULL FUNCT. TEST AFTER MAINT.	1.8800	0.0648	1.066975	3
PROCEDURE W/MANY BACKUP CHECKS	1.8500	0.0638	1.065872	4
DIVERSE PARAMETER INDICATION	0.8500	0.0293	1.029744	15
STAGGERED TESTING	0.0500	0.0017	1.001726	27
HIGH TRAIN. & SKILL	0.4500	0.0155	1.015638	20
MANUFACTURED QUALITY- EXCELLENT	0.0500	0.0017	1.001726	27
KNOWLDG & INVOLVED SUPERV/MGT	0.1000	0.0034	1.003454	26

Table B-7

Common Cause Variable Checklist and Order of Magnitude Probability Ranges

Top Ranking System Variables (by summing % s)
From Compilation of 30 Expert Opinion Survey

Σ of %s

Low Defense Against CCF		Medium Defense Against CCF		High Defense Against CCF	
Rank / %	2E-1 Upper * 2E-2 Mid-point 5E-3 Lower	Rank / %	1E-2 Upper * 7E-4 Mid-point 2E-4 Lower	Rank / %	2E-4 Upper * 1E-5 Mid-point 1.2E-6 Lower
1 / 23	Single active point failure	1 / 14	Visual inspection after maintenance	1 / 17	Minimum interface with other systems
2 / 19	No testing after maintenance	2 / 13	Partial separation or protection	2 / 15	Test - once per month or more often
3 / 14	Many interfaces with other systems	3 / 12	Moderate interface with other systems	3 / 10	Full functional test after all maintenance
4 / 13	Poor separation or protection	4 / 9	Partial diversity	4 / 10	Procedure with many backups
5 / 11	High complexity	5 / 9	Procedure with some backups	5 / 8	Design for most severe accident conditions (system)
6 / 10	No diversity	6 / 8	Single passive failure point	6 / 7	Design for most severe accident conditions (components)
7 / 9	Procedure without backup checks	7 / 8	Designed for some accident condition	7 / 7	No single failure point
		8 / 8	Medium redundancy (>½)	8 / 7	Auto start with remote manual backup
		9 / 7	Single parameter indication	9 / 7	Complete diversity
		10 / 7	Medium complexity	10 / 6	Total separation or protection
		11 / 6	Test - once per 3 to 6 months	11 / 6	Simplicity

* 2nd order least squares fit

Table B-8
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF BY RANKING — Evaluators 1 - 30

	Low Defense Against CC											
	Rank	Variable	Rank #	1 #	2 #	3 #	4 #	5 #	6 #	7 #	8 #	9 #	≥10 #
SYSTEM DESIGN		Single active point failure		11	2	3		1	1				
		Poor separation or protection		2	6	2		1	5	2		1	
		No diversity		2	1	1	2	3		2	1	1	
		Designed for normal operating conditions.			1		1	1			1	1	
		High complexity		2	3	1	1	2	2	1			1
		Minimum redundancy (2/3 or 1/2 of system)			2	1			1		1		2
		No testing before initial reactor criticality.			1	1	1			1			
		Many interfaces with-other systems		2	1	6	1	1	1	3	1	1	
		Procedure not checked before publication			4								
		No dependency check											1
COMPONENT DESIGN		No derating (minimum capacity)					1		2	1	2		
		No fail-safe			1		3	3			1		
		Designed for normal operating conditions.		1		1	2	2	1		1		
		Minimum codes and standards				1			1			2	
		No diversity			1	2			1		1		
		Prototypical		1	1		1			2			
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test once per year				1	1		1			1	
		Test-all trains together			1		2	1	2			1	
		No outage time limitation					2	2			8		
		Local manual standby											
		Manual start, only			1	1		1	1				
		Test-same personnel and shift				1	2	2	2				
		No testing after maintenance		3	3	3	4	5	1	2		1	
		Procedure without backup checks			3	4	2	2	2	1			
		Few control room indications		1			1	1	1	1	1		
		Poor training procedure		1	1								
		Manufacured quality - poor											1
		Inadequate functional testing		1									
		Minimal operator training		2									
		Poor supervision			1								

Table B-9
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF BY RANKING — Evaluators 1 - 30

	Medium Defense Against CC												
	Rank	Variable	Rank #	1 #	2 #	3 #	4 #	5 #	6 #	7 #	8 #	9 #	≥10 #
SYSTEM DESIGN		Single passive failure point		2	1	3		2		1			
		Partial separation or protection		3	4		5	1	2	1			
		Partial diversity		3	3	2		1	1				
		Designed for some accident condition		2		1	2	2	2				
		Medium complexity		1	2	1	2	2				1	
		Medium redundancy (greater than 1/2)		2	3	1			2		1		
		Some testing before initial criticality					2	1					
		Moderate interfaces with other syste		4	3	2	4	2					
		Procedure not checked before publication						1					
		System dependency review										1	
COMPONENT DESIGN		Some derating (some added capacity)					2	1	1				
		Some fail-safe				2	1	1	2				
		Designed for moderate accident conditions			1		4		1			1	
		Moderate codes and standards								1			
		Partial diversity			1	2	1		1				
		Some prototypical and proven		2	1		1	2		2			
		No diversity		1									
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per 3 to 6 months		1	1		1	1	1	2			
		Test-one train at a time									1		
		Long outage time limitation		1	1	1	1	1					
		Remote manual standby											
		Auto start, only		1		1		2	1	1			
		Test-different personnel and shift		1			1		2	1			
		Visual inspection after maintenance		2	2	5	1	2	1	1			
		Procedure with some backup checks			2	4		2		1			
		Single parameter indication		2		2	1	1	1		1		
		Moderate training / intermediate skill level		2	1	1							
		Manufactured quality - good								1			
		Inadequate functional testings			1			1	1				
		Adequate supervision			1								

Table B-10
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF BY RANKING — Evaluators 1 - 30

	High Defense Against CC											
	Rank	Variable	Rank #	1 #	2 #	3 #	4 #	5 #	6 #	7 #	8 #	9 #	≥10 #
SYSTEM DESIGN		No single failure point		1	2	2			2				
		Total separation or protection		2	1	2	1	2	1				
		Complete diversity		2		2		2	2				
		Designed for most severe accident conditions		1	1	1	2	2	1	1			
		Simplicity		1	3	1	1						
		High redundancy (much greater than 1/2)			1	4	2						
		Complete testing before criticality					4						
		Minimum interfaces with other systems		6	1	1	2	2		1			
		Design review		1									
COMPONENT DESIGN		Adequate derating (more than adequate capacity)		1									
		Fail-safe					2	1	1			1	
		Designed for most severe accident conditions			2	2	3	1	1		1		
		Stringent codes and standards					1	1					
		Complete diversity			1	1	1						
		All components proven			2	1		1	1		1		
		No diversity		1									
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per month or more frequently		5		2	1	4					1
		Test-automatic recovery from test					1						
		Short outage time limitations				3	1	1					
		Automatic standby		1	1	1			1				
		Auto start with remote manual backup		2	3				3				
		Test - automatic recovery from test		2	1		1	3					
		Full functional test after all maintenance		1	3	3		1	5	2			
		Procedure with many backup checks		1	5	1	2	1		1			
		Diverse parameter indications			2		2			2		1	
		Staggered testing								1			
		High training & high skill, simulator(military type)		1		1			1				
		Manufactured quality - high									1		
		Knowledgable & involved supervisor with solid management backing								1			

Tables B-11, B-12, and B-13 present the variable rankings for low, medium, and high defense against CCF for the following categories:

- o Ranked the most time (regardless of ranking order)
- o Ranked No. 1
- o Ranked No. 1 and No. 2
- o Ranked No. 1, No. 2, and No. 3
- o Ranked No. 1, No. 2, No. 3, and No. 4
- o Ranked No. 1, No. 2, No. 3, No. 4, and No. 5.

Table B-11, "Low Defense Against CCF," indicated for the above six methods of ranking the following key variables:

- o Single active point failure - 1st
- o No testing after maintenance - 2nd
- o Poor separation or protection - 3rd

In Table B-12, "Medium Defense Against CCF," the important variables are:

- o Moderate interface with other systems - 1st
- o Partial separation or protection - 2nd
- o Visual inspection after maintenance - 3rd

In Table B-13, "High Defense Against CCF," the important variables are:

- o Minimum interface with other systems - 1st
- o Tests - once per month or more often - 2nd
- o Procedure with many backups - 3rd
- o Functional test after all maintenance - 4th

Table B-14 presents the summary of all rankings.

Table B-15 presents the summary of the top five rankings.

Table B-11
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM COMPILATION OF EXPERT OPINION - LOW DEFENSE AGAINST CCF Evaluators 1 - 30

	Low Defense Against CC		Σ of All Rankings	Σ of Top Ranking	Σ of Top 2 Rankings	Σ of Top 3 Rankings	Σ of Top 4 Rankings	Σ of Top 5 Rankings				
			Σ of RANKINGS									
	Rank	Variable	Rank / #	Rank / #	Rank / #	Rank / #	Rank / #	Rank / #				
SYSTEM DESIGN		Single active point failure	3 / 18	1 / 11	1 / 13	1 / 16	1 / 16	2 / 17				
		Poor separation or protection	2 / 19	2	2 / 8	2 / 10	3 / 10	4 / 11				
		No diversity	7 / 13	2	3	4	6	7 / 9				
		Designed for normal operating conditions.	5		1	1	2	3				
		High complexity	6 / 13	2	4 / 5	6	7	6 / 9				
		Minimum redundancy (2/3 or 1/2 of system)	7		2	3	3	3				
		No testing before initial reactor criticality.	4		1	2	3	3				
		Many interfaces with other systems	4 / 17	2	3	4 / 9	4 / 10	5 / 11				
		Procedure not checked before publication	4		4	4	4	4				
		No dependency check	1									
COMPONENT DESIGN		No derating (minimum capacity)	6				1	1				
		No fail-safe	8		1	1	4	7				
		Designed for normal operating conditions.	8	1	1	2	4	6				
		Minimum codes and standards	4			1	1	1				
		No diversity	5		1	3	3	3				
		Prototypical	5	1	2	2	3	3				
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test once per year	4			1	2	2				
		Test-all trains together	7		1	1	3	4				
		No outage time limitation	5				2	4				
		Local manual standby										
		Manual start, only	4		1	2	2	3				
		Test-same personnel and shift	7			1	3	5				
		No testing after maintenance	1 / 22	2 / 3	3 / 6	3 / 9	2 / 13	1 / 18				
		Procedure without backup checks	5 / 14		3	5 / 7	5 / 9	3 / 11				
		Few control room indications	6	1	1	1	2	3				
		Poor training procedure	2	1	2	2	2	2				
		Manufactured quality - poor										
		Inadequate functional testing	1	1	1	1	1	1				
		Minimal operator training	2	2	2	2	2	2				
		Poor supervision	1		1	1	1	1				

Table B-12
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - MEDIUM DEFENSE AGAINST CCF — Evaluators 1 - 30

Σ of RANKINGS

	Medium Defense Against CC		Σ of All Rankings	Σ of Top Ranking	Σ of Top 2 Rankings	Σ of Top 3 Rankings	Σ of Top 4 Rankings	Σ of Top 5 Rankings				
	Rank	Variable	Rank / #	Rank / #	Rank / #	Rank / #	Rank / #	Rank / #				
SYSTEM DESIGN		Single passive failure point	6 / 9	2	3	6	6	6 / 8				
		Partial separation or protection	1 / 16	2 / 3	2 / 7	4 / 7	4 / 7	3 / 12				
		Partial diversity	4 / 10	3 / 3	3 / 6	3 / 8	3 / 8	3 / 9				
		Designed for some accident condition	7 / 9	2	2	3	5	7				
		Medium complexity	9 / 9	1	3	4	6	7 / 8				
		Medium redundancy (greater than 1/2)	8 / 9	2	4 / 5	6	6	6				
		Some testing before initial criticality	3				2	3				
		Moderate interfaces with other syste	2 / 15	1 / 4	1 / 7	1 / 9	1 / 13	1 / 15				
		Procedure not checked before publication	1					1				
		System dependency review	1									
COMPONENT DESIGN		Some derating (some added capacity)	5				2	3				
		Some fail-safe	6			2	3	4				
		Designed for moderate accident conditions	7		1	1	5	5				
		Moderate codes and standards	1									
		Partial diversity	5		1	3	4	4				
		Some prototypical and proven	8	2	3	3	3	4				
		No diversity	1	1	1	1	1	1				
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per 3 to 6 months	7	1	2	2	3	4				
		Test-one train at a time	1									
		Long outage time limitation	5	1	2	3	4	5				
		Remote manual standby										
		Auto start, only	6	1	1	2	2	4				
		Test-different personnel and shift	5	1	1	1	2	2				
		Visual inspection after maintenance	3 / 14	2	5 / 4	2 / 9	2 / 10	2 / 12				
		Procedure with some backup checks	5 / 9		2	6	6	5 / 8				
		Single parameter indication	8	2	2	4	5	6				
		Moderate training 7 intermediate skill level	4	2	3	4	4	4				
		Manufactured quality - good	1									
		Inadequate functional testing	3		1	1	1	2				
		Adequate supervision	1		1	1	1	1				

Table B-13
System Common Cause Evaluation

SYSTEM: FLUID-MECHANICAL SYSTEM — COMPILATION OF EXPERT OPINION - HIGH DEFENSE AGAINST CCF — Evaluators 1 - 30

	High Defense Against CC		Σ of All Rankings	Σ of Top Ranking	Σ of Top 2 Rankings	Σ of Top 3 Rankings	Σ of Top 4 Rankings	Σ of Top 5 Rankings				
	Rank	Variable	Σ of RANKINGS Rank / #	Rank / #	Rank / #	Rank / #	Rank / #	Rank / #				
SYSTEM DESIGN		No single failure point	7	1	3	5	5	5				
		Total separation or protection	7 / 9	2	3	5	6	6 / 8				
		Complete diversity	7	2	2	4	4	6				
		Designed for most severe accident conditions	6 / 9	1	2	3	5	7				
		Simplicity	6		1	5	6	6				
		High redundancy (much greater than 1/2)	7		1	5	6 / 7	7				
		Complete testing before criticality	4				4	4				
		Minimum interfaces with other systems	2 / 13	1 / 6	1 / 7	1 / 8	1 / 10	1 / 12				
		Design review	1	1	1	1	1	1				
COMPONENT DESIGN		Adequate derating (more than adequate capacity)	1	1	1	1	1	1				
		Fail-safe	5				2	3				
		Designed for most severe accident conditions	5 / 10		2	4	5 / 7	5 / 8				
		Stringent codes and standards	2				1	2				
		Complete diversity	3		1	2	3	3				
		All components proven	6		2	3	3	4				
		No diversity	1	1	1	1	1	1				
							1	1				
MAN-MACHINE INTERFACE, HUMAN FACTOR & OTHERS		Test-once per month or more frequently	3 / 13	2 / 5	3 / 5	3 / 7	3 / 8	2 / 11				
		Test-automatic recovery from test	1				1	1				
		Short outage time limitations	5			3	4	5				
		Automatic standby	4	1	2	3	3	3				
		Auto start with remote manual backup	7 / 8	2	4 / 5	5	5	5				
		Test - automatic recovery from test	7	2	3	3	4	7				
		Full functional test after all maintenance	1 / 15	1	4	2 / 7	4 / 7	4 / 8				
		Procedure with many backup checks	4 / 11	1	2 / 6	4 / 7	2 / 9	3 / 10				
		Diverse parameter indications	7		2	2	4	4				
		Staggerered testing	1									
		High training & high skill, simulator(military type)	3	1	1	2	2	2				
		Manufactured quality - high	1									
		Knowledgable & involved supervisor with solid management backing	1									

Table B-14
Common Cause Variable Checklist and Order of Magnitude Probability Ranges
(Top Ranked Variables)

From Compilation of 30 Expert Opinion Survey

Σ of ALL RANKINGS

Low Defense Against CCF		Medium Defense Against CCF		High Defense Against CCF	
Rank / #	2E-1 Upper * 2E-2 Mid-point 5E-3 Lower	Rank / #	1E-2 Upper * 7E-4 Mid-point 2E-4 Lower	Rank / #	2E-4 Upper * 1E-5 Mid-point 1.2E-6 Lower
1 / 22	No testing after maintenance	1 / 16	Partial separation or protection	1 / 15	Full functional test after all maintenance
2 / 19	Poor separation or protection	2 / 15	Moderate interface with other systems	2 / 13	Minimum interface with other systems
3 / 18	Single active point failure	3 / 14	Visual inspection after maintenance	3 / 13	Test - once per month or more often
4 / 17	Many interface with other systems	4 / 10	Partial diversity	4 / 11	Procedure with many backup checks
5 / 14	Procedure without backup checks	5 / 9	Procedure with some backup checks	5 / 10	Designed for most severe accident conditions(comp)
6 / 13	High complexity	6 / 9	Single passive failure point	6 / 9	Desined for most severe accident conditions(sys)
7 / 13	No diversity	7 / 9	Designed for some accident conditions	7 / 9	Total separation or protection
		8 / 9	Medium redundancy (greater than 1/2)	8 / 8	Auto start with remote manual backup
		9 / 9	Medium complexity		

* 2nd order least squares fit

Table B-15
Common Cause Variable Checklist and Order of Magnitude Probability Ranges
(Top Ranked Variables)

From Compilation of 30 Expert Opinion Survey

Σ of Top 5 Rankings only

Low Defense Against CCF		Medium Defense Against CCF		High Defense Against CCF	
Rank	2E-1 Upper * 2E-2 Mid-point 5E-3 Lower	Rank	1E-2 Upper * 7E-4 Mid-point 2E-4 Lower	Rank	2E-4 Upper * 1E-5 Mid-point 1.2E-6 Lower
1 / 18	No testing after maintenance	1 / 15	Moderate interface with other systems	1 / 12	Minimum interface with other systems
2 / 17	Single active failure point	2 / 12	Visual inspection after maintenance	2 / 11	Test - once per month or more often
3 / 11	Procedure without backup checks	3 / 12	Partial separation or protection	3 / 10	Procedure with many back-up checks
4 / 11	Poor separation or protection	4 / 9	Partial diversity	4 / 8	Full functional test after all maintenance
5 / 11	Many interfaces with other systems	5 / 8	Procedure with some back-up checks	5 / 8	Designed for most severe accident conditions
6 / 9	High complexity	6 / 8	Single passive failure point	6 / 8	Total separation or protection
7 / 9	No diversity	7 / 8	Medium complexity		

* 2nd order least squares fit

B2. Development of Order of Magnitude Failure Probability Ranges

The order of magnitude failure probability ranges per demand were developed from the first 30 expert opinion returns. The overall results using three different methods are presented in Table B-16.

