EVALUATION OF THE USE OF ENGINEERING JUDGMENTS APPLIED TO ANALYTICAL HUMAN RELIABLITY ANALYSIS (HRA) METHODS

A Thesis

by

KATHERINE D. KOHLHEPP

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2005

Major Subject: Nuclear Engineering

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Approved by:

Chair of Committee,	William E. Burchill
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ABSTRACT

Evaluation of the Use of Engineering Judgments Applied to Analytical Human Reliability Analysis (HRA) Methods. (December 2005)

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Chair of Advisory Committee: Dr. William E. Burchill

Due to the scarcity of Human Reliability Analysis (HRA) data, one of the key elements of any HRA analysis is use of engineering judgment. The Electric Power Research Institute (EPRI) HRA Calculator™ guides the user through the steps of any HRA analysis and allows the user to choose among analytical HRA methods. It applies Accident Sequence Evaluation Program (ASEP), Technique for Human Error Rate Prediction (THERP), the HCR/ORE Correlation, and the Caused Based Decision Tree Method (CBDTM). This program is intended to produce consistent results among different analysts provided that the initial information is similar. Even with this analytical approach, an HRA analyst must still render several judgments. The objective of this study was to evaluate the use of engineering judgment applied to the quantification of post-initiator actions using the HRA Calculator. The Comanche Peak Steam Electric Station (CPSES) Level 1 Probabilistic Risk Assessment (PRA) HRA was used as a database for examples and numerical comparison. Engineering judgments were evaluated in the following ways:

1) Survey of HRA experts. Two surveys were completed, and the participants provided a range of different perspectives on how they individually apply engineering judgment.
2) Numerical comparison among the three methods.
3) Review of CPSES HRA and identification of judgments and the effects on the overall results of the database.

The results of this study identified thirteen areas in which an HRA analyst must interpret and render judgments on how to quantify a Human Error Probability (HEP) and recommendations are provided on how current industry practitioners render these same judgments. The areas are: identification and definition of actions to be modeled, identification and definition of actions to be modeled, definition of critical actions, definition of cognitive portion of the action, choice of methodology, stress level, rule-, skill- or knowledge-based designation, timing information, training, procedures, human interactions with hardware, recoveries and dependencies within an action, and review of final HEP.

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NOMENCLATURE

ATHEANA	A Technique for Human Event Analysis
ABN	Abnormal Conditions Procedures
AOP	Abnormal Operating Procedures
ASEP	Accident Sequence Evaluation Program
ASME	American Society of Mechanical Engineers
ATWS	Anticipated Transient Without Scram
AFW	Auxiliary Feed Water
BOP	Balance of Plant
BWR	Boiling Water Reactor
CBDTM	Caused Based Decision Tree Method
CREAM	Cognitive Reliability and Error Analysis Method
CPSES	Comanche Peak Steam Electric Station
CR	Control Room
CRS	Control Room Supervisor
CD	Core Damage
CDF	Core Damage Frequency
DHR	Decay Heat Removal
DF	Dependency Factor
DC	Direct Current
EPRI	Electric Power Research Institute

ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EFW	Emergency Feed Water
EOP	Emergency Operating Procedure
ERF	Emergency Response Facility
ERG	Emergency Response Guidelines
EOC	Error of Commission
EOO	Error of Omission
FLIM	Failure Likelihood Index Method
FSAR	Final Safety Analysis Report
HDT	Holistic Decision Tree
HEP	Human Error Probability
HFE	Human Failure Event
HI	Human Interaction
HRA	Human Reliability Analysis
HSI	Human System Interface
JPM	Job Performance Measures
LWR	Light Water Reactor
LOCA	Loss of Coolant Accident
LD	Low Dependency
MCR	Main Control Room

MFW	Main Feed Water
MLB	Main Line Break
MBLOCA	Medium Break Loss of Coolant Accident
MD	Medium Dependency
MAAP	Modular Accident Analysis Program
NPSH	Net Positive Suction Head
ND	No Dependency
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
OTC	Offsite Technical Center
OSC	Operations Support Center
PSF	Performance-shaping factor
PORV	Power-operated relief valve
PRV	Pressurizer Relief Valve
PWR	Pressurized Water Reactor
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Analysis
RCS	Reactor Coolant System
RO	Reactor Operator
RWST	Refueling Water Storage Tank
RHR	Residual Heat Removal

RNO	Response Not Obtained
SE	Shift Engineer
SS	Shift Supervisor
STA	Shift Technical Advisor
SLC	Standby Liquid Control
SBO	Station Black Out
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SLIM	Success Likelihood Index Method
SPC	Suppression Pool Cooling
TSC	Technical Support Center
THERP	Technique for Human Error Rate Prediction
T-H	Thermal-hydraulic
TRC	Time Reliably Curve
TDFW	Turbine Driven Feed Water
WOG	Westinghouse Owners Group
WCAP	Westinghouse Topical Report

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CHAPTER I

INTRODUCTION

Human Reliability Analysis (HRA) in the context of Probabilistic Risk Assessment (PRA) has been the subject of numerous critical reviews because no one method is considered acceptable and appropriate for all conditions. Each plant-specific HRA represents a highly iterative analytical process. System analysts and human reliability analysts work together to define the operator actions to be modeled in the PRA. HRA methods and techniques must be evaluated in a consistent and logical manner, and there needs to be sufficient analytical resolution so that the plant-specific aspects of the procedures, plant design, and training practices are reflected in representation and quantification of human error probabilities (HEP).[1]

Because human error is dynamic and involves individual and crew experiences, it is challenging to calculate a single failure rate to describe a specific action. It would be ideal to collect the frequency of each human action failure on a large data sample of Nuclear Power Plant (NPP) operators. But, this is impractical because error probabilities are very small, and in any reasonable amount of time not enough errors would occur to collect a meaningful distribution of data points. Thus, actual data of human failures in NPPs is sparse.

With the development of NPP simulators, studies have been completed to try to collect HRA data. In 1990, Electric Power Research Institute (EPRI) conducted the

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This thesis follows the style of *Nuclear Technology*.

"Operator Reliability Experiments Using Power Plant Simulators" which attempted to collect HEP data from simulators.[2] The objectives of this study were two-fold: first, to collect operator response and reliability data using full-scale NPP simulators and actual operating crews and second, to examine the validity of the Human Reliability Correlation for use in HRA.[3] This study examined operator actions in simulators for 40 accident scenarios, and data was collected on timing information and the specific steps taken by the crew. The results provided a small collection of simulator data for specific operator actions, but this is in no way representative of all accident scenarios or all operator actions within a NPP.

Due to the lack of physical HRA data, one of the key elements of any HRA analysis is use of engineering judgment. The application of the engineering judgment can vary between methods and range in the degree of subjectivity. In some instances there will be no actual data available for an analysis, and HRA experts will have to estimate an HEP value based entirely on their experience. Various HRA models have been developed around the use of engineering judgment. Finally, there are HRA methods based on analytical approaches using generic data, but occasionally these methods produce unrealistic results which require adjustment by the use of engineering judgment.

In 1984, Stillwell[4] published a study on generating human reliability estimates using expert judgment. HRA experts were asked to rank a series of tasks based on their estimated importance and then give an estimate of the HEP value and its lower and upper bounds. The ranking and the HEP estimates were compared among experts, and the results showed consistent agreement (same order of magnitude). It was concluded that this was an acceptable solution for gathering HEP data.

Just because experts are consistent in their judgment, does not necessarily mean they are accurately modeling the action. Observations of operators during simulator training exercises have shown that sometimes when scenarios were expected to be routine and easy, the crews find them challenging, while other times complex actions are performed error-free. Furthermore, HRA experts often have to estimate timings for actions, and when observed in the simulator, the timings are often incorrect; or the experts were expecting a different chain of events to occur and the estimated timing is no longer relevant.

Not all HRA methods rely entirely on engineering judgment, the Success Likelihood Index Method (SLIM) and Failure Likelihood Index Method[5] (FLIM) are based on the combination of known anchor values and estimates of the HEP for a particular human action and Performance Shaping Factors (PSF) which are influences that affect the system. The values and weighting of the PSFs are determined by the use of expert judgment.

Analytical HRA methods are the more commonly used methods for the quantification of HEP values. These methods begin by using generic data, not necessary from NPPs, and adjustments are made using PSFs. Widely used methods include, Technique for Human Error Rate Prediction (THERP)[6], ASEP[7], the Caused Biased Decision Tree Method (CBDTM)[8] and the Human Cognitive Reliability/Operator Reactor Experiments (HCR/ORE)[2].

In 1983, Swain and Guttman published the Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications[6] (THERP). This pioneering study laid the foundation for current standards and techniques used in practice today. It presents a methodology that enables analysts to make quantitative or qualitative assessment of the occurrence of human errors that may affect the availability or operational reliability of engineering safety features and components in nuclear power plants. The THERP handbook gives tabulated human failure data from a military facility for potential errors, errors of omission, and errors of commission and gives recommendations on how to adjust these valves for NPPs by the use of a PSF.

The Accident Sequence Evaluation Procedure (ASEP)[7] presents a shortened, less detailed version of THERP which enables analysts to make estimates of HEPs and other performance characteristics that are sufficiently accurate for the needs of PRAs. ASEP begins by categorizing human actions into two categories: pre-accident tasks and post-accident tasks.

Pre-accident tasks are activities done under normal operating conditions including special conditions such as startup operation or other activities that affect the availability of equipment needed to cope with an abnormal event. Pre-accident tasks are synonymous with test and maintenance. The method is based on assigning each critical action a basic HEP equal to .03 and summing over the total number of steps. For each one of the recovery factors present in the action, the basic HEP is multiplied by 0.1. Recovery factors are environmental influences that will alert the operator when an error is committed; examples include alarms and peer checking.

Post-accident tasks are all tasks required to cope with an abnormal event. These tasks can be further divided into diagnosis and post-diagnosis actions. ASEP makes two large simplifications in post-accident tasks. First, it assumes that any failure to diagnose correctly an abnormal event within the allowable time will result in core damage; and second it assumes that the total time available can be segmented into two independent parts: first, the time it takes for operator to diagnose the problem and second, the time it takes him to respond physically.

Both THERP and ASEP rely on the use of generic data for their analysis, other HRA methods have been developed around the use of simulator data. The HCR/ORE correlation used in the calculation of HEP values is one such example. This correlation describes and predicts the operating crew's success probability as a function of time. Unlike THERP and ASEP this model examines the probability of failure for an operating crew as opposed to individual actions. The correlation was first hypothesized then modified to match actual simulator data conducted during the Operator Reliability Experiments.[2]

The CBDTM[8] approach to calculating HEP values is part of the SHRAP1 HRA Frame-work methodology.[3] It is based upon using an event tree as opposed to a fault tree like other methods to describe the action. Failure of the action can be divided into two parts, failure to initiate timely correct response (P_{cog}) and failure to execute the correct response. (P_{exe}).

P_{cog} is intended to predict the average crew behavior. Ideally P_{cog} would be determined by the use of a simulator. If this option is not available, a secondary approach is to determine the potential causes of errors and decompose them into failures associated with plant information-operator interface and failures associated with operator-procedure interface. P_{cog} is then the sum of all these small contributors. EPRI Report TR-100259[8] gives specific decision trees and failure probabilities to be used for decomposing the action.

To determine P_{exe} engineering judgment must be used in considering the following: how the operator interacts with the control panel, quantification of manipulation probabilities, and relevant hardware failures or events. If only a simple switch manipulation is required, the analyst could either reference an available data set or use an ASEP screening value of .003. If the action is more complex the analyst can choose to use a method such as THERP to calculate P_{exe}.

The EPRI HRA Calculator[9] is a computerized tool for HRA analysis. This program guides the user through the steps of any HRA analysis. The program allows the user to choose among analytical HRA methods and applies ASEP, THERP, the HCR/ORE correlation, and CBDTM. The software is intended to produce consistent results among different analysts provided that the initial information is similar.

By using the HRA calculator, or any analytical HRA method, one would expect if the HRA procedures were followed, the end result would be an acceptable and consistent HEP value. This is not always the case, because an analyst must render judgments on many different parameters and small variations in input parameters in some situations can change the final HEP value by several orders of magnitude. In addition, an analyst may apply his personal engineering judgment, because he feel’s that the chosen method does not accurately reflect the action. Other times the final HEP will be adjusted so that it is consistent with an historical value.

This application of engineering judgment is critical in the calculations of HEP values, and it has been accepted and is practiced by HRA analysts. However, there has been little research done to determine its acceptability and consistency among experts. Furthermore, little guidance is available for when or how to apply this subjective judgment.

OBJECTIVE

The objective of this study is to evaluate the use of engineering judgment applied to the quantification of post-initiator actions using the EPRI HRA Calculator^{TM} (From this point forward the EPRI HRA Calculator^{TM} will be referred to as the HRA Calculator) The Comanche Peak Steam Electric Station (CPSES) Level 1 PRA HRA was used as a database for examples and numerical comparison. Engineering judgment was evaluated in the following ways:

1) Survey of HRA experts. These experts provided a range of different perspectives on how they individually apply engineering judgment.
2) Numerical comparison among the three methods.
3) Review of CPSES and identification of judgments and the effects on the overall results of the database.

This study primarily focuses on judgments made within the context of the using the HRA Calculator. It addresses issues such as choice of stress level, and identification of rule, skill or knowledge based actions, training, and clarity of procedures. The endpoint of the judgment evaluation is defined to be the point at which a value has been quantified by HRA Calculator. External to the HRA Calculator the user may determine the value calculated by the HRA Calculator is not acceptable, but this decision making process is outside the scope of this project. The intended results of this study will aid in the development of guidelines for HRA Calculator users.

LENS MODEL OF JUDGMENT APPLIED TO ANALYTICAL HEP CALCULATIONS

The lens model of judgments developed by Parkin[10] in 1996 presents a logical well-suited model for understanding the use of engineering judgment in analytical HEP calculations. This model suggests that we do not perceive the essence of an object or a situation but rather a number of 'cues' received by our cognition.

> "An object may be judged to be a table as a result of our integration of cues such as color, mass, function, and other cues we have come to associate over time with tables. These measurable cues may be seen and interpreted correctly by most observers. However, when we are contemplating ambiguous social situations, no such agreement is likely. The cues tend to be ill- defined, complex, and entangled and not easily interpreted by our cognition. In response, our cognition will only register a few of the numerous available cues. This lens of cues bares only a statistical relationship with attributes of the situation we are contemplating and, therefore, have less than 100% validity as a basis for judgment. Each individual will perceive different cues and interpret them differently but luckily the cues that can be perceived are normally interrelated, and therefore a high redundancy will exist within the lens of cues. This redundancy reduces the effect of differential selection and weighting of cues and makes many judgments rather robust." [10]

This same approach to judgment is observed in the engineering judgment applied to HEP calculations. The lens would be the HRA analyst and the analytical HRA framework that he has chosen to use. The cues can be thought of as input parameters such as stress level, timing information, procedures, training, method chosen and so forth. When each parameter is examined external to any HEP calculation, most HRA experts will identify the same parameters as influences on the human failure probability. However, when the HRA analyst is asked to calculate a specific HEP value for a single human failure event, there tends to be large discrepancy on how to interpret and quantify each of these parameters. When examining the different results from different analysts, this becomes quite obvious, because the parameters used by analysts were weighted differently. However, the end results show that most analysts can agree within the same order of magnitude for any HEP calculation.

Among HRA analyses, not only are there different HRA analysts, but there are also different methodologies. The information is not only filtered by the analysts, but it is also filtered by the quantification method. The HRA Calculator has attempted to remove the filter around the quantification stage, but the analyst must render judgments on how to input parameters.

The lens model is simplistic in design, and it has been demonstrated that cognitive information is primarily completed within the short-term memory, and short-term memory has limited capacity. It has been found that short-term memory can only manipulate up to approximately seven ‘chunks’ of information at any one time. This corresponds rather nicely to the lens model. [11]

HEP calculations can be broken up into ‘chunks’ of information as well. For any HEP calculation there are eight broad areas that the HRA Calculator requires the user to address as input parameters. These cues or ‘chunks’ of information are required for each calculation regardless of which method is used. How the information is used is dependent upon the method chosen. shows how chunks of information relate to the field of HRA.

HRA analyses are seldom completed by a single analyst, and each analyst has his own personal biases that affect cue selection. Mullen and Roth have identified the following five biases for cue selections,[12] and these can be observed in the quantification of input parameters for HEP calculations. (See Table 1)

Identification of these biases in use of engineering judgment is useful in understanding how an HRA analyst renders judgment in an HEP calculation. These theories suggest that is not possible for any two HRA analysts to render identical judgments for an entire analysis, but it does suggest that if the framework for the judgments are the same, then the HRA analyst will arrive at the same overall conclusions. (See Table 2) In the field of HRA this is typically all that is expected because of the limited data availability to benchmark results. For any calculation an analyst must determine an estimate for a human failure event in a consistent, well-justified, logical format, and this study is intended to create a framework for this process.

Table 1

How HRA Relates to the Len Models Groups (‘Chunks’) of Information

Procedures	The analyst must identify both the procedures the operators will be using during an accident scenario, and then judge clarity of the procedures.
Complexity of the actions	The analyst needs to categorize each action in terms of rule- based, skill-based or knowledge-based. In addition, he must judge whether the execution and cognitive portions of the action are simple or complex
Stress levels	The analyst must choose a stress level of optimal (low), moderate, or high for each action.
Operator cues	The analyst needs to determine what physical cues the operators will receive and use to identify the problem. These include cues such as reactor trip alarm or pressurize water level dropping alarms.
Timing information	Before beginning any calculation, the analyst must determine that there is enough time available to complete the action before core damage will occur. If there is not enough time to complete the action, then obviously the action will be failed, and it is not necessary to do further calculations. In addition, the analyst must determine how long it will take the operators to execute the action and if there is a time delay between the start of the accident and the control room cue the operators would receive.
Training	The analyst must identify how many times a year an action is trained in a simulator and in the classroom.
Dependencies	The analyst needs to determine a dependency level for each critical action. The choices available within the HRA Calculator are: zero dependence, low dependence, moderate dependence, high dependence or complete dependence. The HRA Calculator provides recommendations for dependence levels based on time available, but the analyst has the option to override this function.
Recoveries within an action	The analyst must identify recovery steps listed in procedures and if additional people will be available to aide in the recovery of the scenario.

Table 2

How HRA Is Related to Mullen and Roth's Personal Basis That May Affect Cue Selection [12]

Cue	How It Related to HRA
Availability "If data is easily retrievable, it may cause us to put too much weight on associated cues."[12]	This is observed in HEP calculations in the parameter of timing. If an analyst has access to timing from thermal-hydraulic computer codes, he may use this to obtain exact timing on how long the operator has to complete an action before core damage can occur. Another analyst may not have access to thermal-hydraulic codes, but instead he is able to observe the action in a simulator to determine timing information. The end result is that both analysts have collected timing information but from two different sources, and more than likely the timings are not numerically identically.
Selective perception "Your role will, to a large extent, determines what cues you perceive."[12]	The HRA analyst's background will influence the weighting of certain parameters. For example, a HRA analyst with a background in operations may put more weight on operator interviews as opposed to someone with a background in thermal-hydraulics. Another example would be an analyst who has developed his own HRA methodology. In this case, he may be more confident in his method and be less likely to use an unfamiliar method.
Concrete information "We are more likely to value information derived from past experiences or those from a trusted colleague"[12].	This can be observed in HRA when analysts compare the results to historical values. Even if the original analysis was not well-documented and the historical value is hard to justify using current practice today, many analysts will try to adjust the current calculations to show better agreement with the historical values.
Wishful thinking "Our personal preference may inflate the importance of a cue beyond its real significance"[12].	In the nuclear industry failure of any type is not accepted by the public. If a nuclear accident were to occur, even if there were no risk to the public, the U.S. power industry would suffer serious consequences. This mindset is carried over to the calculations of human failure probabilities. Every U.S. NPP stresses the importance of operator training and spends a great deal of money and effort developing state-of-the art training. Many HRA analysts, especially those who participate in the training programs, may judge the operator training as excellent in every circumstance and consequently over-weight this parameter in HEP calculations.
Halo effect "This is the effect of one particular cue on another –one cue casts a halo over the others. We tend to experience cues in clusters such that one thing goes with another, so that we tend to reject or rationalize any cue that appears to contradict the consistent set"[12].	Typically as the accident progress, the crew's stress level will increase, because they will be frustrated by the fact that their first reactions did not fix the problem. This would be the cluster of cues that one would expect to observe. As time passes, the crew may be proceeding in the correct direction, but there is very little time available before core damage. The analyst may conclude the action will always fail. This may not necessarily be the case, but because the analyst has identified timing as the dominate parameter in this action, and he has rejected all other cues that may lead to success.

CHAPTER II

OVERVIEW OF THE HRA CALCULATOR

The HRA Calculator provides a standardized approach to HRA that promotes uniform methods to achieve comparable results when considering plants that are similar in design, procedures and training. Users of the HRA Calculator belong to the EPRI HRA/PRA Tools User Group. This group currently consists of 19 utilities, three corporate members and two international members. The users work together to aid in the development of the software tool and to achieve a common industry approach to HRA that will assure high marks in PRA reviews and is consistent with the ASME PRA Standard[13].

The software is setup to guide the user through an HEP calculation by interactive windows and is based upon SHARP1[3] for Human Failure Events (HFEs). While the HRA Calculator provides many choices for input values, the user also can add his own input values and comments for documentation.

The user can choose from the following three HRA methods to quantify P_{cog} for post-initiator actions: 1) CBDTM Method, 2) THERP, and 3) ORE/HRC Correlation. For pre-initiators the methods available are THERP and ASEP. (This study is only concerned only with post-initiator actions.)

These methods were selected in the development of the HRA Calculator, because in 2000 the HRA Calculator developers believed that these were the most commonly used methods among U.S HRA analysts for Light Water Reactors (LWR). These methods offer an analytical approach that follows a defined set of steps. Other methods rely more on an approach based around the use of engineering judgment. One of the goals of any HRA analyst must be to produce consistent and acceptable HEP results, and by using one of the methods within the HRA Calculator the user has the best chance of meeting this objective.

The HRA Calculator has the capability of modeling the following types of actions (See Table 3) as defined by SHARP1.

Table 3

SHARP 1 Types of Actions Modeled by the HRA Calculator

Type –A		Pre-initiating event interactions
Type –B		Initiating event related interactions
Type – C		Initiating event interactions
	Cp	Interactions that are dictated by operating procedures
	Cr	Interactions that are dictated by recovery of equipment that has failed earlier in the sequence.

In the current configuration the program is best equipped to handle Type A and C actions. Type B actions would to be difficult to model, because there is no ideal place to document the sequence of events that follows an initiating event. However, these types of actions tend not to be explicitly modeled in PRAs. Instead, the impact of theses events is explicitly accounted for within initiating event frequencies. The user is explicitly asked to distinguish between Type A and Type C actions, and this choice influences the other information that is required to complete the calculations.

