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Recovery Actions in PRA for the Risk Methods Integration and Evaluation Program (RMIEP)

Volume 2: Application of the Data-Based Method

Donnie W. Whitehead

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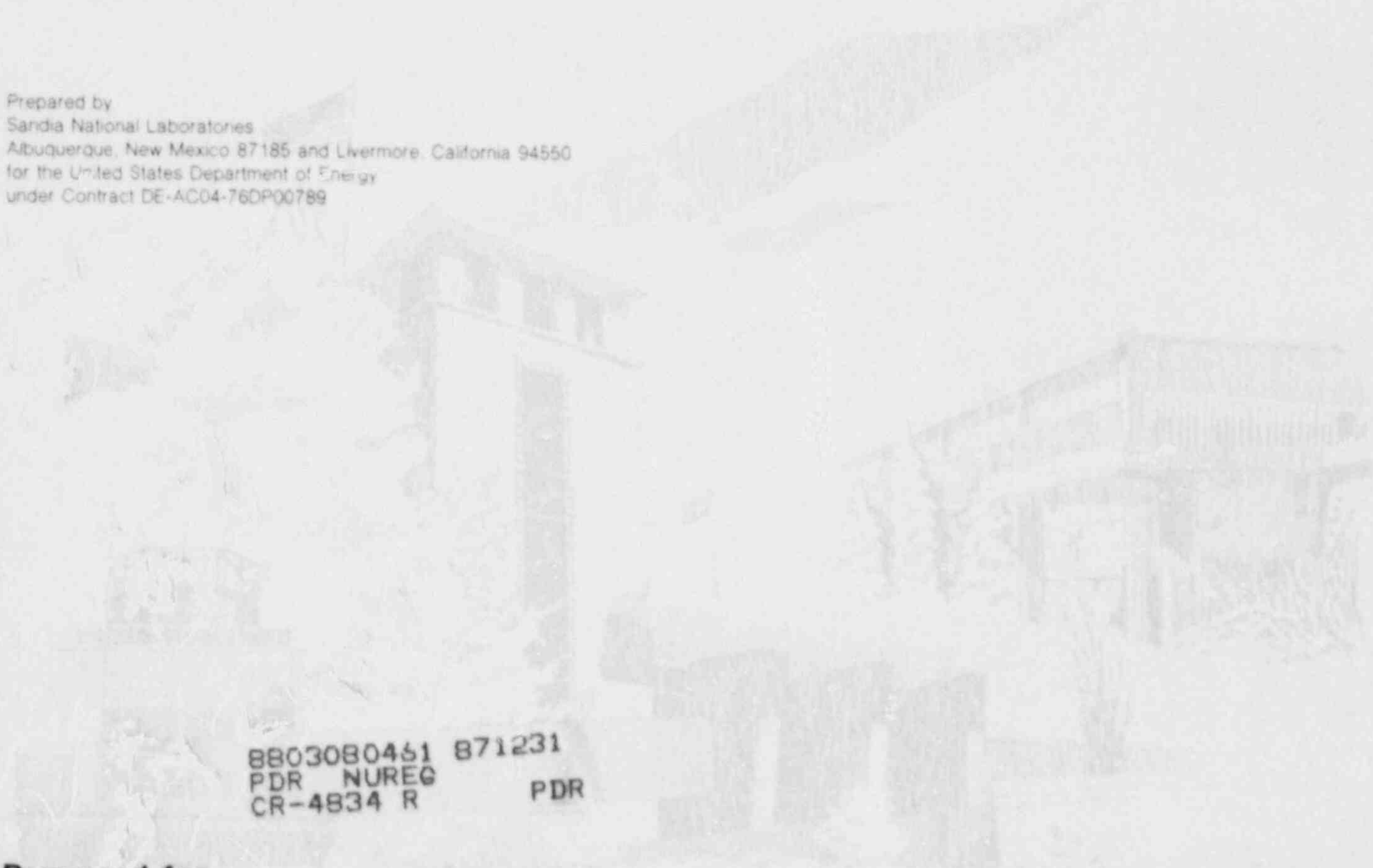

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Abstract

In a Probabilistic Risk Assessment (PRA) for a nuclear power plant, the analyst identifies a set of potential core damage events and their estimated probabilities of occurrence. These events include both equipment failures and human errors. If operator recovery from an event within some specified time is considered, the probability of this recovery can be included in the PRA.

This report provides PRA analysts with a step-by-step methodology for including recovery actions in a PRA. The recovery action is divided into two distinct phases: a Diagnosis Phase (realizing that there is a problem with a critical parameter and deciding upon the correct course of action) and an Action Phase (physically accomplishing the required action). In this methodology, time-reliability curves, which were developed from simulator data on potentially dominant accident scenarios, are used to provide estimates for the Diagnosis Phase, and other existing methodologies are used to provide estimates for the Action Phase.

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1.0 INTRODUCTION

The contribution of human errors to the potential risk from hypothesized accidents at nuclear power plants has been a concern since risk was first addressed quantitatively in the Nuclear Regulatory Commission's (NRC's) Reactor Safety Study [1].

In Volume 1 of this report [2] (sponsored by the NRC's Division of Reactor System Safety), a data-based model was developed for estimating the impact of human errors that occur during an accident. This model was developed to support the operator recovery analysis in the Risk Methods Integration and Evaluation Program (RMIEP). RMIEP is conducting a probabilistic risk assessment (PRA) for the LaSalle Unit 2 nuclear power plant and has as one of its objectives to evaluate PRA technology developments and to lay the basis for improved PRA procedures.

In this volume (Volume 2), a complete methodology for including recovery actions in a PRA is developed. A recovery action is defined as an action which must be accomplished by the operators to prevent or mitigate an undesirable outcome during an accident. It is modeled as consisting of two distinct phases: (1) a diagnosis phase (recognizing that a problem exists with one of the critical parameters and deciding what to do about it), and (2) an action phase (physically accomplishing the action(s) decided upon in the diagnosis phase).

The recovery methodology can be summarized as follows:

(1) Appropriate recovery actions are identified. This includes both recovery actions that are to be placed directly on the event trees and/or fault trees and recovery actions that result from examination of the information contained in the cut sets.

(2) The recovery actions not included in the event trees or fault trees are applied to the cut sets.

(3) The recovery actions are modeled as consisting of a diagnosis phase and an action phase.

(4) Estimates of the failure probabilities for each phase are provided using separate models (i.e., the diagnosis phase uses the data-based model developed in Volume 1, and the action phase uses existing models.

(5) Estimates for each phase are combined to produce a single nonrecovery probability.

(6) The original cut set failure probability is multiplied by the nonrecovery probability of the recovery action to give the new cut set failure probability. This new cut set failure probability now reflects the operator's contribution in reducing or mitigating the undesirable outcome (e.g., core damage).

The data-based model for estimating the contribution from the diagnosis phase was developed using information obtained from simulator drills. These simulator drills were based on preliminary results from the LaSalle PRA. These preliminary results were used to define realistic plant-specific accident scenarios that could potentially lead to core damage. The drills were used to obtain time data on the operator team's ability to respond to the accident scenario. These time data, along with the grouping of operator actions based upon the underlying operational similarity of the actions, provide the basis for the model of the diagnosis phase of the recovery action.

This report describes in a step-by-step manner how the recovery methodology developed in Volume 1 is applied in a PRA. Each step is explained, recommendations are made on how to accomplish each step, and limitations are discussed where appropriate.

The remainder of this report is divided into two sections:

- Section 2 describes the recovery methodology in a step-by-step manner.

- Section 3 presents the conclusions and points out the strengths and limitations of the data-based recovery methodology.

2.0 A STEP-BY-STEP DISCUSSION OF THE RECOVERY METHODOLOGY

In the following sections, the recovery methodology is discussed in a step-by-step manner. Each step is explained and appropriate data sources are identified.

2.1 Recovery Methodology

Figure 2.1-1 provides a flow chart for the recovery methodology. The steps that follow for the recovery methodology correspond to the step numbers in Figure 2.1-1.