Table B-16
Estimates of Probability Ranges

	Probability Ranges		
	Arithmetic Mean	Median	Geometric Mean
	Low Defense Against CCF		
Upper	2.5E-1	2E-1	6.0E-2
Midpoint	2.5E-2	2E-2	
Lower	4.4E-3	5E-3	1.3E-3
	Medium Defense Against CCF		
Upper	1.4E-2	1E-2	2.1E-3
Midpoint	1.6E-3	7E-4	
Lower	7.0E-4	2E-4	2.8E-5
	High Defense Against CCF		
Upper	7.4E-4	2E-4	6.4E-5
Midpoint	6.7E-5	1E-5	
Lower	7.1E-6	2E-6	5.0E-7

The upper and lower probability ranges were taken from Tables A-5, A-6, and A-7 and graphically presented in Figs. B-1, B-2, and B-3.

B2.1 Arithmetic Mean

The first method consisted simply of determining the arithmetic mean of the upper, mid-point and lower estimates of the expert opinion survey. The extreme upper and lower values were excluded. The results are shown in Table B-16.

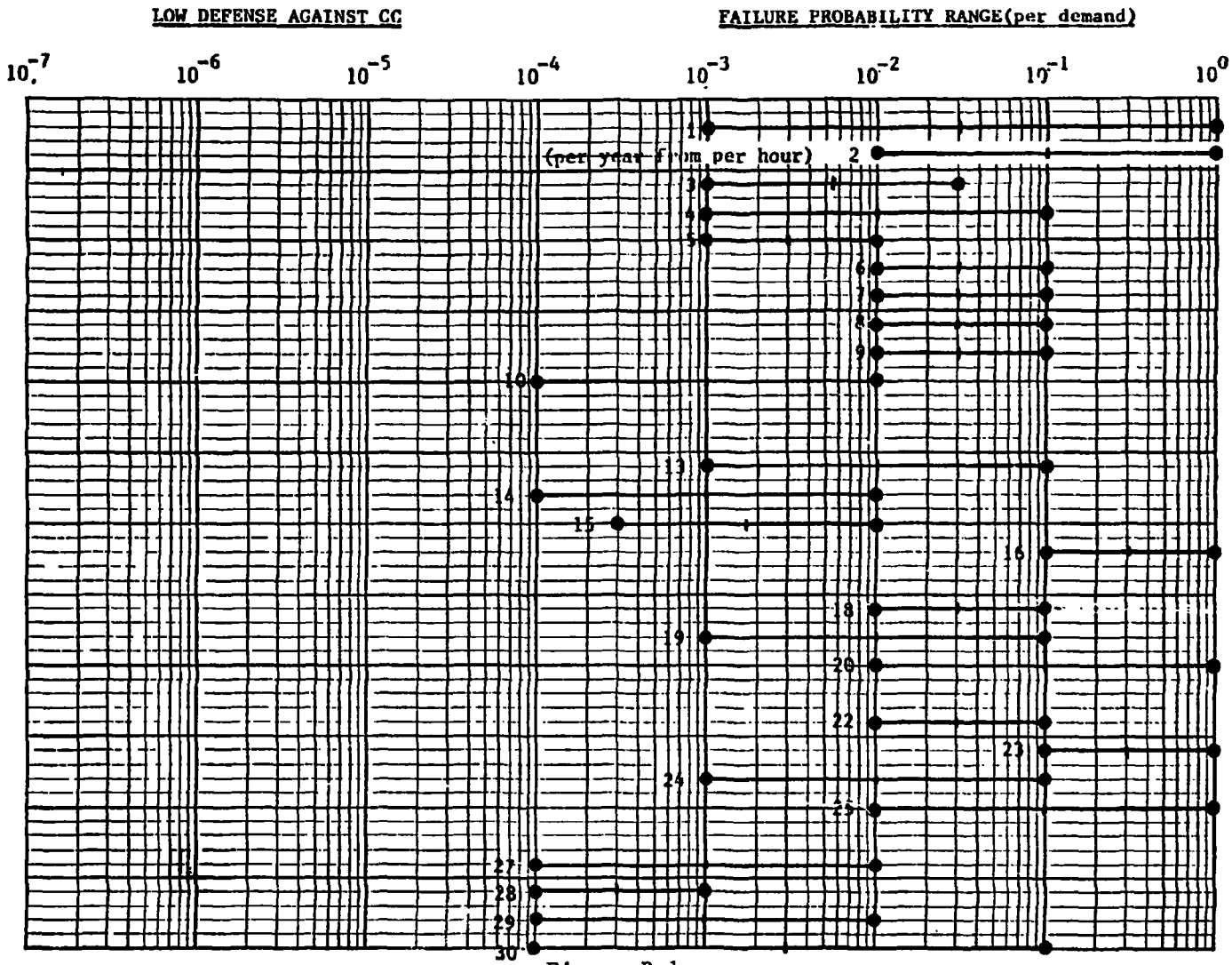

LOW DEFENSE AGAINST CC
FAILURE PROBABILITY RANGE(per demand)
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
(per year from per hour)
1
2
3
4
5
6
7
8
9
10
13
14
15
16
18
19
20
22
23
24
25
27
28
29
30

Figure B-1

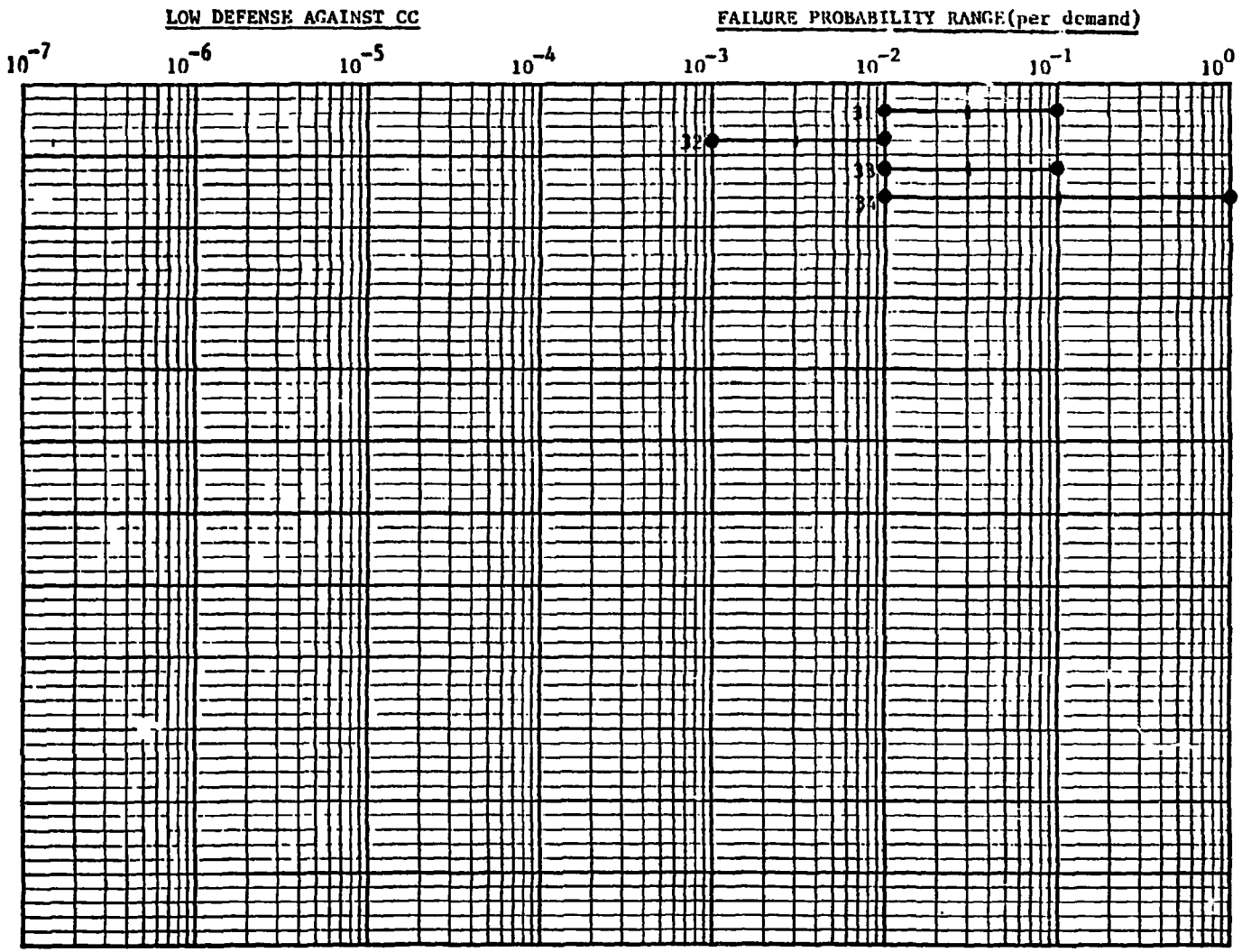


Figure B-1 (Continued)

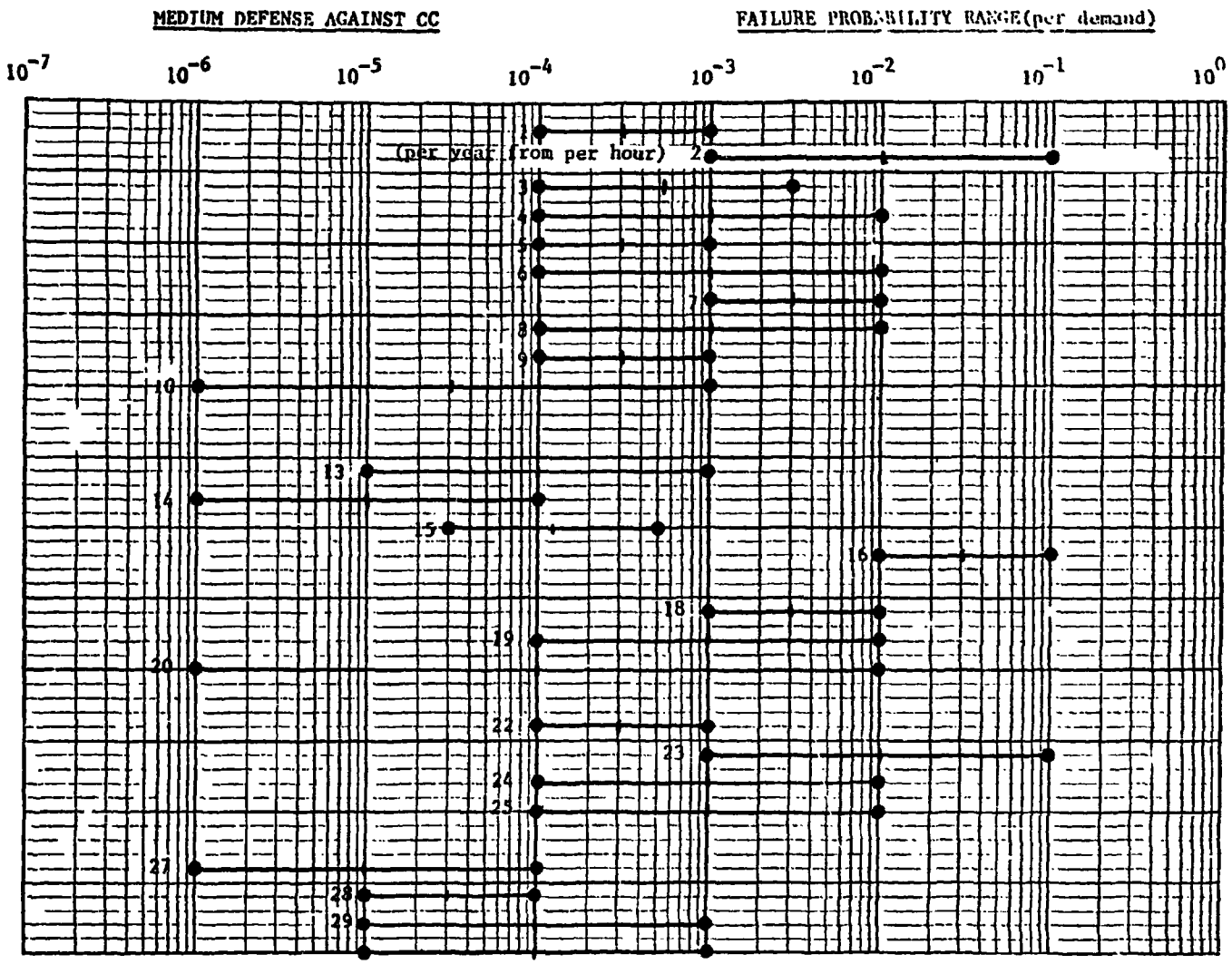

MEDIUM DEFENSE AGAINST CC
FAILURE PROBABILITY RANGE(per demand)
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
(per year from per hour)
1
2
3
4
5
6
7
8
9
10
13
14
15
16
18
19
20
22
23
24
25
27
28
29