The user must further separate Type C actions into control room and ex-control room actions. In version 2.0 of the HRA Calculator, there is no mathematical difference between control room and ex-control room actions. For post-initiator actions the user must identify for documentation purposes where the actions take place. Because there is no mathematical difference between control room and ex-control room actions, the user could be creative and adjust other input parameters such as stress and timing information to reflect the location of the actions. If this is done, it must be well-documented so that the final result is justifiable during peer review.

Once the action has been defined, the user must identify a method for quantification. The HRA Calculator breaks every HEP calculation into two parts: failure to execute the action correctly (P_{exe}) and failure to recognize the need for human intervention and determine the correct action to take (P_{cog}). P_{exe} is calculated using the traditional THERP method regardless of the method chosen, and P_{cog} will vary among methods used.

PROBABILITY OF EXECUTION FAILURE (P_{exe})

To calculate P_{exe} the user is asked to identify each critical action, a task that if failed would lead to core damage. Each critical action is then assigned an error of omission and an error of commission. These failure probabilities come from THERP with some modifications based on recommendations stated in THERP on how to account for exceptionally well-written procedures.[6,9] Each error of omission and error of commission is then multiplied by a PSF based upon the stress level chosen (Table 4).

Table 4

Stress Levels and Corresponding PSF Applied by THERP and HRA Calculator[6,9]

Stress Level	PSF
Optimal (low) Stress	1
Moderate Stress	2
High Stress	5

These new errors of omission and errors of commission are related by an OR gate to obtain the unrecovered probability of failure.

$$P(AUB) = P(A) + P(B) \quad [1]$$

Next, the analyst must identify steps within the procedure that could act as recoveries and assign a dependency level to each. The HRA Calculator provides a minimum recommendation level based on time available for recovery as shown below in

Fig. 1.

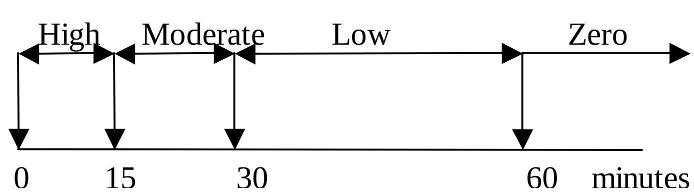

Fig. 1 Time Available for Recovery as It Relates to the HRA Calculator Recommended Minimum Dependency Level [9,14]

From the chosen dependency level the HRA Calculator calculates the conditional probabilities between the recovery and the critical action using the formulas described in Table 5.

Table 5

Quantitative Interpretation of Qualitative Dependence Levels [6, 15]

Dependence Level	Formula	Minimum Conditional Probability
Complete	$P(A \wedge B) = P(A)$	1.0
High	$P(A \wedge B) = P(A)\left[\frac{1 + P(B)}{2}\right]$	0.5
Moderate	$P(A \wedge B) = P(A)\left[\frac{1 + 6 \bullet P(B)}{7}\right]$	0.14
Low	$P(A \wedge B) = P(A)\left[\frac{1 + 19 \bullet P(B)}{20}\right]$	0.05
Zero	$P(A \wedge B) = P(A) \bullet P(B)$	P(B)

To obtain the final execution probability the conditional probabilities are again related by an OR gate.

PROBABILITY OF COGNITIVE FAILURE (P_{cog}) USING ANNUNCIATOR RESPONSE MODEL

The Annunciator Response Model comes from THERP[6] and provides a simple approach to model cognitive failure. In this model the user selects P_{cog} from a table of failure probabilities based on the number of annunciators present in the control room. As the crew receives more alarms, the probability of success will decrease. THERP has defined an annunciator as a set of alarms that trained operators regard as a single unit. Table 6 gives the tabulated values for the choices of P_{cog} using the Annunciator Response Model.

Table 6

Tabulated P_{cog} Values Using Annunciator Response Model [9]

	Order in which operator responds												
Total Number of Ann.	1	2	3	4	5	6	7	8	9	10	Pr[Fj]	EF	Mean
1	1.00E-04										1.00E-04	10	3.00E-04
2	1.00E-04	1.00E-03									6.00E-04	10	1.50E-03
3	1.00E-04	1.00E-03	2.00E-03								1.00E-03	10	3.00E-03
4	1.00E-04	1.00E-03	2.00E-03	4.00E-03							2.00E-03	10	5.00E-03
5	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03						3.00E-03	10	8.00E-03
6	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02					5.00E-03	10	1.40E-02
7	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02				9.00E-03	10	2.40E-02
8	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02			2.00E-02	10	4.00E-02
9	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01		3.00E-02	10	8.00E-02
10	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01	2.50E-01	5.00E-02	10	1.40E-01
11 to 15	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01	2.50E-01	1.20E-01	10	3.10E-01
16 to 20	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01	2.50E-01	1.50E-01	10	4.00E-01
21 to 40	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01	2.50E-01	2.00E-01	10	5.30E-01
> 40	1.00E-04	1.00E-03	2.00E-03	4.00E-03	8.00E-03	1.60E-02	3.20E-02	6.40E-02	1.30E-01	2.50E-01	2.50E-01	10	6.70E-01

In version 2.0 of the HRA Calculator, the user can only select from the mean values given in the last column of Table 1. But, in the newer versions of the HRA

Calculator the user can choose any value listed in the table. The values provided within THERP were for median values with an error factor of ten. The values shown in Table 1 have been converted to mean values for consistency with all other probabilities used within the HRA Calculator.[9] For this method, there is no override function available.

PROBABILITY OF COGNITIVE FAILURE (P_{cog}) USING HCR/ORE CORRELATION

The HCR/ORE correlation uses the following formula derived from simulator data to calculate P_{cog}.

$$P_{cog} = 1 - \Phi[\frac{\ln(\frac{T_w}{T_{1/2}})}{\sigma}] \quad [2]$$

where,

σ = logarithmic standard deviation

$T_{1/2}$ = crew median response time

Φ = standard normal cumulative distribution

$$\frac{1}{\sqrt{2z}} \int_{-\infty}^{z} e^{-\frac{u^2}{2}} du \,. \quad [3]$$

T_w = time window for cognitive response and is calculated by:

where,

$$T_W = T_{SW} - T_M \quad [4]$$

T_{sw} = the total time from the initial event to the point were the action can no longer succeed.

T_M = time required to complete the action

σ represents the variation among different crews in responding to a specific set of cues. Factors that influence σ include: diagnostic difficulty, degree and kind of procedural guidance, level of operator experience, communication among crew members.[15] The HRA Calculator calculates σ using decision trees based on procedures, operator training and stress level. An example of the decision tree is shown in Fig. 2[9] This decision tree was developed as part of the HRA Calculator and presents an alternative to tabulated σ values provided in EPRI Report TR-100259.[8]

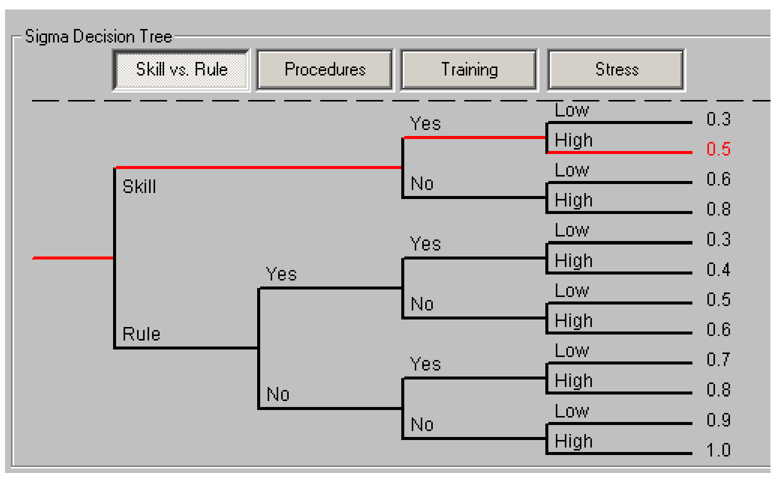

Fig. 2 Decision Tree Used for Determining Sigma Using HCR/ORE Correlation[9]

An assumption behind the decision tree is that following an initiating event, as the accident proceeds further into the response, one can expect to see larger deviations in crew response times. A large σ can be indicative of difficult diagnosis, the need for deriving diagnoses by monitoring annunciators, or use of different response strategies. Thus, σ is an indication of how demanding and stressful the scenario is for the operators.[15]

PROBABILITY OF COGNITIVE FAILURE (P_{cog}) USING CBDTM METHOD

The CBDTM Method calculates P_{cog} by the use of eight decision trees and then applies recovery by identification of time available for recovery and credit for additional personal present in the control room. Table 7 provides the failure mechanisms each tree addresses. The complete set of decision trees is shown in Appendix A. No changes were made between EPRI Report TR-100259 and the HRA Calculator.

Table 7

CBDTM Failure Mechanisms [15]

Type	Decision Tree	Description
Failures in the Operator–Control Room Interface	Pca	Data not available
	Pcb	Data not attended to
	Pcc	Data misread or miscommunicated
	Pcd	Information misleading
Failures in the Operator-Procedure Interface	Pce	Relevant step in procedure missed
	Pcf	Misinterpret instruction
	Pcg	Error in interpreting logic
	Pch	Deliberate violation

The CBDTM Method allows the possibility that there may be time to review and to correct errors in detection, diagnosis, or decision-making related to an interaction.

EPRI Report TR-100259 provides general qualitative guidance on how to apply these recoveries, but the HRA Calculator has defined more specific guidance so that recoveries are applied in a consistent manner. As stated in EPRI Report TR-100259 there are five groups of possible recoveries. For any given human interaction, one or more of these recovery measures may be possible. But the HRA Calculator only allows one recovery per decision tree to be credited. Not only does the HRA Calculator provide recommendations when additional crew can be credited, it provides recommendations on minimum dependency levels. The qualitative scale suggested in THERP is used to define numerically a minimum dependence level, and formulas are the same as those used within P_{exe}. Table 8 gives the times after initiating event the additional people can be credited for recovery of post-initiator actions.

Table 8

Times at Which HRA Calculator Considers Taking Credit for Additional People

Time	**People**
0-15 minutes	Self Review
10 -15 minutes	STA
1 hour	ERF
6 hours	Shift Change

Once P_{cog} and P_{exe} have been calculated, they are related to one another by an OR gate.

ERROR FACTORS

Once a point estimate has been calculated, the HRA Calculator assigns an error factor based on recommendations provided by THERP (See Table 9).

Table 9

Error Factors Applied Within the HRA Calculator[9]

HEP	**Error Factor**
Estimated HEP < 0.001	10
Estimated HEP > 0.001	5
Estimated HEP > 0.1	1

CHAPTER III

IDENTIFICATION OF ENGINEERING JUDGMENTS WITHIN THE HRA CALCULATOR

Both literature and HRA analysts agree that HRA can not be completed without the use of engineering judgments. Before one can understand how to apply the use of engineering judgment, the judgments themselves must be identified. The types of judgments will vary among methods used for quantification. This study has identified the types and locations of engineering judgment a user of the HRA Calculator would need to consider for quantification of post-initiator actions.

The HRA Calculator was developed to fit within the four stages of the SHARP1 HRA framework. Most of the judgments made within the HRA Calculator are made within the Define and the Quantification Stages, and this study will focus primarily in the Quantification Stage.

The following presents a complete list of places where users of the HRA Calculator must render engineering judgments, and the following assumptions should be noted:

- There is not always a one-to-one correlation between the original methodology and the application within the HRA Calculator. Unless otherwise stated, this study refers to the methods as used within the HRA Calculator.
- HRA can consider crew behavior or a single operator behavior. Within this study, it will be assumed that the analysis is focusing on crew behavior unless otherwise stated.

- The judgments identified will numerically effect the HEP calculations. There are some judgments that the HRA Calculator asks the user to render which are used for documentation purposes only.
- The judgments identified are intended for post-initiator actions.

STAGE 1: DEFINE

Within the Definition Stage of HRA the HRA analyst must render the following four categories of judgments.

Identification and definition of actions to model within the HRA Calculator

The first step of an HRA is to identify and explicitly to define which human actions to model using the HRA Calculator. The judgments made in identifying the actions in this stage influence every other decision made in the HRA. Identification of the actions is not completed by a single HRA analyst but comes from discussion with the PRA model developers and understanding the accident sequences. Once the analyst understands the PRA model, only then can the actions be identified as actions that will be quantified using the HRA Calculator.

The next step is to define explicitly each action. For each action the following areas must be addressed:

- Why is the human interaction required?
- How is success of this action defined?
- How does the operating crew interact with the hardware?

- Can this action be acceptably modeled using the HRA Calculator?

Categorization of actions as pre- or post-initiators and grouping actions

By classifying each action as a pre- or post-initiator, the analyst begins to conceptualize how the HEP will be quantified. Based on the definitions of pre- and post-initiators, the distinction between the two is self-evident. An analyst may determine that an action needs to be broken down into small actions so that it can be unambiguously classified, and each analyst has their own method of how to sub-subdivide further each action. Furthermore, the quantification methodology varies significantly between pre- and post-initiators, and this designation needs to be made so that the action can be quantified appropriately.

For a complete HRA there can be several hundred pre-initiator actions, and modeling each action individually will be an overwhelming task for any HRA analyst. A reduction in the number of analyses can be made by grouping similar actions together. Because quantification methods for pre-initiator actions often involve screening probabilities, the grouping of pre-initiators will have little or no effect on the final results. For example, an HRA analyst may decide to group all level transmitter calibrations together. While there are several different types of level transmitters, the same general procedures will be followed, and the choices for errors of commission will be the same. Thus, the final HEPs for all level transmitters will be identical.

The HRA calculator is best suited to handle each pre-initiator separately. The input for documentation tends to be directed toward a single action. Nowhere within the pre-initiator calculations is the user asked to address the issue of grouping events and identifying which actions fall within this group. If a grouping approach is employed the user must document this type of information external to the HRA Calculator.

Within an HRA there are usually less than 100 post-initiators identified for quantification. To reduce the number of independent analyses further, it is not uncommon for analysts to use the same calculation for actions which have different initiating events, but the operators are expected to respond in a similar fashion. This grouping of actions can vary among analysts; and if not clearly stated in the documentation of the calculation, this can lead reviewers to question the similarities between actions with different initiating events.

Definition of critical actions

Within the definition stage it is important for the HRA analyst to identify the critical actions. Within the calculation of P_{exe} the analyst must identify the critical actions and assign a probability of failure to each action. The analyst must identify the procedure being used and the step number which addresses each critical action.

Definition of cognitive portion of the action

Before the cognitive portion of any action can be quantified, it must first be defined. For example, this could be as simple as the operating crew transferring from a general Emergency Operating Procedure (EOP) to a more specific procedure. Another example may include the action of diagnosing the accident by the use of a specific cue in the control room.

Nowhere within the HRA Calculator is the analyst asked to state explicitly the definition of the cognitive action. The analyst's definition will influence every other judgment made within the P_{cog} calculation, and furthermore, the definition many vary among analysts. For each action within the HRA Calculator the user is asked to calculate P_{cog} once. If the analyst identifies that there is more than one P_{cog} action, the analyst would need to break the action into two separate calculations to be quantified using the HRA Calculator.

Within the definition of the cognitive portion of the action, the HRA analyst must identify the cue that will alert the operating crew to perform the specific task. The analyst can use any cue he chooses, and the definition of the cue will influence the choices made about the following parameters: human interactions with hardware, timing and procedures.

Annunciator Response Model

In this model, the cue must be defined as an annunciator; otherwise this model can not be used.

HCR/ORE Correlation

The cue definition will directly effect how T_{delay} and $T_{1/2}$ are calculated, and these values will affect the results of the mathematical correlation.

CBDTM Method

The cue definition will affect the analyst's decisions about the choices made in decision trees: Pca, Pcb and Pcg. Specifically, the definition of the cue will affect how the analyst answers questions about the clarity of control room indicators and clarity of procedures.

The cue definition would also influence the timing sequence of the actions. Based on the timing information, the HRA Calculator gives recommendations of recoveries applied to the results of the CBDTM decision tress.

STAGE 2: QUANTIFICATION

Once the action has been defined, the HRA analyst must employ the use of engineering judgment several more times in order to quantity each HEP, and these judgments will vary among methods. Within the quantification stage the HRA analyst must render the following judgments.

Choice of methodology

The HRA Calculator allows the user to choose among the THERP, ASEP, CBDTM, and HCR/ORE methods for post-initiator events and THERP and ASEP for pre-initiators. When choosing which method to use the HRA analyst must consider and judge some of the following parameters: ease of use, data required for the type of actions being modeled, and traceability of the final results. The analyst must also decide if one method will be used for the entire analysis, or the method will vary among actions.

Stress level

The HRA Calculator requires the user to identify the stress level of the operating crew. It requires that the stress level be judged as optimal (low), moderate or high. Once the analyst chooses the stress level, the HRA Calculator gives recommendations (the user can override any of these options) on other parameters such as recoveries and dependencies. Twice within any post-initiator calculation the user is required to identify a stress level, first for the calculation of P_{cog} and second for the calculation of P_{exe}.

Within the calculation of P_{exe}, the user must identify the stress level for each critical action, and this decision influences the results of P_{exe} as a PSF. One would typically expect that the stress level for each critical action would be the same, but the user can vary the stress level among actions.

Within the calculation of P_{cog} the choice of stress level influences the results differently depending on the method used. Regardless of method chosen, the user is required to determine a stress level.

Annunciator Response Model

Stress level is not explicitly used in the calculation of P_{cog} within the Annunciator Response Model and is for documentation only. The user may, however, implicitly consider stress level when selecting a probability to represents the probability of failure due to the number of annunciators present. As more alarms begin to sound in the control room, the stress level of the operating crew may increase and, thus, increase the probability of cognitive failure.

HCR/ORE Correlation

Stress level choices influence the determination of sigma using the HCR/ORE correlation. Fig. 2 (Shown in Chapter II - HCR/ORE section) shows that stress level is the last branch of the decision tree, and the user must identify the stress level as high or low. Prior to reaching this screen within the HRA Calculator the user was asked to determine stress level, and the choices were optimal, moderate or high. In the determination of sigma there is no option for moderate stress, unless the override function is used. The analyst must apply judgment on how to handle a moderate stress choice made in the previous steps. For example, if the user determines a moderate stress level, he could interpolate between high and low stress results of the decision trees.

CBDTM Method

Using the CBDTM method the HRA analyst again must determine a stress level as optimal, moderate or high for documentation. Within the eight decision trees of the CBDTM the question of stress level is never explicitly addressed. This method does address issues that should implicitly affect stress levels such as training and clarity of the procedures. By close examination of the decision tress one can observe that in many cases the same branches of the decision trees could be used for both high stress and low stress actions. For example, the analyst may decide the overall action is high stress because there are only a couple of minutes available to complete the action. In the decision trees he has justified that there is a low work load and only monitoring of the control panel is required. These same choices could be made for low stress actions where there was a larger amount of time available. Decisions made within the CBDTM decision trees are not effected by timing information.

Rule-, skill-, or knowledge-based designation

For every HEP calculation the HRA Calculator user is asked to classify each action as rule-based, skill-based, or knowledge-based for documentation. Only within the HCR/ORE Correlation does this parameter have a numerical effect. Within the HCR/ORE Correlation the user must define the action as rule- or skill-based. If an action is determined to be knowledge-based, the user would have to consider extrapolating the results produced by skill-based or rule-based actions. This parameter has no effect on the calculation of P_{exe} but may influence P_{cog}.

Annunciator Response Model

The Annunciator Response Model in not influenced by categorizing the actions as rule- or skill-based.

HCR/ORE Correlation

Classification of actions as rule-based or skill-based influences the calculation of sigma in the HCR/ORE correlation, as shown in Fig. 2. (Shown in Chapter II - HCR/ORE section) Knowledge-based actions are not considered within the sigma calculation. If the analyst determines that the action is knowledge-based in the documentation section, for consistency he must then apply additional judgment to extrapolate a final sigma value.

CBDTM Method

The classification of rule-based and skill-based actions has no numerical effect on the results of the CBDTM method. However, this many implicitly affect the results of the decision tree, failure of attention. Within this tree the analyst is ask to distinguish between high and low workloads, and one way the analyst may make this decision is to look at the action as a simple skill-based action or a complex rule-based action.

Timing information

Regardless of method used to calculate P_{cog}, the HRA Calculator requires the user to complete the timeline shown in Fig. 3

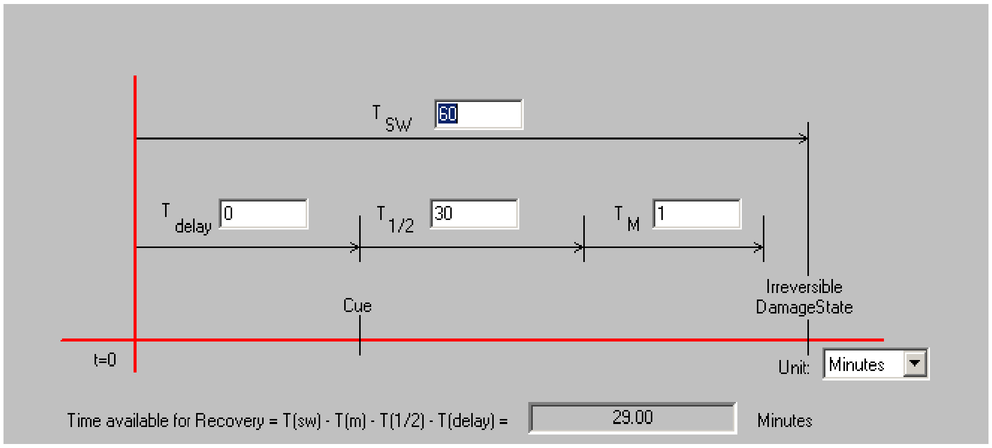

Fig. 3. Timing Diagram

There are three general questions the analyst must answer when completing this diagram.

1) Is there enough timing available to complete the action? If not, the HRA Calculator will not allow the user to proceed.
2) How is the timing information going to be obtained?
3) How accurate does the timing information need to be?

Timing affects the results of P_{cog} differently depending upon method chosen. The numerical inputs into Fig. 3 have no effect on the numerical results when calculating P_{exe}. But the identification of critical actions in P_{exe} will affect the timing values identified. For example, in order to determine the manipulation time the analyst must consider the number of critical actions and how long it takes to complete them individually.

Annunciator Response Model

The identification of the timing information presented in Fig. 3 has no explicit effect on the numerical results of P_{cog} using the Annunciator Response Model. However, probabilities for this method were intended to be interpreted such that as time increases the severity of the accident will also increase. There will be more alarms which the operators will need to address, and additional alarms will lead to an increase in confusion. Thus, as time increases the probability of cognitive failure also increases. This is shown in the tabulated probabilities used within the model.

HCR/ORE Correlation

Timing is the dominating parameter in the HCR/ORE Correlation, especially $T_{1/2}$ and T_w. The HRA Calculator uses Eq 2 to determine P_{cog}.

$$P_{cog} = 1 - \Phi\left[\frac{\ln\left(\frac{T_w}{T_{1/2}}\right)}{\sigma}\right] \qquad [2]$$

where,

σ = logarithmic standard deviation

$T_{1/2}$ = crew median response time

$T_w = T_{sw} - T_m$

Φ = standard normal cumulative distribution

The dominating term in this equation is the ratio of $T_w/T_{1/2}$ and P_{cog} is sensitive to small changes in this ratio. The high degree of sensitivity produces large uncertainty in the calculations of P_{cog}. This is especially true when T_w is very short (less than about 5 minutes).