Step 1 - Identify appropriate recovery actions. This includes recovery actions that are to be placed directly on the event trees and/or the fault trees and recovery actions that result from the examination of the information contained in the cut set.

Step 2 - For the recovery actions that are not included in the event trees or fault trees, apply the appropriate recovery action identifier to the cut set.

Step 3 - Obtain an estimate for the failure probability of the recovery action by following Step 4 for estimating the diagnosis phase failure probability, and following Step 10 for estimating the action phase failure probability of the recovery action.

Step 4 - Estimate the diagnosis phase failure probability of the recovery action by identifying the group which best describes the recovery action (Step 5) and estimating the time available to diagnose the recovery action (Steps 6 through 8).

Step 5 - Identify from Table 2.1.5-1 the group that best describes the recovery action. The analyst should examine the actions in each group and choose the group that contains actions that are most similar to the one of interest. If the recovery action cannot be described by one of the groups in Table 2.1.5-1, then the analyst must either obtain simulator data for the new recovery action or use another model to provide an estimate for the diagnosis failure probability of the new recovery action.

Step 6 - T_M (the maximum time in which both phases of the recovery action must be completed) is estimated using thermohydraulic computer codes which provide information on core or containment parameters (i.e., pressure, temperature, water level, etc.), and/or information based on equipment failure characteristics (loss of room cooling, seal cooling, etc.).

Step 7 - T_A (the time required to physically accomplish the action phase) can be conservatively estimated as the sum of the maximum time required to reach the area where the action is to be accomplished and the time required to accomplish the action -- these should be based on actual measurements where possible.

Step 8 - Estimate the time available to diagnose the recovery action by the following expression:

$$T_D = T_M - T_A$$

Step 9 - Obtain an estimate of the failure probability for the diagnosis phase, P(ND), at time T_D, using the table corresponding to the action group identified in Step 5.*

Step 10 - Estimate the action phase of the recovery action by estimating the failure probability for the action phase, P(NA)(Step 11).

Step 11 - An estimate for the failure probability for the action phase, P(NA), can be computed from any number of different sources. As considerable work has been done in this area, no new models for action probabilities were developed in this project. For application to RMIEP, the models in the Handbook (NUREG/CR-1278) [3] will be used.

Step 12 - Estimate the total failure probability for the recovery action, P(NR), using the following expression:

$$P(NR) = P(ND) + P(NA) - P(ND)\,P(NA)$$

---

*Note: Tables 2.1.9-1 through 2.1.9-10.

Step 13 - The new cut set probability, allowing for recovery, is then:

$$P(\text{cut set})_{new} = P(\text{cut set})_{original} * P(NR).$$

2.1.1 Step 1 - Identify Appropriate Recovery Actions

It is recognized that some recovery actions can be included in the event trees and fault trees. Recovery actions that are not included in the event trees or fault trees are applied to the cut sets as a result of the examination of the information contained in the cut sets.

Recovery actions that can be included in the event trees or fault trees are the high-level procedural actions, which are prescribed in the Emergency Procedures Guidelines (EPGs) of the plant. There are two basic types of prescribed actions that should be considered for inclusion in the event trees and/or fault trees. They are:

(1) Those actions that direct the control room operators to start or to verify the start of automatically actuated systems when the operators reach that checkpoint in the EPGs and

(2) Those actions that direct the control room operators to start manually actuated systems when specified conditions exist.

An example of a type (1) action might be: verify the start of the high pressure core spray (HPCS) system given that the water level in the reactor vessel has reached the setpoint for automatic initiation of the HPCS system. An example of a type (2) action might be, initiate cooling to the suppression pool when the suppression pool temperature exceeds a predetermined setpoint.

Actions that fall into these two categories should be considered during the construction of the event trees and the fault trees. For the recovery actions that are applied directly to the cut set, a cut set must be examined to determine if any of the failures contained in the cut set can be recovered, or if there is an alternate means of accomplishing one of the failures represented in the cut set. As an example, consider the following cut set with an original probability of 1.65E-6 that might result from a PRA on a boiling water reactor (BWR):

DC-A-IE * HPCS-P01-BKR-LF * /OP-FAILS-ADS * LPCS-PMS-LF * RHRF04B-VCC-CC

where DC-A-IE is an initiating event (i.e., the failure of emergency DC power bus A) that results in a plant trip and the loss of all emergency equipment whose control power is provided by train A of DC power.

HPCS-P01-BKR-LF is a local fault failure of the electric power breaker that supplies power to the HPCS pump,

/OP-FAILS-ADS represents the successful use of the Automatic Depressurization System (ADS) by the operators. (Note: This is an example of a recovery action that was included in the event tree),

LPCS-PMS-LF is the local fault of the low pressure core spray (LPCS) pump, and

RHRF04B-VCC-CC is the failure of the control circuit which opens the motor operated valve (MOV) RHRF04B.

Failure of MOV RHRF04B results in the loss of the final means of injecting water into the reactor vessel.

From previous decisions, the recovery analyst has decided that events DC-A-IE, HPCS-P01-BKR-LF, and LPCS-PMS-LF are not recoverable. Since /OP-FAILS-ADS is a recovery action itself, the only basic event that can potentially be recovered is RHRF04B-VCC-CC. The recovery analyst knows that MOV RHRF04B is accessible and that the MOV also has a hand crank which allows manual operation of the valve. The analyst decides that this basic event, RHRF04B-VCC-CC, can be recovered.

If more than one recovery action is possible, the analyst must decide how many or how few recovery actions will be considered. Some items that should be considered when deciding upon the number of recovery actions to allow in a cut set are:

(1) Who will be doing the recovery action? If two completely separate groups of people will be attempting different recovery actions, e.g., control room operators and people attempting to restore offsite power, then credit for both recovery actions should be considered.

(2) How much time separates the actions? If different actions are separated by enough time (i.e., 1 to 2 hours), then credit for more than one action should be considered. For example, consider a cut set which has two possible recovery actions:

   (a) reestablishing containment cooling anytime within 27 hours, and

(b) venting the containment after the pressure has reached a specified setpoint in 21 hours.

Since containment cooling can be re-established any time within 27 hours and venting only becomes necessary after 21 hours, taking credit for both of these recovery actions should be considered.

Other items that should be considered when dealing upon the number of recovery actions to allow in a cut set are:

(1) Where are the recovery actions accomplished,

(2) how clearly do the indications available to the operators suggest specific recovery actions, and

(3) do the recovery actions affect different critical parameters (e.g., water level, vessel pressure, containment pressure, etc.)?

2.1.2 Step 2 - Apply Recovery Action(s) to Cut Set

For the recovery action(s) identified by examining the information contained in the cut set, an appropriate recovery action identifier must be applied to the cut set. The form of the identifier is left to the analyst's discretion, but as a minimum the recovery action identifier should indicate:

(1) what the action is and whether the action takes place in the control room or takes place locally (i.e., outside the control room),

(2) the underlying basis of the action (e.g., does the action restore a system or component that failed to automatically operate), and

(3) how much time the operators have to accomplish the recovery action.

Continuing with the example from Section 2.1.1, the analyst could represent the recovery action by the literal, RA-2-3-80M. In this example, the literal is defined as follows:

(1) "RA" indicates that this is a recovery action which resulted from the examination of a cut set,

(2) "RA-2" indicates that the recovery action is the local operation of a value,

(3) "RA-2-3" indicates that the recovery action is the local operation of a valve which should have automatically operated, and

(4) "RA-2-3-80M" indicates that the recovery action must be accomplished within eighty (80) minutes to prevent or mitigate some undesirable outcome which in this case is possible core damage.

2.1.3 Step 3 - Obtain Estimate for Recovery Action

After the recovery action identifier has been applied to the cut set, the analyst obtains an estimate for the failure probability of the recovery action. Since the recovery action is modeled as consisting of two phases (i.e., diagnosis phase and action phase), the procedure for estimating the failure probability of the recovery action is broken into two parallel paths. The diagnosis failure probability is estimated by following Steps 4 through 9 (Sections 2.1.4 through 2.1.9 and the action failure probability is estimated by following Steps 10 and 11 (Sections 2.1.10 and 2.1.11).