Figure B-2

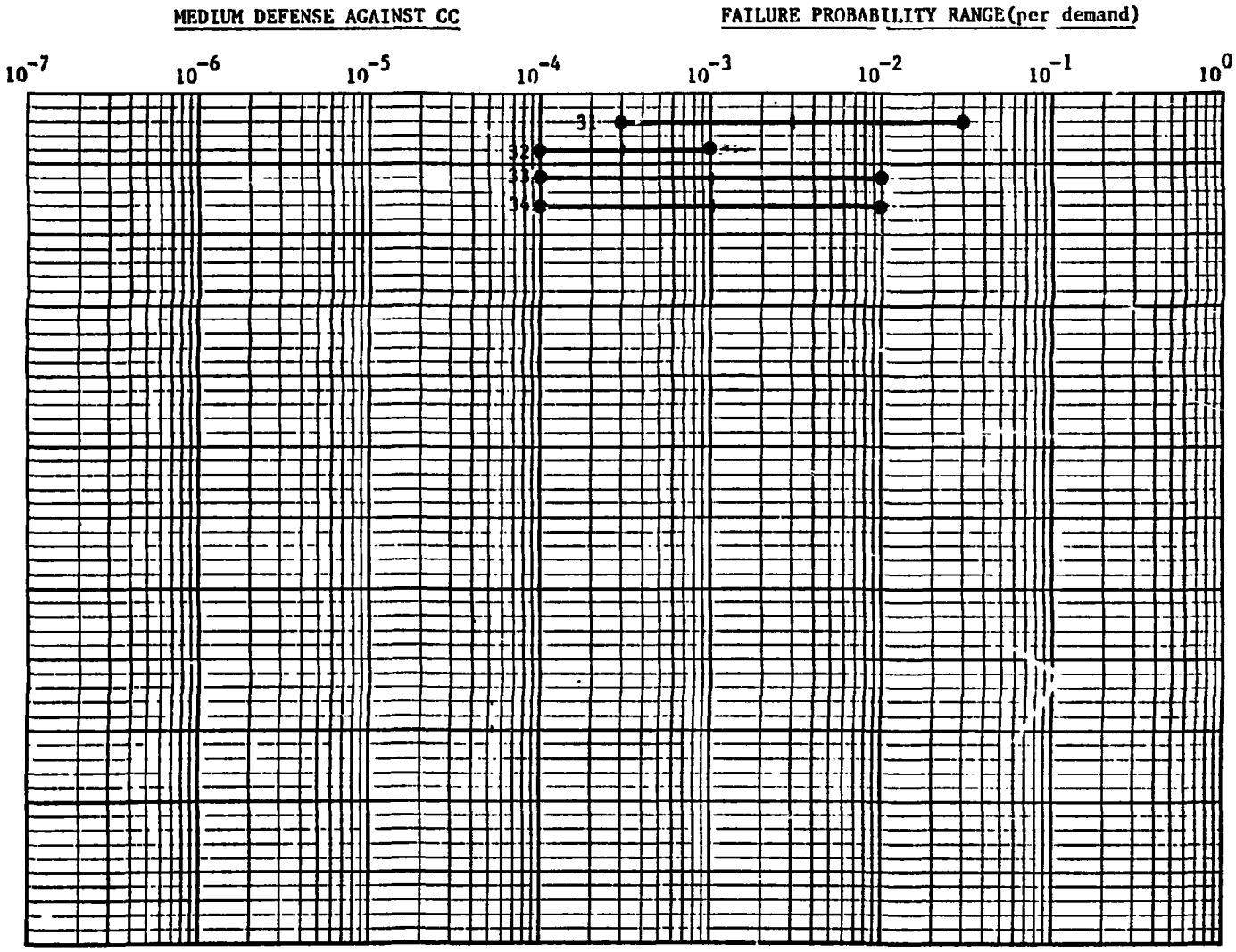
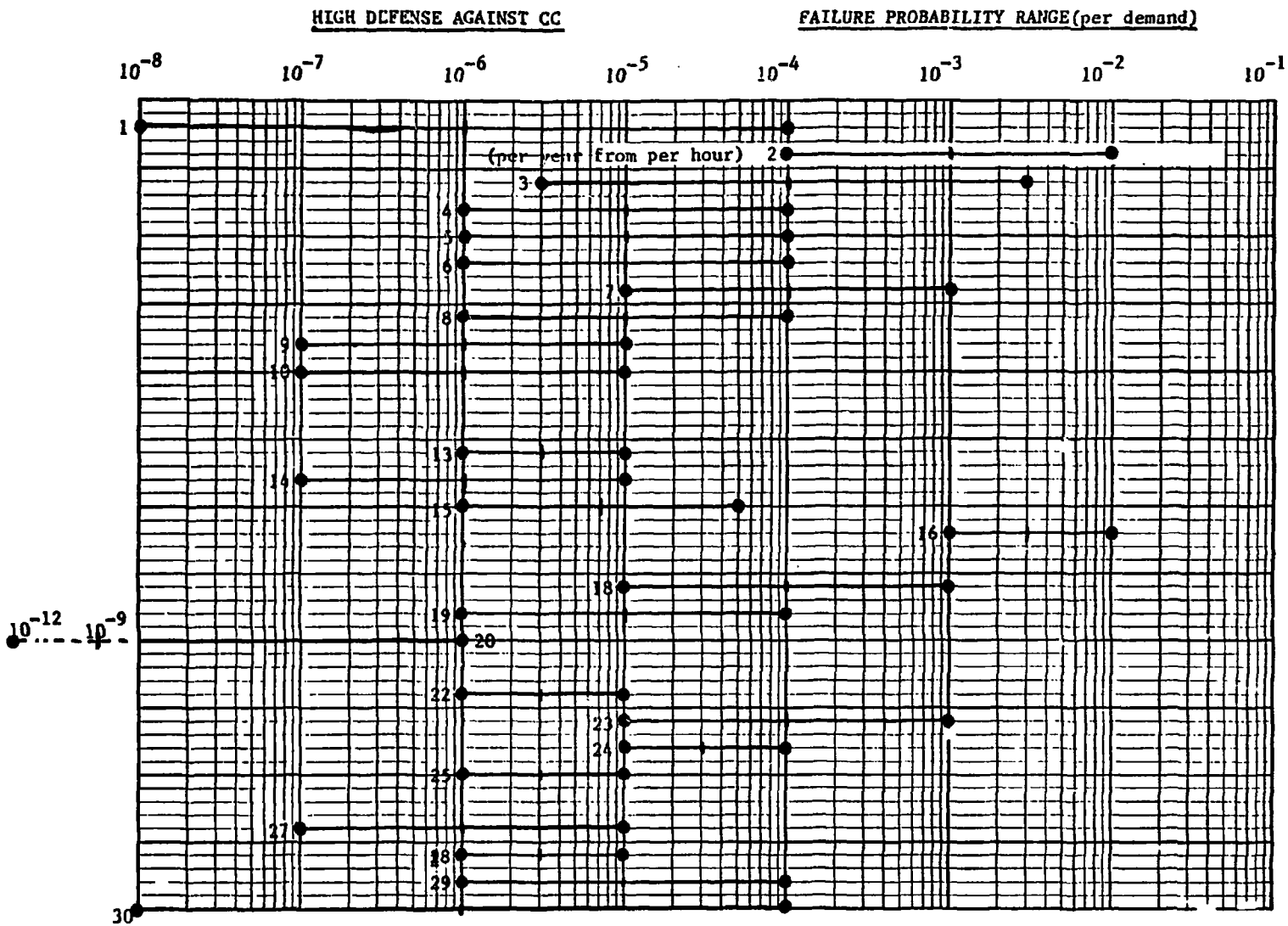


Figure B-2 (Continued)


HIGH DEFENSE AGAINST CC
FAILURE PROBABILITY RANGE(per demand)
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
(per year from per hour)
10^{-12}
10^{-9}
1
2
3
4
5
6
7
8
9
10
13
14
15
16
18
19
20
22
23
24
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27
28
29
30

Figure B-3

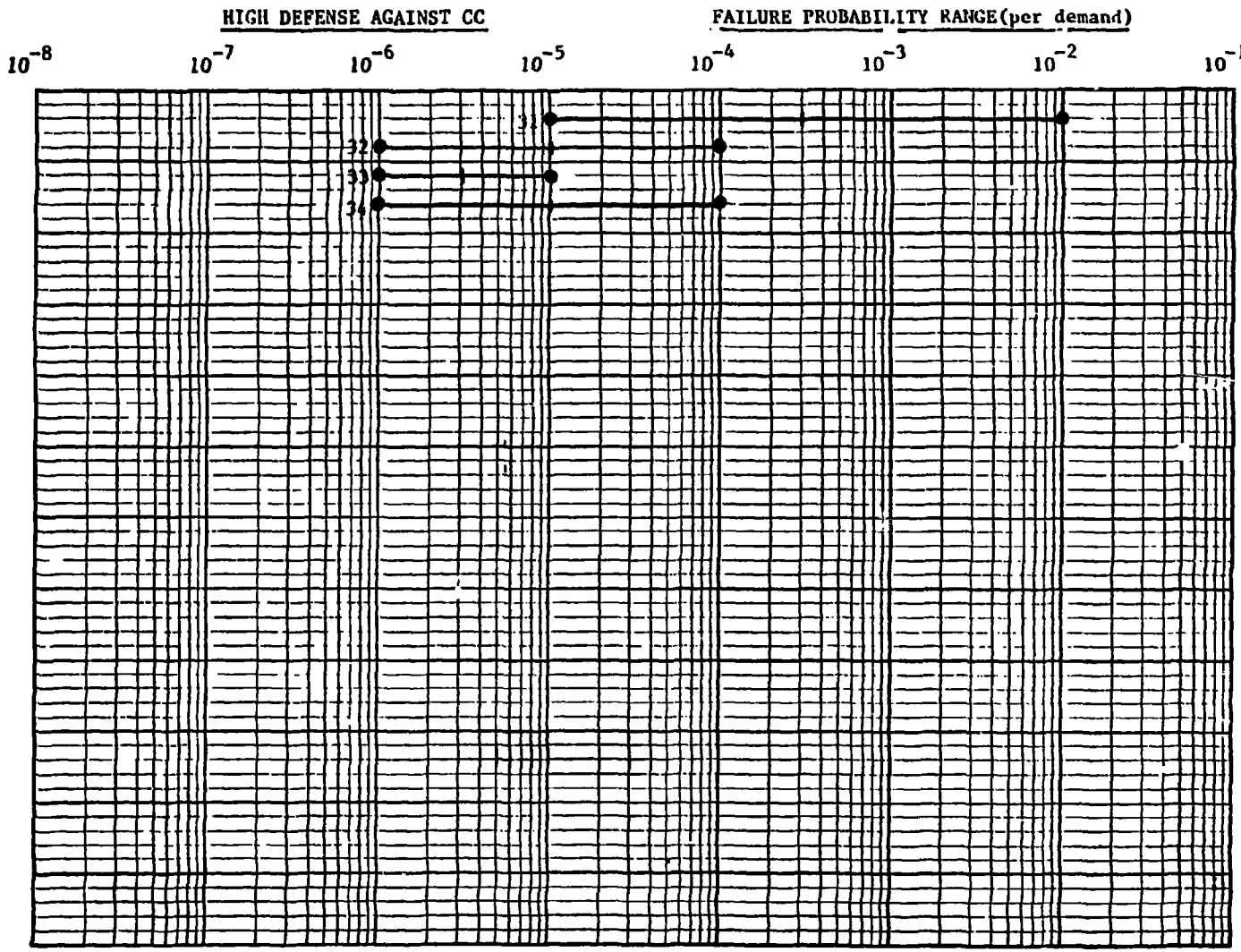

Figure B-3 (Continued)

B2.2 Median

The second method involved determining the median of the upper, midpoint, and lower estimates of the expert opinion data.

Figures B-4, B-5, and B-6 are the frequency distributions of the expert opinion probability estimates plotted against the probability values.

The frequencies were converted to percentages. The cumulative frequency percentages were plotted against the probability estimates using the computer code SUPER*PLOT which employed a "second order least squares fit." Figures B-7, B-8, and B-9 present the results. From these curves, the median estimates were determined and shown in Table B-16.

B2.3 Geometric Mean

Mr. Uppuluri of ORNL calculated the geometric mean of the data provided by the evaluators, and the results are given in Tables B-17, B-18, and B-19.