CBDTM Method

Using the CBDTM method, timing influences the calculation in two areas. First, the HRA Calculator uses the timing information to provide recommendations on considering additional crew who may be available for recovery. The longer the sequence progresses, the more people will become involved, and their presence may be credited in cognitive recovery. In this sense timing has the opposite effect on the P_{cog} compared to the Annunciator Response Model.

The second place timing influences P_{cog} is in answering the questions: is there enough time available to complete the action? Before addressing the decision trees this question must be answered, because the decision trees assume that there is enough time for the crew to complete the action.

Training

For documentation purposes the HRA Calculator requires the user to identify what type of training is completed. The user must identify the training as none, classroom or simulator.

The distinction between simulator training and classroom training should have very little subjectively among HRA analysts. Again for documentation purposes the analyst must identify how often each type of training occurs. This identification of training can be rather subjective. Many times a single action will be discussed within several different training sessions, and the analyst must decide whether to count each discussion as a single training session or only count the total number of training sessions dedicated to the specific action being modeled.

Annunciator Response Model

The Annunciator Response Model is not influenced by the parameter of training, and thus the purpose of defining how often and what type of training is completed is for documentation only.

HCR/ORE Correlation

Using the HCR/ORE correlation, the parameter of training is addressed in the decision tree used to calculate sigma. Fig. 2 (Shown in Chapter 2 - HCR/ORE section) This parameter occurs in the middle of the decision trees, and its impact on the results on P_{cog} can not be independently characterized.

CBDTM Method

Within the CBDTM decision trees, judgments about training are made in the following decision trees:

- Pca – Availability of Information
- Pcd – Information Misleading
- Pcf – Misinterpret Instructions

- Pcg – Misinterpret Decision Logic

In all of the trees the issue of training is a middle or final decision node, and it is difficult to determine what effect a single decision will have on the overall results of the P_{cog} calculations. Within any one tree the decision about training can vary from having no effect on the final tree value to influencing the results from a negligible value to 1E-2.

Procedures

In addition to identifying which procedures will be used during the accident scenario, the HRA analyst must also address the high level question: how does the use of procedures affect the probability of failure? This question can be further broken into small questions with sometimes rather subjective answerers.

- How will the operating crew know to transfer to another procedure if necessary?
- How are the procedures used by the operating crew? Are the actions completed from memory, or are procedures used in hand? How does the clarity of the procedure affect the actions of the operating crew?
- How accurately does the operator or operating crew follow the procedures?

Within the calculation of P_{exe}, the procedures will be used to identify both critical actions and recoveries of the critical actions.

Annunciator Response Model

The annunciator response model is not influenced by the any judgments made about procedures.

HCR/ORE Correlation

Using the HCR/ORE correlation, the judgments made about procedures are again addressed in the decision tree used to calculate sigma. (See Fig. 2 in Chapter 2 - HCR/ORE section) This parameter occurs in the middle of the decision trees, and its impact on the results of P_{cog} can not be independently characterized. It is interesting to note that the judgments made about the procedure use have the same effect as training on the P_{cog} calculation.

CBDTM Method

Table 10 shows the CBDTM decision trees, where analysts must render judgments about procedures. Decisions about procedures and their use during the accident scenario being analyzed are the dominating contributor within the P_{cog} calculation. Within the eight decision trees the analyst must render a total of 10 different judgments. More judgments are made about procedures than any other parameter within the calculation of P_{cog}.

Table 10

CBDTM Decision Trees That Require Judgments About Procedures

Pcd Information Misleading	The user must answer the following question: Are cue states or parameter values as stated in the procedure? A yes response to this question will lead to a negligible probability and will have no effect on the results of $P_{cog.}$
Pce Skip a Step in the Procedure	Every node in this tree is answered by examining the procedures to identify the probability that an operator will skip a critical action stated in the procedure. Within the eight decision trees used to calculate P_{cog} this is the only tree that gives a non-negligible value for every decision path. Therefore, the results of this tree are always a dominating contributor to P_{cog}
Pcf Misinterpret Instructions	Within this tree, there are two nodes addressed by procedures, and the analyst must answer the following questions: o "Does the step include unfamiliar nomenclature or an unusual grammatical construction?"[9] o "Does anything about the wording require explanation in order to arrive at the intended interpretation?"[9] o "Does the proper interpretation of the step require an inference about the future state of the plant? "[9] o "Does the step present all information required to identify the actions?" [9]
Pcg Misinterpret Decision Logic	Three out of the four nodes in this tree address the clarity of procedures. The user must identify if for any critical step there is a NOT, AND, or OR statement which could lead the operating crew to misinterpret the instructions.

Human interactions with hardware

Within the category of human interactions with hardware the HRA analyst must render judgments within the following two broad areas:

1) Errors of Commission (EOC) and Errors of Omission (EOO) – The analyst must render judgment on what the possible errors of commission and errors of omission are and assign a probability of failure to each error. Analysts typically use data from Chapter 20 of THERP for these failure probabilities. There is not always a probability for every action, and the analyst must render judgment on

how to extrapolate the small sample of data to best represent the action under consideration.

2) Control room signals layout and its effect on cognitive failure.

Annunciator Response Model

The Annunciator Response Model is impacted only by this parameter. The analyst must determine how many annunciators the operating crew will observe before they diagnose and respond to the problem. If every action could be observed in a simulator, the analyst would not have to render any judgments as to the exact numbers of annunciators present in the control room. However, this would be extremely time consuming, so analysts typically estimate the number of annunciators. Furthermore, analysts could group alarms together, because they act a single annunciator, and this would affect the total number of alarms each analyst counts.

HCR/ORE Correlation

The HCR/ORE does not explicitly address how the operating crew will interact with hardware. This parameter will be implicitly addressed within the timing information. The analyst can not determine the manipulation time if he is not aware of what type of hardware interactions need to be completed.

CBDTM Method

Within the CBDTM decision trees, judgments about the control room layout and its effect on cognitive failure are made in the following decision trees shown in Table 11

Table 11

CBDTM Decision Trees That Require Judgments About Human Interactions with Hardware.

Pca Availability of Information	The user must determine whether there are indications available to diagnose the accident correctly and then to determine if the indicators are accurate. The indicators could be malfunctioning due to the progression of the accident. If an indicator is determined to be inaccurate, the analyst must address potential recoveries available either by training or procedures by additional decision nodes.
Pcb Failure of Attention	First, the analyst determines whether the work load of the crew is high or low. Then, the analyst must examine whether the control panel needs to be continuously monitored or checked only once.
Pcc Misread/miscommunication	The user must answer the following questions: o “Is the layout, demarcation, and labeling of the control boards such that it is easy to locate the required indicator?” [9] o “Does the required indicator have human engineering deficiencies that are conducive to errors in reading the display?” [9]

A total of six judgments must be rendered within the calculation of $P_{cog.}$ Most of these decision are made in the beginning of trees, and without knowing the failure probabilities of each subsequent node, is not possible to identify how each decision directly affects the results of $P_{cog.}$ But, because there are so many judgments made about human interactions with hardware, it is important to identify and to understand that as a group the judgments impact the results of $P_{cog.}$

Recoveries within the action

The HRA Calculator does not address the issue of recovery actions between individual actions. It does incorporate smaller steps and identification of parameters that may affect the crew's ability to recover within an action. Within the calculation of $P_{exe,}$ the HRA Calculator asks the user to identify steps listed within the procedure that would act as recovery. The analyst must judge what to credit as a recovery step. If too many recoveries are credited, then P_{exe} will be unrealistically low. If no recoveries are credited, then the results will be overly conservative.

Annunciator Response Model

The Annunciator Response Model does not account for any recoveries.

HCR/ORE Correlation

The HCR/ORE Correlation does not account of any recoveries explicitly. This method was developed from actual simulator data, and within the scenarios observed the crew was not restricted in attempting to recover an error.

CBDTM Method

The HRA Calculator asks the user to account for recoveries made by the presence of additional people after completing each decision tree. The more time available to complete the action, the more people may become available for recovery. While there is a minimum amount of time available to allow for additional crew, the user is not required to take credit for any recovery. Also, without using the override function, the user can only take credit for one recovery per decision tree.

Review of final HEP

Once an HEP calculation is complete one final judgment must be rendered. The analyst must address the following two questions about the final HEP value.

1) Is the final value realistic?

2) Does the final value appear to be consistent compared to other actions within the same analysis?

Not only must the final result make physical sense, the analyst may screen both P_{exe} and P_{cog} and render judgments about their individual physical significance.

Annuciator Response Model

When applying the Annuciator Response Model the analyst must simply choose a P_{cog} value from the provided list. The lower bound limit is the lowest possible P_{cog} value (3E-4), and this is considered to be conservative.

CBDTM Method

The CBDTM Method does not apply a lower bound to $P_{cog.}$ However without using the override feature it is unlikely to obtain probabilities below about 1E-8. Applying multiple recoveries to a single action is the primary reason for obtaining unreasonably low P_{cog} probabilities.

HCR/ORE Correlation

Using the HCR/ORE Correlation it is not unrealistic to obtain P_{cog} values of 1E-10. This occurs when relatively long (over 1hour) periods are considered. The HRA Calculator sets a lower bound of 1E-16, and anything below this is considered to be zero.

CHAPTER IV

JUDGMENTS WITHIN THE CPSES DATABASE

To begin this study the Comanche Peak Steam Electric Station's (CPSES) complete HRA for Level 1, full power, post-initiator actions was used as an example database.[16] The purpose of analyzing a complete database was to observe how one renders engineering judgments and to understand the types of judgments actually made within a complete analysis. It was not to critique individual calculations.

The CPSES analysis was completed in 2004 as an update to the 1999 version and performed as part of the PRA update for the entire plant. The HRA Calculator was used exclusively for quantification, and specifically the CBDTM Method was used for every post-initiator action. While there may be discussion about the appropriateness of this method for every action, it does provide consistency within the entire HRA.

This database consisted of 52 post-initiator actions, and Table 12 summarizes the types of actions modeled. The analysis included operator interviews for every action, and a documented MAAP or RELAP calculation was used to determine timing information. The HRA Calculator allows easy documentation of the input parameters, and the analyst did a thorough job of documenting all calculations. Because of the documentation, it was possible to re-calculate the HEP values using different methods without collecting additional information.

Table 12

Summary of Post-Initiator Actions

Post-Initiator Actions	52 Total actions 45 Control room actions 7 Ex-control room actions
Rule-Based Actions	44
Skill-Based Actions	7
Knowledge-Based Actions	1
High Stress Actions	17
Moderate Stress Actions	15
Optimal (Low) Stress Actions	20
Total time for scenario	Ranged from 10 to 4800 minutes
Time required for manipulation	Ranged from 1 to 30 minutes
$T_{1/2}$	Ranged from 3 to 35 minutes

The seven ex-control room actions were excluded from this study, because the sample size and the specific actions chosen do not give a statistical representation of all ex-control room actions. The HRA analyst chose to model only actions for which there was an excessive amount of time available to complete the action i.e.,. more than 90 minutes. If there was a short time available to complete the action, the analyst used a conservative approach and considered the final HEP to be 1.

In addition to the types of ex-control room actions that were chosen, the analyst has identified that the environmental conditions are other than ideal. The HRA Calculator (Version 2.01) does not consider environmental PSFs such as radiation, lighting and temperature explicitly in its numerical algorithms.

Within the CPSES HRA Calculation Notebook, the HRA analyst did document 30 assumptions. Some of these assumptions fit within the twelve areas of judgments (Defined in Chapter III), but others were outside the scope of this study. The complete set of assumptions was used as part of the Pilot survey.

The Pilot survey and the Phase II survey were derived from examination of this database. Also, every action within the database was recalculated using the Annunciator Response Model and the HCR/ORE Correlation to show the numerical comparisons among actions and methods.

STAGE 1: DEFINE

Identification and definition of actions to model within the HRA Calculator

According to the CPSES HRA Calculation Notebook the following approach was taken to identify and to define the actions to be modeled using the HRA Calculator.

> "In general, human interactions were identified and defined as part of the plant response modeling in the accident sequence development and the system models. The human interactions were then classified as pre or post-initiators. The screening analysis used the method developed for the HRA in the IPE.[16]
>
> The post-initiator actions were identified from the system models and the PRA accident sequences analysis. The operator follows the actions specified in the Emergency Response Guidelines (ERGs) and Abnormal Conditions Procedures (ABNs). These operator responses form the bases for each branch in the event trees. Each human interaction event is modeled as having a cognitive and an execution portion. The HRA success criteria follow the event tree success criteria, and are based on a "best-estimate" plant response. While the HRA starts with input from the PRA and deterministic calculations, operator interviews were used to define the human interactions and performance shaping factors.
>
> All post initiator HFEs in the PRA model had their Risk Achievement Worth (RAW) calculated using the PRA current model. To ensure that the risk significant HFEs were included in this recalculation, several risk significant systems had one train removed and then the HFE RAWs were calculated. The HFEs were ranked and the top 30 were recalculated using the HRA calculator. Many HFEs were based on the same calculations so they were recalculated even though they may not have been in the top."[16]

Categorization of actions as pre- or post-initiators

The categorization of actions as pre- or post-initiators was based upon the definitions in SHARP1 for Type A actions (pre-initiators) and Type C actions (post-initiators). Type B actions were not explicitly modeled within the PRA.

The HRA analyst defined three types of pre-initiators to be model using the HRA Calculator.[16]

- Test of safety equipment;
- Maintenance of safety equipment;
- Calibration of safety sensors and actuators.

These three groups were further subdivided into groups according to their path through the CBDTM decision trees. Each subgroup was then modeled only once, and the calculated HEP was used for all actions in the group. For post-initiator actions each action was modeled individually.

Definitions of critical actions

Engineering judgments about how to define critical actions and recoveries were based upon operator interviews, and by direct identification of tasks stated in the procedures. Only critical actions stated in the procedures were credited.

Definition of cognitive portion of the action

During operator interviews the HRA analyst specifically asked the operators to identify a cue for each action. Typically the cue definition was based on a control room alarm or signal to which the crew would respond following steps of an EOP. The cue was defined to be the beginning of the timing sequence.

STAGE 2: QUANTIFICATION

Choice of methodology

For pre-initiator actions the THERP methodology was always applied, and for post-initiator actions the CBDTM Method was always applied. Judgments about which methodology to use were based upon three consideration:

1. Choosing the method that identified the most parameters and completes the analysis in the greatest amount of detail.
2. Using a method that is consistent with current industry use.
3. For consistency purposes the same methodology was applied to every action.

Stress

First an optimal level of stress was assumed for each action, because the operators were assumed to be highly skilled and experienced. Then, during operator interviews the operators were asked to identify a stress level. If there was disagreement about stress levels, then the operator’s choice was used. There was some attempt to include timing effects within the stress level choice to increase it from a low to moderate level.

Within the calculation of P_{exe} there were several cases in which different stress levels were used for different critical actions. This was done because the analyst believed that some of the tasks were simpler to perform. Also, if there was significant time between two critical actions, the stress level was lowered for the second task.

In summary, engineering judgments about stress level were based primarily on operator interviews but also training, time available and number of tasks influenced the decision.

Rule-, skill-, and knowledge-based actions

This classification was only for documentation. This decision was taken directly from the operator interviews. The operators were provided with definitions of rule-based, skill-based or knowledge-based as defined in THERP and then asked to classify the action. The HRA analyst always used the operator's opinions. If an action was considered to be knowledge-based, it was not modeled within the HRA Calculator.

Timing information

For each post-initiator action the HRA analyst collected a MAAP or RELAP run similar to the situation being modeled. This was used to determine T_{sw}. The start of the action was defined as the cue, and therefore T_{delay} was typically zero. The manipulation time was always taken from ASEP recommendations even if the operators gave more optimistic times. For most actions $T_{1/2}$ was collected from operator interviews.

The CPSES HRA states that additional people could be credited for recovery at the times given in Table 13. However, only in two actions was credit taken for anyone other than self review, and this makes the complete database almost independent of time.

Table 13

CPSES Times for Crediting Additional Crew for Recovery

Self Review	Immediately
STA	More than 15 min
ERF	More than 1 hour
Shift Change	Never take credit for

Engineering judgments about timing were based on interpretation of thermal-hydraulic calculations, operator estimates for $T_{1/2}$ and ASEP recommendations for manipulation time. Judgments about times at which to consider additional crew for recovery were based on the recommendations of the HRA Calculator.

Training

It was assumed that all CPSES operators are highly skilled and well trained, because the training programs are constantly being updated and improved upon. Therefore, judgments about training were based upon identifying and using the most optimistic values within the CBDTM decision trees. The number of times an action was trained and type of training on each action was obtained by interviewing operators.

Procedures

Within the CPSES analysis only proceduralized tasks were credited for control room actions. It was assumed that all actions begin with EOP 0.0 for diagnoses of the problem, then transfer to additional procedures. Therefore, EOP 0.0 was not included in counting how many procedures were being used.

For judgments about the clarity of procedures it was assumed that all procedures are well written and have been updated to remove any ambiguous or confusing wording. For decisions about the clarity of procedures the most optimistic values provided within the CBDTM method were used. A procedure step was considered graphically distinct if it was the only step on the page or was boxed by a CAUTION or NOTE statement.

Human interaction with hardware

The HRA analyst addressed the issues of how the crew interacts with hardware during operator interviews. This provided a general understanding of the action being modeled. It was assumed that each individual present in the control room is well trained and responsible for completing their individual assigned tasks. Within the control room the following people were assumed to be present: Control Room Supervisor (CRS), Reactor Operator (RO) and Balance of Plant Operator (BOP), Shift Supervisor (SS) and a Shift Engineer (SE, who is also the STA).

According to the CPSES HRA analyst the control room design and layout is continuously being updated to correct for any human factors issues that have been identified, and thus, for decisions about the clarity of the control room layout the most optimistic values were used. Also, control room indications were assumed to be functioning unless failed by the initiating event.

For choices of errors of omission and errors of commission the HRA analyst has assumed that the modified HRA Calculator values taken from THERP are appropriate to use in all cases, because the procedures are in the response/response-not-obtained format.

Recoveries within an action

In general, recoveries within an action were accounted for by the analyst's interpretation of EPRI Report TR-100259 report and the recommendations provided by the HRA Calculator. Only recoveries stated within the procedures were credited, and for almost every action self-review was credited, because this is a site policy. The dependency level recommended by the HRA Calculator was always used even if the operator interviews provided conflicting opinions.

During operator interviews the following two questions (specific to the CBDTM Method) were asked:

1) "What P_{cog} recovery factors can be applied to this action?" [16]
2) "What P_{exe} recovery factors can be applied to this action?" [16]

The responses provided the analyst with insight as to what he may want to consider, but the exact response was rarely used as stated.

Review of final HEP

The final HEP values were compared against previous models to check for consistency. However, no final values were modified within the HRA Calculator as a result of the final review. It is expected that this was because many of the actions that had the potential to produce unrealistic results were screened out prior to completing the analysis and were conservatively set to one.

CHAPTER V

NUMERICAL COMPARSION AMONG THE THREE METHODS EMPLOYED BY THE HRA CALCULATOR

It is common knowledge among HRA analysts that applying different methods for the same calculation will produce a range of HEP final values. If an analyst is attempting to provide consistent and justifiable results, it is important for an HRA analyst to understand the variations among the different methods. Understanding this variation helps an analyst render better judgments within his calculations. This chapter shows the variation and agreements among the three methods employed by the HRA Calculator. For this analysis, the CPSES database was used as the base model, and all actions were recalculated using both the Annunciator Response Model and the HCR/ORE Correlation.

The following assumptions were made in order to achieve consistency among methods and actions.

- The stress level chosen by the CPSES HRA was not changed among methods. In the HCR/ORE correlation the HRA Calculator does not allow a moderate stress level in the calculation of sigma. Therefore, a median value between high stress and optimal stress was used for moderate stress actions.
- A single annunciator was used as the number of annunciators present in the control room when calculating the P_{cog} using THERP. This was done simply because there was not enough information available to determine the exact number of annunciators present.

- Ex-control actions were excluded from this comparison..
- None of the figures show error bars or error factors. This is because the HRA Calculator simply assigns error factors based on the final HEP point value estimate recommended by THERP. The error factors are independent of methodology used. Table 9 (Shown in Chapter II) shows the three choices for error factors, and it is hypothesized that adding these error factors would not change any of the following analysis and conclusions.

Fig. 4 shows that in 80% of the actions the HCR/ORE Correlation and the CBDTM Method agree to within the same order of magnitude. There tends to be greater variation between the two methods when there is high stress and the median response time in less than 5 minutes. These are the two dominating factors in the HCR/ORE Correlation but are only two of many in the CBDTM Method. The CBDTM Method does not use timing information explicitly, but it is considered in the application of recovery factors applied to P_{cog}.

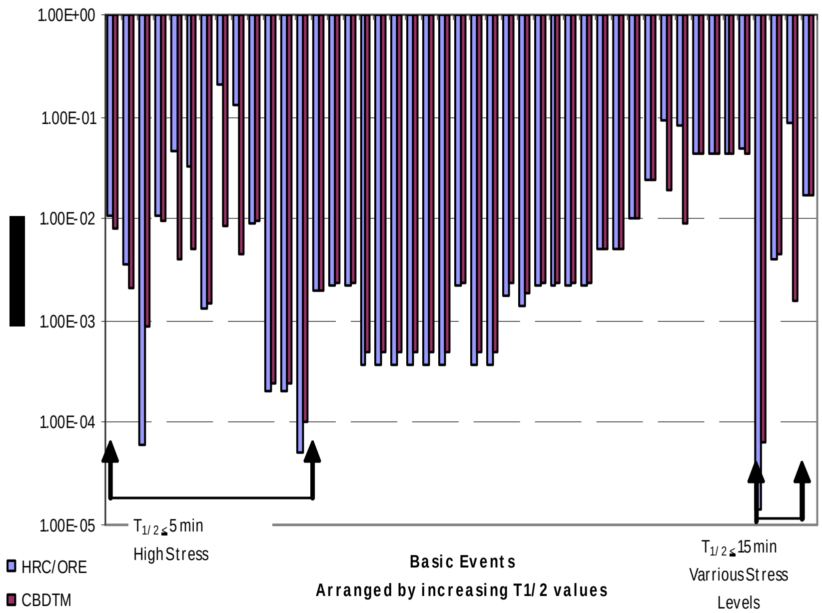

Fig. 4 Comparison of Final HEP Values Using CBDTM Method and HCR/ORE Correlation

One would expect to see greater variation between methods for these types of actions, because at short response times the HCR/ORE Correlation has been logarithmically extrapolated beyond the data from which it was derived giving higher values for P_{cog}. Using the CBDTM Method only a discrete number of values can be chosen from the decision trees. Many choices in the decisions trees lead to negligible probabilities (below 1E-5), but there are few (less than 5) decision paths that give a value higher than 1E-1. For actions considered high stress and short time available, the CBDTM Method does not allow an exponential increase from other actions like in the HCR/ORE Correlation. (While many values in the CBDTM Method and HCR/ORE Correlation can be overridden in the HRA Calculator, this function was not applied.)