2.1.4 Step 4 - Diagnosis Phase Estimate

Before estimating the diagnosis phase failure probability of the recovery action, two tasks must be accomplished. First, the analyst must identify the group which best describes the recovery action of interest, Step 5 (Section 2.1.5), and second, must estimate the time available for the operators to diagnose the recovery action, Steps 6 through 8 (Sections 2.1.6 through 2.1.8).

2.1.5 Step 5 - Identify Group That Best Describes Recovery Action

From the results of the data analyses, which are discussed in detail in Appendix B of Volume 1 of this report, it was found that the full spectrum of identified recovery actions could be represented by ten recovery action groups. Table 2.1.5-1 lists the groups, gives a generic description for each group, and lists the actions that were included in the group based upon operational similarity and statistical testing.

To identify the group that best describes the recovery action, the analyst should examine the actions in each group in Table 2.1.5-1 and choose the group that contains actions that are most similar to the one of interest. If the recovery action cannot be described by one of the groups in Table 2.1.5-1, the analyst must either obtain simulator data for the new recovery action or use another model to provide an estimate for the diagnosis failure probability of the new recovery action. In the example from Section 2.1.1, the analyst has decided that the basic event RHRF04B-VCC-CC is recoverable. In addition to knowing that the valve is accessible and has a hand crank, the analyst knows that this valve failure prohibits the low pressure injection (LPCI) system from injecting water into the reactor vessel. Having decided that the basic event can be recovered by having someone go to the valve and open it by using the hand crank, the analyst searches Table 2.1.5-1 until the group that contains actions similar to this is found. In this example, the LPCI system should have automatically operated. Knowing this, the analyst chooses Group 3 (i.e., Manual operation of systems or components that failed to automatically actuate (operate)) as the group that best describes the recovery action.

2.1.6 Step 6 - Estimate Time T_m

In order for the analyst to be able to provide an estimate for the diagnosis phase of the recovery action, the maximum time available to the operators must be estimated. T_m is the maximum time during which both phases of the recovery action (i.e., diagnosis phase and action phase) must be completed to ensure the prevention or mitigation of some undesirable outcome. T_m is estimated using thermal-hydraulic computer codes to provide information on core or containment parameters (i.e., pressure, temperature, water level, etc.) or information on equipment operability (i.e., room cooling requirements, seal cooling, etc.) Any computer codes used should be as realistic as possible. For example, the conservative decay heat curve that is required in licensing calculations should be replaced with a decay heat curve that more closely predicts reality. For this example, where all high pressure injection has been lost, the operators have successfully depressurized the reactor vessel, and low pressure injection has failed, the analyst has computer calculations which indicate that if injection of water is restored within eighty (80) minutes, no core damage occurs. If core damage is the undesirable outcome, then T_m is 80 minutes.

2.1.7 Step 7 - Determine T_A

After an estimate for T_m has been obtained, the amount of time required to physically accomplish the action, T_A, must be determined. T_A can be estimated as the maximum amount of time required by the operator(s) to reach the area where the action is to be accomplished plus the time required to accomplish the action. Whenever possible, these times should be based on actual measurements. These measurements can be taken during a plant visit which is an integral part of a PRA.

For our example, the analyst has determined that an operator requires a maximum of ten (10) minutes to travel between the two most distant points at the plant. The analyst also knows that the maximum amount of time required to open a MOV manually is five (5) minutes. Adding the five minutes required to manually open the valve to the ten minutes required to reach the valve results in a conservative estimate of fifteen minutes to physically accomplish the action (i.e., T_A = 15 minutes).

2.1.8 Step 8 - Estimate Time Available to Diagnose the Recovery Action, T_D

To estimate the time available to diagnose the recovery action, T_D, the following expression is used:

$T_D = T_m - T_A$, where

T_m is the maximum time in which both phases of the recovery action must be completed to prevent or mitigate an undesirable outcome during the accident, and

T_A is the time required to physically accomplish the action(s) decided upon in the diagnosis phase.

For our example, T_m = 80 Minutes (from Step 6), T_A = 15 minutes (from Step 8), thus

$$T_D = 80-15$$

$$T_D = 65 \text{ Minutes}$$

2.1.9 Step 9 - Obtain Estimate of Failure Probability for Diagnosis Phase P(ND) at T_D

To estimate the failure probability for the diagnosis phase of the recovery action, the first thing that must be done is to identify the table from Tables 2.1.9-1 through 2.1.9-10 that corresponds to the group identified in Step 5. Tables 2.1.9-1 through 2.1.9-10 provide point estimates with lower and upper 95% confidence limits for each group identified in Table 2.1.5-1. The tables include the standard errors of the point estimates of the failure probabilities (labeled Standard Deviation of Point in the tables). For times at which the failure probabilities are fairly high, the confidence limits are approximately the point estimate ± two times the standard error. However, for times at which the failure probabilities are low, the confidence limits are not symmetrical. See Volume 1 of this report for a discussion on how the numbers in the tables were generated.

Once the table that corresponds to the group chosen in Step 5 has been identified, the analyst can use the information contained within the table to obtain an estimate of the diagnosis phase failure probability. The following paragraphs discuss the various ways in which the information contained in the tables may be used, with recommendations for the most appropriate.

The information contained in Tables 2.1.9-1 through 2.1.9-10 were obtained using the CENSOR computer code [4]. The code uses maximum likelihood theory to produce distribution parameter estimates by iterating until estimates for the mean

(μ) and standard deviation (σ) (of logarithms) are found that maximize the product of the likelihoods for each group of operator actions. In addition to estimating distribution parameters, the code also provides estimates and approximate confidence limits for distribution failure probabilities. The diagnosis failure probability at any given time ($P_{ND}(t)$) was calculated using:

$$P_{ND}(t) = Z(x)$$

where t is time

Z(x) is the value from the cumulative standard normal distribution at x,

$$x = (-\log_{10}(t) + \mu)/\sigma, \text{ and}$$

μ and σ are the values for the mean and standard deviation, respectively, of the fitted function. It is recognized that as time increases beyond the final value for time given in each table that the diagnosis failure probability decreases. However, it is recommended that the curves not be extrapolated beyond this point.

Three reasons for this recommendation are:

(1) The amount of data currently available does not support continued extrapolation,

(2) Human error probabilities much lower than 10^{-3} begin to compete with random equipment failures that could prohibit the operator from using a piece of equipment even if the operator has decided to use the equipment and; therefore, there is a lower bound beyond which the PRA analyst would be taking too much credit for the operator action, and

(3) If the operators have failed to diagnose the recovery action within some specified period of time, it may be that additional time will not provide more reduction in the operator's failure probability since, for some reason, the operators are either not identifying this as a possible action or have bypassed this by performing some other action.

The code calculates the confidence limits for the failure probabilities by assuming a normal distribution about the failure probability Z(x). A Taylor series expansion is used, and the normal approximation is improved by making a transformation to log-odds, ln(Z(x)/(1-Z(x))). After calculating confidence intervals for the log-odds, transforming back yields approximate confidence limits for the failure probability $P_{ND}(t)$. Since x is lognormal, the distribution about the failure probability should be approximately lognormal. Since maximum likelihood theory was used to obtain μ and σ, the failure probability at any time t should be the median value of the distribution about the failure probability. If the failure probability at any time t is the median value of the lognormal distribution about the failure probability, then the error factors, which can be calculated by dividing the upper 95% confidence limit by the failure probability and by dividing the failure probability by the lower 95% confidence limit, should be equal. This is generally the case for the information in Tables 2.1.9-1 through 2.1.9-10. However, as the curve is extrapolated beyond the data, the confidence limits become less symmetrical; hence, the error factors which can be calculated using these confidence limits become unsymmetrical. Another result of the extrapolation of the curve beyond the data is that the error factors increase as the amount of time available to diagnose the recovery action increases.