Figure B-4

LOW DEFENSE AGAINST CC

DISTRIBUTION OF PROBABILITY ESTIMATES

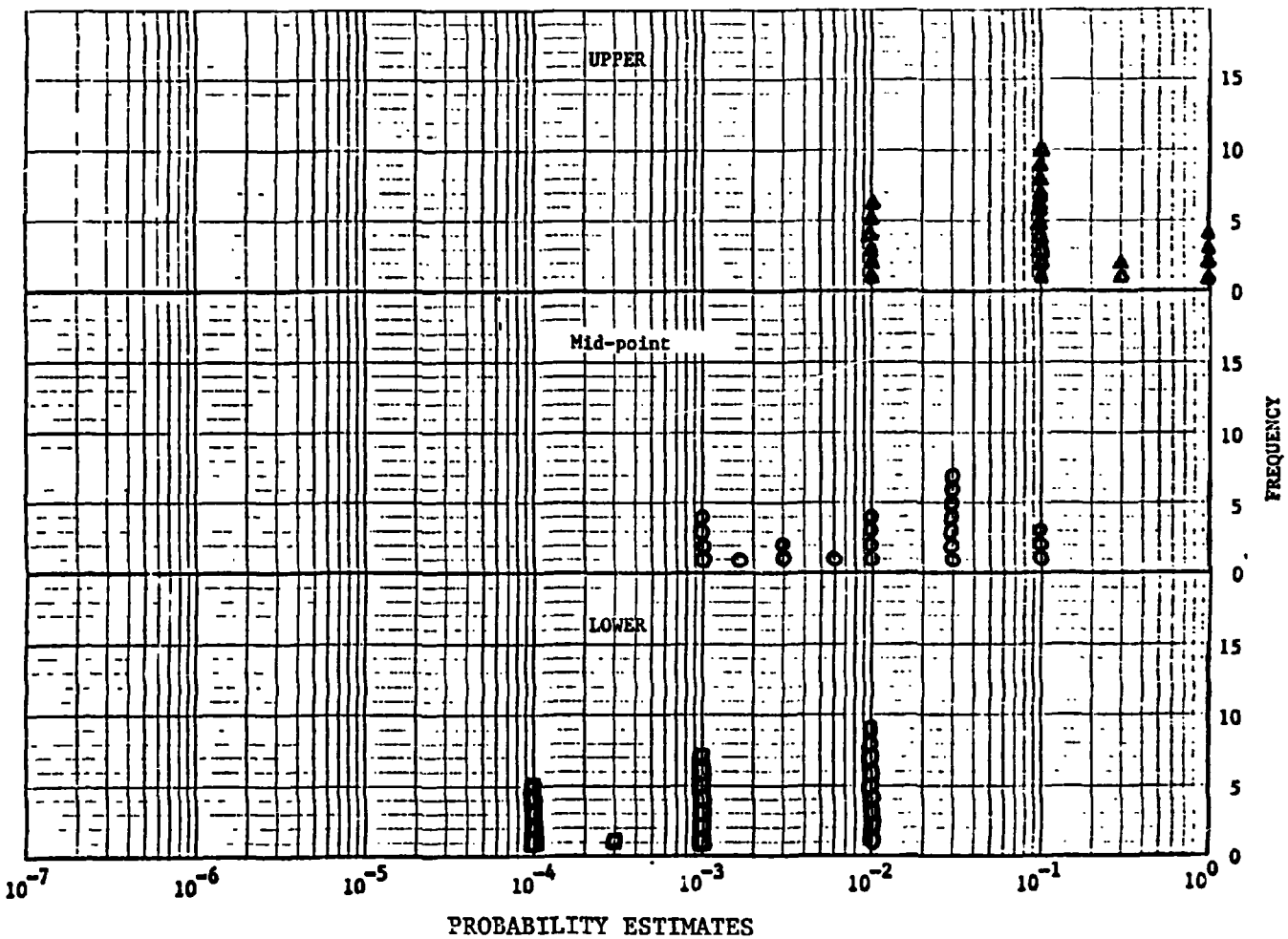

Figure B-5

MEDIUM DEFENSE AGAINST CC

DISTRIBUTION OF PROBABILITY ESTIMATES

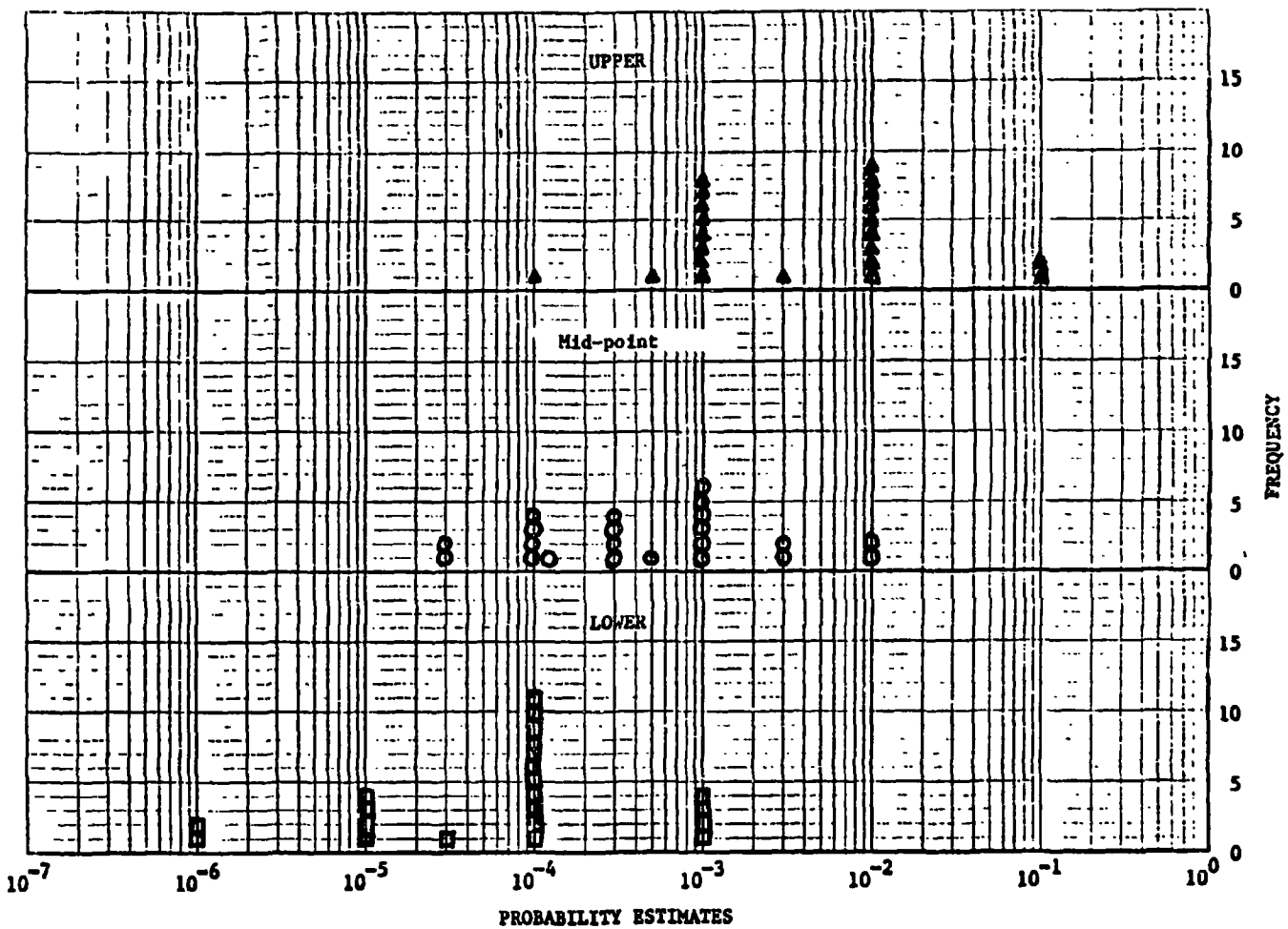

Figure B-6

HIGH DEFENSE AGAINST CC

DISTRIBUTION OF PROBABILITY ESTIMATES

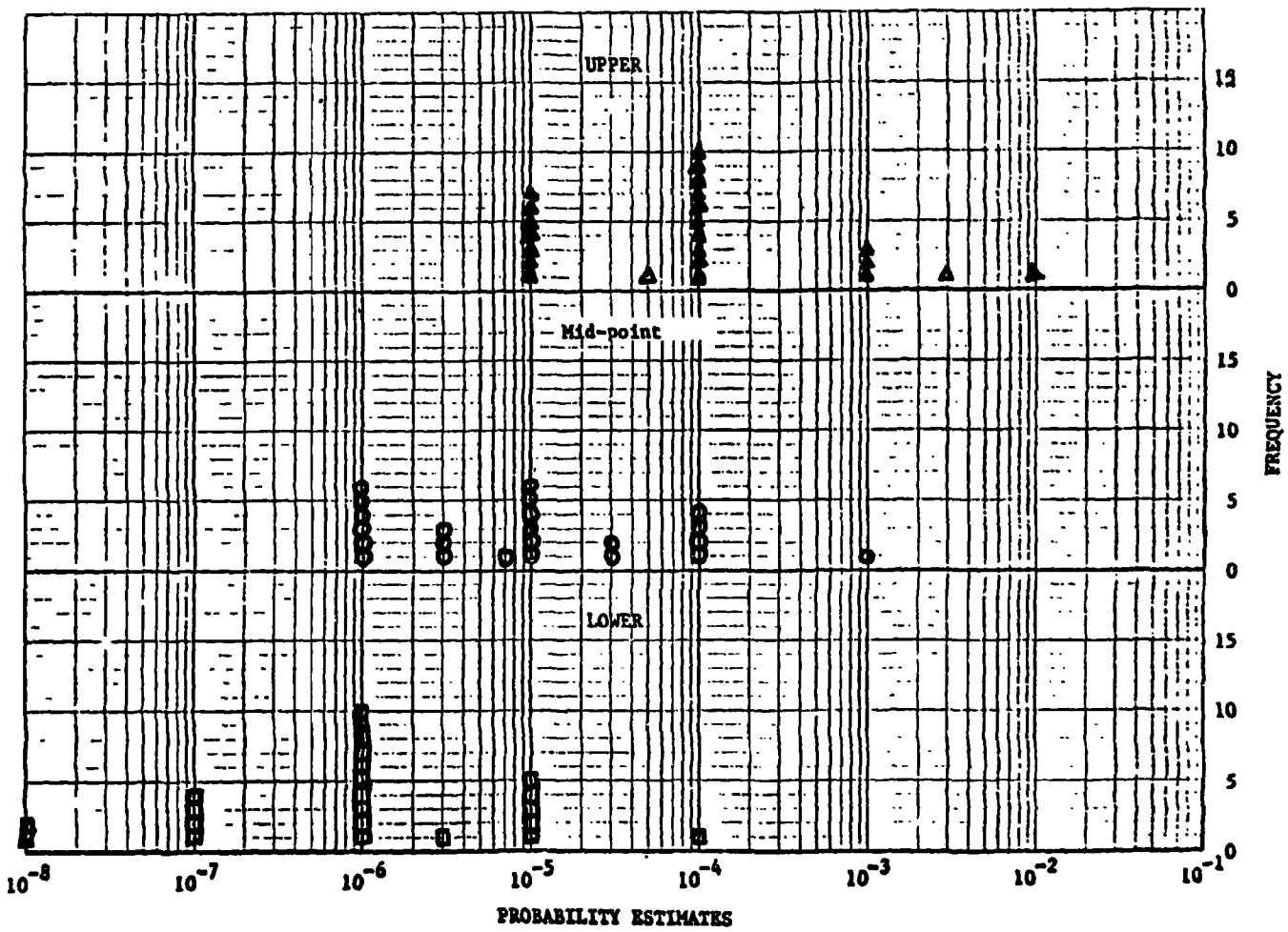

Figure B-7
Low Defense Against CCF — Cumulative
Frequency Distribution

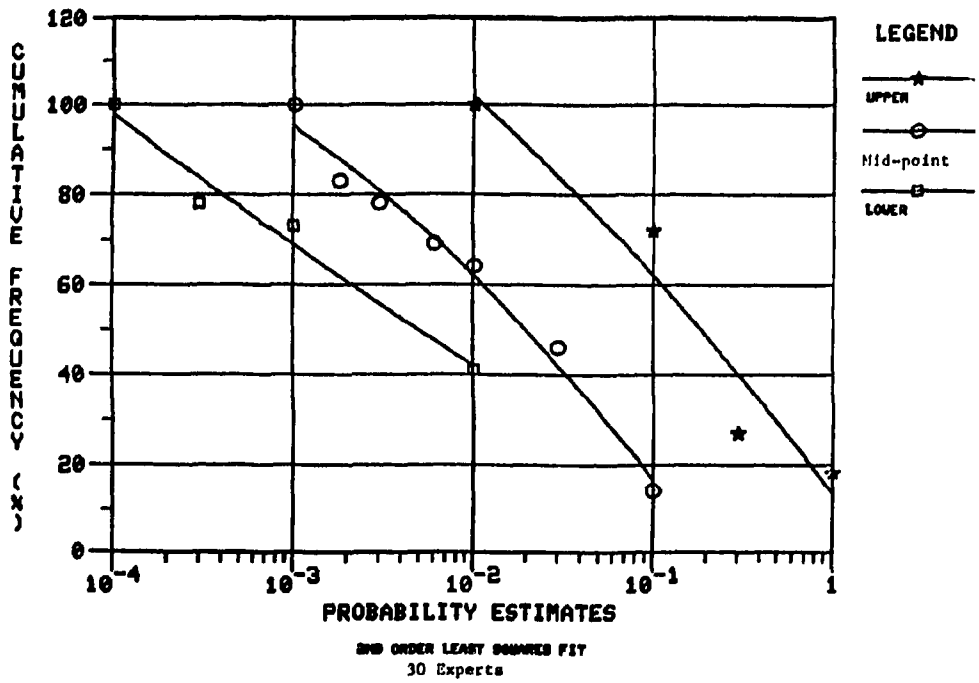

Figure B-8
Medium Defense Against CCF — Cumulative
Frequency Distribution

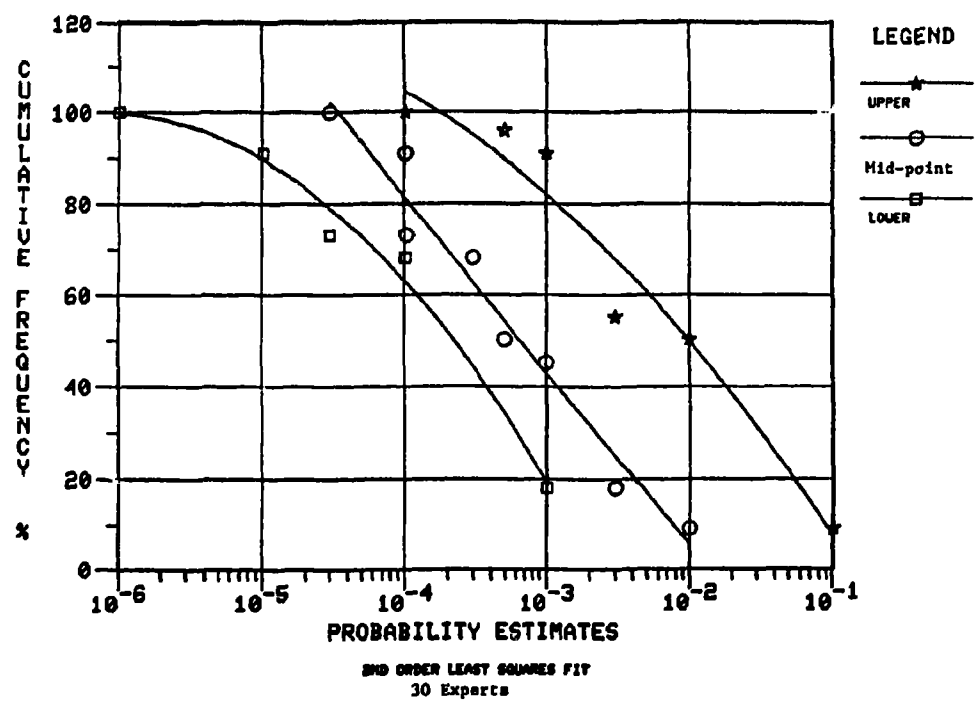

Figure B-9
High Defense Against CCF — Cumulative
Frequency Distribution

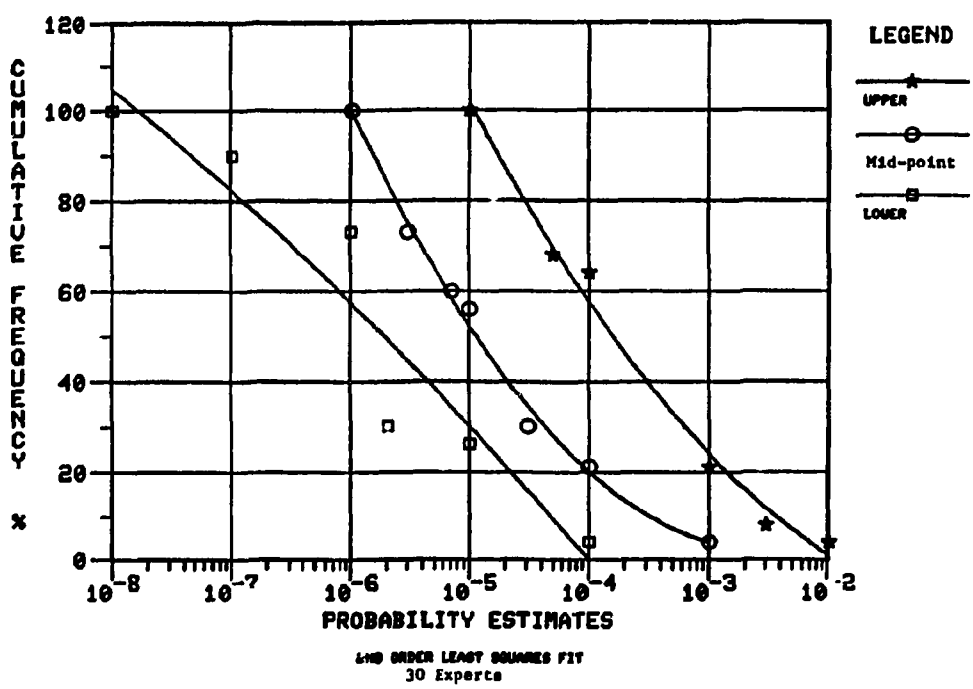

Table B-17
Low Defense Against CCF

XLV= 0.000000E+00	XUV= -3.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -5.228787E-01	XUV= -3.000000E+00
XLV= -1.000000E+00	XUV= -3.000000E+00
XLV= -2.000000E+00	XUV= -3.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -1.000000E+00	XUV= -3.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -3.522879E+00
XLV= 0.000000E+00	XUV= -1.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -1.000000E+00	XUV= -3.000000E+00
XLV= 0.000000E+00	XUV= -2.000000E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= 0.000000E+00	XUV= -1.000000E+00
XLV= -1.000000E+00	XUV= -3.000000E+00
XLV= 0.000000E+00	XUV= -2.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -3.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -1.000000E+00	XUV= -4.000000E+00

SUML= -3.052288E+01 SUMU= -7.252288E+01

LOW DEFENSE AGAINST CCF
G. M. LOWER = 6.012912E-02 G. M. UPPER = 1.256275E-03

Table B-18
Medium Defense Against CCF

XLV= -3.000000E+00	XUV= -4.000000E+00
XLV= -5.000000E+00	XUV= -7.000000E+00
XLV= -2.522379E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -3.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -3.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -3.000000E+00	XUV= -4.000000E+00
XLV= -3.000000E+00	XUV= -6.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -3.301030E+00	XUV= -4.522879E+00
XLV= -1.000000E+00	XUV= -2.000000E+00
XLV= -2.000000E+00	XUV= -3.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -6.000000E+00
XLV= -3.000000E+00	XUV= -4.000000E+00
XLV= -1.000000E+00	XUV= -3.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -2.000000E+00	XUV= -4.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -4.000000E+00	XUV= -5.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00

SUML= -6.682391E+01 SUMU= -1.105229E+02

MEDIUM DEFENSE AGAINST CCF
G. M. LOWER = 2.123453E-03 G.M. UPPER = 2.793891E-05

Table B-19
High Defense Against CCF

XLV= -4.000000E+00	XUV= -8.000000E+00
XLV= -6.000000E+00	XUV= -8.000000E+00
XLV= -2.532879E+00	XUV= -5.522879E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -5.000000E+00	XUV= -7.000000E+00
XLV= -5.000000E+00	XUV= -7.000000E+00
XLV= -5.000000E+00	XUV= -6.000000E+00
XLV= -5.000000E+00	XUV= -7.000000E+00
XLV= -4.301030E+00	XUV= -6.000000E+00
XLV= -2.000000E+00	XUV= -3.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -6.000000E+00	XUV= -1.200000E+01
XLV= -5.000000E+00	XUV= -6.000000E+00
XLV= -3.000000E+00	XUV= -5.000000E+00
XLV= -4.000000E+00	XUV= -5.000000E+00
XLV= -4.000000E+00	XUV= -5.000000E+00
XLV= -5.000000E+00	XUV= -7.000000E+00
XLV= -5.000000E+00	XUV= -6.000000E+00
XLV= -4.000000E+00	XUV= -6.000000E+00
XLV= -4.000000E+00	XUV= -8.000000E+00
SUML= -1.048239E+02	SUMU = 1.575229E+02

HIGH DEFENSE AGAINST CCF
G. M. LOWER= 6.418740E-05 G. M. UPPER = 5.001322E-07

C.1 Failure Data

Table C-1 lists six AFW pump common cause events derived from materials provided to us by JBF Associates, Inc.[19] Table C-2 describes failure events related to the auxiliary feedwater system of all PWRs from January 1972 to June 30, 1981. Note that Event 4, which occurred at Calvert Cliffs on 5/04/76, was not considered to be a common cause event in Table C-2 (see page 147), since oil change for two pumps occurred in sequence, and did not render both pumps inoperable at the same time.

C.2 Application of the CCF Checklist

In order to use the worksheet presented in Section 6.5 (Fig. 6-1), one must be familiar with the variables derived from the survey of experts (Tables 4-1 and 4-2) and those derived from experience data (Table 6-3). When critiquing a system one looks for the presence or absence of these variables. All but one of the 12 variables derived from experience data are contained in the experts' lists. Two of the twelve variables were from events which were not strictly CCF. They were included because the sample base was small. However, when substantial data is available, only those variables derived from CCF events should be used.

From the experience data checklist, if the defense against a CCF variable was incorporated in the plant's AFS, it was rated as +(good); if not, it was rated as -(poor). Two variables, test after maintenance and manual backup to the autostart circuit, were the dominant variables for defense against CCF (see Section 6.3). All automatic start circuits were manually backed, both remotely and locally. Time did not permit investigating each plant procedure after maintenance. If the available information mentioned test after maintenance, it was rated +(good); if not, it was rated -(poor).

Table C-1
AFWS Pump Common Cause Events

EVENT 1

A steam driven emergency feedwater pump failed due to outboard pump bearing failure. The failure cause was originally given as a random failure, however, see Event 2. This steam-driven pump is one of two pumps, the other being motor-driven. (See attached LER).

EVENT 2

The same pump as in Event 1 failed due to bearing failure. During the repair they realized the siteglass for oil level indication was incorrectly installed and allowed a low oil condition to go unnoticed. Applicability to the other pump was not addressed. The occurrence was in the first few months of commercial operation.

EVENT 3

Two one liners describe this event which is failure of a turbine-driven AFW pump due to vibration causing closure of the pump governor. The station review board identified this as a design error and requested a modification. The event occurred in the first few months of commercial operation.

EVENT 4

Two turbine-driven AFW pumps were declared inoperable on the same day due to water contamination of lubricating oil. Periodic oil sampling had disclosed water contamination due to oil cooler leaks. No coordinating mechanism was described for the two failures. These represent all AFW pumps for the plant. (See attached abstract)

EVENT 5

Two of three turbine-driven AFW pumps failed to start due to over-tight packing. Defective maintenance procedures were given as the cause of failure. (See attached abstract)

EVENT 6

This event includes reported failure in the same day of all three (2 motor-driven and 1 turbine-driven) AFW pumps at this station. One pump was out of service having previously sustained damage. In the morning one additional pump failed to continue to run due to becoming airbound. In the afternoon, the third pump failed to start due to airbinding. In both cases, one pump responded as required. The follow-up report indicated the damaged pump was damaged due to airbinding. A modification was accomplished to provide a high point vent in the pump suction. (See attached LER's).