Excluding actions with high stress and $T_{1/2}$ less than 5 minutes, the two methods agree to the same order of magnitude in 94% of the actions. This type of agre ement between the HCR/ORE Correlation and CBDTM Method is expected, becaus both methods are modeling the same action, and these methods (or variation of these methods) are the most commonly used method among industry experts. Even with the use of simulators today, human failure data is sparse and there is not a complete database available for benchmarking these methods. If HRA analysts can not justify their HEP calculations by the use of physical data, it becomes increasing important to ensure consistency between methods.

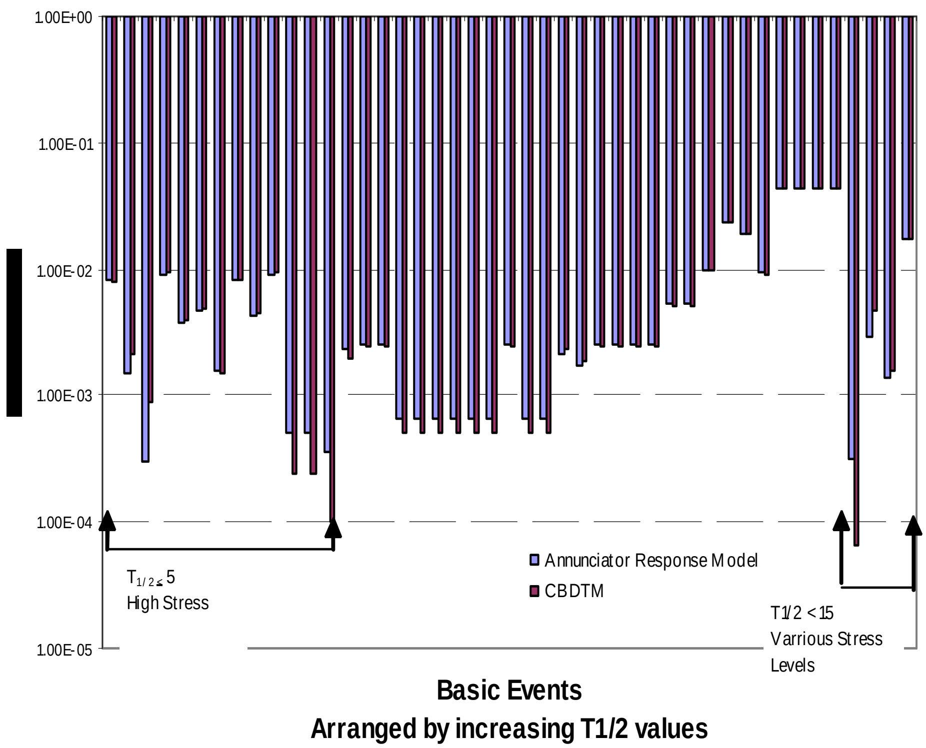

Fig. 5 Comparison of Annunciator Response Model and CBDTM Method

Fig. 5 shows that generally the Annunciator Response Model and CBDTM Method agree to within the same order of magnitude. In 62% of the actions the methods agree to within one significant digit. The largest variation again occurs for actions that are considered high stress and there is less than 5 minutes response time available to complete the action. Both the CBDTM Method and the Annunciator Response Model do not use timing information or stress level as numerical inputs into the calculation of P_{cog}. However, in the derivation of both these models stress level and timing information were considered in the tabulated values.

The CBDTM Method considers stress implicitly in the choices made in the decision trees, and timing is taken into account in the application of recovery factors; as time increases more people will be available to help diagnosis and recover the problem. The CPSES HRA has only taken credit for the recovery of self–review, which the HRA Calculator allows the user to credit regardless of time available. Only in two actions did the CPSES HRA account for additional time by applying recovery factors to $P_{cog.}$

In the Annunciator Response Model the tabulated P_{cog} values are based upon the idea that if there is only one annunciator present, then the operator will attend to it directly with no distractions. As time increases the operator will receive more annunciators, and his stress level will increase. For this analysis the assumption that there is only one annunciator present for every action removes any dependency among timing, stress level and the calculation of P_{cog}.

Using the Annunciator Response Model it is not possible to model P_{cog} for a high stress, short time available, because the model assumes that as time increases stress also increases. One would expect the final HEP values for these types of actions to disagree with other methods.

The Annunciator Response Model is based on a single operator failure probability without crediting additional crew for recovery. The CBDTM Method was developed around a crew failure probability where additional people can be credited for recovery. In Fig. 5, it was assumed that only one person will be attending to the annunciator, and no credit was taken for additional people available for recovery. However, in the control room there are at least three people present at all times, and one could justify in many circumstances taking credit for these additional people. (RO, BOP and the control room supervisor). THERP describes at length how to account for the additional people present in the control room for recoveries. Fig. 6 below shows even better agreement between The Annunciator Response Model and the CBDTM Method if the Annunciator Response Model is modified, external from the HRA Calculator, to account for recoveries for additional crew.

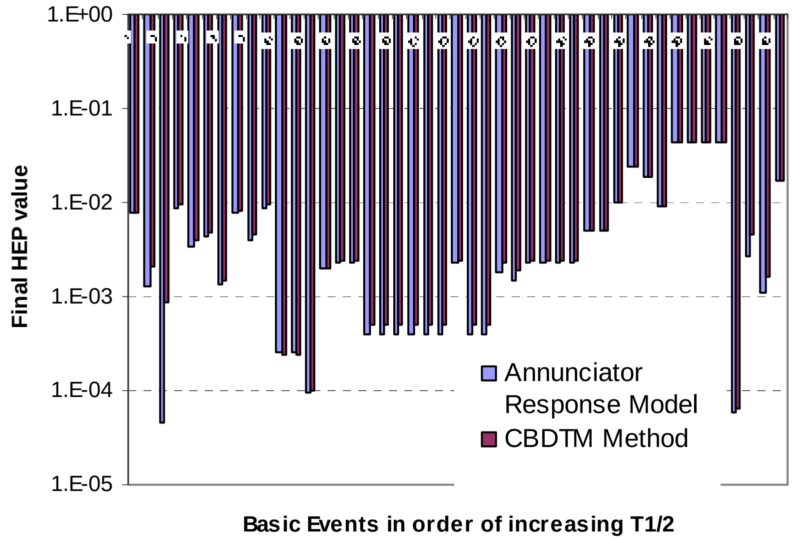

Fig. 6 CBDTM Method Compared to a Modified Annunciator Response Model to Account for Additional Personal in the Control Room.

In Fig. 6, 97% of the actions agree to the same order of magnitude and furthermore, 68% of the actions agree to within one signification digit. In these calculations, both methods are representative of the probability of crew failure, and one would expect better consistency than in the Fig. 5

Fig. 7 shows the comparison between the Annunciator Response Model and the HCR/ORE Correlation. Again, there is greater variation for actions that involve high stress and there is less than 5 minutes available to complete the actions. One would expect to see a greater variation between the HCR/ORE Correlation and the Annunciator Response Model as compared to the previous comparisons. As discussed previously, the Annunciator Response Model does not explicitly account for time or stress dependence, and the HCR/ORE Correlation is only dependent upon these two parameters.

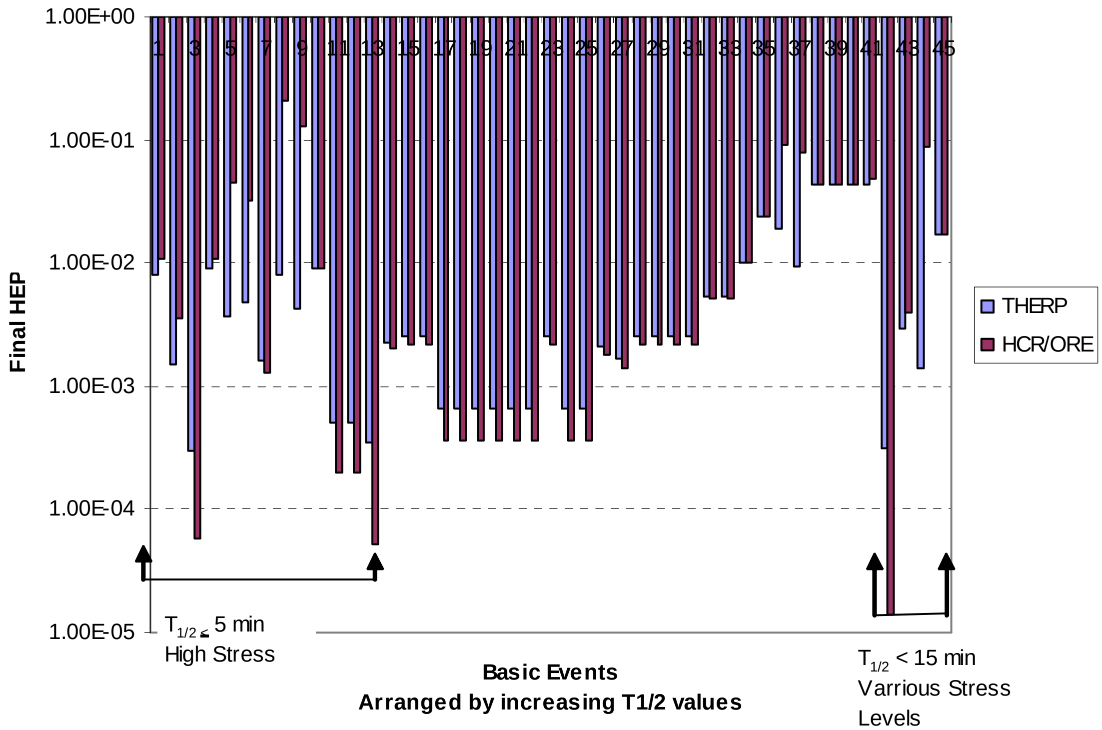

Fig. 7. Comparison of Annunciator Response Model and the HCR/ORE Correlation

In Figs. 5 and 7, the two actions that show large variations among all three methods are: failure to start a standby pump manually, and operator failure to align a single valve manually. As shown in Fig. 8 below, P_{exe} for both of these actions is orders of magnitude lower than other actions in the database. This is because both contain only one simple critical action. P_{cog} is the dominating term in both actions, and the failure probability is very low. In the other actions, P_{cog} and P_{exe} are more evenly weighted. The HRA Calculator does not have a lower truncation limit for P_{exe} values, but it seems unrealistic not to set a lower limit. Using the tables provided in the THERP, most execution probabilities range from 6E-3 to 1E-1. In both of these actions multiple recoveries have been applied to a low failure probability of 1E-3. Thus, the large variations shown among the three methods in the final HEP value is not due to the method choice for the calculation of P_{cog} but due to the unrealistically low P_{exe} value.

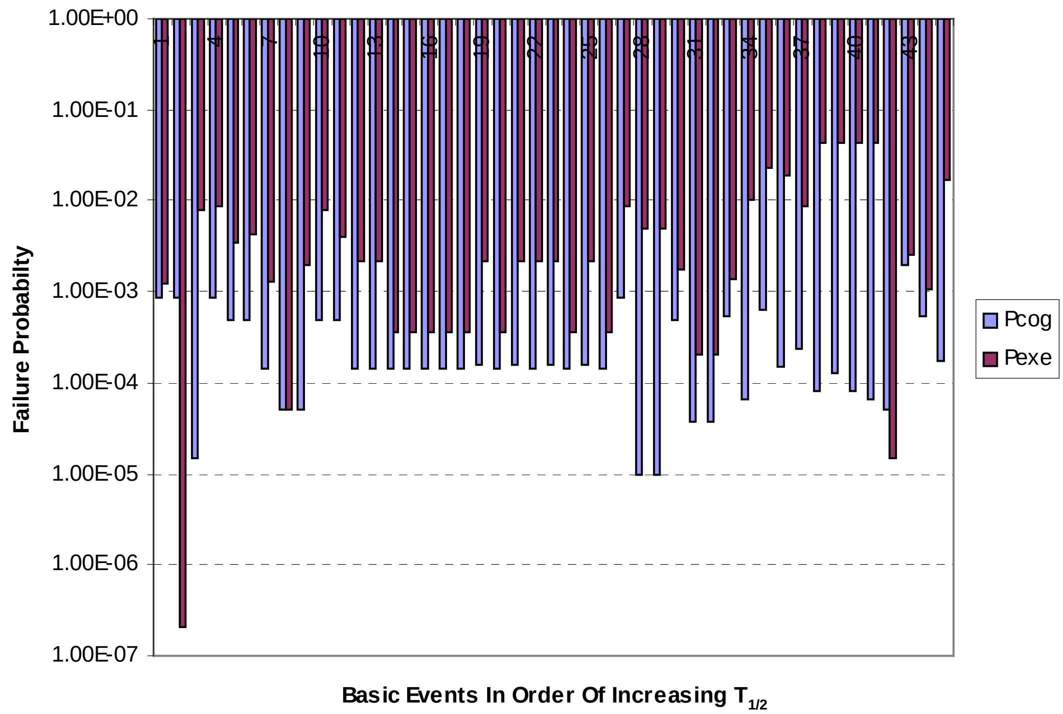

Fig. 8. P_{cog} Compared to P_{exe} Calculated Using CBDTM Method

The HRA Calculator breaks every HEP calculation into parts P_{cog} and P_{exe}. P_{exe} is always calculated by the THERP method regardless of the method chosen by the user. It is interesting to compare only the calculation of P_{cog} for different actions, because unlike in the comparison of final HEP values, P_{cog} can vary by several orders of magnitude among methods. Because a single annunciator response was used for the Annunciator Response Model, P_{cog} is the same for every action. Fig. 9 shows that the HCR/ORE Correlation varies by orders of magnitude among actions, and the range of values is extremely large. The HRA calculator uses a cut off value for P_{cog} of 1E-16. Values less than this are set equal to zero.

Fig. 9 shows that generally for the HCR/ORE Correlation as the stress level increases, P_{cog} increases. However, the CBDTM Method does not show this trend. In the HRA calculator the user is required to address explicitly the stress level in the selection of σ, but in the CBDTM Method the analyst does not directly consider the stress. One would expect that both methods should show the same trend, because the CBDTM Method addresses issues that should implicitly affect stress levels. These branches include workload, training, and clarity of the procedures.

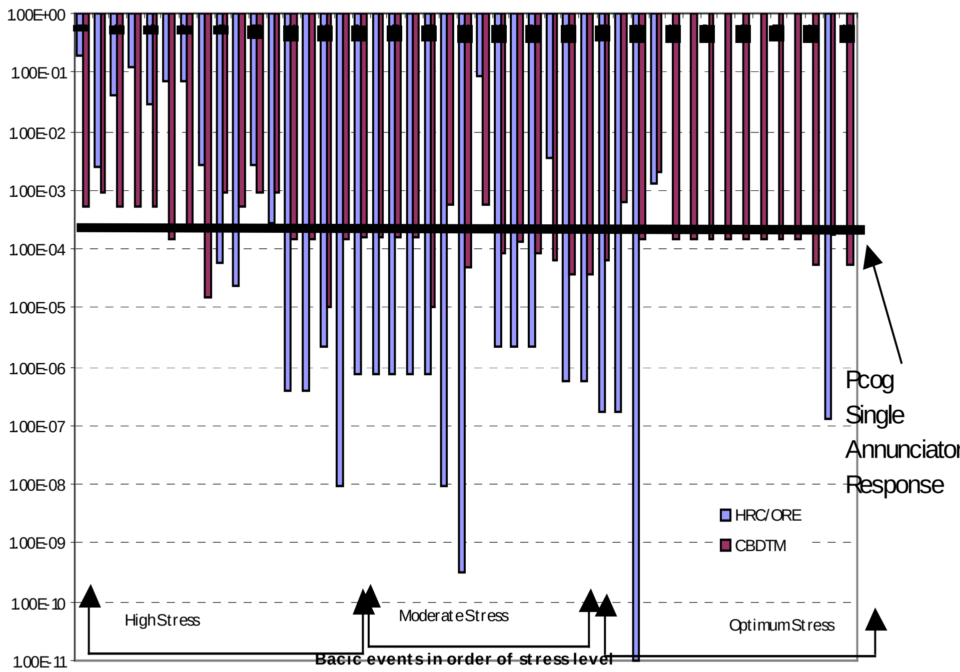

Fig. 9 Comparison of P_{cog} Calculated by All Three Methods

Even though the CBDTM Method implicitly addresses stress by a variety of parameters, an analyst could address each parameter and not consider it in relationship to stress level. Many of the same choices could be made for both high stress and low stress actions. The CPSES HRA, for example, uses several of the same choices for both high stress and low stress actions, and this explains why the CBDTM actions show no relationship to stress in Fig. 9.

THERP provides a chart of probability of failure to diagnosis compared to time after compelling signal of an abnormal situation. This is presented as an alternative to the Annunciator Response Model to calculate $P_{cog.}$ While this chart is not used in any calculation applied by the HRA Calculator, it is interesting to observe the large discrepancies between P_{cog} calculations. One would have hoped to see a stronger agreement between this THERP time-dependent model and the HCR/ORE Correlation, because both models are explicitly dependent upon time, and both methods are taking into account the crew's response as opposed to a single operator. (Fig 10)

A commonly made statement among HRA experts is that the HCR/ORE Correlation gives unrealistically low HEP values when there is a large amount of time available to complete the action and unrealistically high values when there is little time available to complete the action. Fig. 11 below tests this statement. For smaller ratios of $T_w/T_{1/2}$ the HCR/ORE Correlation is orders of magnitude higher than both the CBDTM Method and the Annunciator Response Model. For larger ratios the HCR/ORE Correlation gives slightly lower values.

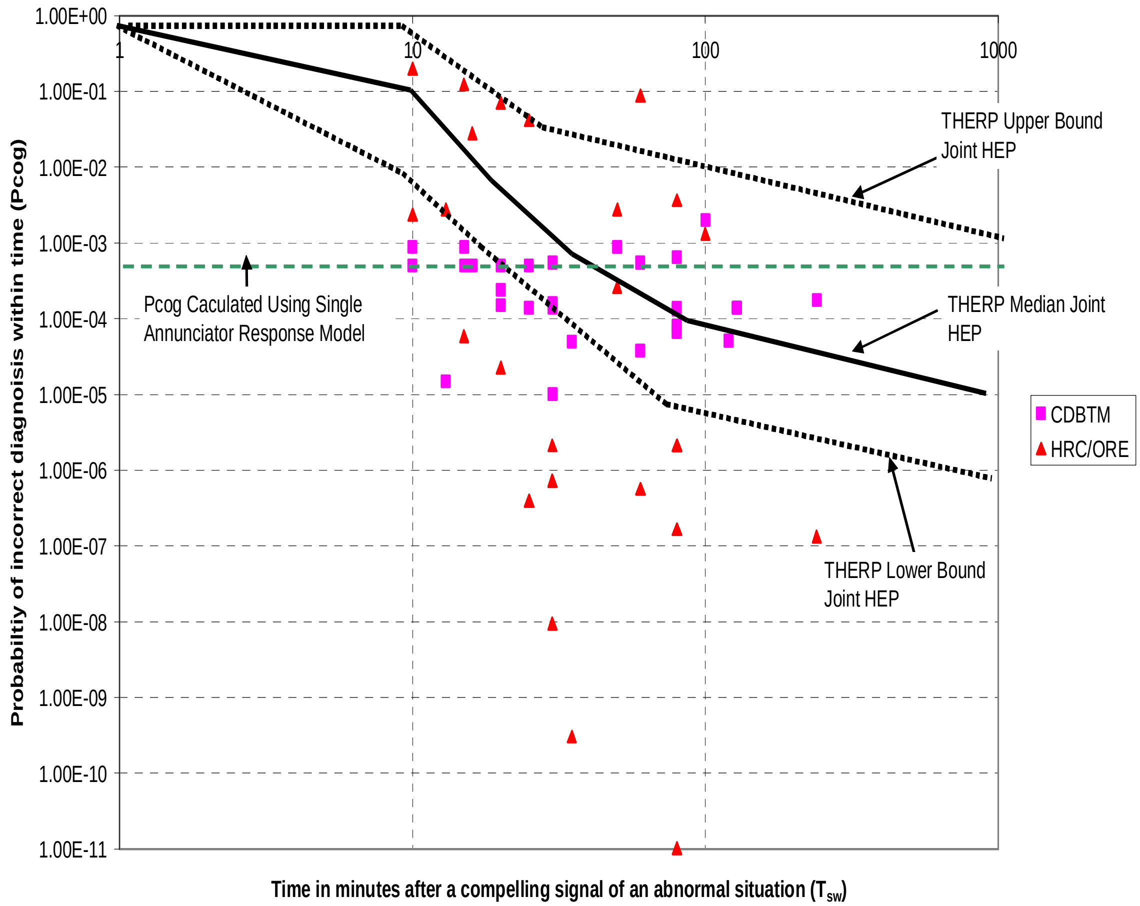

Fig. 10 THERP Prediction of Incorrect Diagnosis as a Function of Time[6] Compared to P_{cog} Calculated by the HCR/ORE Correlation and CBDTM Method.

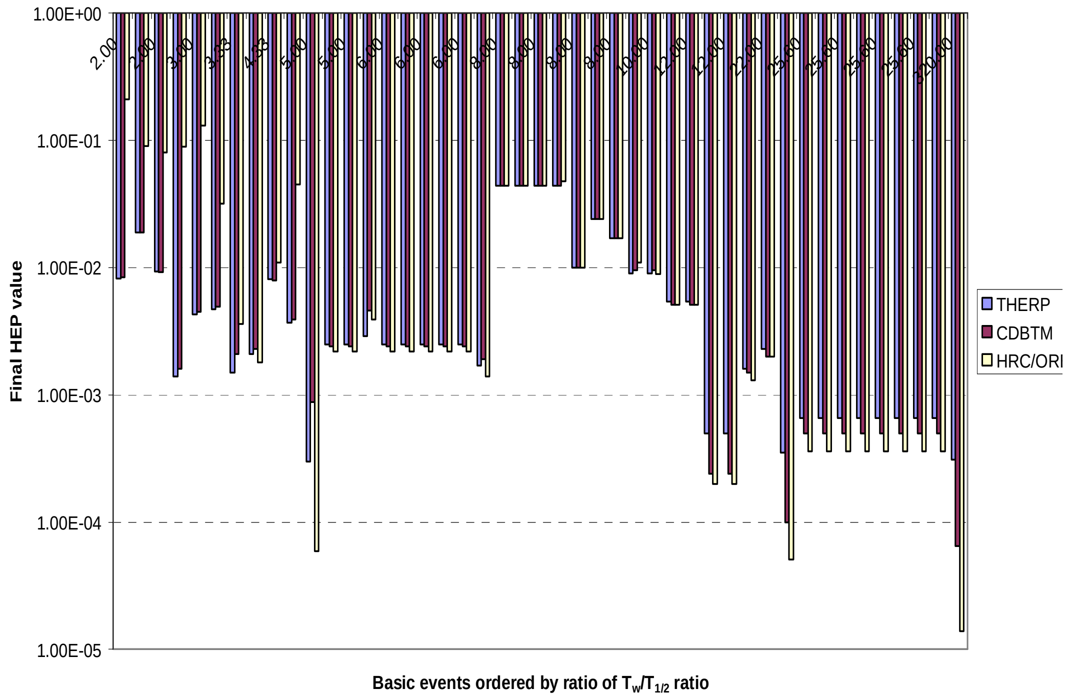

Fig. 11 Comparison of Final HEP Values Using All Three Methods Listed in Order of $T_w/T_{1/2}$ Ratio.