With these points in mind, the following recommendations are made:

(1) The point estimates should not be extrapolated beyond those given in the tables.

(2) The point estimates for each time t should be considered as median values of a lognormal distribution.

(3) The upper error factor (UEF), which can be calculated by dividing the upper 95% confidence limit by the point estimate, should be used to obtain the mean value for the failure probability at time t, since this provides assurance that the human error probability will not be underestimated. If the error factor that is calculated by the above method is greater ten (10.0), an error factor of ten should be used when calculating the mean value for the failure probability. Since the error factors, which can be calculated for the actual time data itself, are all less than ten (see Tables 2.1.9-1 through 2.1.9-9), an error factor of 10.0 insures a two order-of-magnitude envelope of the diagnosis phase estimate.

The analyst can now estimate the diagnosis phase failure probability for the identified recovery action. This is accomplished by:

(1) Determining the median value for the failure probability ($P(ND)_{median}$) at time T_D from the table which corresponds to the group identified in Step 5.

(2) Use the median value identified in (1) to calculate the UEF. If UEF is greater than 10.0, use 10.0 as the value of UEF.

$$\text{UEF} = \text{Upper 95\% Confidence Limit} \div \text{Median}$$

(3) Calculate the mean value for the diagnosis failure probability ($P(ND)_{mean}$) at time T_D using the UEF from (2) and the median value from (1) by the following formula:

$$P(ND)_{mean} = (P(ND)_{median})(\exp[(\ln \text{UEF}/1.645)^2/2])$$

(4) Use the mean value calculated in (3) as the diagnosis failure probability (P(ND)) for the recovery action being analyzed.

Continuing with the example from Section 2.1.1 yields:

(1) T_D is 65 minutes, P(ND) median is 0.00099 from Table 2.1.9-3 (Note: 0.00099 is the value for 62 minutes. Since this is the last value in the table, no further extrapolation was attempted.

(2) $\text{UEF} = 0.040/0.00099$

$\cong 40.4$

Since UEF > 10.0, set UEF = 10.0

(3) $P(ND)_{mean} = (P(ND)_{median})(\exp((\ln \text{UEF}/1.645)^2/2))$

$= (0.00099)(\exp((\ln 10.0/1.645)^2/2))$

$= 2.6\text{E-}3$

(4) $P(ND) = P(ND)_{mean}$

$= 2.6\text{E-}3$

2.1.10 Step 10 - Estimate the Action Phase of the Recovery Action

To estimate the action phase failure probability of the recovery action, P(NA), the analyst can use the recommendations made in Step 11.

2.1.11 Step 11 - Estimate the Failure Probability for the Action Phase, P(NA)

An estimate for the failure probability for the action phase, P(NA), can be computed from any number of different sources. As considerable work has been done in this area, no new models for action failure probabilities were developed in this project. For application to RMIEP, the models in [2] will be used, hereafter referred to as the Handbook.

Continuing with the example from Section 2.1.1, the analyst now estimates the action phase failure probability of the recovery action. Since in this case, an operator would have directed someone to manually open the valve and is waiting for the flow to be established, the estimate for P(NA) is obtained by the following: Given that the operator has diagnosed the recovery action (see Sections 2.1.4 through 2.1.8), the operator calls a B-man to go and manually open the failed low pressure injection valve. The operator will be monitoring a control room indicator (e.g., flow meter) that will provide feedback to the operator as to the success of the B-man. From Step 7 (Section 2.1.7), the time required to physically accomplish the action, T_A, has been determined.

To estimate the action phase of the recovery action (i.e., the probability that the B-man will fail to open the low pressure injection valve), a HRA event tree (Chapter 5 of the Handbook) is constructed. This HRA event tree, in conjunction with the human error probabilities (HEPs) given in Chapter 20 of the Handbook, provide a means of estimating the action phase of the desired recovery action.

For this example, the HRA event tree is shown in Figure 2.1.11-1. From the HRA event tree, the probability of failing to accomplish the action phase is found by:

$$
\begin{aligned}
P(NA) = F_1 + F_2 + F_3 + F_4 &= 0.0 + (0.001)(1.25)^*(0.003)(1.25) \\
&\quad + (0.001)(1.25)(0.003)(1.25) \\
&\quad + (0.001)(1.25)(0.003)(1.25) \\
&= 1.4E\text{-}5
\end{aligned}
$$

---

*1.25 is the multiplier used to convert a median value to a mean value assuming a lognormal distribution.

2.1.12 Step 12 - Estimate the Total Failure Probability for Recovery Action, P(NR)

After the analyst has obtained estimates for the diagnosis phase and the action phase, the total failure probability for the recovery action, P(NR) can be determined. The failure probability for the recovery action is calculated as the probability of either failing to diagnose the appropriate action or failing to perform the recovery action. P(NR) is calculated using the following expression:

$$P(NR) = P(ND) + P(NA) - P(ND)P(NA)$$

where P(NR) is the failure probability for the recovery action,

P(ND) is the failure probability for diagnosing the required action within time T_D, and

P(NA) is the failure probability for physically accomplishing the action within time T_A.

Continuing with the example from Section 2.1.1:

From Step 9, the failure probability for the diagnosis phase of the recovery action is 2.6E-3.

From Step 11, the failure probability for the action phase of the recovery action is 1.4E-5.

Therefore, P(NR) = 2.6E-3 + 1.4E-5 - (2.6E-3)(1.4E-5)

= 2.61E-3

≅ 2.6E-3

2.1.13 Step 13 - Requantify the Cut Set

The new cut set probability, allowing for recovery, is then:

$$P(\text{cut set})_{new} = P(\text{cut set})\ \text{original} * P(NR)$$

For the example from Section 2.11:

$$P(\text{cut set})_{new} = P(\text{cut set})_{original} * P(NR)$$

$$= 1.65E-6 * 2.6E-3$$

$$= 4.29E-9$$

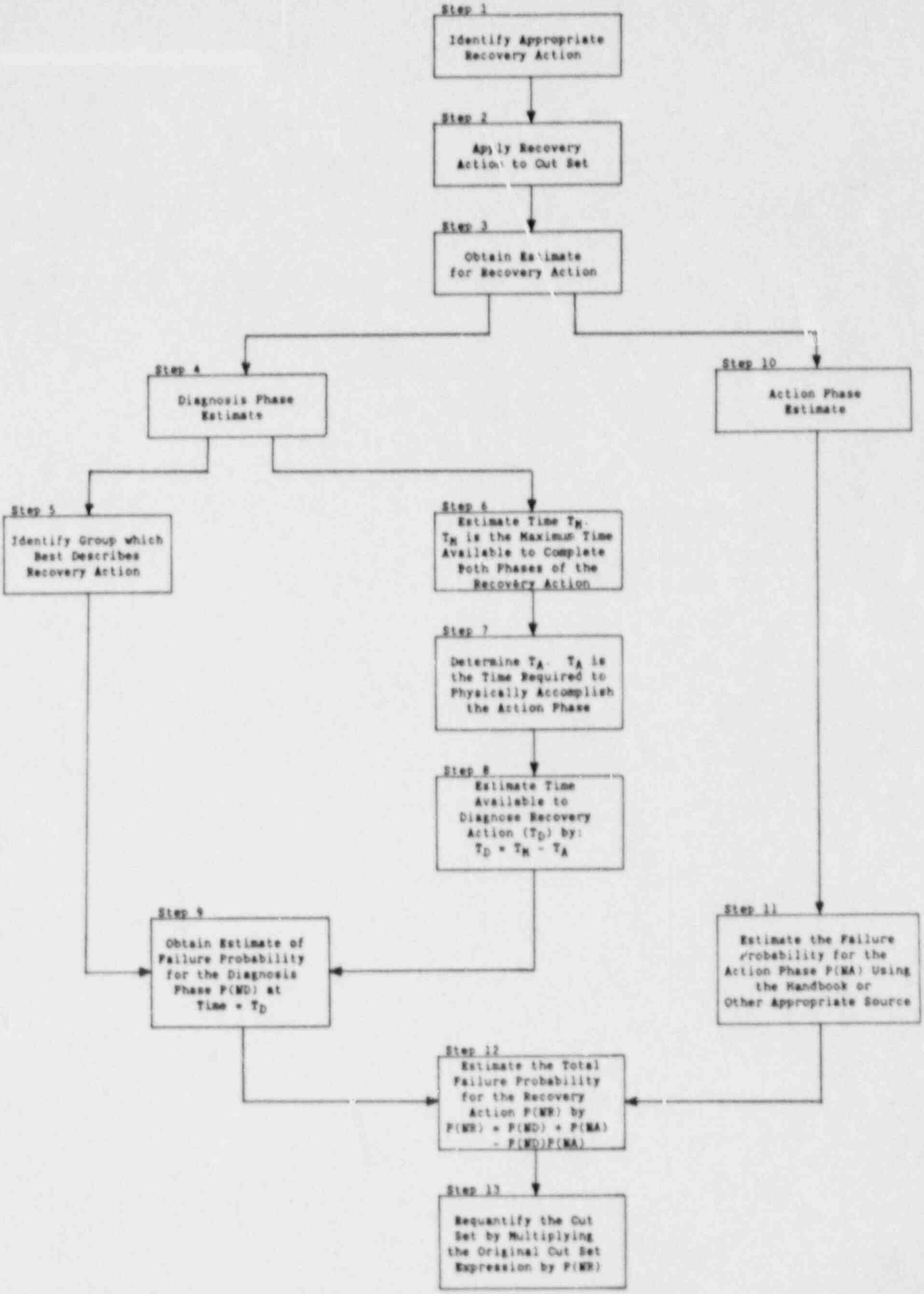

Figure 2.1-1. Recovery Methodology Flow Chart

Table 2.1.5-1
Summary of Ten Groups of Crew Recovery Actions*

Group**	Description of Recovery Actions	
1	Manual operation of system or component to control a critical parameter prior to the automatic actuation (if it has automatic actuation) of the system or component.	1. Drill 1 -- Initiate RHR after ATWS. 2. Drill 2 & 2B -- Initiate SP cooling after RX Trip. 3. Drill 3 -- Initiate RCIC after station blackout. 4. Drill 4 -- Initiate SP cooling after DG1A loads. 5. Drill 6 -- Close MSIVs after Level 7 alarm. 6. Drill 6 -- Close FW valve 1A after Level 7 alarm. 7. Drill 6 -- Initiate SP cooling after RX trip. 8. Drill 8 -- Initiate SP cooling after RX trip.
2	Use of low pressure systems when high pressure systems are unavailable.	1. Drill 8 -- Depressurize after RCIC failure. 2. Drill 8 -- Inject LP after RCIC failure.
3	Manual operation of systems or components which failed to automatically actuate (operate).	1. Drill 3 -- Send B-man to open F013 after F013 failure. 2. Drill 4 -- Reset RCIC isolation after DG 1A loads. 3. Drill 8 -- Request RCIC investigation after RCIC failure.
4	Restoration of safety-related in-house electrical buses or supply equipment.	1. Drill 3 -- Request DG 0 repair after station blackout. 2. Drill 3 -- Request DG 1B repair after station blackout. 3. Drill 3 -- Request DG 1A repair after station blackout. 4. Drill 4 -- Request DG 1B repair after SAT failure. 5. Drill 4 -- Recover DG 1A after DG 1A trouble. 6. Drill 6 -- Request DG A investigation after DC A failure.
5	Restoration of off-site-supplied nonsafety-related electrical buses or supply equipment.	1. Drill 3 -- Request X-tie after station blackout. 2. Drill 3 -- Request SAT repair after station blackout. 3. Drill 4 -- Request SAT repair after SAT failure. 4. Drill 4 -- Request X-tie after SAT failure. 5. Drill 6 -- Restore Bus 151 locally after RX trip.
6	Manual backup of an automatic shutdown function.	1. All Drills -- Mode switch after RX trip. 2. All Drills -- Manual scram after RX trip.
8	Manual override of a system that automatically functions when automatic operation of the system would challenge a critical parameter.	1. Drill 1 -- Jumper VP after drywell isolation. 2. Drill 4 -- Restore VP after drywell isolation. 3. Drill 6 -- Restore VP after DC A failure. 4. Drill 8 -- Restore VP after drywell isolation.
10	Request to use last line of (GARBAGE)*** systems for level control.	1. Drill 4 -- Depressurization after station blackout. 2. Drill 4 -- Request diesel fire pump after station blackout.
11	Local operation of manually controlled components normally operated from the control room when control-room operation fails.	1. Drill 2 & 2B -- Send B-man to close SDV valves after scram reset attempt. 2. Drill 6 -- Request air restoration after service air pressure low alarm.
12	Manual override of a false control signal when no direct indication exists that the control signal is false or erroneous.	1. Drill 4 -- Request bypass of RCIC isolation after RCIC isolation because of room overheating.

*The items listed in this table refer to the correct diagnosis of the required action.
**See corresponding table (Tables 2.1.9-1 through 2.1.9-10) for information to be used in estimating.
***GARBAGE systems are those systems which are used only as a last resort to prevent core damage. These systems inject "dirty" (nonreactor grade) water into the vessel and are used only if no other means of injecting water into the vessel are available.

EP or HEP	Event	Value for F^P or HEP	Source*
Δ	Mechanical or physical failure prohibits operator from getting message to B-man	ε	--
A	Error in message from operator	.001 (EF = 3)	Table 20-8 Item (1a)
B	Operator fails to monitor feedback (recovery action)	.003 (EF = 3)	Page 20-13
C	B-man misunderstands message	.001 (EF = 3)	Table 20-8 Item (1a)
D	Operator fails to monitor feedback (recovery action)	.003 (EF = 3)	Page 20-13
E	B-man selects incorrect valve	.001 (EF = 3)	Table 20-13 Item (5)
G	Operator fails to monitor feedback (recovery action)	.003 (EF = 3)	Page 20-13

*All values are from the Handbook, except the value for Δ. The value for Δ is based on engineering judgment.

Figure 2.1.11-1. HRA Event Tree for Example Application

Table 2.1.9-1

Group 1, Parameter Estimates from Fit of Lognormal Function (N = 63, Mean = .19, Standard Deviation = .43)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.048	.67	.76	.57
2	.049	.39	.49	.30
3	.044	.25	.34	.17
4	.038	.17	.25	.10
5	.032	.12	.19	.066
6	.027	.083	.15	.043
7	.023	.061	.12	.029
8	.019	.047	.10	.021
9	.016	.036	.085	.015
10	.014	.028	.072	.011
11	.012	.023	.061	.0081
12	.010	.018	.053	.0061
13	.0087	.015	.046	.0047
14	.0075	.012	.040	.0037
15	.0066	.010	.036	.0029
16*	.0057	.0086	.032	.0023
17	.0050	.0072	.028	.0018
18	.0044	.0061	.025	.0015
19	.0039	.0052	.023	.0012
20	.0035	.0045	.020	.00099
21	.0031	.0039	.018	.00081
22	.0028	.0034	.017	.00068
23	.0025	.0030	.015	.00056
24	.0022	.0026	.014	.00047
25	.0020	.0023	.013	.00040
26	.0018	.0020	.012	.00034
27	.0016	.0018	.011	.00029
28	.0015	.0016	.010	.00025
29	.0014	.0014	.0092	.00021
30	.0012	.0012	.0085	.00018
31	.0011	.0011	.0079	.00016
32**	.0010	.0010	.0074	.00014

*Extrapolated beyond time = 15.1 min.
**For times greater than 32 min., use last line of table.