Table C-2
AFWS Failure Events for PWRs

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Arkansas 1 (D)	2	6/24/77	Leak found in emergency feedwater line.	Probably corrosion; leak was discovered in the emer. feedwater line to SGA between the AFS pump and valves.	No	5	Cold shutdown	14
		Jan. 1980	SG EFW valve failed to close on demand.	Lack of hydraulic pressure caused by air in the system. The accumulator did not indicate low oil.	No	2	Hot standby	10
		Nov. 1979	EFW control valve failed.	Lack of hydraulic pressure caused by a low fluid level in the hydraulic accumulator because of leakage.	No	2	Hot standby	10
		Dec. 1979	EFW control valve failed.	Lack of hydraulic pressure caused by a low fluid level in the hydraulic accumulator because of leakage.	No	2	Hot standby	10
Arkansas 1 (D)		Sept. 1979	AFW pump turbine overspeed.	Water in the steam supply header to turbine driver.	No	1	0% power	10
		June 1979	Motor-driven EFW pump failed.	Outboard journal bearing failed due to improper installation of bearing shims causing uneven load distribution.	No	1	0% power	10
Arkansas 1		June 1979	Turbine-driven pump failed.	Inboard journal wiped due to insufficient lubrication.	No	1	0% power	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		June 1979	Steam-driven AFW pump tripped on overspeed.	Water in steam supply line.	No	1	0% power	10
		May 1979	AFW supply valve inoperable.	Tripper bar pickup was out of adjustment and oil level was low.	No	2	Hot standby	10
		May 1979	AFW flow control failed to open and would not respond to the demand signal.	Pressure switch malfunctioned.	No	2	0% power	10
		Jan. 1978	Steam driven AFW pump steam supply valve failed to open.	Valve generator torque switch defective.	No	2	99%	10
		Dec. 1978	Flow control valve failed to operate, resulting in no FW flow to SGA for AFW pump.	Loose motor power connection on valve operator.	No	2	2%	10
		Apr. 1981	EFW pump tripped after start.	Worn trip mechanism.	No	1	Shutdown	10
		6/16/79	Motor AFP failed.	Maintenance error - bearing shims installed improperly, causing uneven load distribution of bearing.	No	1	0%	10
		7/80	AFP turbine overspeed trip.	Studs broken as governor steam valve to turbine.	No	1	100	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Arkansas 2		Apr. 1980	Loss of suction to EW pumps.	Flashing in the main feedwater train forcing hot water thru startup and blowdown demineralizers for the EFW pump suctions, where it flashed to steam.	Yes	2 (2 occur)	15 min after trip from 99% due to LOOP	10
		Oct. 1978 (prior to initial critic.)	Emergency FW valve hydraulic pump motor failed.	Not determined	No	2		10
		Dec. 1980	Electric-driven AFP indicated no flow or discharge press.	Failed pump shaft caused by heat stress due to failure of radial and thrust bearings.	No	1	Hot standby	10
		Mar. 1981	EFW pump packing leakage; water in lube oil.	Shaft packing leakage.	No	1	35%	10
		May 1980	Steam EFW pump tripped 3 times due to over-speed.	Mech. adjustments to pump and turbine driver controller.	No	1 (3 occur)	45%	10
		July 1980	EFW valve failed to open from control room.	Valve actuator electric motor failed due to loose break connection.	No	2	Shutdown	10
		May - Oct. 1980	Steam EFP tripped on overspeed on 7 occasions.	Design related; exact cause undetermined.	No	1 (7x)	100%	10
		7/23/80	Steam EFP inoperable.	Loss of control power.	No	3	100%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		11/3/80	Steam EFP inoperable.	Broken terminal connection screw w/c defeated the auto ramp initiation signal.	No	13		10
Cyrstal River 3	2	3/01/77	EFW pump tripped on overspeed while starting on main steam.	Slow governor response on remote start.	No	1		11
		4/16/77	EFW pump tripped while attempting to start on main steam.	New governor slow response with main steam.	No	1		11
		6/02/77	EFW pump tripped on overspeed on initial start.	Water in steam supply line.	No	1		11
		6/16/77	Steam driven EFW pump in recirc mode was S/D.	Failure of the outboard pump bearing.	No	1		11
		7/17/77	Steam driven EFW pump overspeed trip on auto-start.	Modified train system and bypass around inlet valve.	No	1		11
		11/22,	Steam driven EFW pump tripped after running 10 min.	Inboard-outboard bearing failure. erroneous sight glass level.	No	1		11
		May 1981	Emergency feedwater pump inoperable.	Packing gland overheated due to routine wear.	No	1	Shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Davis Besse 1	2 (I)	3/16/78	Chk valves AF39 & 72 leaked internally.	Cause of reverse leakage not given.	No	2		10
	2	3/16/78	AFP stop valve failed to open.	Limit switch on vlv motion not adjusted properly.	No	2		13
		4/10/78	Shutdown AFP due to steam leak on MS-735.	Bad cover gasket and surf.	No	2		10
	2	11/8/77	Turbine pump - governor valve closed due to surging vibrations.	No force to hold governor open - mod. requested.	No	1		11
		12/11/77	AFP turbine control lost.	Mechanical binding of governor.	No	1		11
		12/28/77	AFP turbine 2 speed control lost.	Failed relays in control circuit.	No	3		11
		1/06/78	AFP turbine 1 loss of speed control.	Relay failures; speed control circuit modified.	No	3		11
		Oct. 1977	AFP turbine governor valve vibrated closed.	Excessive vibration of the governor valve linkage caused by surging of the startup FW pump motor would close the governor valve.	No	1	Hot standby	10
		July 1977	AFW steam supply check valve leaking steam around the bonnet.	Gasket failed due to loose bolts.	No	2	Shutdown	10
		Aug. 1978	Steam supply check valve leaking steam.	Scratched gasket.	No	2	70%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		10/20/77	Both aux. feed pump ducts. lined up to deaerator str. tank.	Personnel error, configuration cooling water lineup.	No	2		13
		Feb. 1979	AFW valve could not be closed by the operator but could be closed by the motor operator.	Faulty torque switch in the motor operator.	No	2	87%	10
		July 1979	AFW valve motor failed.	Electrical failure due to damage of motor lead during installation or maintenance.	No	2	Cold shutdown	10
		Oct. 1979	AFW pump turbine inboard bearing had no visible oil level in sight glass.	Sight glass loosened by vibration of pump turbine and oil drained from the loose fitting.	No	1	80%	10
		Jan. 1980	AFW pump turbine governor failed.	Failure to readjust the slip clutch mechanism to compensate for normal wear. In addition, a burr was present on the high-speed stop pin, which caused the pin to hang up prior to reaching the high-speed position.	No	1	0%	10
		10/25/77	Valve AF3872 failed to stroke when given open signal.	Open torque switch defective.	No	2		13

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Davis Besse 1		Jan. 1979	Main steam valves (2) w/c supplied steam to AFP failed to operate properly.	Dirt buildup on valve stems.	Yes	2 (2 occur)	83%	10
		Mar. 1980	AFP turbine steam valve shut.	Possible loose control relay connection.	No	2	Shutdown	10
		Aug. 1977	AFP discharge valve control lost.	Valve control power fuses blown - ground in terminal board of AFP turbine speed switch.	No	2	Hot standby	10
		Aug. 1977	AFP turbine did not start on loss of FW signal.	Disconnect switch for valve steam supply bumped out of the "remote" position.	No	3	Hot standby	10
		Aug. 1977	AFP turbine speed control lost.	Blown fuses in control power circuit.	No	3	Hot standby	10
		Aug. 1977	AFP turbine inoperable due to loss of power to main steam line to AFPT inlet header isolation valve.	Construction equip. shorted one of the wires, causing trip of BE1101.	No	3	Hot standby	10
		11/17/77	Aux. feed. valves closed.	Procedural deficiency.	No	2		13
	2	12/16/77	Aux. feed. valves shut; AS107A, AF3871 and 72 Bk D.	Personnel error. improper valve lineup.	No	2		13
Oconee 1 & 2	1	Feb. 1980	Cracks found in AFW nozzle thermal sleeves. Similar cracking observed for units 1 and 2 in 1976 and 1977.	Welding defects.	No	5		10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Oconee 3	1	4/30/75	AFW pump fails to start.	Maintenance error. A leaking packing gland had been repaired 11 days earlier and new packing was set too tight.	No	1		14
Oconee 2	1	4/1/75	AFW valve fails to open.	Valve jammed on seat.	No	2		14
Oconee 1	1	Jun. 1981	Turbine AFP inoperable because of governor valve on the turbine stuck in open position.	Contamination of system.	No	2	100%	10
Oconee 2	1	April 1981	Turbine AFP trip mechanism in tripped position.	Valve shut, loose trip plat, on reset lever.	No	2	100%	10
		Mar. 1981	Motor AFP inoperable due to arcing in the motor.	Short in the coil slot 6 in. into the starter from the outboard end of the motor.	No	1	74%	10
Rancho Seco	2 (D)	10/30/74	AFW pump fails.	Seal rings frozen to the bushings. Operator failed to open suction valve to pump.	No	1	Cold shutdown	14
		2/22/75	AFW bypass valve fails to open.	Valve stem bound by by packing.	No	2	92%	10
		5/19/75	AFW pump stops.	Relay coil lock nut came loose.	No	1		11

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Rancho Seco		2/18/77	Steam drive to AFW turbine pump tripped.	Operator failed to reset trip after test.	No	1		11
Three Mile Island-1	3 2M/1T	8/20/75	Press. switch in valve control circuit fails to keep valve open.	Design press. switch exposed through design to high ambient temperature. This degraded matls. and permitted steam leakage into electrical portion of switch.	No	2	100%	14
TMI-2	3	3/28/79	Aux. feedwater not admitted to 2 SGs following reactor trip because emergency feedwater discharge valves were shut.	Operator error.	Yes	2 (2 occur)	Trip from 100%	10
Calvert Cliffs 1	2 T/T	Nov. 1978	AFP throttle valves could not be reset after pump test.	Mechanical binding - lubrication required.	No	2	97%	10
		Apr. 1981	AFP turbine bearing overheated.	Steam seal carbon rings badly worn.	No	1	100%	10
		Mar. 1981	AFP turbine (No.12) bearing scored.	Improper oil level or contaminated oil.	No	1	100%	10
		Feb. 1981	AFP turbine (No.11) bearing failed.	Bearing journal worn out, contaminated oil.	No	1	100%	10
		Jan. 1981	Low AFWS flow to SGs.	Operator error - AFWS flow control modified but testing omitted.	No	5	Shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		12/03/75	AFW pumps supply valve found closed.	Operator error - Instructions not adequate. Same error at Rancho Seco-1 on 10/30/74.	Yes*	2		14
		5/04/76	2 AFW pumps out of service for oil change.	Slight water contamination. Turbine driven AFWS pump 11 was placed out of service for an oil change. It was returned to service and pump 12 removed from service for an oil change also.	No	1 (2 occur)	100%	14
		5/05/76	AFW pump out of service for maintenance.	Tappet nut incorrectly sized.	No	1	100%	14
Calvert Cliffs-2	2 T/T	Mar. 1977	Leak on the service water supply line of the AFW pump.	Crack in threaded portion of the line where it entered the bearing housing	No	4	Shutdown	10
		11/14/77	AFW pump low pressure bearing temp. alarm - water in casing.	Rust from turbine casing.	No	1		11
		11/16/77	AFW governor control knobs binding.	Bent pin on manual speed setting knob.	No	1		11
		Jan. 1979	AFP throttle valve would not reset.	Acme thread of the travelling nut disengaged.	No	2	Startup	10

*No AFW supply to two pumps.

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Calvert Cliffs-2		8/19/77	Aux. feed pump throttle stop valve broke	A person applied excess force with vlv. wrench.	No	2		13
Ft. Calhoun	2	9/21/78	Vlv YCV-1045 failed to open (AFP steam inlet).	Instrument air supply to val. closed.	No	2		13
	2	10/10/73	AFW pump failed to start during test.	Backpressure trip device malfunctioned.	No	1		11
		Nov. 1978	AFW check valve oriented wrong.	None given.	No	2	Refueling	10
Millstone 2	3 2M/1T	7/03/77	H_2O in "B" Aux feed thrust bearing damaged bearing.	H_2O entered along pump shaft.	No	1		11
		7/12/77	Steam driven AFW pump failed to trip on overspeed.	Hardened grease in trip/throttle valve.	No	1		11
		9/11/75	AFW pump governor fails to respond.	Worn motor clutch.	No	1		12
Millstone 2		3/09/76	AFW turbine steam valve fails to open.	Loose contact in switch.	No	2	80%	13
		11/19/76	Cond. stor. tank level decreases below limit.	Excessive blowdown rates.	No	4	88%	14
		7/24/76	AFW pump inlet steam valve fails to open.	Valve shaft sheared.	No	2		13
		June 1980	Turbine driven AFW pump tripped 670 rpm below normal trip set point.	Worn out emergency trippet nut.	No	1	100%	10
		March 1980	AFW pump leaking.	Natural end of life of the pump packing due to wear.	No	1	Shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		Jan. 1980	Turbine driven AFW pump failed due to turbine inboard, outboard and thrust bearing failures.	Excessive bearing wear most likely accelerated by lack of cooling water during previous turbine overspeed testing.	No	1	100%	10
		June 1979	Turbine driven AFW pump inoperable due to a failure of inboard pump bearing.	Contamination of bearing oil with water due to a leakoff from pump packing.	No	1	Startup	10
		May 1981	AFP turbine bearings failed.	Inadequate lubrication; oil sight glass marks changed.	No	1	100%	10
		Apr. 1981	AFP turbine packing required replacement.	Natural end-of-life.	No	1	100%	10
		Mar. 1980	AFP leaked from worn gland packing.	Natural end-of-life of packing due to wear.	No	1		10
		3/15/77	Steam trap iso. val. leaking externally.	Normal packing wear.	No	2		13
Maine Yankee	2		No reported failures.					-
Palisades	3	4/02/72	Flow fom motor driven AFW pump 50% of normal.	Hydrostatic bearing failed - no recirculation.	No	1		10
St. Lucie 1	3	Feb. 1978	AFW pump flow control valve failed to cycle.	Partially shorted winding in the valves limit torque motor operator.	No	2		10
		3/21/76	Steam driven AFW pump fails to start.	Control valve malfunction.	No	2	Hot standby	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
St. Lucie 2		12/8/76	Steam driven AFWS pump fails to start.	Moisture corroded the trip solenoid latch w/c then failed to engage and prevented pump start (valve).	No	2		11
		7/9/76	Steam driven AFW pump inlet vlv failed to open.	Moisture in control circuit (trip valve).	No	2		13
		8/11/77	Steam driven AFW pump failed to start.	?	No	1		14
		5/21/76	MO AFP steam supply valve failed to open.	No signal to valve/ command fault.	No	2		13
Beaver Valley	3 2M/1T	3/3/79	AFP turbine inoperable.	Steam supply trip valve would not close. Nut and washer found in the line.	No	2	Startup	10
		7/28/77	Aux. feedwater cont. vlv would not open electric.	Binding torque switch.	No	2		13
		8/25/76	AFW pump damaged.	Probably design deficiency of the recirc. flow orifice and recirc. line size.	No	1	25%	11
		3/10/77	Steam AFP failed to start when R/X tripped.	Undetermined	No	1	50%	11
		4/03/77	Loud noise in Turb. AFP.	Loose coupling guard rubbing on coupling.	No	1		11