It is reasonable to believe that as the timing ratio increases, the probability of failure should decrease regardless of the method chosen. On the log-log scale shown in Fig. 12, the data shows that all methods show this trend to some degree.

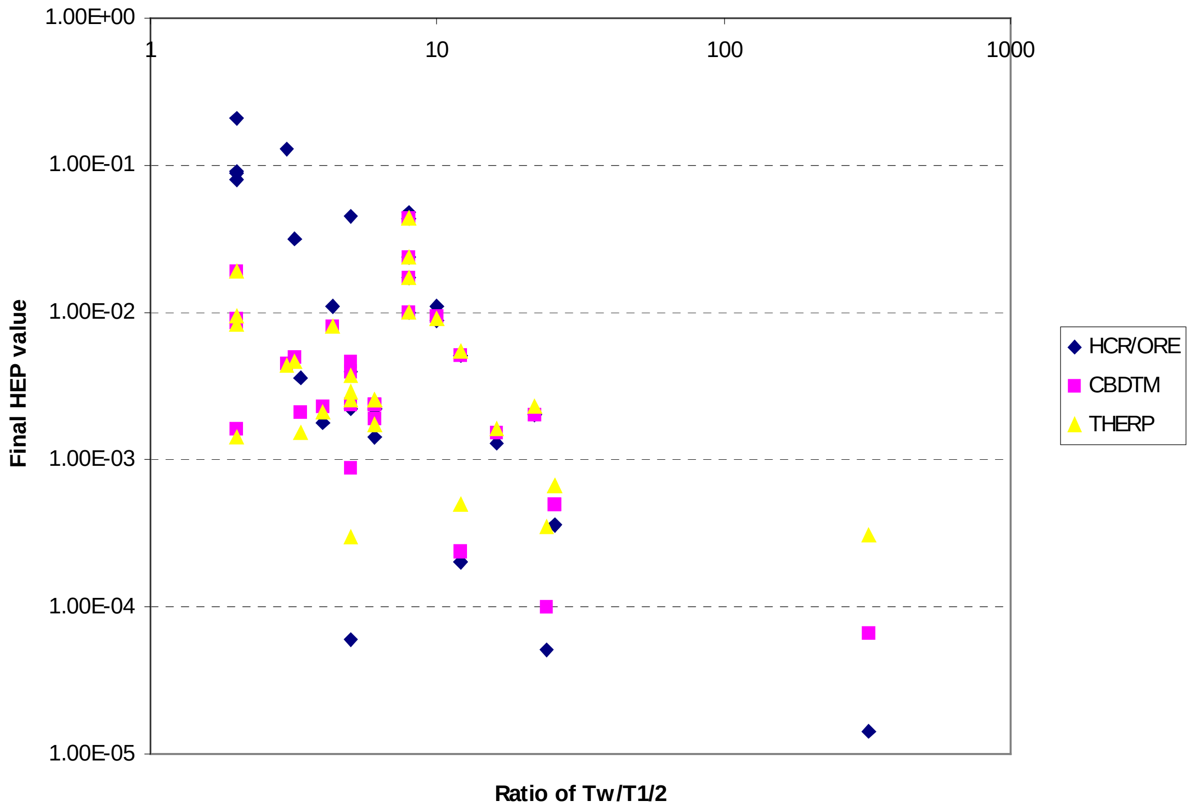

Fig. 12. HEP Values Compared to $T_w/T_{1/2}$

From the data it is hard to draw definitive conclusions, but it does show that for ratios less than about 8, the HCR/ORE Correlation predicts higher values. As the ratio increases, the results of the HCR/ORE Correlation appear to decrease at a much faster rate than the CBDTM Method and the Annunciator Response Model.

This difference in decreasing rate as a function of time is because the HCR/ORE Correlation uses a logarithmic correlation with no lower or upper bounds. Both the CBDTM Method and the Annunciator Response Model use a combination of tabulated values with only a finite number of possibilities. The CBDTM Method considers any probabilities less than 1E-5 negligible and disregards that parameter in the calculation of

P_{cog}. It is nearly impossible to produce the same large range of HEP values using those two methods.

The overall conclusion of this numerical comparison is that for the same input the three methods of the HRA Calculator will generally produce HEP values on the same order of magnitude with two large exceptions:1) actions that are high stress and $T_{1/2}$ is less than 5 minutes and 2) actions in which the P_{exe} value is exceptionally low (below about 5E-4).

In 44% of the actions in this study the Annunciator Response Model gave a final HEP value less than CBDTM Method, and in 40% of the cases gave a lower value than the HCR/ORE Correlation. However, when the HCR/ORE Correlation is compared to CBDTM Method, the HCR/ORE Correlation gave a higher value in 75 % of the actions.

Aside from the numerical comparison, this study has also shown that the user of the HRA Calculator can easily and often unintentionally remove the implicitly dependent parameters from a calculation. This is shown in Fig. 9 in the use of the CBDTM Method to calculate P_{cog}. When the actions are compared against each other using stress level there is no relationship between P_{cog} and stress level.

CHAPTER VI

PILOT SURVEY

A pilot survey was done in order to ensure that the researcher would receive responses that were useful in meeting the needs of the study. For the pilot survey ten experts were asked to complete two tasks:

1) From the complete set of documented assumptions presented in the CPSES HRA Calculation Notebook the participants were asked to identify and to discuss whether they would have made alternative or additional assumptions if performing this analysis.
2) After reviewing the HEP calculation for the action of Feed and Bleed using the CBDTM, the participants were asked to evaluate the calculation by answering fourteen questions.

The complete pilot survey is shown in Appendix B.

Of the ten participates who received the survey six responses were received from the following groups of participants:

- Three industry experts – two currently work for a nuclear utility and one is an independent consultant
- Two methodology developers
- One academia expert

It should also be noted that none of the experts who responded to this survey are currently using the HRA Calculator. They all claim to be familiar with at least one of the methods employed by the HRA Calculator.

The first comment that several experts made was that they were not sufficiently familiar with HRA Calculator or the CBDTM method to answer every question. This comment was taken into consideration when creating the Phase II survey. This comment was also observed in the responses received. Because the experts were not familiar with the method, sometimes they would disagree with how a parameter was calculated simply because they use a different method for quantification. For this survey (shown in Appendix B), the experts were not asked to critique the methodology, but instead they were asked questions about the application of the CBDTM method. Even so, many experts felt the need to critique the methodology.

Experts were given two weeks to respond to the survey, and it was expected that the survey should have taken no more than a couple hours to complete. However, from the responses to the survey and many of the comments, it was determined that the experts spent a large amount of time (up to 15 hours) completing the survey, and the Phase II survey was shorted significantly.

CPSES DOCUMENTED ASSUMPTIONS

The experts were asked to provide comments on the complete set of 30 assumptions documented in the CPSES HRA. The experts were asked to analyze each assumption and to identify and to discuss where they would have made alternative or additional assumptions. From the comments received it was intended that one could draw general conclusions about how one renders judgments about the specific area each assumption addresses. In some instances this has been completed; comments on other assumptions were used to create additional questions for the Phase II survey. Since the participants were only asked to comment on assumptions they would make differently, it was assumed that by not commenting on an assumption the participant agreed with the stated assumption.

While the experts were given the complete set of assumptions, they did not have access to the database and were not able to see how the assumptions were actually applied within the analysis. The following summarizes each assumption as stated in the CPSES HRA Calculation Notebook and the comments received about it. The numbers correspond to the assumption number give by the CPSES HRA.

Assumption 1

> "Operators are highly skilled in performing the necessary tasks, each having more than six months experience and most with several years experience. In most cases, "optimum stress" is applied due to the level of experience, the nature of the event and lack of an undue challenge in performing the proceduralized tasks. Some events, however, result in a high stress situation. For example, a steam generator tube rupture (SGTR) event would in general result in a high stress situation and the nominal human error rates would be modified as appropriate."[16]

The HRA Calculator asks the user to choose an operator stress level. The choices available are optimum, moderate and extreme. This assumption says that the optimum stress level will be chosen as a default value, because operators are highly skilled and most have several years of experience. Assumption 30 gives an exception to the default value. The expert's comments are shown in Table 14.

Table 14

Responses to Assumption 1

Response
• There ought to be some guidelines on how to recognize the characteristics of an accident scenario that requires elevation the of the stress level.
• While I agree that the operating crews are highly trained and experienced, I would disagree with the assumption that stress is generally optimum during accident scenarios that lead to core damage. In order to approach core damage, various equipment or operator actions have failed. Every time that the plant does not respond as expected, the operating crew will get more frustrated and stressed. We generally use high stress for most post-initiator actions.
• Instead of saying operators are highly skilled I would say they are highly capable.
• In THERP, the stress model includes two levels of high stress- moderately high and extremely high stress. I hope that in the CPSES HRA that more than an optimum level of stress was applied to more than just one abnormal event, the steam generator tube rupture. If there were other abnormal events analyzed, surely it would be appropriate not to assess optimum stress to all of them.

There are two independent parts to this assumption as noted by the experts. First, operators are highly skilled and second, during most scenarios the stress level of the operators will be considered optimal. It is interesting to observe that within the 52 post-initiator actions in the CPSES database optimal stress was used only eight times.

For every action, the CPSES analyst has identified that the operators have excellent training and chosen to use the most optimistic stress values for quantification. It seems unrealistic that every action would have excellent training and that the quality of training would not vary among actions. If this assumption were actually applied, the overall results of the complete analysis would be independent of the training parameter.

From this assumption and comments the following conclusion can be drawn: engineering judgments about stress level applied, i.e., the associated PSFs, should be based on more than a single factor such as training.

Assumption 2

> "Control room indication is provided for equipment status, with visual and audible alarm indications of equipment failures or parameter deviations. The control room indication is assumed to be available, unless affected by the initiating event."[16]

Examination of the CPSES HRA shows that this assumption was consistently applied, and according to the CPSES HRA analyst every action modeled within the HRA Calculator database is diagnosable by an indication in the control room. With this additional clarification to this assumption, the experts and the CPSES are in consistent agreement about how to credit control indications. Table 15 shows the expert comments on this assumption. It is concluded that engineering judgments about main control room indication availability should be based on the consideration of human actions required.

Table 15

Response To Assumption 2

Response
• The first half of this assumption appears to indicate that instrumentation is available for any equipment included in the HRA. If this is a correct interpretation to the assumption I disagree with it. If it is not known whether indication exists for a particular piece of equipments, I would assume it is not available. With respect to the man machine interface issues for the indicators I would likely assume nominal conditions (not worst case). I do agree with the second half the assumption and would not assume instruments are unavailable unless there is an accident-based reason to assume it fails.

Assumption 3

> "Visual and audible alarms demand (or serve as prompts for) initial operator responses. Some events, such as Loss of Component Cooling Water and Loss of Safety Chill Water, are diagnosed within their respective Abnormal Operating Procedures. For any other abnormal plant condition resulting in a reactor trip or the need for reactor trip, the

> operators' activities begin with the proceduralized steps in EOP-0.0, within which diagnosis of the event is conducted. The operators are not led from the alarm indications directly to diagnosis of the event without going through the EOP-0.0 procedure."[16]

By examination of the database it was determined that this assumption was applied by assuming that the operating crew always starts at procedure EOP 0.0. No actions were analyzed in which the crew diagnosed an event using other procedures. The first expert's comment, (Shown in Table 16) is the correct interpretation of this assumption. It is concluded that engineering judgments about the sequence of procedures to be followed in response to any initiating event should be based on procedures requirements and operator training.

Table 16

Responses to Assumption 3

Response
• It is not clear what this assumption means. At our plant, the alarm procedures generally will instruct the operating crew to another procedure, not just the two procedures that are mentioned above. I would expect the same for CPSES. I think what is intended with this assumption is that regardless of whether a reactor trip is automatic or manual, the operating crew will always go to EOP -0.0 following the reactor trip. EOP 0.0 gives a generic list of post-trip actions that must be performed whether the event is diagnosed or not.
• "The operators are not led from the alarm indication directly to diagnosis for the event without going through the EOP 0.0 procedures" this is a very strong and probably an unrealistic assumption.

Assumption 4

> "It is assumed that each operator is responsible for completing specific tasks. In addition to the Control Room Supervisor (CRS), Reactor Operator (RO) and Balance of Plant Operator (BOP) who are normally in the control room, there is a Shift Supervisor (SS) and a Shift Engineer

> (SE, who is also the STA) on each operating crew. The RO and BOP operators are familiar with the operations and controls in the entire control room; each is assigned one position for a shift, but can be rotated to the other position on a different shift. For non-time critical actions, where the extra crew members are not specifically assigned to other tasks, a recovery factor for the extra crew member can be credited. Credit for STA actions, generally Critical Safety Function Status Tree related, are not credited until 15 minutes after the initiating event occurs, if credit is taken."[16]

This assumption applies directly to the calculation of P_{cog} using the CBDTM method. The user of the HRA Calculator can only credit extra crew if there is more than 15 minutes available to complete the action. What is not clear in this stated assumption is that just because there is more than 15 minutes available for recovery of the action, it does not necessary mean that the extra crew will be credited. At the 15 minute time interval the HRA Calculator gives the user the option for crediting extra crew. Extra crew was only credited in five of the 52 post-initiator actions even though in 41 actions there was more than 15 minutes available to recovery the action. In all these actions the analyst noted that extra crew was credited because there was more than one hour available for recovery. The expert's comments are shown in Table 17

Table 17

Responses to Assumption 4

Response
• I would not allow a recovery factor for the extra crew because I would assume high or complete dependence between any extra crews and nominal crew. No exceptions to the other material.
• Assessing zero credit for recovery factors by the STA for 15 minutes shows reasonable conservatism. However, as an evaluator of the HRA I would want to know how the following recovery factor is determined: "For non-time critical actions, where the extra crew members are not specifically assigned to other tasks, a recovery factor for the extra crew can be credited."
• I would only allow extra crew recovery if there was a reason (i.e. procedure or acceptable practice) why the crew member would be checking. In other words, I would not give credit for casual or accidental recovery.

From this assumption and comments the following conclusion can be drawn: engineering judgments about the recovery by extra main control room crew and shift technical advisor should be made by considering primary and collateral assigned duties in addition to time available.

Assumption 5

> "Usually only one recovery factor is taken for each HFE. Since "self checking" is a site wide policy that has received high management attention, this is the recovery most often credited. Credit is taken for STA actions for the HRA events that need to be accomplished at a relatively long period of time after the initiating event has occurred." [16]

Table 18 shows that some experts would not apply self checking in this optimistic manner. However, there were four experts who did not comment on this assumption, and from this it is inferred that they felt the assumption for crediting self checking is acceptable. In the second part of this survey, the experts were asked again if they would have taken credit for self checking, and three out of the four experts who provided comments agreed that taking credit for self checking is overly optimistic unless specifically addressed in procedures or other compelling reasons.

Table 18

Responses to Assumption 5

Response
• Self-checking should not be allowed for the CBDTM failure modes that involve misinterpretation. This should in the "rules" of the CBDTM.
• The self checking credit would be a red flag for me. This reeks of extreme optimism, so if I were evaluating the HRA I would be very skeptical. I remember a NPP HRA in which this type of recovery factor was assessed almost every task done under routine conditions. This optimism was further increased by assuming zero dependence between the original self checking so that the original HEP was squared.

From this assumption and comments the following conclusion can be drawn: engineering judgments for crediting self-checking should be based on the availability of, and be directed by, scenario-specific prompts for self-checking.

Assumption 6

> "Time critical actions are those which take a long time to diagnose and perform relative to the length of the time window available. The time critical actions are primarily identified either through the operator interview process or via an examination of the relevant procedures, and an examination of the time windows available from thermal-hydraulic analyses (such as RELAP or MAAP) or other engineering calculations. The operator interview process ascertains the cues and steps in the procedure that the operators use to diagnose the event and the time at which this diagnosis takes place. Then, the steps judged to be critical to that particular HI [Human Interactions] are confirmed and the overall time to successfully complete these steps determined. The overall time accounts for potential delays due to additional, non-critical procedural steps that must be executed first, time required for the component to change state (e.g. to start a turbine-driven pump), and limitations that may be present due to crew manning. If the available time window is less than

> the diagnosis time plus the time required to successfully complete the action, then the action is assumed to be failed. If the available time window is longer than the diagnosis time plus the time required to successfully complete the actions, then the probability of failure is adjusted through selection of the stress factor and the allowed credit for recovery. For example, if there is a 30-minute time window and the action takes 5 minutes to diagnose and 15-20 minutes to execute, then an optimum to moderately high [Moderate in the HRA Calculator] level of stress is taken and no credit is given for recovery. Alternately, if the time window is 1 hour, and the action is at the end of the success branches on the event tree (e.g. LOCA followed by successful injection, cooldown, and depressurization such that the time window starts several hours after the initiator), and the competition from other actions is low, then the stress is taken as optimum and credit may be given for recovery. In each case the operator actions are examined within the context of the scenario to determine the potential impact of time constraints."[16]

From the wording of the assumption it was not clear to the reviewers that the entire CPSES HRA was completed using only the CBDTM method. No time reliability curves were used within this analysis, and the analyst had to account for additional time-based stress factors using other methods. The expert's responses are shown in Table 19.

Table 19

Responses to Assumption 6

Response
• I would not add additional time-based stress factors as the time reliability curves should implicitly account for time-related stress. Application of stress factors based on a perceived threat to the plant or public safety, which is not necessarily directly related to time, is considered to explicitly address the stress factor. My concern is that double counting the stress factor may yield overly conservative results.
• I assume that if the action is time critical, then the probability from the HCR/ORE methodology will be higher than the CBDTM probability, and thus the HCR/ORE probability will be used for diagnosis failure.

This assumption and responses show that experts agree that there should be some relationship between time and stress for time-critical actions. The relationship could be either explicit by increasing stress level for short time periods, or an indirect relationship could be established such as the use of time reliability curves to relate stress and time. Further questions about timing were asked in the Phase II survey.

Assumption 7

This assumption was disregarded from this study because it's interpretation might be ambiguous.

Assumption 8

> "Execution errors are calculated using the THERP tables in Reference 5 [Reference 9 of this study]. Values from these tables for errors of omission are divided by three based on Swain's notes in Chapter 15 of THERP. These notes describe adjustments to the nominal Swain values, in particular to credit the layout of the procedures into a "response/response not obtained" format". [16]

This assumption is built into the HRA Calculator. The user can choose values from tables within the HRA Calculator for errors of omission and errors of commission. The tabulated values have been divided by 3 based on THERP. However, the user can choose to enter any appropriate value and is not limited to the tabulated values. The experts were not aware of this detail within the HRA Calculator when reviewing this assumption and their comments are shown in Table 20

Table 20

Responses to Assumption 8

Response
• I have read Chapter 15 multiple times and I think that the application of this assumption is incorrect for CPSES. First NUREG/CR-1278 page 15-16 states that the operators made 1/3 fewer errors with the columnar format that the narrative format. Therefore, the failure rate would be 2/3 of the values rather than 1/3 of the values from Chapter 20. However, in reading the EOPs, it is clear that within the response/response not obtained format, the steps are often narrative rather than the columnar formats as shown on pages 15-17. For example, EOP 0-0, Step 1.b is very much a narrative rather than columnar format.
• This division by three does come from page 15-15 of THERP, but this really should be applied very sparingly. It depends so much on how good the written procedures really are, and I have seen some poorly written EOPs. If I were evaluating the HRA, I would want the task analysis to include a detailed evaluation of written procedures, especially EOPs

The other four reviewers did not comment on this assumption which means that they agreed with the CPSES assumption as stated. These comments show that the experts were equally divided about how to interpret pages 15-15 thru 15-17 of THERP. By close examination of the referenced pages and data provided in Chapter 20 of THERP, the HRA Calculator has modified the data provided in THERP. In some instances the values have been divided by 3 to account for response/non-response-not-obtained procedures; other times this has not been considered. The second comment came from the author of THERP, and his comments on how to interpret his original work should be weighted more than others who are interpreting the work.

From the stated assumption it would seem that sometimes the division by 3 for errors of omission and errors of commission would not be used simply because not all procedures are identical. For the CPSES, every error of omission and commission was divided by 3 since the analysis was done using the HRA Calculator which applied this division. While this assumption does seem valid from the interpretation of THERP,

THERP also cautions that this assumption should be used sparingly; within the CPSES analysis it appears to have been over used.

From this assumption and comments the following conclusion can be drawn: Engineering judgments about dividing THERP[6] Chapter 20 HEP values by 3 based on THERP page 15-15 should be based on considering whether the plant's procedures are consistent with what is stated in THERP.

Assumption 9

> "A procedure step is considered graphically distinct, as used in decision tree "e" of the cognitive error calculation (p_c–e), if it is preceded by a boxed CAUTION or NOTE or is the only step on the page" [16]

While this assumption seems rational, one would expect within any complete analysis that an analyst would encounter both distinct and graphically distinct steps. Within the CPSES HRA database, every step was considered graphically distinct. Furthermore, if one examines the procedures referenced in each action, there are several cases where there is no caution or boxed step or the only step on the page and the steps were considered graphically distinct. Within the CBDTM method the user of the HRA Calculator is not asked to document which procedure step is under consideration within each decision tree, and therefore, one cannot determine if this assumption was consistently applied. From examination of the procedures it appears that this assumption needs further clarification, and this is noted by the experts as shown in Table 21.

Table 21

Responses to Assumption 9

Response
• I would apply “graphically distinct” to other types of steps as well, including: Steps in flowcharts that are distinct from others steps around it. I think this definition is too narrow for defining graphically distinct.
• EPRI TR-100259 states that the caution and notes are diluted if over used. You need to account for this fact in the HRA evaluation. If more than 2-3 cautions or notes on a page, then the distinction are diluted.

This assumption and responses show that judgments about how to determine graphically distinct can be based on identifying a caution box, note or the only step on the page. However, because only two experts responded this subject was further questioned in the Phase II survey.

Assumption 10

> “The Emergency Response Facility (ERF) Review recovery factor is not applied if the operator action took place less than one hour into the sequence, or if the time available for the operator action is less than one hour. The Technical Support Center (TSC) and Operations Support Center (OSC) are typically manned within one hour of an emergency plan declaration.” [16]

Within the HRA Calculator, only the CBDTM method credits recovery factors for the presence of additional people, and without using the override function only one recovery can be credited. For most of the actions within the CPSES HRA database, the single recovery credited is self review. Recovery from ERF was never applied to any action. As stated, this assumption refers to when the HRA Calculator allows ERF to be credited and is not reflective of when the analyst made this choice. Only one response was received (See Table 22). However, it is implied that the lack of responses shows that experts are in agreement with the HRA Calculator and feel it is appropriate to consider taking credit for the ERF and TSC after one hour. Therefore, it is concluded that the engineering judgment to take credit for the ERF and TSC after one hour is reasonable.