Table 2.1.9-2

Group 2, Parameter Estimates from Fit of Lognormal Function
(N = 10, Mean = .95, Standard Deviation = .12)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.00000	1.0	1.0	1.0
2	.00000	1.0	1.0	.97
3	.00014	1.0	1.0	.92
4	.0041	1.0	1.0	.85
5	.025	.98	1.0	.77
6	.064	.92	.99	.67
7	.10	.81	.94	.54
8	.12	.65	.84	.39
9	.13	.48	.71	.26
10	.12	.33	.59	.15
11	.11	.22	.48	.075
12	.087	.13	.40	.035
13	.067	.081	.34	.015
14	.049	.048	.29	.0061
15*	.034	.027	.25	.0024
16	.022	.015	.22	.00088
17	.015	.0087	.19	.00032
18	.0092	.0048	.17	.00011
19	.0057	.0027	.16	.00004
20	.0035	.0015	.14	.00001
21**	.0021	.00081	.13	.00000

*Extrapolated beyond time = 14.2 min.
**For times greater than 21 min., use last line of table.

Table 2.1.9-3

Group 3 Parameter Estimates from Fit of Lognormal Function
(N = 18, Mean = .36, Standard Deviation = .46)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.079	.78	.90	.59
2	.094	.55	.72	.37
3	.093	.40	.59	.24
4	.088	.30	.49	.16
5	.081	.23	.43	.11
6	.074	.18	.37	.079
7	.068	.15	.33	.057
8	.062	.12	.30	.043
9*	.056	.10	.27	.032
10	.051	.084	.25	.025
11	.046	.071	.23	.019
12	.042	.061	.21	.015
13	.038	.052	.20	.012
14	.035	.045	.19	.0095
15	.032	.039	.18	.0077
16	.029	.034	.17	.0063
17	.027	.030	.16	.0052
18	.025	.027	.15	.0043
19	.023	.024	.14	.0036
20	.021	.021	.14	.0030
21	.019	.019	.13	.0025
22	.018	.017	.12	.0021
23	.017	.015	.12	.0018
24	.015	.014	.11	.0015
25	.014	.013	.11	.0013
26	.013	.011	.11	.0011
27	.012	.010	.10	.00098
28	.012	.0095	.098	.00085
29	.011	.0087	.094	.00074
30	.010	.0080	.091	.00064
31	.010	.0073	.088	.00056
32	.0089	.0067	.085	.00049
33	.0084	.0062	.082	.00043
34	.0079	.0057	.080	.00038
35	.0074	.0053	.077	.00034
36	.0070	.0049	.075	.00030
37	.0066	.0046	.073	.00027
38	.0062	.0042	.071	.00024
39	.0058	.0039	.069	.00021
40	.0055	.0037	.067	.00019

*Extrapolated beyond time = 8.2 min.

Table 2.1.9-3 (Continued)

Group 3 Cont., Parameter Estimates from Fit of Lognormal Function (N = 18, Mean = .36, Standard Deviation = .46)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
41	.0052	.0034	.065	.00017
42	.0050	.0032	.063	.00015
43	.0047	.0030	.062	.00014
44	.0044	.0028	.060	.00012
45	.0042	.0026	.059	.00011
46	.0040	.0024	.057	.00010
47	.0038	.0023	.056	.00009
48	.0036	.0022	.055	.00008
49	.0034	.0020	.053	.00007
50	.0033	.0019	.052	.00007
51	.0031	.0018	.051	.00006
52	.0030	.0017	.050	.00006
53	.0028	.0016	.049	.00005
54	.0027	.0015	.048	.00005
55	.0026	.0014	.047	.00004
56	.0025	.0014	.046	.00004
57	.0024	.0013	.045	.00004
58	.0022	.0012	.044	.00003
59	.0022	.0012	.043	.00003
60	.0021	.0011	.042	.00003
61	.0020	.0010	.041	.00003
62*	.0019	.00099	.040	.00002

*For times greater than 62 min., use last line of table.

Table 2.1.9-4

Group 4, Parameter Estimates from Fit of Lognormal Function
(N = 30, Mean = .13, Standard Deviation = .32)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.070	.66	.78	.52
2	.068	.30	.45	.19
3	.051	.14	.27	.067
4	.036	.072	.18	.026
5*	.025	.039	.13	.011
6	.017	.022	.093	.0049
7	.011	.013	.070	.0023
8	.0080	.0091	.054	.0012
9	.0057	.0052	.043	.00061
10	.0040	.0034	.034	.00033
11	.0029	.0023	.028	.00019
12	.0022	.0016	.023	.00011
13	.0016	.0011	.019	.00006
14**	.0012	.00078	.016	.00004

*Extrapolated beyond time = 4.6 min.
**For times greater than 14 min., use last line of table.

Table 2.1.9-5

Group 5, Parameter Estimates from Fit of Lognormal Function
(N = 24, Mean = 1.05, Standard Deviation = .44)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.011	.99	1.00	.90
2	.034	.95	.99	.82
3	.053	.90	.97	.74
4	.065	.84	.93	.67
5	.072	.78	.89	.61
6	.077	.73	.85	.56
7	.079	.68	.81	.51
8	.081	.63	.77	.46
9	.082	.58	.73	.42
10	.083	.54	.69	.38
11	.084	.50	.66	.35
12	.084	.47	.63	.31
13	.084	.44	.60	.29
14	.084	.41	.58	.26
15	.084	.38	.55	.24
16	.083	.36	.53	.22
17	.083	.34	.51	.20
18	.082	.32	.49	.18
19	.081	.30	.48	.17
20	.080	.28	.46	.15
21	.080	.27	.45	.14
22	.079	.25	.43	.13
23	.077	.24	.42	.12
24	.076	.22	.41	.11
25	.075	.21	.39	.10
26	.074	.20	.38	.093
27	.073	.19	.37	.086
28	.072	.18	.36	.079
29	.070	.17	.35	.073
30	.069	.16	.35	.068
31	.068	.16	.34	.063
32	.067	.15	.33	.059
33	.065	.14	.32	.055
34	.064	.14	.31	.051
35	.063	.13	.31	.047
36	.062	.12	.30	.044
37	.060	.12	.29	.041
38	.059	.11	.29	.039
39	.058	.11	.28	.036
40	.057	.10	.28	.034

Table 2.1.9-5 (Continued)

Group 5 Cont., Parameter Estimates from Fit of Lognormal Function(N = 24, Mean = 1.05, Standard Deviation = .44)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
41	.056	.099	.27	.032
42	.054	.095	.27	.030
43	.053	.091	.26	.028
44	.052	.088	.26	.026
45	.051	.084	.25	.024
46	.050	.081	.25	.023
47	.049	.078	.24	.022
48	.048	.075	.24	.020
49	.047	.072	.24	.019
50	.046	.069	.23	.018
51	.045	.067	.23	.017
52	.044	.064	.22	.016
53	.043	.062	.22	.015
54	.042	.060	.22	.014
55	.041	.058	.21	.014
56	.041	.056	.21	.013
57	.040	.054	.21	.012
58	.039	.052	.21	.011
59	.038	.050	.20	.011
60	.037	.048	.20	.010
61	.037	.047	.20	.0097
62	.036	.045	.19	.0092
63	.035	.044	.19	.0088
64	.034	.042	.19	.0083
65	.034	.041	.19	.0079
66	.033	.040	.18	.0075
67	.032	.038	.18	.0071
68	.032	.037	.18	.0068
69	.031	.036	.18	.0065
70	.030	.035	.18	.0061
80*	.025	.026	.16	.0038
90	.021	.020	.14	.0025
100	.017	.015	.13	.0016
110	.014	.012	.12	.0011
120	.012	.0096	.11	.00077
180	.0050	.0030	.073	.00012
240	.0024	.0012	.054	.00003
300**	.0013	.00059	.042	.00001

*Extrapolated beyond time = 71.0 min.
**For times greater than 300 min., use last line of table.

Table 2.1.9-6

Group 6, Parameter Estimates from Fit of Lognormal Function
(N = 82, Mean = -.93, Standard Deviation = .38)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1*	.0045	.0074	.024	.0022
2**	.00061	.00064	.0042	.00010

*Extrapolated beyond time = 0.68 min.
**For times greater than 2 min., use last line of table.