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		12/15/77	Steam AFP governor failed to maintain speed constant.	Malfunctioning governor valve.	No	1		11
Cook 1	3	7/03/75	Condensate Stor. tank level less than limit.	Decision to maintain maximum blowdown caused the low level.	No	4		12
		8/27/75	AFP not tested as required.	Inadequate maintenance test procedures.	No	1	81%	12
		4/20/76	AFW regulating valve installed improperly.	Construction deficiency.	No	2	Shutdown	14
		8/06/76	AFP trips without giving control room alarm.	Defective solenoid.	No	1	100%	14
		9/06/76	AFP turbine fails to start.	Limit switch set screws fail to hold.	No	1		14
		10/13/76	AFW pump failed to start from control room.	Trip linkage sticky.	No	1		11
		Nov. 1978	Wire broke on aux. switch in valve operator.	Undetermined	No	2	90%	10
		June 1978	Motor driven AFP failed to achieve required min. disch. pressure.	Impeller ring separated.	No	1	Startup	10
		7/06/77	AF valve failed with crack in body.	Water hammer and vibrations.	No	2		13
		11/28/78	No flow from MDAFP to SG No. 3.	Aux. feed throttle valve would not close electrically.	No	2	90%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Cook 1		Feb. 1981	Motor AFP check valve leaked.	Dirt found in valve caused valve to stick.	No	2	100%	10
		Aug. 1976	AFP turbine found tripped and alarm failed to annunciate in the control room.	Trip limit switch found loose.	No	1	100%	10
		2/08/76	AFMOV failed to close.	Command/Loose elec. connect.	No	2		13
Cook 2	3 2M/1T	Oct. 1978	A manual isolation valve in the flow test circuit of turbine drive AFW unlocked and open; the pneumatic flow test valve also defective.	Undetermined	No	2 (2 occur)	90%	13
		Jan. 1979	AFW motor operated valve would not close.	Broken wire in operator.	No	2	2%	10
		3/18/78	AFS chk vlv from SG sticks open.	Unknown	No	2		13
		Jan. 1980	1. AFW pump failed and throttle valve unlatched.	1. Burned up reset coil on the trip and throttle linkage.	No	1		10
			2. Later the same day, unit failed to start in a low SG level signal during reactor trip.	2. Linkage not engaging properly due to wear of 2 mating surfaces.	No	1	Reactor trip	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		Mar. 1980	Aux. feed valve for No. 2 SG did not operate.	Armature lead from the limitorque valve operator motor had pulled out of its wire lug.	No	2	100%	10
		May 1980	With turbine AFP in the non-running auto standby position an alarm was received that pump had tripped.	Turbine control linkage had disconnected from the throttle valve as if an overspeed had taken place.	No	1	100%	10
		Jan. 1981	Motor drive AFP malfunctions.	Overpressurized AFW pump suction strainer resulting i[illegible] crack in the str[illegible] casing.	No	1	72%	10
		Jan. 1979	Aux FW MOV would not close.	Broken wire found in the operator.	No	2	2%	10
		Oct. 1978	Man. isolation valve in the flow test circuit of the turbine AFP was found unlocked and open.	Operator error.	No	2	90%	10
		July 1981	AFP check valves leaked.	Valve did not seal completely.	No	2	90%	10
		Mar. 1979	AFP turbine bearing overheated.	Not determined.	No	1	100%	10
Conn. Yankee (Haddam Neck)	2 T/T	Ju 1981	Turbine AFP recirc. valve numbers reversed in procedure.	Procedural error.	No	2		10
		Jan. 1979	AFP output deficient.	Storage tank steam supply valve failed open, overheating the water supply to AFP.	No	2	100%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Conn. Yankee (Haddam Neck)		5/18/76	RV on steam supply to AFP lifted early.	Unknown	No	2		13
		8/01/77	Chk valve on AFP leaking externally.	Unknown	No	2		13
		7/05/76	2 AFP would not develop proper disch. pres.	Both pumps vapor bound - faulty chk. valve unknown.	Yes	1 (2)	Startup	14
Indian Pt-2	3 2M/1T	5/22/74	Malfunction of AFP.	Dirty switch contacts.	No	1	92%	14
		5/26/75	Condensate Stor. tank level below min. specification.	Design error. Out of specif. Water is normal supply of makeup.	No	4		14
		12/15/77	AFP fails.	Sparking motor.	No	1		11
Indian Pt-3	3 2M/1T	4/12/77	Attempt to put AFP on line unsuccessful.	Shaft sheared.	No	1		11
		Aug. 1978	Aux. boiler FW pump unable to reach full discharge pres.	Bearing failures.	No	1	91%	10
Farley 1	3 2M/1T	Jan. 1979	AFP (turbine) failed to start when the trip/throttle valve tripped shut.	AFP(T) mini-flow valve spring tension insufficient to hold valve full open.	No	2	Shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		Mar. 1981	AFP turbine speed could not be increased above minimum speed.	Design error. Design change provided for modifying pump's local control panel wiring. Instructions erroneously moved contact closure for start ramp generator from the normally closed steam admission valve to normally open stop throttle valve.	No	2	0%	10
		11/13/77	Steam supply valve HV3226 leaking externally.	Lower seat gasket blown.	No	2		13
		9/09/78	Control was lost on flow cont. valves 3228 A, B & C.*	Defective relay in TPAFP control circuit.	Yes*	2* (3 occur)		13
		12/03/77	AFP turbine started but failed to reach max. speed.	Signal converter fails.	No	1		11
		3/25/78	MDAFP & TDAFP recirc. bypass iso. valves open.	Personnel error.	Yes	2 (2 occur)		11
Kawaunee 1	3 2M/1T	10/2/74	AFW pump fails to start automatically.	Relay failure.	No	1		14
		10/15/75	2 AFW pumps fail to start.	Defective W-2 control switches.	Yes	1 (2 occur)		11

*Affect DAFP only.

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Kawaunee 1		11/05/75	AFW pump flows restricted.	Demineralizer resin plugged fine mech. strainer between condensate tank and pumps.	Yes	6 (3 occur)		11
		12/04/75	AFW pump fails to start.	Breaker accidentally opened during operation.	No	1		11
		1/24/75	AFW pump fails to start.	Spare breaker out of adjustment.	No	1		14
		2/07/75	AFW pump fails to start.	Spare breaker was slightly different from normal breaker.	No	1		14
		4/29/75	Coil in AFWS pump control circuit fails.	Coil voltage rating incorrect.	No	3		14
		8/01/74	2 AFPs did not start until third attempt.	Did not allow oil pressure to build up.	Yes	1 (2 occur)		11
		1/04/75	AFP failed to start after R/X trip.	Under investigation.	No	1		11
		2/07/75	AFP failed to start in lo-lo SG level.	Breaker guide bar "position" notch too small.	No	1		11
		3/12/76	AFP failed to start.	Faulty lube oil pressure switch.	No	1		11
		9/27/76	AFP failed to start.	Sticking actuating relay.	No	1		11
		9/06/74	AFW pumps fail on manual start.	Improper starting technique.	Yes	1 (2 occur)		14

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
North Anna 1	3 2M/1T	Jan. 1980	Steam driven AFP relief valve malfunctions.	Sealing surface of valve cut and damaged due to excessive valve chattering.	No	1		10
		Sept 1979	Lube oil pressure for motor AFP lower than usual.	Lube oil strainer partially clogged.	No	6	92%	10
		Sept 1979	AFP steam trip valves leaked.	Gaskets deteriorated.	Yes	2 (2 occur)		10
		Mar. 1978	Restricting orifices in 3 AFW pump recir. lines were found to be made of wrong material.	Undetermined.	Yes	1 (3 occur)		10
North Anna 1		10/13/80	AFP inoperable.	Relief valve failed to reseat.	No	1		10
		10/15/80	Turbine trip valve tripped on steam driver AFP while testing.		No	1		10
		July 1980	AFP (motor) output deficient.	Design deficiency. Root cause undetermined.	No	1	100%	10
North Anna 2	3 2M/1T	Feb. 1981	AFP turbine overspeed trips (2).	Improper alignment of the turbine over-speed trip device to trip valve leakage due to worn parts.	No	1 (2 occur)	100%	10
		5/14/78	AF valves PCV-F2-159A, -159B improper lineup.	Checkoff does not list norm. valve position.	No	2		13
		10/04/78	Improper valve lineup, AFP to A,B,C SG.	Oper. personnel error.	No	2		13

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Prairie Island-1	3 2M/1T	12/12/74	AFP inoperable.	Suction strainer plugged.	No	6	100%	11
	3 2M/1T	6/18/77	AFP disch. valve fails.	Open lead in operator/ limit torque.	No	2		13
IM Share of Unit 2		8/21/75	AFP removed from auto control while opposite train out of service.	Defective procedures.	No	1		14
		5/1/77	Turbine AFP tripped twice on overspeed.	Low governor oil level.	No	1 (2 occur)		11
		8/13/74	AFP failed to start.	Open breaker.	No	1	100%	14
		3/27/75	AFP malfunction.	Dirty governor control valve linkage.	No	1	81%	14
		Dec. 1979	Motor for inlet steam supply valve to AFP turbine tripped on overload.	Motor end bell screws loosened and fell into motor causing binding.	No	2	100%	10
Prairie Island-2	3 2M/1T	11/10/77	AFP turbine tripped on overspeed.	Loose linkage on governor to press. compensator.	No	1		11
		5/19/77	AFP inlet valve found nearly shut.	Position requirement will go on checklist.	No	2		13
	3	9/13/75	AFP fails to start.	Defective pressure switch to lube oil pump.	No	1	63%	14
		Apr. 1980	Trip throttle valve for turbine AFP accidentally tripped.	Valve reset operator complex and not well understood by many operators.	No	2	100%	10
		12/23/77	TDAFP steam supply valve fail to open.	Motor lead grounded to junction box.	No	2		13

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Point Beach 1 & 2	3 2M/1T	4/07/74	Pump suction strainers.	In-line comical strainer plugged.	Yes	6 (2 occur)		11
		4/18/75	8 gals. low level rad. water leaked via steam-driven aux. feed.	Shaft glands leaked; shut discharge valve.	No	5		11
		1/08/76	AFWS pump valve fails to close.	Valve operator ring worn.	No	2		14
Point Beach-2		7/01/76	AFWS pump valve fails to open.	Torque switch set point drift.	No	2		14
R. Ginna	3 2M/1T	12/14/73	2 AFPs lost suction.	Air in suction header.	Yes	1 (2 occur)		11
		1/08/75	Turbine AFP failed to start.	Low lube oil press. regulator setting.	No	1		11
		5/9/74	Malfunction of AFW pump discharge valves.	Undetermined.	Yes	2 (2 occur)		14
		12/09/74	AFP flow low.	Procedural error.	Yes	2 (2 occur)		14
Robinson 2	3 2M/1T	7/09/73	AFP tripped on initiation of manual start.	-	No	1		11
		11/19/74	AFP turbine tripped on overspeed during test.	Governor out of adjustment.	No	1	100%	11
		7/16/74	2 of 3 steam supply valves for turbine AFP malfunctioned.	Mechanical binding.	Yes (No loss of train.)	2 (2 occur)	99.2%	14
		8/31/74	AFP discharge valve fails to open.	Burr on seal ring.	No	2	Hot shutdown	14

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Robinson 2		10/15/74	AFW valve fails to open.	Torque switch malfunction.	No	2		14
		11/13/74	AFP discharge valve fails to open.	Torque switch failure.	No	2		14
		11/15/74	Motor-driven valve operator separated from valve.	Improper bolt material.	No	2		14
		7/15/75	AFP discharge valve fails to open.	Torque switch malfunction.	No	2		11
		11/02/75	AFP fails to start.	Tarnished switch contacts.	No	1		11
		8/17/76	AFP valve fails to open.	Valve binding to seat.	No	2	100%	14
		12/22/77	AFP turbine tripped during test.	Steam leakage back thru valve.	No	1		11
		4/11/78	AFP turbine failed to start.	Worn circuit breaker trip arm.	No	1		11
		4/13/78	AFP failed to start.	Inst. trip coils setting found to be low.	No	1		11
		6/11/81	AFP tripped on low disch. pressure.	Improperly positioned discharge valve.	No	2	Startup	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		6/16/81	AFP tripped.	Cavitation caused by steam as a result of backleakage through no disch. valve and check valve (also real cause of 6/11/81 event).	No	2 (2 occur) 2 valves failed	93%	10
		12/21/77	AFP disch. valve failed to open.	Excess seating pres. caused by overheat.	No	2		13
		12/22/77	Remotely op. valves leaking internally.	Insufficient valve stem lubrication.	No	2		13
		Mar. 1977	AFP discharge valve failed to open.	Motor operator torque not sufficient to open the valve.	No	2	Shutdown	10
		Aug. 1977	AFP discharge valve had slight packing leak.	Packing gland loose.	No	2	Shutdown	10
		July 1979	AFP motor tripped.	Excessive start - stop cycling of the pump.	No	1	Startup	10
		Aug. 1977	FW entered TDAFP discharge line.	Check valve did not close. Burr on hinge prevented proper operation.	No	2	100%	10
		Aug. 1977	AFP discharge valve failed to open.	Valve operator trip fingers worn and broken.	No	2	80%	10
Sequoyah	3 2M/1T	May 1981	Turbine AFP failed to deliver full flow.	Speed control set pt. for pump turbine had drifted.		1	Hot shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Sequoyah		Mar. 1981	AFP motor bearing failed.	Deterioration of inboard bearing insulation.		1	0%	10
		Mar. 1981	AFP check valve failed	Normal valve wear.	No	2	Cold shutdown	10
Salem 1	3 2M/1T	1/8/77	AFP failed to start.	Personnel error - turb. manually tripped.	No	1		11
		Jun 1978	AFW storage tank level low.	Supply valve operator malfunctioned.	No	4	Hot standby	10
		6/15/78	AF makeup valve failed to operate.	Unknown.		2		13
		8/24/78	AFP steam valve failed to open.	Stem disengaged from actuator.	No	2		13
Salem 2		May 1981	AFP bearing went into high-temp. alarm.	Outboard bearing and seal assembly had failed.	No	1	9%	10
San Onofre 1	2 M/T	8/8/78	Hydraulic valve opened accidently during circuit maintenance.	Signal to valve/ command fault.	No	2		13
	2	Dec. 1979	AFP inboard bearing failed.	Lack of lubrication.	No	1	100%	10
Surry 1	3 2M/1T	5/2/74	AFP discharge valve fails to open.	Contact malfunction.	No	2	100%	10
		3/15/74	Failure of FW valve and a train of auxiliaries.	Circuit design error. A shaft in the relay failed to move and actuate a micro switch.	No	2	Hot shutdown	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		11/30/75	AFP discharge valve fails to open.	Switch out of adjustment. Redundant valve operated satisfactorily.	No	2		14
		12/11/75	AFP discharge valve fails to open.	Timing relay failure.	No	2		14
		Aug. 1973	Steam supply valve of turbine-driven pump failed to open.	Torque switch in the motor operator circuitry was open.	No	2		10
		May 1974	"A" train AFW valve failed to open.	Faulty operation of time delay relay.	No	2		10
		May 1974	"B" train FW auxiliary failed to operate.	Error made during a recent modification of circuitry.	No	2		10
		3/18/76	AFP valve fails to open.	Timing relay malfunction.	No	2	Shutdown	14
Trojan	2 D/T	12/19/75	AFP diesel fails to start.	Design error. Slow oil pressure buildup during a cold start.	No	1		11
		1/04/76	Diesel-driven AFP trips on overspeed.	Loose signal lead to governor.	No	1	Startup	14
		1/09/76	Diesel AFP fails to start.	Change in engine conditions.	No	1	Hot standby	14
		1/23/76	Diesel AFP fails to start.	Design error. Slow buildup of oil pressure on cold start.	No	1	31%	14

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Trojan		3/28/76	Diesel AFP trips on overspeed.	Improper design. Overspeed governor set point variable resulting in insufficient margin between engine peak speed during start and the overspeed of set point.	No	1		14
		5/12/76	Steam-driven AFP fails to start.	Trip mechanism not reset.	No	1	Startup	14
		10/05/76	Steam-driven AFP trips on overspeed.	Governor speed sensor card failure.	No	1	60%	14
		10/19/76	Steam-driven AFP fails to start.	Trip/Throttle valve reset improperly.	No	1	Shutdown	14
		9/2/76	Diesel AFP tripped on high jacket water temp.	Loose spring in temp. switch.	No	1	8%	14
		9/9/76	Diesel AFP tripped on high jacket water temp.	Maintenance error. Cause of 9/2/76 event diagnosed incorrectly. Had correct diagnosis been made, this event would not have occurred on 9/9/76.	No	1		14
		9/3/76	Diesel AFP failed to autostart.	Blown fuse in autostart circuit.	No	3	10%	14
		11/16/76	AFPs failed to autostart.	Lifted leads mislogged.	Yes	1 (2 occur)	24%	14
		Apr. 1979	Diesel AFP fuel line fitting cracked.	Due to vibration.	No		60%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		4/29/76	Condensate storage tank level low.	Incorrect valve lineup. Operator error.	No	4	1%	14
		3/24/77	Diesel AFP tripped on L.O. pressure.	Broken crankshaft on diesel.	No	1		11
		12/17/77	DDAFP failed to start. TDAFP started and ran out.	Microswitch out of adjustment.	No	1		11
		12/17/77	Turbine AFP could not be reset after running and stopped. DDAFP available.	Limit switch failure.	No	1		11
		Aug. 1980	Diesel AFP would not start - manual.	Bad cell in starting battery.	No	1	100%	10
		Feb. 1980	Cooling water hose found broken in diesel AFP.	Deterioration of rubber.	No	1	90%	10
		Jan. to Oct. 76	1. Overspeeding of turbine AFP.	1. Oil drainage from the governor actuator and supply lines during long shutdown periods.	No	1	Startup	10
			2. Overspeeding of both pumps.	2. Low equipment temperatures after long standby periods.	Yes	1 (2 occur)	Startup	10
		11/27/77	AF check valve failed to operate.	Motor oper. failed/ water came through gasket.	No	2		13
		10/3/80	Both D&T pumps fail to autostart; assume manual start.	Wiring error. Leads to stave relay connected to wrong terminals.	No	3 (2 occur)	98%	10