Table 22

Response to Assumption 10

Response
• In addition, I will only credit TSC/OSC if it is clear that the TSC/OSC have sufficient information to diagnose the action remotely.

Assumption 11

> "The immediate action steps in Emergency Operating Procedures are steps performed from memory without reference to the written procedures. However, immediate action steps are reviewed after the actions are performed to ensure all required actions are taken. Recovery credit is typically not applied in this analysis of the final cognitive error (pc) estimation even though reading the procedure serves as a check/recovery of the operator's immediate actions. This is conservatively held as a potential future recovery". [16]

There were no comments made about this assumption, and from this it is inferred that all experts agreed with this assumption. Also within the database this assumption was clearly and consistently applied. What is not stated in this assumption is that if the steps were considered memorized, even if the operators were following an EOP, the cognitive portion of determining that a second procedure is required was never considered in the quantification of $P_{cog.}$ Additional questions about procedures and cognitive recovery were asked in the Phase II Survey.

Assumption 12

> "There are a few instances where the CBDTM may be inappropriate for estimating the cognitive human error probability(pc). Operator response to events indicated by a Main Control Board alarm(s) rather than a reactor trip are often skill-based in nature and do not require a decision or diagnosis. Initial operator guidance is typically provided in the appropriate Alarm Response Procedure(s), rather than in the Emergency Operating Procedures. For this type case, pc is validated by comparison to the THERP Annunciator Response Model."[16]

Within the CPSES HRA database every action was modeled using the CBDTM method. The Annunciator Response Model within the HRA Calculator was never used. The experts comments were as shown in Table 23. It should be noted that the experts did not have access to the database while analyzing the assumption.

Table 23

Responses to Assumption 12

Response
• I disagree with this assumption. Alarm responses are guided by procedure and often lead to either the EOPs or system operating procedures to respond to the alarm condition. Alarm responses are invaluable to diagnosing the event.
• I am not familiar with any reasons why the CBDTM would not be adequate for a Main Control Board Response alarm response. Without a specific example, I can't really make a judgment.
• This is a very loose usage of the term "validate." I think this word is inappropriate here. Perhaps, "compared with" would be a more appropriate.

All experts addressed different areas within this assumption. The intention of this assumption was to state when the CBDTM Method would not be used for an HEP calculation. Only one expert commented on this aspect of the assumption. This shows that more specific questions need to be asked in order to understand how one renders judgments about methodology choice. Additional questions about methodology choice were asked in the second section of this survey and in the Phase II survey.

Assumption 13

> "The Emergency Operating Procedures are written in a columnar "response/response not obtained" format. They incorporate checkoffs and have provisions for place keeping. Use of both of these aids is practiced during operator training on the simulator. These assumptions are important to the EPRI CBDTM assessment of procedure usage performance shaping factors. "[16]

There were no comments made about this assumption and from this it is inferred that all experts agreed on this assumption. Also within the database this assumption was clearly and consistently applied. Therefore, it is inferred that experts agree that is appropriate to take credit for response/response not obtained format as applied within the CBDTM Method, and to verify this conclusion additional questions about the use of response/response-not-obtained procedures were asked in the Phase II Survey.

Assumption 14

> "For control room action, only proceduralized recoveries are credited."[16]

Within the CPSES database, only proceduralized actions inside and outside the control room were modeled. If an action was considered not proceduralized, then the action's HEP was conservatively set to one. Within the CPSES database both proceduralized recoveries as well as additional crew were credited. It is believed that this assumption was specifically written to address recoveries within the P_{exe}. Within P_{exe}

only proceduralized recoveries were credited. Furthermore, the HRA Calculator is setup to address only proceduralized recoveries for P_{exe}. The HRA Calculator requires the user to insert a procedure number for every critical action and recovery. The user can not proceed without providing this information. The expert's comments are shown in Table 24.

Table 24

Responses to Assumption 14

Response
• Regardless of whether the actions are performed locally or in the control room, we only take credit for proceduralized actions. [This assumption states is only concerned with procedurized recoveries not action]
• Further explanation is needed for this comment. For instance, are the actions outside the control room credited? Does the PSA credit non-proceduralized actions outside the main control room?
• I agree assuming that this does not exclude shift changes, etc.
• This is a contradiction to assumption 4.

Without further justification on why this assumption was stated one can not draw conclusions on how one would render judgments on how to credit proceduralized recoveries. The responses to this assumption do show that with one exception the reviewers were not looking at the general overview of the assumptions but were more specifically concerned with each individual action. Furthermore, Assumption 4 conflicts with this assumption. Therefore, it is concluded that engineering judgments about crediting only proceduralized steps should be made on a case-by-case bases.

Assumption 15

This assumption was disregarded from this analysis because it referenced other documents used for timing information that were not available for this study.

Assumption 16

> "In applying recovery, moderate dependence is usually assumed when the instruction that provides the recovery mechanism for an action is on the same page of the procedure as the instructions to perform the action, the rationale being that one way to miss a procedural step is to skip a page. The equation for conditional probability for moderate dependence from THERP Table 20-17 is used."[16]

This assumption was applied to the calculation of P_{exe} and without having access to every page of procedure referenced it is not possible to determine how this assumption was consistently applied within the database. The expert's comments are shown in Table 25.

Table 25

Responses to Assumption 16

Response
• This is not an assumption that I make. I am not sure that this assumption is logical when viewed in terms of an operating crew rather than a single operators. If the procedure has been performed many times, then it is very unlikely that the operating crew will not recognize that a whole page has been skipped. Note that this assumption contradicts assumption # 1, which implies that the procedures are so well known and well practiced that the crew is under very little stress.
• I would probably not allow page location to hold this much influence over the recovery dependency level and do not agree with assigning moderate dependence to recovery just because it is on the same page as the initial action step.

Two of the experts disagree while the four others did not comment. This shows that there is considerable disagreement on the appropriateness of assigning a moderate dependency level based on the page placement of the recovery step. Therefore, it is concluded that engineering judgments about dependency levels for proceduralized recoveries should be based on more than page placement of recovery steps.

Assumption 17

> "If the recovery instruction is on a different procedural page, the recovery factor used is usually the Error of Omission (EOM) (from Table 20-7) for the procedure step." [16]

This assumption was consistently applied within the analysis. However, for each error of omission identified as a recovery the HRA Calculator requires the user to identify an associated dependency level. This assumption does not address how the dependency level was chosen. One expert commented on this observation as shown in Table 26 and Table 27.

Since only one response was received, it is implied that it is justifiable to apply only an error of omission for a recovery factor if the recovery instruction is on a different procedural page. Due to the lack of responses additional questions about errors of omission were asked in Phase II.

Table 26

Response to Assumption 17

Response
• We do not generally assume zero dependence for recovery instructions, as is implied here. We use a dependency model which is shown in • Table 27.

Table 27

Dependency Model Used by One HRA Expert

Time Available	Definition	Dependency Level		
		Diagnosis	Execution	
			Control Room	Local
Very Short	t ≤ 5 min	Complete	Complete	Complete
Short	5 < t ≤ 15 min	High	High	Complete
Nominal	15 < t ≤ 60 min	Moderate	Moderate	High
Long	1 < t ≤ 6 hrs	Low	Low	Moderate
Very Long	t > 6 hrs	Zero	Zero	Low

Assumption 18

> "In determining the EOM pe values, if the operator action takes place within ten procedural steps from the start of the accident sequence, Item 20-7(1) [short list, with checkoff provisions] from THERP is used. If the operator action takes place > 10 steps into the sequence, Item 20-7(2) [long list, with checkoff provisions] is used. Items 20-7(3) and 20-7(4) [no checkoff provisions] are usually used when the procedure is not an Emergency Operating Procedure."[16]

Table 28 shows that there was disagreement between the two experts. This same question was asked again in the Phase II survey.

Table 28

Responses to Assumption 18

Response
• I do not understand this. I think I would analyze the actions in groups that are associated with a specific task and done my counting at that level. However, THERP was never intended to analyze these types of procedures.
• I would apply the checkoff provisions based on what is in the procedures.

Assumption 19

> "Table 20-13 from THERP is for local manual valve operation. This table is also applied to operation of other local components such as switchgear breakers and room doors."[16]

No experts commented on this assumption. This assumption was consistently and clearly applied within every action. The HRA Calculator does not mathematically differentiate between control room and ex-control actions. Additional questions about this assumption were asked in the Phase II survey.

Assumption 20

> "Application of stress factors in quantifying human error probabilities tends to be quite subjective, and can vary considerably between analyses and analysts. For the CPSES HRA, stress is considered objectively in the following manner:
>
> a. Stress is implicitly included in the EPRI TR-100259 determination of cognitive errors (pc) through some of the selections in the decision trees such as workload and the recovery credit; stress is explicitly modeled in the determination of the execution errors (pe) (Reference 5) as outlined below;

b. Optimum stress (x1) is usually used for the pe portion of operator actions directed by the "base" emergency procedures. In some cases, such as steam generator tube rupture, the stress level is judged to be higher and a moderately high stress (x2) is applied;

c. For those operator actions where the operators are following instructions in the Function Restoration (FR) procedures or the Emergency Contingency Action (ECA) procedures, moderately high stress (x2) is applied to pe to reflect the increased stress caused by the failure(s) that put the operators in those procedures; and

d. If operator action is required as a result of subsequent equipment failure while in a FR or ECA, extremely high stress (x5) is applied to the pe for the additional action. "[16]

No experts commented on this assumption. Within the HRA Calculator the user must choose a stress level of optimal, moderate or high, and this is the foundation of this assumption. In this assumption, the analyst has simply stated how the HRA Calculator applies stress within an HEP quantification. Because this assumption is built into the HRA Calculator, it was consistently applied within the entire CPSES analysis. It is satisfying to identify that experts agree with HRA Calculator, because a disagreement on this assumption would be very difficult to compensate for within a calculation. Therefore, it is concluded that the approach within the HRA Calculator for assigning stress levels is a reasonable application of engineering judgments.

Assumption 21

"The dependence between elemental human error probabilities in the subtasks that make up each pe are handled using the dependency rules in THERP (Table 20-17 of Reference 5). For example: If an operator action required 2 of 2 manipulations for success within one HEP calculation, pe includes HEPs for EOC(1)+ EOC(2). [EOC - Error Of Commission] If an operator action required 1 manipulation, with 2 switches available, failure to manipulate the first switch can be recovered by operating the second switch: EOC(1) * EOC(2). Consideration must be given that EOC(2) may have a link or dependence with EOC(1) based on the time available. A similar consideration exists for core damage sequences containing multiple operator action failure events. In this case the degree of dependence between the events representing different functions (no common elements) is determined using the following guidelines:

a. Two operator action failures separated in time by an essential successful action are regarded as independent.

b. The time available for most operator actions varies from minutes to hours. The degree of dependence between operator actions is varied accordingly:

Time Separation (min.) Dependence
$0 < t < 15$ High
$15 < t < 30$ Moderate
$30 < t < 60$ Low
$60 < t$ Zero

c. Events initiated by the same cue and on parallel success paths are treated as having a common pc element.

d. Responses to memorized IMMEDIATE ACTION steps are independent of actions taken later in the procedure. Similarly, the IMMEDIATE ACTION steps are independent if they are performed by different crew members.

e. For cases where an operator action failure significantly reduces the time window for a subsequent operator action, high dependence would be assessed on the second operator action.

f. For cases where an operator action failure guarantees failure of a subsequent operator action, complete dependence would be assessed.” [16]

From this assumption and comments (See Table 29) the following conclusions can be rendered: general engineering judgments about how to assign dependency levels should be based upon the recommendations provided by THERP and some type of pre-determined timing intervals.

Table 29

Responses to Assumption 21

Response
• These appear to be reasonable guidelines and are things I would consider in a dependency analysis; however, I would not explicitly create events for cognitive and execution portions of the actions as it is resource intensive and typically does not add a lot of benefit.
• In response to part a, we take credit for "intervening" successes, but we don't necessarily assume zero dependence. We have created our own, decision tree matrix to model dependencies between separate operator actions. In response to part b, we use the dependency matrix shown in assumption 16 to account for dependency within-crew dependency for one action. This dependency level differs from that used above and in the current EPRI HRA Method, which assigns zero dependence after 1 hour. It was judged that based on the same crew being involved in the response until the next shift turn over (6 hours on average), some dependency will most likely still be present. Therefore, zero dependence was not assumed until 6 hours. For local actions, the level of dependence was increased to the next highest level given the fact that local actions are not as easily recoverable due to the limited amount of independent verification, additional time required to perform and verify the action, and general lack of direct indication of component status.

Assumption 22

> "The HRA was conducted using the Emergency Response Guidelines and Abnormal Procedures from Unit 1. Discussions with the operators indicate the procedures are close enough for Unit 2 that they can be assumed to be identical."[16]

No experts commented on this assumption, and it is inferred that they unanimously agreed. This assumption appears to be well justified, but only experts that have a detailed understanding of both units can comment if this assumption is appropriate.

Assumption 23

> "In the quantification of human error probabilities, a lower bound of 1E-5 was used as the minimum allowed value for single, or combinations of multiple, human interactions." [16]

The HRA Calculator applies 1E-5 as a lower bound for final HEP values. The HRA Calculator does not set lower bounds for the P_{cog} portions or the P_{exe}. The experts' comments are shown in Table 30, and one can see the variation among experts. Since there was disagreement among experts, in the Phase II survey experts were again asked questions about lower bounds.

Table 30

Responses to Assumption 23

Response
• I have never used any 1E-5 for a single human action. In my long life experience, I cannot even come up with a 1E-4 low HEP.
• 1E-5 might be a bit high for long term actions. I might used 1E-7 for actions over 24 hours.
• I use a lower bound for 1E-5 for single events and 1E-6 for HRA combinations.
• The HEP for any individual post-accident action is not allowed to be less than 1E-5. In addition, the minimum HEP that I use for the joint probability of multiple post-accident human errors occurring in a given accident sequence or cutest was not allowed to be less than 1E-6 due to uncertainty associated with determining the actual dependence between multiple operators actions and the ability to precisely quantify human performance.

Assumption 24

This assumption was not considered in this study because it references a previous PRA analysis and other references not available for use in this study.

Assumption 25

This assumption was not considered in this study, because it deals with documentation within the PRA model. This was more of a statement about previous HRA analyses than an assumption about the current analysis.

Assumption 26

> "The default value for time required to manipulate a switch on the control board is 3 minutes. This value is used as the minimum time, even if the operator stated a shorter time in the operator interviews, required by the operator to find and manipulate the switch." [16]

Within the CPSES analysis three minutes was consistently used as the minimum manipulation time. However, observation of operator interviews consistently shows that the operators estimated significantly shorter manipulation times. This assumption has not been justified (especially in conjunction with assumption one) relative to the basis of the three minutes. The expert's comments are shown in Table 31.

It is concluded that engineering judgments about assigning a default manipulation time are difficult to justify and a better approach would be to evaluate a manipulation time for each action. Furthermore, the training and crew experience should have some influence on identifying a manipulation time.

Table 31

Responses to Assumption 26

Response
• I use two minutes as a default time. However, there are cases (e.g during ATWS events) where I take credit for shorter times
• This assumption is in direct conflict to assumption one. The operating crew is highly skilled and experienced. The operators do not have to "find" a control panel switch. There minutes is a long time to turn a switch.
• Three minutes is too long and its use would imply core damage in many short response scenarios which are commonly successful in simulator exercises and even in actual operations. One minute may be more appropriate and 30 seconds maybe applicable for some actions such as stand by liquid control (SLC) injection.

Assumption 27

> "The default value for time required to recognize and respond to an inidication/annuciator in the control room is 5 minutes. This value is used as the minimum time even if the operator stated a shorter time in the operator interviews, required by the operator to respond to an inidication/annuciator in the control room." [16]

In addition to the stated assumption, it should also be added that for actions that had less than five minutes available to recognize and to respond only memorized actions were credited. If an action requires the use of procedures and less than five minutes are available to recognize and to respond, the HEP was conservatively set to one.

As in assumption 26, the five minutes was consistently used as the minimum response time. However, observation of operator interviews consistently shows that the operators estimated significantly shorter times. This assumption has not justified (especially in conjunction with Assumption 1) the basis of the five minutes. The expert's responses are shown in Table 32.

Table 32

Responses to Assumption 27

Response
• This time is also likely too long as this can be nearly instantaneous. Also, the conditions in the control room are so variable that believing we can model the operators' response times down to the time it takes to respond to an annunciator may be a bit dangerous and could mask more meaningful contributors. I would not use this.
• This assumption could really skew the time based diagnosis from the HCR/ORE methodology. We will look at the priorities and what other actions could be required at the same time when determining the median response time. For time critical actions, it is very likely that the median response time is 1-2 minutes.
• We accounted for this time in the overall execution or response time.

In conclusion, engineering judgments about assigning a default response time are difficult to justify and a better approach would be to evaluate a response time for each action. Furthermore, the training and crew experience should have some influence on identifying the response time.

Assumption 28

> "The value used for the dependency in the recovery of an execution error was the value determined by the HRA Calculator (i.e. zero, low, medium, and high), this is in lieu of any comments made during operator interviews." [16]

For each action analyzed operator interviews were conducted. The documented results of the interviews show that dependency in the recovery actions was not addressed. The HRA Calculator assigns a minimum dependency level for each recovery action based on the amount of time available. The experts comments are shown in Table 33.

Table 33

Responses to Assumption 28

Response
• We use the following, as described in the matrix given in Assumption 16 [See Table 27]
• The assumption does not mention when recovery credit is taken. We will normally credit self-review and other crew review for actions inside the MCR [Main Control Room] (time permitting). However, for actions outside the MCR, we would generally not credit other crew review because normally only one crew member would be assigned to perform this task.
• Factors identified in operator interviews that could impact the assumptions made in the HRA analysis should be considered in the assessment of dependence. That is what the interview is for.

From the responses shown in Table 33, it is concluded that engineering judgments about how to determine dependency levels should be based upon some consistent set of criteria and consideration of the results of the operator interviews. These criteria could be given within the HRA Calculator or available within internal guidance.

Assumption 29

This assumption was not considered in this study because it deals with procedure numbering internal to CPSES.

Assumption 30

> "The stress level (optimal, medium, high) was determined during the operator interviews and are not annotated in each HFE detailed calculation. The stress level was based on time and actions required to complete the task."[16] [This assumption is an exception to the default stress level chosen in assumption 1]

No comments were received on this assumption. The use of operator interviews was the preferred method for determining the stress level within the CPSES analysis. Further questions about stress levels were asked in the Phase II survey.

IDENTIFICATION OF TYPES OF JUDGMENTS EACH ASSUMPTION ADDRESSES

Table 34 gives the assumption number which addresses each area of judgment defined in the previous section. From the expert comments it is observed that the most disagreement among HRA analysts is within the judgment categories of Stress, Procedures, and Timing Information. While the experts did disagree with several of the assumptions directed at judgments made about recoveries within a specific action, it is clear from the comments that this group of assumptions were confusing, and it was not clear to the reader how they were applied. Without making additional judgments about what the intention of the assumption was and how assumptions were actual applied further conclusions can not be drawn. The comments the experts provided about recoveries within an action show that this area is one that requires several judgments and can be challenging to document appropriately.

The entire CPSES analysis was completed using the CBDTM Method, and it is interesting to note that many of the assumptions made have no influence on this method. For example, the only timing information required for the CBDTM method is to answer the question: Is there enough time available to complete the action? The HRA Calculator, requires the user to enter the manipulation and median response time for documentation purposes only. While the reviewers were probably not aware of this fact, they all commented that they would make different assumptions on how to collect this information. The same is true for judgments rendered about stress level.

Table 34

Classification of Assumptions Based on Which Category of Judgment They Address

Judgment Area	Assumption Number	Comments
Definition of Critical Actions	11	
Definition of Cognitive Actions		There is no stated assumption about how the cognitive actions were defined
Choice of Methodology	12	The CBDTM method was used for every action within the database
Stress Level	1, 20, 30	
Rule vs Skill		This designation is not required when using the CBDTM method for quantification
Timing Information	6, 26, 27	
Procedures	3, 9, 13, 14, 22	Only procedurized actions were credited within the database
Human Interaction with Hardware	2 , 8, 17, 18, 19	
Cue	2	Every action within the database was diagnosable by a control room indication.
Training	1	Interviews with the CPSES HRA analyst confirmed the following assumption: The most optimistic values for training were always used in quantification because operators are perceived as highly and well trained
Recoveries within an action	4, 5, 10, 16, 21, 28	
Review of final HEP		The CPSES HRA general assumptions did not include this type of review.

REVIEW OF SAMPLE CALCULATION USING CBDTM METHOD

For the second part of this survey, the experts were asked to review a complete HEP calculation within the CPSES HRA database. The action chosen was Feed and Bleed with the initiating event of general transient. This action was used as a model action, because it was assumed that every expert participating would be familiar with this action and may have actually completed an analysis for this action for a different plant. In addition to the complete analysis using the CBDTM method the participants were also provided with the results of the operator interviews and relevant pages of the procedures referenced.

Of the six experts who responded to the survey two of them choose not to comment on this section. Four responses is not enough data points to draw general conclusions on how to render judgments, but their comments do provide insight on understanding the use of engineering judgments and what types of things outside reviewers identify as questionable uses of engineering judgment. For this section, each expert has been assigned an alias of expert A, B, C, or D, and this is helpful in understanding the set of comments each expert provided.

Before responding to the specific questions about the analysis, two of the experts provided general comments shown in Table 35.

Table 35

General Comments About Pilot Survey

Response	
Expert A	I could not find the transition into FRH-0.1 in the EOP, I guess because it's in the critical safety function procedure, which was not provided. It seems to me that there are two cognitive steps in this HFE. The first is recognizing you have to transition to FRH-0.1, and the second, in FRH-0.1 is the initiation of feed and bleed (i.e, step10). I think the analysis is focused on the latter and there's no evidence of the former being considered. So my responses are based on that interpretation.
Expert B	The timing figure shows T_w as 20 minutes, $T_{1/2}$ as 10 minutes and T_m as 2 minutes. Based on the operator interviews, I do not see how this was obtained. It would seem to me that $T_{1/2}$ would be 1-2 minutes and T_m would be 2 minutes, which would leave 16-17 minutes available for diagnosis. According to the figure, only 8 minutes appear to be available for diagnosis. I am assuming that it takes about 8 minutes to receive the cue. One problem I have with the HRA Calculator is that it does not actually quantify the PSF identified in the execution errors. Our HRA does explicitly quantify PSFs, although not necessarily the one give in the analysis.

Expert A's interpretation of which cognitive portion of the action is being addressed in this analysis is correct. While not documented in the analysis, interviews with the CPSES HRA analyst confirmed this assumption. There was no consideration of the transition from the EOP to FRH-0.1.

Expert B's interpretation of the timing information is justified; however, CPSES choose to override information provided by the operator interviews in most of their analysis. This is one such example, and there is little justification given on why this was done.