Table 2.1.9-7

Group 8, Parameter Estimates from Fit of Lognormal Function
(N = 24, Mean = .58, Standard Deviation = .52)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.062	.87	.95	.70
2	.081	.71	.84	.53
3	.084	.58	.73	.41
4	.083	.49	.64	.33
5	.081	.41	.57	.27
6	.079	.35	.52	.22
7	.076	.31	.47	.18
8	.074	.27	.43	.15
9	.071	.24	.40	.13
10	.068	.21	.37	.11
11	.066	.19	.35	.092
12	.063	.17	.33	.079
13	.060	.15	.31	.068
14	.058	.14	.30	.059
15	.056	.13	.28	.052
16	.053	.12	.27	.046
17	.051	.11	.26	.040
18	.049	.098	.24	.036
19	.047	.091	.23	.032
20	.045	.084	.22	.028
21	.043	.078	.22	.025
22	.042	.072	.21	.023
23	.040	.067	.20	.020
24	.038	.063	.19	.018
25	.037	.059	.19	.017
26	.036	.055	.18	.015
27	.034	.052	.18	.014
28	.033	.048	.17	.012
29	.032	.046	.17	.011
30*	.031	.043	.16	.010
31	.029	.040	.16	.0094
32	.028	.038	.15	.0086
33	.027	.036	.15	.0079
34	.026	.034	.15	.0073
35	.026	.032	.14	.0067
36	.025	.031	.14	.0062
37	.024	.029	.14	.0057
38	.023	.028	.13	.0053
39	.022	.026	.13	.0049
40	.022	.025	.13	.0046
41	.021	.024	.12	.0042

*Extrapolated beyond time = 29.3 min.

Table 2.1.9-7 (Continued)

Group 8 Cont., Parameter Estimates from Fit of Lognormal Function(N = 24, Mean = .58, Standard Deviation = .52)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
42	.020	.023	.12	.0039
43	.020	.022	.12	.0037
44	.019	.021	.12	.0034
45	.018	.020	.11	.0032
46	.018	.019	.11	.0030
47	.017	.019	.11	.0028
48	.017	.017	.11	.0026
49	.016	.017	.11	.0024
50	.016	.016	.10	.0023
51	.015	.015	.10	.0021
52	.015	.015	.10	.0020
53	.014	.014	.098	.0019
54	.014	.014	.096	.0018
55	.014	.013	.095	.0017
56	.013	.013	.093	.0016
57	.013	.012	.092	.0015
58	.012	.012	.090	.0014
59	.012	.011	.089	.0013
60	.012	.011	.087	.0012
61	.012	.010	.086	.0012
62	.011	.010	.085	.0011
63	.011	.0097	.083	.0011
64	.011	.0094	.082	.0010
65	.010	.0090	.081	.00095
66	.010	.0087	.080	.00090
67	.0098	.0084	.078	.00085
68	.0096	.0082	.077	.00081
69	.0094	.0079	.076	.00077
70	.0091	.0076	.075	.00073
80	.0072	.0056	.066	.00045
90	.0057	.0042	.059	.00029
100	.0046	.0032	.053	.00019
110	.0038	.0025	.048	.00013
120	.0032	.0020	.043	.00009
180*	.0012	.00065	.027	.00002

*For times greater than 180 min., use last line of table.

Table 2.1.9-8

Group 10, Parameter Estimates from Fit of Lognormal Function
(N = 8, Mean = .16, Standard Deviation = 1.01)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.14	.56	.80	.30
2	.14	.44	.71	.21
3	.14	.38	.66	.16
4	.13	.33	.62	.13
5	.13	.30	.59	.11
6	.13	.27	.57	.094
7	.12	.25	.55	.082
8	.12	.23	.53	.073
9	.12	.22	.52	.065
10	.12	.20	.51	.059
11	.11	.19	.50	.053
12	.11	.18	.49	.049
13	.11	.17	.48	.045
14	.11	.16	.47	.041
15	.10	.16	.47	.038
16	.10	.15	.46	.035
17	.10	.14	.45	.033
18	.099	.14	.45	.031
19	.097	.13	.44	.029
20	.095	.13	.44	.027
21	.094	.12	.43	.026
22	.092	.12	.43	.024
23	.091	.12	.43	.023
24	.089	.11	.42	.022
25	.088	.11	.42	.021
26	.087	.11	.42	.020
27*	.085	.10	.41	.019
28	.084	.10	.41	.018
29	.083	.098	.41	.017
30	.082	.096	.40	.016
31	.081	.093	.40	.016
32	.080	.091	.40	.015
33	.079	.089	.40	.014
34	.078	.087	.39	.014
35	.077	.085	.39	.013
36	.076	.083	.39	.013
37	.075	.081	.39	.012
38	.074	.080	.38	.012
39	.073	.078	.38	.011
40	.072	.076	.38	.011
41	.071	.075	.38	.011

*Extrapolated beyond time = 26.9 min.

Table 2.1.9-8 (Continued)

Group 10 Cont., Parameter Estimates from Fit of Lognormal Function(N = 8, Mean = .16, Standard Deviation = 1.01)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
42	.071	.073	.38	.010
43	.070	.072	.38	.0099
44	.069	.071	.37	.0096
45	.068	.069	.37	.0093
46	.067	.068	.37	.0090
47	.067	.067	.37	.0087
48	.066	.066	.37	.0084
49	.065	.065	.37	.0082
50	.065	.063	.36	.0080
51	.064	.062	.36	.0077
52	.063	.061	.36	.0075
53	.063	.060	.36	.0073
54	.062	.059	.36	.0071
55	.062	.059	.36	.0069
56	.061	.058	.36	.0067
57	.060	.057	.36	.0065
58	.060	.056	.35	.0064
59	.059	.055	.35	.0062
60	.059	.054	.35	.0060
61	.058	.053	.35	.0059
62	.058	.053	.35	.0057
63	.057	.052	.35	.0056
64	.057	.051	.35	.0054
65	.056	.051	.35	.0053
66	.056	.050	.35	.0052
67	.055	.049	.35	.0051
68	.055	.049	.34	.0050
69	.054	.048	.34	.0048
70	.054	.047	.34	.0047
80	.050	.042	.33	.0038
90	.047	.038	.33	.0031
100	.044	.034	.32	.0026
110	.041	.031	.32	.0022
120	.039	.028	.31	.0019
180	.029	.019	.29	.00089
240	.023	.014	.28	.00051
300	.019	.011	.27	.00032
360	.016	.0087	.26	.00022
420	.014	.0073	.26	.00015
480	.013	.0062	.25	.00011
540	.011	.0054	.25	.00009

Table 2.1.9-8 (Concluded)

Group 10 Cont., Parameter Estimates from Fit of Lognormal Function(N = 8, Mean = .16, Standard Deviation = 1.01)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
600	.010	.0047	.25	.00007
660	.0092	.0042	.24	.00005
720	.0084	.0037	.24	.00004
780	.0078	.0034	.24	.00004
840	.0072	.0030	.24	.00003
900	.0067	.0028	.23	.00003
960	.0062	.0026	.23	.00002
1020	.0058	.0024	.23	.00002
1080	.0055	.0022	.23	.00002
1140	.0051	.0020	.23	.00001
1200	.0049	.0019	.23	.00001
1260	.0046	.0018	.23	.00001
1320	.0044	.0017	.22	.00001
1380	.0041	.0016	.22	.00001
1440	.0039	.0015	.22	.00001
1500	.0038	.0014	.22	.00001
1560	.0036	.0013	.22	.00001
1620	.0034	.0012	.22	.00001
1680	.0033	.0012	.22	.00001
1740	.0032	.0011	.22	.00000
1800	.0030	.0011	.22	.00000
1860	.0029	.0010	.22	.00000
1920*	.0023	.00097	.21	.00000

*For times greater than 1920 min., use last line of table.