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Turkey Point 3	3 3T	5/08/74	Malfunction of 2 AFW pumps.	Mechanically bound due to tight packing.	Yes	1 (2 occur)		11
		5/08/74	AFP failed to start.	Sticking governor linkage.	No	1		11
		Nov. 1979	AFP failed to start.	Steam pressure control valve failed due to misalignment between the manifold plugs of valve and its mounting base assembly.	No	1		10
		Oct. 1979	AFP failed to start.	Press. control valve inoperable due to water introduced into the instrument air system when temp. connected to unit 1&2 air system.	No	1	100%	10
		Oct. 1979	AFP found to have seized shaft.	Pump overheated. Cause undetermined.	No	1	100%	10
Turkey Point 4		6/18/73	Auto start of AFPs did not occur on scram.	Fuses for auto start logic circuit not installed.	Yes	1 (2 occur)	Low power testing	11
Turkey Point 3		Dec. 1978	AFP overheated.	Steam leakage to AFP turbine.	No	1	100%	10
Zion 1	3 2M/1T	4/30/74	Failure of AFP to run.	Air in suction line.	No	1	6%	11
		5/14/74	AFW pump overspeed trip.	Overspeed trip valve tripped closed, blocking steam flow to turbine even though the steam inlet valve was opened.	No	1		11

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
		6/6/74	AFP inoperable.	Overspeed trip valve tripped.	No	1	75%	11
		7/11/74	AFP fails to start.	Breaker off.	No	1	Hot standby	11
		9/19/74	AFP fails.	Undetermined.	No	1	85%	11
		3/05/76	AFP fails to start.	Turbine water bound.	No	1	Shutdown	11
		8/08/76	AFP 1A tripped from overspeed.	Sticking governor valve.	No	1	Reactor trip	11
		8/08/76	AFP 1C failed to develop full discharge pressure.	Strainer plugged.	No	6	Reactor trip	11
		12/03/77	AFP would not start.	Steam flow control valve solenoid stuck in energized position.	No	2		11
		12/08/77	AFP would not start.	Steam flow control valve solenoid stuck in energized position.	No	2		11
Zion 2		2/11/74	AFP failed to start.	Apparently damaged from air binding.	No	1		11
		3/12/74	AFP failed to start.	Oil pressure start interlock switch would not close.	No	1		11
		2/15/74	2 AFP trip.	Air in suction line.	Yes	1 (2 occur)		11
		2/17/74	2 related abnormal occurrences on DG:					
			1. DG tripped on overspeed.	1. Syncro-speed setter set at 13.5 instead of 12.	No	5		15

Table C-2 (Continued)

Plant	Loops	Date	Failure	Cause	CCF	Component Category	Plant Condition	Reference
Zion 2			2. Output breaker would not close on bus.	2. A loose screw lodged in the pivot.	No	5		15
		2/26/74	AFP failed.	Trip valve failed due to slag particles from the steam line wedging between the valve plug and body.	No	1		11
		2/26/74	AFP failed.	Valve sticking due to differential heating of valve components.	No	2		11
		12/07/77	AFP failed to start.	No apparent cause for failure.	No	1		11
		2/16/74	Failure of service water supply valve to AFP.	· .ction valve failed to open fully due to low torque setting.	No	2	Hot shutdown	14
		8/31/75	AFW stop valve fails to open.	Relay contacts fail to close.	No	2		12

From the expert opinion checklists, variables incorporated in the AFS were assessed as having low, medium, or high defense against CCF.

Engineering judgement was used to estimate the rating given to the system based on the expert opinion checklist assessment "weighted" by experience data.

For the analysis of the auxiliary feedwater system (AFS), the following approach was taken:

1. Overall
   a. How many pump trains?
   b. How many steam generators (SGs)?
   c. What are the piping and valving arrangements?

2. Detail - Water Source to SG to steam supply valves for turbine drive auxiliary feed pump (TDAFP)
   a. Water Source
      (1) Condensate Storage Tank (CST)
      (2) Backup Water Supply
         (a) Local manual switch in (Lo defense)
         (b) Remote manual switch in (Med defense)
         (c) Automatic switch in (Hi defense)
      (3) Valving to AFPs
         (a) Single passive failure (Med defense)
         (b) Redundant valves (Hi defense)
   b. Pumps
      (1) Redundancy
         (a) Minimum (1/2) (Lo defense)
         (b) >Minimum (1/3) (Med defense)
      (2) Diversity - partial
         (a) No (Lo defense)
         (b) Yes (Med defense)
      (3) 1 AFP must be independent of AC power
         (most severe accident - total loss of all AC power)

c. Valving

(1) NO or NC (Normally Open or Normally Closed)

(2) AC or DC (Alternating Current or Direct Current)

(3) AOV or MOV (Air Operated Valve or Motor Operated Valve)

(4) FO/FC/FAI (Fail Open/Fail Close/Fail As Is)

To illustrate the use of the worksheet, the analysis of Davis Besse AFS as shown in Table C-3 is explained in more detail below:

1. Two single passive failures (CST to AFP valves in series) were noted. This variable would be placed in the "med" defense, but the automatic transfer of the back-up water supply was assumed to practically negate this effect.
   Experience data = none (blank).

2. The backup water supply to service water system (SWS) is an auto-transfer system on low suction. Automatic action = high defense against CCF.
   Data = none.

3. Two pump system or minimum redundancy = low defense.
   Data = -(poor).

4. Identical pumps or no diversity = low defense.
   Data = -(poor).

5. AFS is automatically started with manual backup = high defense.
   Data = +(good).

6. Normally closed motor operated valves (NC MOV) powered by 1E Inst. Bus (most severe accident) = high defense.
   Data = none.

7. Testing (recirc) every 3 months = med defense.
   Data = -(poor).

   In general recirculation, or recirculation to CST, testing is inadequate and prone to problems, especially if valve alignments are required. In this case, no valve alignment is required. The adequate testing is a full flow test from CST into the SGs, which several plants do during power operation.

8. Minimum interface with other systems = high defense.
   Data = +(good).

On simplified drawings, as well as the P&IDs, it may not be easy to see the subtle interfaces that may exist in these systems. Arkansas 2 had a CCF problem on 4/7/80 when flashing in the main FW train forced hot water startup and blowdown dimineralizer to the EFP suctions, where it flashed to steam and caused loss of suction. The P&ID from the docket file FSAR for this area was reviewed (poor copies), but interfaces could not be found.

9. Simplicity = high defense.
   Data = +(good).
   Minimum system configuration with safety requirements to perform its function.

10. Turbine driven auxiliary feedwater pumps (TDAFPs) are independent of all AC power = high defense (most severe accident).
    Data = none.
    NC MOV powered by 1E Inst. Bus, but Inst. Bus backed by DC batteries.

11. No mention of testing after maintenance = (need more plant information).
    Data = -(poor) Most dominant variable.

12. Recirc. Testing - med. defense.
    Data = -(poor).
    Same as 7 above.

Other variables that are not shown or reported on readily available drawings and reports must be reviewed, such as:

Separation
Design adequacy
Procedures
Testing after maintenance
Procedure or testing before rise-to-power or criticality
Operator training
Supervision and management

The Davis Besse AFS was rated as having a medium defense against CCF, with a failure probability of 5E-4.

Davis Besse is one of the plants that had a CCF during a test. Both steam admission valves failed to open because of dirt buildup on the valve stems caused by recent construction activities. The plant was at 83% but no plant outage was indicated according to the Greybook on the date of occurrence. Causes and defenses against this CCF were determined to be:

Causes for CCF	Defenses Against CCF
No diversity	Diversity
3-month test intervals	More frequent testing
No separation	Separation

In a similar manner, 33 PWR plants were rated and presented in Tables C-4 through C-36.

Table C-3

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Davis Besse NSS: B&W SOURCE: NUREG-0560

FSAR 50346-49 Chp. 10

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	SYSTEM VARIABLE
LO	MED	HI		
	-*			2 single passive failure - valves in series CST to AFPs
		X		*Auto transfer of water supply to SWS on low suction
X			-	Minimum redundancy (1/2)
X			-	No diversity (2 TDAFPs)
		X	+	Auto start w/manual backup on both pumps
		X		NC MOV powered by 1E Inst. Bus (most severe accident)
	X		-	Testing - every 3 months, recirc., no valve alignment
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X		TDAFPs independent from AC power except 1E Inst. Bus (most severe accident)
			-	No mention of testing after maintenance
	X		-	Recirc. testing (inadequate testing)
	5E-4			RATING

Evaluator: L. Lisiewski

Date: 11/30/81

Table C-4

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Arkansas 1 NSS: B&W SOURCE: NUREG-0560

FSAR 50313-28 chp 10

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
			N	No details CST to EFPs and no Tech Specs
X			-	Minimum redundancy
	X		+	Partial diversity (MDEFP & TDEFP)
	X			Remote manual backup water supply
X				MDEFP not on 1E bus, takes 15 min to put on 1E (normal operation)
	X		+,-	TDEFP - auto start with manual backup. MDEFP - manual start
X				TDEFP dependent on AC ducts to MOV to SG, local manual (most severe accident)
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of testing after maint.
	X		-	Recirc testing (inadequate testing)
	X		-	Testing frequency - assumed 3 months internal like other B&W plants
	1E-3			RATING

Evaluator: L. Lanigucki

Date: 11/30/81

Table C-5

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Crystal River 3 **NSS:** B&W **SOURCE:** NUREG 0560

FSAR 50302-21 Chp. 10

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 2E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		Docket 50302-21 Chapter 10 does not show EFWPs.
	X			Single passive failure - valve from CST to EFWPs
X			-	Minimum redundancy (1/2)
	X		+	Partial diversity (MDEFWP & TDEFWP)
X				Local manual backup water supply from hot well w/vacuum breeder
		X	+	Auto start of manual backup on both pumps
		X		Valves (NO) to SG's (simplicity)
		X		MDEFWP on 1E bus (some accident)
			N	TDEFWP independent of AC power (most severe accident)
X			-	Pump testing needs manual closing for recirc. and reopening (Inadequate testing + complexity)
	X		-	Testing frequency-? assume 3 months frequency like other B&W plants
		X	+	Minimum interface with other system
		X	+	Simplicity
			-	No mention of testing after maintenance.
	5E-4			RATING

Evaluator: L. Sciaqueli

Date: 11/30/81

Table C-6

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Davis Besse **NSS:** B&W **SOURCE:** NUREG-0560

FSAR 50346-49 Chp. 10

Defense Against CCF				
From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	-*			2 single passive failure-valves in series CST to AFPs
		X		*Auto transfer of water supply to SWS on low suction
X			-	Minimum redundancy (1/2)
X			-	No diversity (2 TDAFPs)
		X	+	Auto start w/manual backup on both pumps
		X		NC MOV powered by 1E Inst. Bus. (Most severe accident)
	X		-	Testing-every 3 months, no valve alignment required, recirc. (inadequate testing)
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X		TDAFPs independent from AC power except IE Inst. Bus. (most severe accident)
			-	No mention of testing after maintenance
	5E-4			RATING

Evaluator: L. Lanigucki

Date: 12/1/81

Table C-7

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Oconee 1, 2 & 3 NSS: B&W SOURCE: NUREG-0560

FSAR 50269-8
270-8
287-5

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE (Single Train AFS - not applicable for CCF analysis)
2E-1 2E-2 5E-3	1L-2 7E-4 2E-4	2L-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		
X				Many single active failures - 1 TDAFP
		X	+	Auto start with manual backup on loss of both FWP and all RCPs
X				Local manual transfer of other AFS to and from any other units
		X	+	NO suction and discharge valves (simplicity)
X			-	Testing require manual opening full flow recirc. valves and manual closing discharge valves (complexity)
		X		Steam supply valve AO/FO (simplicity)
			N	TDAFP independent of all AC power (most severe accident)
	X		-	Recirc. testing (inadequate testing)
4E-2				RATING

Evaluator: L. Lenguichi
Date: 12/1/82

Table C-8

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Rancho Seco **NSS:** B&W **SOURCE:** NUREG 0E60

FSAR 50312-30 Chp. 10

Defense Against CCF: From Check List (2E-1, 2E-2, 5E-3) LO	From Check List (1E-2, 7E-4, 2E-4) MED	From Check List (2E-4, 1E-5, 1E-6) HI	From Data (+ good, - poor, N No info.)	SYSTEM VARIABLE
		X		No single failure - CST to AFPs
			N	No details on backup water supply from demineralize system
X				Minimum redundancy (1/2)
	X		+	Partial diversity (MDAFP & TDAFP)
		X	+	Auto start with manual backup
	X		-	Testing on 3 month interval
	X		-	Testing by recirc. need to local manually open valve for full flow and reclose. (complexity)
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of testing after maintenance.
	X		-	Recirc. testing (inadequate testing)
	5E-4			RATING

Evaluator: S. Doiguchi

Date: 12/2/81

Table C-9

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: TMI-1 **NSS:** B&W **SOURCE:** FSAR 50289-23 Chp. 10

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		
		X		No single failure
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X	+	Auto start w/manual backup
		X	+	Minimum interface with other systems
		X	+	Simplicity
	X		-	Test frequency - assume 3 month interval and recirc.
			-	No mention of testing after maintenance
			N	TDAFP independent of AC power with discharge valve (most severe accident)
	X		-	Recirc. testing (inadequate testing)
	2E-4			RATING

Evaluator: L. Lanegucci

Date: 12/2/82

Table C-10

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: TMI-2 **NSS:** B&W **SOURCE:** 50320-195 Amend. 36, 50320-3 Chp. 10

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
		X		No single failure
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2 MDAFPs & 1 TDAFP)
		X	+	Minimum interface with other systems
	X		-	Strainer in suction line - Fig. 10.1-2 (complexity)
	X		-	Testing frequency-? Assume 3 months, recirc. & discharge valve needs closing (complexity)
			-	No mention of testing after maintenance.
			N	TDAFP independent of AC power including MOV discharge valves (most severe accident)
	X		-	Recirc. testing (inadequate)
	7E-4			RATING

Evaluator: L. Lewiecki

Date: 12/2/81

Table C-11

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Arkansas 2 **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		
	X			Single passive failure - valve from CST to EFPs
	X			Backup water supply can be remote manually switched in.
X			-	Minimum redundancy (1/2)
	X		+	Partial diversity (MDEFP & TDEFP)
		X		TDEFP and train independent of AC power (most severe accident)
		X	+	Auto start with manual backup
		X		MDEFP on 1E bus (some accidents)
		X	+	Test on monthly basis
		X	+	Minimum outage time on EFPs
			-	No mention of test after maintenance.
			-	No mention of full flow test into SG (full functional test)
	5E-4			RATING

Evaluator: L. Lenzicki

Date: 12/3/81

Table C-12

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Calvert Cliffs 1 & 2 **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	SYSTEM VARIABLE
LO	MED	HI		
	X			2 single passive failures - valves from CST to AFPs
X				Local manual lineup of valves for backup water
X				Minimum redundancy (1/2)
X				No diversity (2 TDAFPs)
X				Semi-dedicated operator remote manual start
X				Local manual start on LOAC-steam admission valves are 1 EAC power operated (most severe accident)
		X	+	Testing on a monthly basis
	X		-	Test by recirc. (inadequate testing)
		X	+	Testing after maintenance
		X	+	Minimum outage for pumps
X			-	No separation
1E-2				RATING

Evaluator: L. Lempicki

Date: 12/3/81

Table C-13

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Fort Calhoun **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
	X			Single passive failure-valve EFWST to AFPs
		X		EFWST automatically maintains level by CST, DML, CS
X			-	Minimum redundancy (1/2)
	X		+	Partial redundancy (MDAFP & TDAFP)
		X		TDAFP and train independent of AC power (most severe accident)
X				MDAFP not on 1E power, must be manually connected to D/G bus (normal operation)
		X	+	Auto start with manual backup: TDAFP in LMFW, LOSP & LOAC; MDAFP in LMFW
		X	+	Time limit on pump outage
		X	+	Testing on monthly basis plus AFS used for SU and SD operation
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of test after maintenance
	X			Recirc. testing (inadequate testing)
	1E-3			RATING

Evaluator: L. Lanigan

Date: 12/3/81

Table C-14

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Maine Yankee **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			Single passive failure - valve from DMLST to AFPs
X				Backup water supply - local manual actuation
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial redundancy (2MDAFPs and 1TDAFP)
X			-	Remote manual start of AFS
		X		AO/FO flow control discharge valve power from vital inst. bus. (most severe accident)
		X		TDAFP independent of AC power except AO/FC Cont. Iso valve, manual override unknown- (exceeds most severe accident)
		X	+	Minimum interface with other systems
		X	+	Testing on monthly basis plus used for SU and SD operation
	X		+	No minimum outage time on pump
			-	No mention of testing after maintenance.
	X		-	Recirc. testing (inadequate testing)
	5E-3			RATING

Evaluator: L. Lenczuch

Date: 12/3/81

Table C-15

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Millstone 2 **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
		X		No single failure
X				Local manual operation for backup water supply
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		EDAFPs and all MOVs on 1E AC (some accident)
X				TDAFP steam supply valve on 1E AC bus. Local manual control for LOAC (most severe accident)
X			-	Remote manual start for AFS
		X	+	Testing on monthly basis and used for SU and SD operation
		X	+	Minimum outage time on one train
		X	+	Simplicity
			-	No mention of testing after maintenance
	X		-	Recirc. testing (inadequate testing)
	3E-3			RATING