The experts were specifically asked to answer a list of questions about the analysis. Below is the set of questions asked and the responses received from the experts

Question 1

Question 1: "When completing an HRA analysis do you or your company follow a set of guidelines?"

Table 36

Responses to Question 1 of Pilot Survey

Response	
Expert A	Yes, SPAR-H model [This is the NRC Model]
Expert B	Yes, Internal guidance
Expert C	Yes, Internal guidance
Expert D	Yes, IDAC HRA Manual Procedure

Table 36 shows that there is no one consistent methodology used among the experts, because the guidance documents referenced all apply different methodologies.

Question 2

Question 2: "If possible without doing an independent calculation, what would you expect a typical HEP value for this Human Failure Event (HFE) to be? Based on your intuition do you agree with the model HEP value?"

The responses given in Table 37 show that while every expert had an estimate of what a typical result might be, when compared against each other the estimated values encompass four orders of magnitude. The final HEP calculated by CPSES was 1.9E-2 which falls in the middle of the spectrum. This is important when discussing the use of engineering judgment, because in this question all experts were provided with the same information, and they all chose to answer the question differently.

Table 37

Responses to Question 2 of Pilot Survey

Response	
Expert A	Something in the range of 1E-3 to 1E-01
Expert B	I would expect the HEP to be in the range of 5E-3 to 2E-2. Therefore, I believe the estimation given in the analysis is reasonable.
Expert C	I would normally expect the HEP for Feed and Bleed to be in the range of 1E-2 to 1E-4 depending on the time available. However, based on the timeline in this analysis, I would expect the HCR/ORE diagnosis to dominate the cause-based diagnosis and the over all HEP to be >0.2
Expert D	The main factors contributing to failure of initiating Feed and Bleed, in my opinion, is not from wrong diagnosis or execution error but the hesitation of the operators wanting to initiate Feed and Bleed due to the system damage would result from such action. In the analysis, the operators would take ten minutes to identify the problem and additional two minutes to execute the procedures instructions, if the operators decide to do so. There are eight minutes available for the operators to deciding whether go for Feed and Bleed, as instructed by the procedures, or restoring AFW/MFW to have less system damage. Based on this type of analysis, I would expect a higher HEP and estimated it to be around 1E-1.

Questions 3 and 4

Questions 3: “Are there assumptions within this action that you feel are invalid or lacking justification?” Question 4: “If asked to complete an independent analysis, would you have chosen to make the same assumptions? Please note your different assumptions and justification.”

The responses to Question 3 (See Table 38) show that with the exception of timing information the assumptions are adequately justified and documented. Furthermore, the responses to Question 4 (See Table 39) show that even though the experts agree on these assumptions, they would have still chosen to make different judgments for this same calculation if completing it dependently.

Table 38

Responses to Question 3 of Pilot Study

Response	
Expert A	In general, the assumptions seem OK
Expert B	No
Expert C	The timing diagram shows 10 minutes as the median response time and 20 minutes for the time window. Neither of these is adequately justified. The operator interviews said 1-2 minutes for response time. This is consistent with the caution statement in FRH.0.1.B The document states that the 20 minute time window comes from MAAP, but does not state what the time is based on (eg. Time from low SG level to CD or latest time to open PORVs).

Table 39

Responses to Question 4 of Pilot Survey

Response	
Expert B	I would have only taken credit for one recovery step for critical step number 14. I would have also used the same stress level throughout the entire execution error.
Expert C	Expert C – I would have chosen a median response time of 1-2 minutes based on the caution statement in FRH.0.1B. I would have also addressed the action for different accident scenarios rather than picking the most limiting case. With the assumptions on the timeline, I can not justify the CBDTM Method vs HCR/ORE for diagnosis. That is the time considerations will dwarf an causal considerations.

Question 5

Question 5: "The methodology chosen for this action was the CBDTM Method. In your opinion, is this the best methodology for this action? Other methods available are HCR/ORE and THERP." The responses are shown in Table 40.

Table 40

Responses to Question 5 of Pilot Survey

Response	
Expert A	Of the three methods, I would have chosen this one.
Expert B	I think the use of the CBDTM method was appropriate.
Expert C	I calculate the diagnosis probability using both the HCR/ORE and the CBDTM methodology then choose the higher probability of the two.
Expert D	If we assume that the operators follow procedure closely no matter what the situation is, the timing becomes the major issue in this case. The HCR would be more appropriate for such situations. As mentioned in Question 2, the main contribution to the HEP is the operators decision of not following the EOPs. Among all the methods available for HEP quantifications, currently only expert judgment based HRA methods could assess the values of such HEPs.

Methodology choice is the first judgment an analyst must render in the quantification stage. In Question 1, every expert answered that in their calculations they currently use a different method. But when asked if the CBDTM method was best choice of methods within the HRA Calculator, three out of four experts agreed that this method was appropriate. Experts A, B, C are all using either the original CBDTM method or a slight variation of this method. Expert D is working on developing new methodologies. (See Table 40) Because of their backgrounds it is expected that experts who use this method will feel its use was appropriate while others developing new methods would choose methods either they developed or apply the same principles of methods they are developing.

Questions 6 and 7

Question 6: "Do you agree with the critical steps assigned to this action?" Question 7: "Would you add or subtract any of the critical steps?"

Questions 6 and 7 show the same results as questions 3 and 4. (See Table 41 and Table 43)

The experts tend to agree with the assigned steps, but if they were completing this calculation independently they would have rendered other judgments.

Table 41

Responses to Question 6 of Pilot Survey

Response	
Expert A	Yes
Expert B	It is not clear to me why resetting the contentment spray signal (Step 17) is a critical action and why it can not be recovered
Expert C	Generally I agree.

Table 42

Responses to Question 7 of Pilot Survey

Response	
Expert A	No
Expert B	I would not take credit for both Steps 16 and 18 as recoveries for Step 14.
Expert D	I would suggest adding a step “decision for activating Feed and Bleed either before Step 11 or Step 19. The added step is only for HRA modeling but is not stated in the EOPs.

Question 8

Question 8: “Do you agree with the choices made in the decision trees within the CBDTM method?”

The scope of this question is rather large, and the experts each commented on different judgments rendered within the CBDTM trees. (See Table 43) More specific questions about the judgments made within the CBDTM trees were asked in the Phase II survey.

Table 43

Response to Question 8 of Pilot Survey

Response	
Expert A	Yes
Expert B	For decision tree pcb, (data not attended to), it is not clear what alarm would is present to select branch l. It seems branch m is more appropriate.
Expert C	I would disagree on the “check vs monitor” in Pcc. If there is an alarm on low SG level, then the crew would respond to start OTC on this signal. I would also disagree on “single vs. multiple” in pce. In most events, the operating crew will be suing an EOP and an AOP for determining the diagnosis. Therefore, unless the scenario is in the very early stages of the events or very late, then I would say multiple procedures are being used. For decision tree pcg, I would probably say that the procedure contains an “OR” statement based on the “OR” statement in Steps 10 and 12.

Question 9

Question 9: “CPSES has a site policy of self checking. Is this enough justification for ALWAYS taking credit for self checking?”

Question 9 is directly related to assumption number five and confirms that there is controversy among the participating experts about how to apply self checking as a recovery factor within the CBDTM Method. (See Table 44) Within the assumption section, this is one of the most strongly stated and consistently applied assumptions within the CPSES database.

Table 44

Responses to Question 9 of Pilot Survey

Response	
Expert A	I am not sure what self-checking means for monitoring, or for missing a step in the procedure, unless there is a mechanism for triggering the checking. I do not think it is appropriate to assume this unless a mechanism can be identified.
Expert B	It depends on time available. I think that if self-checking were the only recovery mechanism available, the credit should be limited for time-critical actions. However, after 15 minutes, I believe the STA and control room supervisor provide better recovery mechanism for control room actions.
Expert C	Yes
Expert D	No, policy is a work statement that might be different from what has really been practiced. The performance shaping factors "work/safety" culture is more meaningful since it indicates the practice side of policy.

Question 10

Question 10 "Do you agree with the choices of THERP values for errors of omission and errors of commission? If you disagree, then why and what values would you use?"

Table 45 shows the responses to Question 10. The responses show a range of opinions on how to interpret and to extrapolate the small amount of data presented in the THERP tables to calculate P_{exe}. Additional questions about the interpretation of THERP tables were asked in the Phase II survey.

The HRA Calculator provides summarized THERP tables and simply requires the user to choose a tabulated value. The results of P_{exe} are then documented in the tabulated format. There is no documentation provided on how the dependencies between actions are calculated. Expert D's comments reflect this idea. If the intentions of the HRA Calculator are to provide a well-documented calculation to reviewers not familiar with the HRA Calculator, then this goal has not been achieved.

Table 45

Responses to Question 10 of Pilot Survey

Response	
Expert B	I agree
Expert C	No! First given a successful diagnosis of the need for OTC, there are few if any omissions errors that apply. Basically the whole point of OTC is to start the SI pumps and open the PORV's, the operators would not omit these steps. For errors of commission, I would pretty much stick to table 20-12. The SI actuation is a series of push buttons. Since CPSES is a latter plant, I would assume that the control panels have mimic layouts.
Expert D	I am not convinced with these values for the following reasons: The steps between Step 11 (Actuate SI) and Step 20 (Verify bleed path) are aiming the same goal: establishing feed&bleed. Once feed&bleed is decided, the conditional HEPs of the subsequent steps should be much less than their independent HEPs. In other words, the HEPs of subsequent Steps (i.e., Steps 12 to 20) are highly dependent on the success/failure of Step 11. The Errors of Commission (EOCs) mentioned in THERP mainly address the EOCs induced by attention failure. The cognition induced EOCs are not addressed. The operators responses in Davis-Besse lost of heat sink incident in 1985 are an example. In this case, the operators decided not to Feed and Bleed the RPV [Pressurized Relief Valve] (i.e., an error of omission) but tried to restore EFW. [Emergency Feed Water] (this activity is hard to be categorized with use of EOO and EOC classification since the EOO and EOC classification is system-centered rather than human-centered classification). As I stated in question two, I would assign 1E-1 for EOO of Step 11. State EOC only does not have much meaning. EOC make sense only it is associated with a failure mode. As for Steps 12 to 20, their basic HEPs are highly dependent on the success or failure of their preceding steps. The following example calculates EOO of Step 12, the EOOs of other steps can be calculated by the same manner: **Given:** P(Failure of Step 12 | given situation) = 1.3E-3 * 2 = 2.6E-3 **Assume:** success of Step 12 is highly dependent on the success of Step 11.The dependency level is high. **Calculate:** P(Failure of Step 12 | success of Step 11, given situation) = 1 - P(Success of Step 12 | success of Step 11, given situation) P(Success of Step 12 | success of Step 11, given situation) = {1 + [1 -P(Failure of Step 12)]}/2 = (2 – 2.6E-3)/2= .9987 P(Failure of Step 12 | success of Step 11, given situation) = 1 - P(Success of Step 12 | success of Step 11, given situation) = 1 - .9987= **1.3E-3**

Table 45 Continued

Expert D (Continued)	I agree with the value of the EOC of Step 11 shown in your table; however the EOC is only due to attention failure and it does not count cognitive failure. The EOCs of all other steps (Steps 12 to 20) caused by intention failure can be calculated as the same way I calculating the P(Failure of Step 12 | success of Step 11, given situation) in the example above

Question 11

Question 11: “Do you agree with the stress values and how the stress performance shaping factors are applied?”

As with Assumption 1 there is again little agreement among experts not only on what an appropriate choice for stress level should be but also on how to apply stress as a PSF. (See Table 46) Further questions about how to determine a stress level were asked in the Phase II survey.

Table 46

Responses to Question 11 of Pilot Survey

Response	
Expert B	No. The stress factors very from moderate to extreme stress with no explanation for why the stress level would be impacted. Given the failure of AFW, I would assume moderately high stress level (just as the operators said).
Expert C	Expert C - No, I believe that the stress level should be high (x5) throughout the entire execution error. As it stands, lower stress levels were assumed for some critical actions. As a minimum, the justification for using the lower stress level for certain critical actions should be justified in the analysis.

Question 12

Question 12: "How would you determine if this HEP value is acceptable in terms of meeting the needs of the PRA model? What additional information would be needed? What other people would need to be included in this discussion?"

This question was asked to try to understand how an HRA analyst determines if his answer is "correct." Since there is no physical data for comparison, each expert must render judgment on how they justify that their results are complete and will meet the needs of the PRA model. Table 47 shows that each expert rendered judgments on how they define acceptable results. Expert C even commented that he did not know how to interpret what "acceptable" was referring to.

Table 47

Responses to Question 12 of Pilot Survey

Response	
Expert A	I would look at it in relation to the other HEPs and do a comparison based on the scenario specific demands, training etc. To me the absolute value is less important as there is a significant uncertainty associated with HEPs, and this would have to be addressed when using the PRA.
Expert B	I would compare its relative value with other HEPs in the PRA. In addition, I would compare it to similar HEPs at other plants, including the HEP used in the NRC's SPAR model. In addition, operators and/or training personnel should review the final results of the HRA. In terms of additional information the following would be needed, other PRAs or the SPAR model.
Expert C	I am not sure what you mean by the term "acceptable". When I look at the HEPs, I look for consistency. In other words, I would expect that a more difficult action would have a higher execution error than a simple action. Actions that are more time critical will generally have a high probability than non-time critical actions. I also try to be very consistent with the cause based determinations. It is not clear to me what type of walkdowns or control panel reviews or simulator reviews were done to support the HEP analysis. Also, you reference the Reactor Trip procedure and the Functional Recovery procedure. I would also have looked at the Loss of Feedwater procedure and any alarm procedures that would cue the operators to the loss of AFW (pump trip alarms, low SG alarms, etc.).

It was intended that from the responses to this question, all experts would apply the same principles to determining if the results were acceptable. Overall, the three comments suggest that HRA analysts would want to compare their final HEP values to other results within the same PRA model to produce consistent results. However, this statement is too general, and there needs to be some definition on what specifically to compare between HEP values. The comments do provide some ideas such as timing and quantifying the same action using a different method. Question 13 further addresses this same issue. Sometimes HRA analysts may "check" the results of an HEP calculation by comparing it to historical values, and question 13 was attempting to address this issue.

Question 13

Question 13 "Can you determine if the HEP is consistent with historical values and/or similar to other NPPs values? If this value were inconsistent with the historical value, would you question and change this analysis in any way?"

The comments (See Table 48) show that while experts do make comparison with historical values, they all agree that this should be done with caution.

Table 48

Responses to Question 13 of Pilot Survey

Responses	
Expert A	I believe it is in the ballpark of other assessments.
Expert B	I would look at it to see if there are any valid reasons why the HEPs are different. However, if the HRA methodologies have changed, this may explain the difference.
Expert C	For some actions you can look at HEPs developed for the IPE or for past generic studies. However, you also have to be aware of what types of things are driving your HEP and potentially what was driving the HEP in the historical analysis. I believe that it is much more important to be consistent within your PSA. If the HRAs are consistent within the PSA, then if all HEPs are consistently high then the CDF is higher but the system importance ranking identifies the most important systems. With HRA you can always second guess the analysis (no matter how well it is documented), but consistency counts. Again, I am more focused on consistency with other HRAs in the same analysis. However, I would question the value if it were significantly higher or lower than the previous plant HRA analysis.

Conclusion

From the comments on the sample calculations the following conclusion can be drawn. If the calculation is documented appropriately, reviewers of an HEP calculation may not question or criticize assumptions made within an analysis, but if personally asked to render the same judgment they might use a different approach than was used by the analyst.

The questions asked in this survey were directed at identifying where judgments are made within an analysis, and it was intended that the experts' responses could be used to draw conclusions about how the judgments were rendered. This survey succeeded in identifying judgments; however, with only four complete responses no final conclusions can be drawn about how one renders these judgments. Furthermore, the questions asked did not address specifically the issue of how judgments were made. The

Phase II survey was created to address specifically the issue of how one renders judgments.

CHAPTER VII

PHASE II SURVEY

From the results of the Pilot survey the Phase II survey was created. For this survey twenty additional HRA analysts were asked to participate, and a total of eleven responses were received. Five of the responses were from participants of the Pilot survey. Of those who responded four people are currently using the HRA Calculator and the seven others are familiar with the methods employed by the HRA Calculator. All of the participants have completed numerous HRA analyses and have several years of experience.

The Pilot survey showed that the questions asked were too specific to the example to draw general conclusions. The Phase II survey was broken into small sections addressing different areas of judgment. The first section asked general HRA questions not specific to a method. The second section contains questions specific to the HRA Calculator and the use of the CBDTM Method, Annunciator Response Model and the HCR/ORE Correlation. Because most HRA analysts only use one methodology, it was expected that no participant would answer every question.

The following presents each question asked followed by the responses received. The responses are stated exactly as received from the participants, but only the responses that address the question in a context relevant to the HRA Calculator are provided. Several participants answered questions in relation to other methods not applied by the HRA Calculator. The results from both surveys were used to create recommendations on how to render judgments within the HRA Calculator. The complete Phase II survey which includes the introduction and instructions, and sample calculations used for reference are included in Appendix C. The categories in the survey were defined prior to defining the areas of judgments (See Chapter III), and there is not always a one-to-one correlation between survey sections and identified areas of judgments.

COMPLEXITY OF ACTIONS

Question 1

Question 1 "How do you judge whether an action is rule-based, skill-based or knowledge based?"

Table 49 shows that most analysts follow the THERP definitions for rule-based, skill-based or knowledge-based classification (See Chapter VIII). However, they also have generalized and created simplified rules for classification such as rule-based = training + procedures.

Table 49

Responses to Question 1 of Phase II Survey - Complexity of Actions

Responses
• In skill-based processing there is a close coupling between the sensory input and the response action. Actions that are classified as skill-based are typically those that are immediate actions in emergency procedures, for which there is extensive training and practice. In essence, the operating crew is expected to respond immediately to the available cues for skill-based actions, without having to refer to procedures or to discuss the actions extensively with each other. Rule-based cognitive processing is governed by a set of procedures that are expected to be used and followed during the event. It is expected that the operating crew is familiar with and has practiced the use of the procedures, but not necessarily to the extent that the actions are performed by rote. Knowledge-based processing encompasses actions that may require the integration of a more complex set of indications stemming from multiple equipment failures, particularly unusual events, or instrument readings that provide only indirect information regarding plant status. Because the specific conditions may not have been anticipated, response is not necessarily governed directly by procedures. Instead, the performance of the operating crew may depend significantly on their knowledge of the plant design and operating characteristics and their ability to apply this knowledge in formulating an appropriate response.
• I would avoid using time-reliability curves based on the results of the EPRI ORE work, but if I were to use one it would be the ORE version, which did not use the skill/rule/knowledge as a differentiating parameter. This is a hold-over from the original HCR, which was not supported by the ORE project results. However, if I were to make such a judgment, it would be based on whether the response was skill-of-the-craft (i.e., very practiced and done without need to consult procedures) – skill-based, whether the actions were guided by procedure – rule-based, or whether there was some thinking to be done – knowledge-based. While I would not call the actions skill- rule- or knowledge-based, I would differentiate between instinctive actions (e.g., confirmation of reactor scram), procedure based actions, and potential recovery actions that are not procedure based.
• I follow the guidance in NUREG/CR-1278 (THERP). I consider knowledge-based actions to apply to situations that are to some extent unfamiliar to the operator, either due to lack of training or lack of procedures. Rule-based actions apply to situations where the operator relies on procedural guidance for performing a particular action. It is expected that the operator has at least some training on or familiarity with the procedure. Skill-based actions typically apply to actions for which the operator has extensive training or experience. While the actions are usually proceduralized, the operator is capable of performing the required action(s) from memory.
• Judgment. Most actions are procedure-driven, and thus rule-based. Some field actions are considered skill-based, as is normally controlling level in RCS and steam generator. Knowledge-based actions are for actions outside normal EOPs.
• Judgment. Most actions are procedure-driven, and thus rule-based. Some field actions are considered skill-based, as is normally controlling level in RCS and steam generator. Knowledge-based actions are for actions outside normal EOPs.

Table 49 Continued

• Rule-Based: proceduralized, highly trained, compliance based. Skill-based: proceduralized; habit or stored patterns of pre-programmed instructions. Knowledge-based: no procedures, or instructions; highly analytical
• The line between rule based and skill based is difficult to define and may change between operators and/or plants based on training and the content of the procedures. If an operator is considered to have committed a simple step or set of steps to memory, then I might consider it a skill based action (maybe putting the mode switch in shutdown, for example). Other proceduralized actions I would mostly define as rule based actions. Knowledge based actions I tend to think of as those actions that require the operators to interpret symptoms of the plant and determine the correct course of action. With the advent of symptom based EOPs, the knowledge based actions that might be analyzed in a PRA are, in my opinion, not very common because the procedures tend to address the interpretation.
• Actions directed by procedure are typically considered to be rule based. These are typically actions that are pertinent to the cognitive portion of the analysis. Actions directed by verbal communication, such as to an operator in the field, or execution type actions, such as opening a valve, starting a pump, etc are considered to be skill based. Cognitive actions without specific procedural direction are knowledge based. In general, we would consider all troubleshooting type actions, or infrequent evolutions requiring a number of steps without procedural guidance, to be knowledge based.
• Rule-based: Completion of a task requires the operator to follow written procedures. The operator knows the general guidance or direction of the procedures but not to the specific details such as all the procedural steps in their exact sequential order Skill-based: the operating procedure of a task is familiar to the operator. Without the help of written instruction, the operator can comfortably complete the task. Completing a task by reciting the procedure steps which are familiar to the operator also counted as skill-based. Knowledge-based: there are no written procedures/instructions nor formulated solution to complete a task. The operator has to rely on his/her engineering knowledge and system-specific knowledge to act on the task.
• Rule-Based=procedure+training. Skill-Based=procedure+training+frequent practice Knowledge-based=No procedure, only training for qualification exam and college
• When the required action is specially stated in the procedure and the operator has enough time to follow the procedure, I would consider it as Rule-based. When the operator required an immediate action (such as manually tripping the reactor during ATWS event) prior to follow the procedure, I would consider it as Skill-based. When the action is not specially stated in the procedure, I would consider it as Knowledge based.
• I consider that all proceduralized actions are rule-based.
• When the required action is specially stated in the procedure and the operator has enough time to follow the procedure, I would consider it as Rule-based. When the operator required an immediate action (such as manually tripping the reactor during ATWS event) prior to follow the procedure, I would consider it as Skill-based. When the action is not specially stated in the procedure, I would consider it as Knowledge based.

Question 2

Question 2 “Do you use this type of designation in your HEP calculations? If so, how is this information used?”

The responses can be grouped into three categories as shown in Table 50. Some analysts do use this type of designation directly in their HEP calculations and apply it within the use of time reliability curves. Others feel that this information is useful in understanding the action and should have some implicit effect such as skill-based actions should have lower stress values that other knowledge-based actions or less recovery is applied for knowledge-based actions. The third group of participants agree that this classification is not used in any form within their calculations and do not bother to classify actions in this manner.

Table 50

Responses to Question 2 of Phase II Survey - Complexity of Actions.