Table 2.1.9-9

Group 11, Parameter Estimates from Fit of Lognormal Function
(N = 15, Mean = .85, Standard Deviation = .50)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	.039	.96	.99	.78
2	.072	.87	.96	.66
3	.088	.77	.90	.56
4	.096	.69	.85	.48
5	.10	.62	.79	.41
6	.10	.56	.74	.36
7	.10	.51	.70	.31
8	.11	.46	.66	.27
9	.11	.42	.63	.24
10	.10	.39	.60	.21
11	.10	.35	.57	.18
12	.10	.33	.55	.16
13	.10	.30	.53	.14
14	.10	.28	.51	.13
15	.098	.26	.49	.11
16	.096	.24	.47	.10
17	.094	.23	.46	.092
18	.092	.21	.44	.083
19	.090	.20	.43	.075
20	.088	.19	.42	.068
21	.086	.18	.41	.062
22	.084	.16	.40	.056
23	.082	.16	.39	.051
24	.080	.15	.38	.047
25	.079	.14	.37	.043
26	.077	.13	.36	.039
27	.075	.12	.35	.036
28	.073	.12	.35	.033
29*	.071	.11	.34	.030
30	.069	.11	.33	.028
31	.068	.10	.33	.026
32	.066	.097	.32	.024
33	.064	.092	.31	.022
34	.063	.088	.31	.020
35	.061	.084	.30	.019
36	.060	.081	.30	.018
37	.058	.077	.29	.016
38	.057	.074	.29	.015
39	.056	.071	.29	.014
40	.054	.068	.28	.013
41	.053	.065	.28	.012

*Extrapolated beyond time = 28.9 min.

Table 2.1.9-9 (Continued)

Group 11 Cont., Parameter Estimates from Fit of Lognormal Function (N = 15, Mean = .85, Standard Deviation = .50)

Time (min.)	Standard Deviation of Point	Probability of Failure	Upper 95% Confidence Limit	Lower 95% Confidence Limit
42	.052	.062	.27	.012
43	.051	.060	.27	.011
44	.049	.058	.27	.010
45	.048	.055	.26	.0096
46	.047	.053	.26	.0090
47	.046	.051	.26	.0084
48	.045	.049	.25	.0079
49	.044	.048	.25	.0074
50	.043	.046	.25	.0070
51	.042	.044	.24	.0066
52	.041	.043	.24	.0062
53	.040	.041	.24	.0059
54	.039	.040	.24	.0055
55	.038	.038	.23	.0052
56	.038	.037	.23	.0049
57	.037	.036	.23	.0047
58	.036	.035	.23	.0044
59	.035	.034	.22	.0042
60	.034	.033	.22	.0040
61	.034	.032	.22	.0038
62	.033	.031	.22	.0036
63	.032	.030	.22	.0034
64	.032	.029	.21	.0032
65	.031	.028	.21	.0030
66	.030	.027	.21	.0029
67	.030	.026	.21	.0028
68	.029	.025	.21	.0026
69	.028	.025	.20	.0025
70	.028	.024	.20	.0024
80	.023	.018	.19	.0015
90	.019	.014	.17	.00096
100	.016	.011	.16	.00064
110	.014	.0089	.15	.00044
120	.012	.0072	.15	.00031
180	.0051	.0026	.11	.00005
240	.0026	.0012	.093	.00001
300*	.0015	.00060	.079	.00000

*For times greater than 300 min., use last line of table.

Table 2.1.9-10

Group 12, Parameter Estimates from Fit of Lognormal Function*
(N = 4, Mean = 1.02, Standard Deviation = .23)

Time (min.)	Probability of Failure	Time (min.)	Probability of Failure
1	1.00	28	.029
2	1.00	29	.025
3	.99	30	.022
4	.97	31	.019
5	.92	32	.016
6	.86	33	.014
7	.78	34	.012
8	.70	35	.010
9	.62	36	.0088
10	.54	37	.0076
11	.46	38	.0066
12	.40	39	.0058
13	.34	40	.0050
14	.29	41	.0044
15**	.25	42	.0038
16	.21	43	.0033
17	.18	44	.0029
18	.15	45	.0025
19	.13	46	.0022
20	.11	47	.0020
21	.091	48	.0017
22	.077	49	.0015
23	.065	50	.0013
24	.056	51	.0012
25	.047	52	.0010
26	.040	53***	.00092
27	.034		

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*There were insufficient data to generate meaningful estimates of the standard deviation of the point and the 95 percent confidence limits. It is recommended that an error factor of 10.0 be used with the values in this table.

**Extrapolated beyond time = 14.3 min.

***For times greater than 53 min., use last line of table.

3.0 CONCLUSIONS

Using the data-based methodology developed in Volume 1, this report (Section 2) provides a step-by-step methodology for incorporating operator recovery actions into a PRA. As with any methodology, both strengths and areas for improvement exist. The strengths are discussed below.

Data-Based

The time reliability curve for each group of operator actions is based upon time data gathered from simulator exercises. These simulator exercises were developed from preliminary results of a PRA and, as such, are based on accident sequences that could be important in the PRA. The use of accident scenarios identified by the PRA provided realism in the simulation and provided a means of obtaining time data on operator recovery actions which were thought to be important to the PRA.

Identification of Recovery Actions

The simulator exercises allows for the determination of possible recovery actions that are based on the operators' ingenuity, training, and his procedures. Use of simulator exercises does not limit the recovery actions to those that can be identified by the PRA analyst or to the HRA expert.

As with any methodology, areas for improvement exist. Areas for improvement to this methodology are discussed below. It should be noted that many of these areas for improvement are inherent to all recovery methodologies.

Limited Data

The diagnosis failure probabilities for each group of actions are based upon a limited number of data points from a specific plant. The time reliability curves from which the diagnosis failure probabilities are obtained would be strengthened if more data were available from a wider variety of accident scenarios and from other plants (operators).

Stress

Stress is implicitly modeled in the methodology. Evidence of stress responses in the crew members included such things as high involvement (running to accomplish actions), impatience (asking whether requested actions had been accomplished), perseveration (repeating the same unsuccessful action more than once), and obvious physical fatigue. The question is how would the stress generated by a simulated environment compare with the stress of an actual accident situation?

Action Times Uncertain

The amount of time it takes to physically accomplish the action decided upon by the operators is uncertain. The amount of time necessary depends upon such things as: the location of the action, the time of day during which the action must be accomplished, the number of people available, and the action itself, etc. All of these introduce uncertainty into the estimation of the action time. This uncertainty is not limited to this methodology, but exists for any methodology that requires action times to be estimated.

Maximum Time Available for Recovery Uncertain

The maximum amount of time available to the operators to accomplish the recovery action is generally determined from thermohydraulic calculations and from equipment failure times. Each of these introduce uncertainties. Depending on how conservative the thermohydraulic calculations and equipment failure times are, the maximum time available for recovery changes. This change can affect the overall operator failure probability. Since all operator recovery actions depend on the amount of time available for the recovery action, this limitation exists for all operator recovery models.

Long Time Frame Recovery Actions

Some recovery actions need not be accomplished for long periods of time. Simulating accidents with these types of actions would be unrealistic. This implies that data for actions that are similar to the long-term action must be used so that extrapolation to the long term can be made. This presents problems to all methodologies that consider long time frame recovery actions. (See Section 2.1.9 for discussion on how to handle this problem.)

Given the strengths of this recovery methodology and the fact that many of the areas for improvement discussed in this section are inherent to all recovery methodologies, the methodology developed by this project was used in the Risk Methods Integration and Evaluation program.

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13. ABSTRACT (200 words or less)

In a Probabilistic Risk Assessment (PRA) for a nuclear power plant, the analyst identifies a set of potential core damage events and their estimated probabilities of occurrence. These events include both equipment failures and human errors. If operator recovery from an event within some specified time is considered, the probability of this recovery can be included in the PRA.

This report provides PRA analysts with a step-by-step methodology for including recovery actions in a PRA. The recovery action is divided into two distinct phases: a Diagnosis Phase (realizing that there is a problem with a critical parameter and deciding upon the correct course of action) and an Action Phase (physically accomplishing the required action). In this methodology, time-reliability curves, which were developed from simulator data on potentially dominant accident scenarios, are used to provide estimates for the Diagnosis Phase, and other existing methodologies are used to provide estimates for the Action Phase.

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