Evaluator: L. Lenzinski

Date: 12/3/81

Table C-16

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Palisades NSS: CE SOURCE: NUREG-0635

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			Single passive failure - valve from CST to AFPs
	X			Backup water supply can be remote manually transferred
X			-	Minimum redundancy (1/2)
	X		+	Partial redundancy (MDAFP and TDAFP)
X			-	No separation - both pumps in same room
		X		AO/FO discharge valve powered from vital inst. bus. (most severe accident)
		X		AO/FO steam supply valve from 1E DC bus/air accumulator/local manual control (most severe accident)
X			-	Remote manual start of AFS
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X	+	Minimum outage on AFP
			-	No mention of testing after maintenance
			N	Testing frequency not given
	X		-	Recirc. testing (inadequate)
1E-2				RATING

Evaluator: L. Lanzisch

Date: 12/4/81

Table C-17

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: St. Lucie 1 **NSS:** CE **SOURCE:** NUREG-0635

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3 (LO)	1E-2 7E-4 2E-4 (MED)	2E-4 1E-5 1E-6 (HI)	+ good - poor N No info	
		X		No single failure
X				Local manual for all backup water (about 3 hrs. to transfer) must go thru CST and lines from CST to AFPs
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		MDAFPs powered from 1E buses (some accidents)
		X		NC/FAI MOV are all IEAC powered - OK for LMFW and LOOP (some accidents)
X				LOAC-steam admission and pump discharge valves must be local manually opened (most severe accident)
X			-	Remote manual start of AFS
		X	+	Monthly testing of pumps and valves
	X		-	Recirc. testing (inadequate testing)
		X	+	Minimum interface with other systems
		X	+	Minimum outage time for one pump
		X	-	Simplicity
			-	No mention of testing after maintenance
	5E-3			RATING

Evaluator: L. Lenquist

Date: 12/4/81

Table C-18

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Beaver Valley 1 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
		X		No single failure
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X	+	Auto start with manual backup
		X	+	Monthly tests - staggered
	X		-	Recirc. tests - valve alignment (inadequate testing)
		X	+	Test after maintenance per tech specs
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X	+	Tech specs to current standards
		1E-4		RATING

Evaluator: L. Languich

Date: 12/4/81

Table C-19

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: DC Cook 1&2 NSS: W SOURCE: NUREG-0611

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
		X		No single failure
X			-	Complexity - suction strainer
	X		-	Complexity - MDAFPs supply 2 SG's in each unit, or to 4 SG's.
	X		+	Greater than min. redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X	+	Test every 31 days - recirc.
		X	+	Test valve automatically close on auto start of AFS - recirc.
		X	+	Auto start with manual backup
			-	No mention of testing after maintenance
X				TDAFP steam admission valves are 1E AC powered, thus requires local manual opening for LOAC, changing to DC and also changing turbine cooling to DC power (most severe accident)
		X	+	Tech specs to current standards
	X		-	Recirc. testing (inadequate testing)
	2E-4			RATING

Evaluator: L. Lenquist

Date: 12/4/81

Table C-20

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Farley 1 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF				
From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
		X		No single failure
	X			Remote manual switch in on backup water
	X		+	Greater than minimum redundancy
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		TDAFP independent of AC power and MDAFPs powered by 1E AC D/S (most severe accident and some accident)
		X	+	Auto start with manual backup
		X	+	Pumps tested monthly
	X		-	Recirc. tests - valving (inadequate testing)
		X	+	Time limit on one pump outage
			-	No mention of testing after maintenance
		X	+	Minimum interface with other systems
		X	+	Simplicity
		1E-4		RATING

Evaluator: L. Lanigan

Date: 12/4/81

Table C-21

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Ginna **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List (2E-1, 2E-2, 5F-3) LO	From Check List (1L-2, 7E-4, 2E-4) MED	From Check List (2L-4, 1E-5, 1E-6) HI	From Data (+ good, - poor, N No info.)	SYSTEM VARIABLE
		X		No single failure
		X	+	Greater than min. redundancy (2MDAFPs and 1TDAFP) plus (2SB-MDAFPs)
	X			Partial diversity - 3MDAFPs and 1TDAFP
		X	+	Auto start w/manual backup on main AFS plus manual start on SB AFS
X				TDAFP has AC dependency, cooling water and steam supply valves (most severe accident)
		X	+	MDAFP's powered from the 2 1E buses (some accidents)
	X		-	Complexity in backup water to main AFS: with OSP available, CST makeup pump or
				condenser hot well pump can be remote manually activated; with LOSP, remote
				manual suction valve to the TDAFP can be opened or local manual valve operation
				required; and for LOAC, adequate water available for 2 hrs. Can always remote
				manually transfer to SB AFS for LMFW and LOSP initiating events
		X	+	Tech specs approved by NRC after 8/24/79
			-	No mention of testing after maintenance
			N	No details on type of pump testing, recirc. or full flow into SG's
	5E-4			RATING

Evaluator: L. Lanigan

Date: 12/7/81

Table C-22

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Haddam Neck **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
	X			Single passive failure - valve from DMLST to AFPs
X				Backup water supply - local manual operation thru DML ST
X			-	Minimum redundancy (1/2)
X			-	No diversity (2TDAFPs)
X			-	Manual start of AFS
Before X		Now X		TDAFPs needed SWS to cool lube oil coolers, being modified to be AC independent
				(most severe accident)
		X	+	Pumps tested on monthly basis
		X	+	Tests after maintenance
Before X		Now X	- +	Tech specs being changed and proposed
		X	+	Minimum interface with other systems
		X	+	Simplicity
			N	Pump testing - recirc. or full flow into SG's
5E-3				RATING

Evaluator: L. Lanzarotta

Date: 12/7/81

Table C-23

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: H. B. Robinson **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		
	X			Single passive failure - valve from CST to AFPs
X				Backup water supply - local manual controlled
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial redundancy (2MDAFPs and 1TDAFP)
		X	+	Auto start with manual backup
X				TDAFP is AC dependent, SWS for lub oil cooling and pump discharge/steam supply valves (most Severe accident)
		X	+	Pumps and MOV tested monthly - recirc. (discharge MOV are NC)
		X	+	Minimum interface with other systems
		X	+	Simplicity
X			-	No time limit for one pump outage
			-	No mention of testing after maintenance
	X		-	Recirc. testing (inadequate testing)
	5E-4			RATING

Evaluator: L. Lanpuch

Date: 12/7/81

Table C-24

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Indian Point 2 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			2 single passive failures - 2 valves in series CST to AFPs
	X			Backup water supply is remote manually controlled
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		TDAFP independent of AC power (most severe accident)
		X	+	Auto start with manual backup
	X			All AO/FO pump discharge control and steam admission valves are powered from non-
				safety bus, w/manual override (most severe accident)
		X	+	MDAFPs tested monthly - recirc. (full flow to SGs yearly)
	X		-	TDAFP and valves tested on 6 month basis-recirc. (full flow to SGs yearly)
X			-	No time limit outage for one pump
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of testing after maintenance
	X		-	Recirc. testing (inadequate testing)
	3E-4			RATING

Evaluator: L. Langpick

Date: 12/7/81

Table C-25

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Indian Point 3 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5T-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			2 single passive failures - 2 valves in series CST to AFPs
	X			Backup water supply is remote manually controlled
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		TDAFP independent of AC power (most severe accident)
		X	+	Auto start with manual backup
		X	+	All AO/FO pump discharge control and steam supply valves are powered from vital inst.
				bus w/manual override (most severe accident)
		X	+	MDAFPs and TDAFP tested monthly - recirc. (full flow to SGs yearly)
	X		-	Valves tested on 6 month basis - recirc. (full flow to SG's yearly)
X			-	No time limit outage for one pump
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of testing after maintenance
	X		-	Recirculation testing (inadequate testing)
		1E-4		RATING

Evaluator: L. Lanzinski

Date: 12/7/81

Table C-26

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Kewaunee **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3 (LO)	1E-2 7E-4 2E-4 (MED)	2E-4 1E-5 1E-6 (HI)	+ good, - poor, N No info.	
	X			2 single passive failures - valves from CST to AFPs
	X			Remote manual switch in of backup supply water
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		TDAFP independent of AC power, DC MOVs (most severe accident)
		X	+	Auto start with manual backup
		X	+	Pumps tested monthly
	X		-	Recirc. tests (inadequate testing)
X			-	No time limit on pump outage
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention of testing after maintenance
		1E-4		RATING

Evaluator: L. Lenzini

Date: 12/8/81

Table C-27

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: North Anna NSS: W SOURCE: NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3 (LO)	1E-2 7E-4 2E-4 (MED)	2E-4 1E-5 1E-6 (HI)	+ good - poor N No info.	
		X		No single failure
X				Local manual operation for backup water
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
		X		TDAFP independent of AC power (most severe accident)
		X	+	Auto start with manual backup
		X	+	Testing on a monthly basis
	X		-	Recirc. testing (inadequate testing) - valve manipulations
		X	+	Tech specs consistent with standard
		X	+	Minimum interface with other systems
		X	+	Simplicity
			-	No mention to testing after maintenance
	X			Each pump is lined up normally to a dedicated SG. Takes local manual operation to
				align other pumps to other SG's. Does not maximize system capability.
		X	+	Test after maintenance as per tech spec.
		1E-4		RATING

Evaluator: L. Lanyuski

Date: 12/8/81

Table C-28

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Prairie Island 1&2 **NSS:** W **SOURCE:** NUREG-0611, 50282-3 FSAR

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1, 2E-2, 5E-3	1E-2, 7E-4, 2E-4	2E-4, 1E-5, 1E-6	+ good, - poor, N No info.	
LO	MED	HI		
		X		No single failure
	X			Remote manual backup water supply provided by 3MDEPs and 2DDPs
X			-	Minimum redundancy (1/2), third MDAFP can be local manually transferred.
	X		+	Partial diversity (MDAFP & TDAFP)
		X	+	Auto start with manual backup
X				TDAFP depends on AC power thru steam admission MOV, need local manual operation (most severe accident)
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X	+	Test on monthly basis
	X		-	Recirc. test - valve aligning
		X	+	With one unit operating, one pump outage limited to 48 hrs.
	X		-	With two units operating, one pump outage limited to 7 days
			-	No mention of testing after maintenance
	1E-3			RATING

Evaluator: L. Lanigan

Date: 12/8/81

Table C-29

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Pt. Beach 1 & 2 NSS: W SOURCE: NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
		X		No single passive failure point
	X			Remote manual backup water supply, SWS
	X		+	Greater than minimum redundancy (1/3) if both units does not require AFS
	X		+	Partial diversity (2MDAFPs and TDAFP) if both units does not require AFS
X				TDAFP dependent on AC power, SWS for cooling bearing oil (most severe accident)
		X	+	Auto start with manual backup
		X	+	Minimum interface with other systems except with themselves
		X	+	Test monthly-recirc. Full flow CST to SG during refueling and cold SD, not more often than 3 months
	X		-	Recirc. test - inadequate testing
X			-	Unlimited outage of one pump
			-	No mention of testing after maintenance
		X	+	Simplicity
	1E-3			RATING

Evaluator: L. Lanzinski

Date: 12/8/81

Table C-30

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Salem 1 NSS: W SOURCE: NUREG-0611

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1L-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
	X			Single passive failure - valve from AFST to AFPs
X				Local manual backup water supply
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFP and 1TDAFP)
		X		TDAFP independent of AC power with AO/FO/NO valves (most severe accident)
		X	+	Auto start with manual backup
		X	+	After each AF train maint. outage, flow tested to SG
	X		-	MDAFP tested 3 months interval and TDAFP tested 6 month basis
		X	+	Minimum interface with other systems
		X	+	Simplicity
			N	Testing - Recirc.
	7E-4			RATING

Evaluator: L. Lanigan

Date: 12/8/81

Table C-31

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: San Onofre 1 NSS: W SOURCE: NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			Single passive failure - valve from CST to AFPs
X				Local manual backup water supply must go thru CST
X			-	Minimum redundancy (1/2)
	X		+	Partial diversity (1MDAFP and 1TDAFP)
X			-	Manual start of pump plus local manual pump discharge valves
X				TDAFP independent of AC power, but local manual discharge and steam supply valves needed
		X	+	Pumps tested weekly
	X			Recirc. test (inadequate testing)
		X	+	Minimum outage time on one pump
			-	No mention of testing after maintenance
1E-2				RATING

Evaluator: L. Lenquist

Date: 12/9/81

Table C-32

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Surry 1 & 2 NSS: W SOURCE: NUREG-0611

Defense Against CCF				
From Check List			From Data	
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	SYSTEM VARIABLE
LO	MED	HI		
		X		No single active failure
X				Local manual backup water supply
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial redundancy (2MDAFPs and 1TDAFP)
		X	+	Auto start with manual backup
		X		TDAFP independent of AC - all valve NO (most severe accident)
		X	+	Minimum interface with other system, except with other unit AFS
		X	+	Test on monthly basis
		X	+	Test after maintenance on particular system or component
-			-	No limited outage time on one pump
			N	Test recirc. or full flow to SG
		5E-5		RATING

Evaluator: L. Lengyel

Date: 12/9/81

Table C-33

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Trojan **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List (2E-1, 2E-2, 5E-3) LO	From Check List (1E-2, 7E-4, 2E-4) MED	From Check List (2E-4, 1E-5, 1E-6) HI	From Data (+ good, - poor, N No info)	SYSTEM VARIABLE
	X			Single passive failure - valve from CST to AFPs
	X			Remote manual backup water supply, SWS
X			-	Minimum redundancy (1/2)
	X		+	Partial diversity (TDAFP and DDAFP)
		X	+	Auto start with manual startup
X				Both pumps AC dependent for cooling
		X	+	Minimum interface with other systems
		X	+	Simplicity
		X	+	Tests on a monthly basis
	X		-	Recirc. testing (inadequate testing)
		X	+	Minimum outage time for one pump
			-	No mention of testing after maintenance
5E-3				RATING

Evaluator: L. Lenipesh

Date: 12/9/81

Table C-34

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Turkey Point 3 & 4 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info	
LO	MED	HI		
		X		No single failure
				Backup water supply from condensate recovery system - no details
	X		+	Greater than minimum redundancy (1/3) assuming AFS need by one unit, only
X			-	No diversity (3TDAFPs)
X				TDAFPs steam supply valve AC MOV's, can be local manually opened (most severe accident)
X			-	Complexity - AFS shared by Units 3&4. Problem if both units needs AFS together:
				cannot meet single failure criteria in each unit; if one pump is out for maint.;etc.
		X	+	Auto start with manual backup
		X	+	Test monthly
		X	+	Full flow test to SG's while under power
		X	+	Minimum pump outage time
			-	No mention of testing after maintenance
	3E-4			RATING

Evaluator: L. Lanzinski

Date: 12/9/81

Table C-35

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Yankee Rowe NSS: W SOURCE: NUREG-0611

Defense Against CCF: From Check List (2E-1, 2E-2, 5E-3) LO	From Check List (1E-2, 7E-4, 2E-4) MED	From Check List (2E-4, 1E-5, 1E-6) HI	From Data (+ good, - poor, N No info)	SYSTEM VARIABLE
X			-	Single train system - single active and passive failures
X			-	Local manual start of TDAFP by opening steam supply valve and 4 valves to 4 SG's
X			-	Local manual operation of 10 valves to transfer 2 backup AFW supply, charging and
				SI pumps. 52 min. SG boil dry time, or 40 min. modified dryout time
		X	+	TDAFP test every 15 days and SI pumps weekly. Valve positioning verified.
		X	+	AFS must be operable or hot SB in 1 hr. and hot SD in 12 hrs.
				Note:
				o LOOP very reliable, one outage in 19 years of operation
				o No challenge of AFS made during entire operational history
2E-2				RATING

Evaluator: L. Lerigoch

Date: 12/9/81

Table C-36

SAMPLE APPLICATION OF CCF CHECK LIST TO ESTIMATE FAILURE PROBABILITY OF AUXILIARY FEEDWATER SYSTEM (AFS)

PLANT: Zion 1 & 2 **NSS:** W **SOURCE:** NUREG-0611

Defense Against CCF: From Check List			From Data	SYSTEM VARIABLE
2E-1 2E-2 5E-3	1E-2 7E-4 2E-4	2E-4 1E-5 1E-6	+ good - poor N No info.	
LO	MED	HI		
	X			2 single passive failures - 2 valves in series from CST to AFPs
	X			Remote manual backup water supply, SWS, and local manual CST from other unit
	X		+	Greater than minimum redundancy (1/3)
	X		+	Partial diversity (2MDAFPs and 1TDAFP)
X				TDAFP dependent on AC due to SWS cooling for lube oil (most severe accident)
		X	+	Auto start with manual backup
		X	+	Testing on monthly basis
		X	+	Testing - fuel flow to SG's
		X	+	Test after maintenance
		X	+	Minimum interface with other systems
		X	+	Simplicity
		1E-4		RATING

Evaluator: L. Lanigan

Date: 12/9/81

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