Response
• Yes, the HCR model is based on a time-reliability correlation for crew response. The correlation was evaluated separately for three different types of cognitive processing: skill-based, rule-based, and knowledge-based.
• Yes. It is useful to document the analyst’s thoughts and views of the action. It does not have a direct quantitative effect, however there may be specific cases where the information may be used to override an HRA calculator default or value. These cases would typically be those where we feel that we have significantly more uncertainty than is typical.
• Yes, this information used during the procedure step review.
• No, not explicitly
• I do not use the designation of rule-based, skill-based and knowledge-based explicitly in the HRA. However, they are implicitly considered. For example, in general we only take credit for actions that are proceduralized. As such, knowledge-based actions are typically not credited. Instead of designating actions as either skill-based or rule-based, we categorize them based on amount of training and/or experience the operators have with the particular action. We assign levels of high, nominal or low to represent the amount of training/experience on a particular action, with corresponding multipliers of 0.5, 1 and 3, respectively. (These multipliers are consistent with those used in the NRC’s SPAR-H Method).

Table 50 Continued

•	Indirectly. Less recovery for knowledge based actions.
•	Qualitatively it appears that skill-based would have the lowest probability of failure; followed by rule-based, and then knowledge-based.
•	No, the skill, rule, or knowledge-based classification is still too high level to assess HEPs of variant types of tasks in different industries.
•	I do not use the skill/rule/knowledge based distinctions in my HRA evaluations.

Question 3

Question 3: "To what extent do you think the designation between rule-based, skill-based, or knowledge-based actions influences your HEP calculations?" Based on the responses to Question 3 shown in Fig. 13 it is concluded that this designation should influence the HEP calculations.

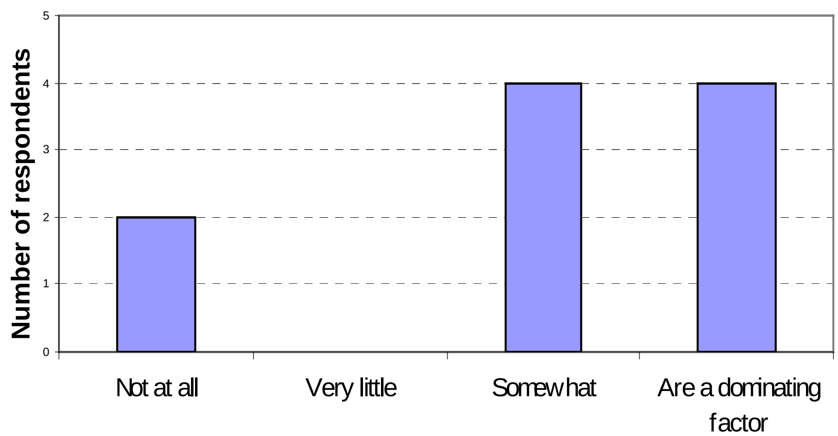

Fig. 13. Participants Opinions on How the Classification on the Complexity of the Action Affects Overall HEP.

Question 4

Question 4: "Do you think your answer to Question 3 is different for different methodologies? If so how? "

The responses to Question 4 (See Table 51) show that there is large disagreement about how the classification should affect the calculations. Again, most participants agree that judgments about the classification of the actions should affect the results of the calculations. The original intent of this question was to identify if one would use different parameters when classifying the actions. Other than the simple No responses, the participants did not consider the question in this context.

Table 51

Responses to Question 4 of Phase II Survey - Complexity of Actions

Response
• No [5 participants]
• Only to the extent that I would differentiate between, instinctive, procedure driven and non-procedure driven recovery actions. However, I would be using different HRA methods for each category, not shifting a parameter within a TRC.
• Our approach is identical to that used in the SPAR-H Method, but probably differs from other methodologies. In fact, some HRA methods may not even quantitatively account for these designations.
• My understanding is some of the methodologies were based explicitly on the rule, others more implicitly or use other variables which are related to these three different factors.
• It depends on whether the methodology specifies that the distinction must be used as an important characteristic of the action's definition and quantification. If it is an integral part of the methodology, then I would use it, but I don't think I would rely on a methodology that required the use of this characteristic.
• Certainly! Surgery operation is skill-based task; answering the midterm examine questions are mostly knowledge-based activities; and setting up a newly purchased equipment is mostly procedure-based activities. The skill-based, rule-based, and knowledge-based activities are not usually the dominant factors affecting HEPs.
• Some methodologies do try to account for the use of skill, rule and knowledge-based actions. For example I used it in the construction of the HCR approach.

Conclusion

When rendering engineering judgments on how to assign a complexity level analysts tend to formulate simple guidelines (unique to each analyst) based upon the complex THERP definitions. The classification should have some implicit effect on the calculation if the methodology does not use this parameter within the numerical algorithms. The responses to the questions in this section show that all analysts agree that this parameter is important to several different portions of the analysis such as methodology development, timing, stress, training, and review of the final HEP.

STRESS LEVEL

Question 1

Question 1: “How do you determine stress level for an action?”

The responses show (See Table 52) that there is no common approach to determining a stress level. Furthermore, the same levels for stress are being used in entirely different contexts. For example, the HRA Calculator uses low, moderate, or high stress, and many of the participants have defined their levels differently. From the responses there are four re-occurring parameters used by experts: operator interviews, time, workload, and consequences of the action the crew fails.

Table 52

Responses to Question 1 of Phase II Survey – Stress Level

Response
• Operator interviews [2 responses]
• Indirectly through consideration of complexity, time constraints, workload (I used the CBDTM Method for the cognitive element and that was constructed to focus on factors a PRA analyst might be able to address, without being an amateur psychologist).
• We classify stress as being in one of three levels: nominal, high and extreme. An extreme stress level is disruptive to the point where performance of most people will deteriorate drastically. Extreme stress is likely to occur when the onset of the stressor is sudden and the duration of the stressing situation is long. This level of stress is also associated with the feeling of threat to one's physical or emotional well-being. An example of an extreme stress situation is one involving catastrophic failures that have the potential for radioactive release. A high stress level is considered to be higher than nominal. Examples include the presence of multiple instruments and annunciator alarms at the same time and unexpectedly; loud and continuous noise which impacts the ability to focus on the assigned task; or the consequences of the task represent a threat to plant safety. A nominal stress level is conducive to good performance.
• Judgmentally. Bases on combinations of perceived time, complexity of sequence, consequences of the actions, expected frequency of the sequence… I start with moderate stress for accident responses actions and upgrade (to high) or downgrade (to low) only if there is a good case.
• Time available, and perceived consequences of the failures to accomplish something, and familiarity with the situation.
• I typically use a time reliability correlation to account for the stress factors as it usually captures important stress issues. For instance, containment failure is a potentially disastrous consequence which could threaten the lives of plant personnel and the general public, but the long time that is generally available to mitigate the conditions that are causing the containment challenge would reduce the stress for completing that action. I think time stress overrides consequence stress in most cases. If I were forced to apply stress levels, I suppose that imminent core damage with limited time available would be extreme or threat stress, high stress when multiple emergency systems have failed but core damage is not imminent, moderate stress for other accident conditions, and low stress for actions a reactor trip situation when all systems are operating properly. That's a pretty simplified approach, but I would view a more detailed approach as limited in benefit due to the fact that the assignment of stress levels will always need to be subjective to address all potential scenarios. A cookbook method is difficult to apply.
• With great difficulty and much discussion. Seriously, this is considered to be one of our most difficult steps of the analysis. The stress level affects the quantitative result within the HRA calculator and the typical sources are not particularly satisfying regarding guidance. We tend to shade to Moderate stress more frequently than the HRA Calculator would recommend. This most often happens for actions that are occur during events where a number of things are simultaneously changing in both the primary and secondary parts of the plant, or for loss of power scenarios.
• Two ways: First, direct assessment by experts or interviewing operators. Second, calculate stress as function of other directly assessable PSFs (e.g., whether reactor tripped, alarms activation state, severity of the situation)
• Guidance in NUREG 1278. Response to an evolving accident leads to MODERATE stress, if operator is under threat of loosing control (no response to prior actions, or additional events), then EXTREME stress is applied.

Question 2

Question 2: "Suppose during operator interviews that the operators conclude that the action is low stress but you believe the action is high stress, how do you determine a stress level?"

Table 53 shows that this scenario does occur in HEP calculations and that analysts have pre-constructed solutions to this problem. The simplest way to acknowledge this disagreement is not to ask operators. However, these three responses came from participants that all had over twenty years of experience. The least experienced analysts both commented that they would defer to operators. Applying weighting factors would be another approach, but it does place more subjectivity on how to weight each response, and there will be variation among analysts.

Table 53

Responses to Question 2 of Phase II Survey – Stress Level

Response
• I would defer to operators as being most knowledgeable.
• I would explain to the operator the criteria described above for classifying stress levels. Beyond that, I would generally defer to the operator's opinion.
• I would pick the high stress. I would also write a justification to document why I picked the high stress level.
• I do not ask the operator about potential stress level. It is not possible to simulate stress level at the Simulator. Instead, I use my own consistent judgment i.a.w. the pre-established guidelines. Later, I review all HRA for consistency of assumed stress levels.
• If operators and trainers agreed unanimously for low stress, I would likely make it nominal stress.
• I probably would use nominal, which average out the differences. Alternatively, I would interview additional personnel to see whether there are other factors not captured in the first interview.
• Provide appropriate weight factors to the operator's assessment and my assessment to obtain a combined result.

Table 53 Continued

• I would not ask directly about stress, but focus on the indirect measures above, which are somewhat more objective.
• After 20 years of daily contact with operators, including interviews, I have concluded that interviews have limited value. Every operator is unique and every interview depends on the immediate context of the interview (your relationship with the operator, is the operator having a "good" day, is the operator interested in the review, etc). Further, in matters like these, operators tend to react like fighter pilots, i.e. they tend to label everything as low stress. I rely more on my view of the context of the action/event and any observations I have made on the simulator or the infrequent real event.
• The best way to proceed if you disagree with an expert's (operator) opinion is to try to observe crews at work on the simulator for a similar accident.

In summary there were four different types of response to this question: 1) simply defer to operators' opinions, 2) use the level determined by the HRA analyst, 3) apply even more subjective judgments and apply weighting factors, and 4) do not ask operators for stress levels but instead focus on indirect measurements or observations in the simulator.

Question 3

Question 3: "To what extent do you think the stress level choice influences your HEP calculations?"

The responses to this question are shown in Fig. 14, and the results show that most analysts consider stress to have a some impact on the HEP calculation.

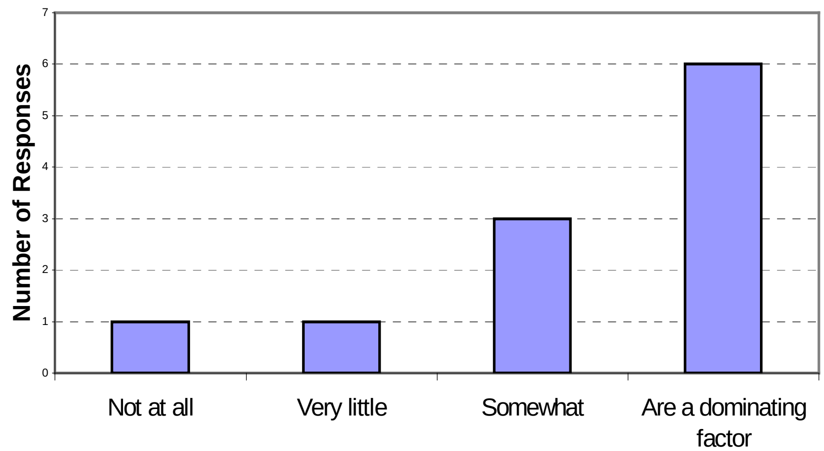

Fig. 14. Participants Opinions on How Stress Influences HEP Calculations.

Question 4

Question 4 “Do you think your answer to Question 3 is different for different methodologies? If so how?”

Five participants responded with a simple No response, but an equal number responded that they do think stress level influences the calculations differently depending on methodology. (See Table 54) If one actually considers several different HRA methods available for quantification, it is easy to reach the conclusion that stress is treated differently by different methods. However, this study is only considering analytical methods applied by the HRA Calculator, and four out of the five participants who responded No are current users of the HRA Calculator. This is most likely because the stress level is asked for as low, moderate, or high, and the same PSF value is used regardless of which method is used to calculate P_{cog}. It is therefore, concluded that a consistent PSF value is more important than the classification.

Table 54

Responses to Question 4 of Phase II Survey – Stress Level

Response
• No [5 responses]
• Yes, because in CBDTM, the question about "stress" are asked differently than they are in THERP
• I think that the choice of stress levels in other methodologies has an appreciable cumulative impact on the HEPs, especially in terms of execution errors.
• My understanding is some of the methodologies considered explicitly the stress, others may use other variables which are related to the stress factors.
• The use of stress could vary depending on the methodologies used, but I don't use many methodologies and don't have the insight as to how the use of stress might change.
• Yes, depend on the context stress is not always a dominant factor. Other factors (e.g., fatigue, biased mind) have superior influence than stress in some situations.
• Yes, for example HCR does not consider stress.

Question 5

Question 5: "When calculating P_{exe} (using the HRA Calculator) is it better to maintain a constant stress level for all critical actions or vary the stress level between actions? Table C-2 and Table C-3 show both scenarios for the Feed and Bleed Action used in the Phase I Survey."

There were three different opinions on how to handle this situation (See Table 55). First, four participants agree that they would generally maintain a constant stress level. Second, four analysts stated that they would attempt to quantify the action as accurately as possible and, therefore, they would vary the stress level among critical actions. The third approach used by three analysts is to use a different methodology approach or to analyze in the action in more detail than applied by the HRA Calculator.

Table 55

Responses to Question 5 of Phase II Survey – Stress Level

Response
• Maintain constant stress level unless involving different people in different environments.
• I would use the same stress value for all critical actions. I couldn't see a basis for me, as an HRA analyst, rather than a psychologist, to make any distinction.
• I would apply a constant stress level for all of the subtasks within an action. There are a couple of reasons for this. The first is that the resources available for HRA are limited and applying stress on a subtask level can be time consuming. The second is that is not clear that the additional rigor makes the answers any better. Step based stress assignments are even more subjective than one for the overall action and an additional layer of guesses does not imply a more accurate answer.
• Largely same stress levels. When reactor operator request an action outside the control room by someone else, that other person will be assigned OPTIMAL stress level.
• I think it is better to quantify HEPs as accurately as possible. Therefore, if the stress level varies between tasks for a specific action, it should be modeled as such. Having said that, I do not believe in practice that the stress level will vary frequently between tasks for a given action.
• I am not sure without doing a more detailed sensitivity studies. My intuition argues for both cases, depending on the different understanding and the plant scenarios of interest.
• Vary stress level only if there is a clear justification. It makes sense that the first step in the example might have higher stress than subsequence actions.
• I believe the stress level should reflect the specific action to the extent possible. Otherwise, may make it difficult to see differences between actions. We are always trying to reduce the subjectivity, but we should be cautious about arbitrary choices during analysis. Our overall objective is consistent application of the methodology so as to better be able to see differences between various actions. Please note that I believe there is a significant difference between consistent action and arbitrary action.
• Since the success of some steps within the procedure are more important then the others, I think the stress level should be vary based on the critical actions.
• It depends on the duration of the task. For the feed-and-bleed scenario, I would use constant pressure level.
• The problem with the table is that it does not deal with the context within which the assessment is being made. The approach is typical of Swain's approach in breaking down tasks into sub-elements and then trying to quantify them and then attempting to account for context by using nominal PSFs. Based purely workload considerations I would say that most of the actions are low workload since they involve the operation of a small number of switches in readily available locations. Establishing N2 and Instrument air could be difficult based on where the various stations in the MCR [Main Control Room] or outside in the Aux room. In the case of errors of commission, I would say the importance of the actions, in sense of core damage frequency, will determine what will even be looked at. If it is looked at then I am not sure that individual steps are looked at in this manner. Again we are back to the Swain way of looking at things, piecemeal. More modern approaches deal with the whole response of the crews to an accident. As for the Table C-3 a & b, the same comments hold.

In general, the participants were equally split on whether it was appropriate to vary the stress levels among actions. In the Pilot Survey only one participant identified the variation in stress levels between critical actions. It was anticipated that with this question there would be strong agreement among participants; however, this was not the case.

Conclusions

Engineering judgments about stress should be considered on an individual bases and no “cookbook” formula can be applied. When determining a stress level analysts do generally consider the following: operator interviews, time, workload, and consequences of the action if the crew fails. This is shown both in the survey responses and the CPSES HRA (See Chapter III). In addition, HRA analysts are using the same classifications in different contexts, so it is better to determine the PSF value as opposed to a level such as low, moderate or high.

To avoid rendering inconsistent engineering judgments during operator interviews analysts tend to have pre-constructed solutions about how to handle disagreement. For example, the CPSES HRA conducted operator interviews and chose to always defer to operators opinions when there was a disagreement about stress levels. However, the survey responses show that the more experienced the analysts, the less weight they place on the operator’s responses to stress level.

Engineering judgments made about varying the stress level between critical actions are difficult to justify if the action is completed by the same person in the same location. Therefore, the engineering judgment should be based on what level of detail is necessary for the analysis. In some instances this would be a time consuming task that would not impact the results, and in other cases, this level of detail is a requirement. One example, where analysts would want to apply additional detail to the calculations could be for actions that are high stress and $T_{1/2}$ is less than 5 minutes. In these types of actions the results of the CBDTM Method and the HCR/ORE Correlation can vary by orders of magnitude.

TRAINING

Question 1

Question 1 “Do you differentiate between simulator training vs. classroom training in HEP calculations? If so, how is this used in your calculations?”

The current configuration of the HRA Calculator does not differentiate between simulator and classroom training, but it does ask the analyst to identify the different types of training for documentation purposes. Two participants responded with a simple no response, and three responded that they do not differentiate between types of training directly.

Four participants responded that they do differentiate among training types. In general they do this either within the design of the methodology, such as CBDTM Method asks the analyst to differentiate between training and actually practicing the action, or using a larger sigma within the HCR/ORE Correlation for classroom training compared to simulator training. Table 56 shows the complete set of responses. This shows that if an analyst chooses to differentiate between simulator and classroom training, this is typically done as prescribed within the methodology or implicitly used to determine other parameters. However, half the participants do not differentiate between training types, and it is implied that this is because the methodology they use does not directly specify this task.

Table 56

Responses to Question 1 of Phase II Survey – Training

Response
• No [2 Responses]
• I would question the relevance and amount of the training more than whether it was simulator or classroom as far as the cognitive element is concerned. However, my bias would be that classroom training would not be as effective, particularly for actions like venting a containment.
• When I refer to the amount of training on a particular action as being high, nominal or low, I do not generally differentiate between classroom training and simulator training, although both types are usually included for most actions credited in the PSA. Note that some actions credited in the PSA are performed locally at the equipment. As such, simulator exercises are of little use. However, such actions typically have corresponding Job Performance Measures (JPMs) which have the operators simulate the actions.
• Only indirectly – use a larger sigma for classroom training to account for larger spread in timing.
• The Cause-Based Method includes consideration for training on steps and for actually practicing the actions. I use these features to account for training and practice.
• Yes. Not generally used in calculation, however this may be a consideration for determination of stress level.
• Yes, I believe most simulator training would include classroom training subjects (such as EOP response from the control room). However, classroom training can also included local actions or recovery actions from different alternatives.
• Yes, I introduce training as a heading in the HDT formulation. I then use training quality as a measure within the training heading. Exposure to training on the simulator is obviously of a higher value than classroom training particularly if data is collected and analyzed.
• It appears to me simulator training would carry more weight; due to the premium demand on the simulator, a surrogate of interviewing simulator instructors appears to be the most pragmatic way of getting the information. It is recognized, however, that simulator instructor may be somewhat biased in his understanding of the scenarios and experience. Most of the simulator instructors still have the design basis mentality, i.e., assume multiple failures and worst case scenarios rather than considering the scenarios on a cutset-by-cutset basis.

Question 2

Question 2: “To what extent do you think training influences your HEP calculations?”

The responses show that most analysts consider that the parameter of training should have some effect on the HEP calculation. (See Fig. 15)

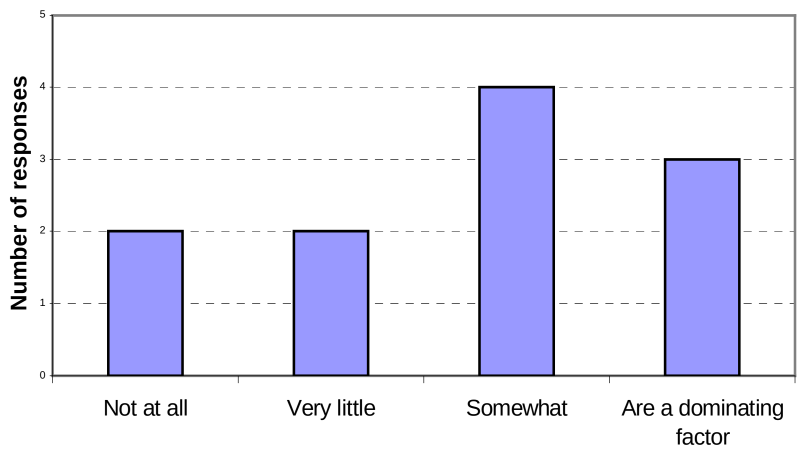

Fig. 15 Participants Opinions on How Training Influences HEP Calculations

Question 3

Question 3: “Do you think your answer to Question 2 is different for different methodologies? If so how?”

Six of the participants agree training has the same influence regardless of which methodology is used. (See Table 57). Only one participant thinks training will influence the results differently between different methods, and his response is more convincing than a simple No response. The section “Choice of Methodology” further addresses questions related to different results from different methods.

Table 57

Responses to Question 3of Phase II Survey – Training

Response
• No (5 responses)
• No, I don't think training would change its significance in different HRA methods. However, I see the training and the products of training (e.g., knowledge, experience, and skills) are as a whole.
• I think that the training influences are different among methodologies for numerous reasons. First, not all methodologies may even quantify the impact of training. The HRA Calculator, for example, does not quantitatively account for the training influence. Our HRA methodology, although based on the EPRI HRA Method, quantitatively assesses the impact of performance shaping factors (PSFs) such as training using an approach similar to the one contained in the NRC's SPAR-H Method. Second, the adjustment factors for HRA methods that do quantitatively account for training may not be the same. Lastly, even for those HRA methods that use the same adjustment factors, the criteria for designating the level of training (e.g., high, nominal, or low) may be different.
• I do not know enough to say how other methodologies might weight training, but I could not analyze it in much more detail than I do now with my current background.

Conclusions

When rendering engineering judgments about how training influences HEP calculations analysts consider what type of training operators receive (classroom vs simulator) either implicitly by incorporating this information into other parameters or following the use prescribed by the methodology. With one exception when rendering engineering judgments about methodology choice analysts do not consider how the parameter of training can vary among methods.

TIMING

Question 1

Question 1: "How would you calculate/determine T_{sw}?"

The participants agreed that they would use some type of thermal-hydraulic model based around the success criteria to obtain $T_{sw.}$ However in addition they also use other sources including: operator interviews, manufacturers' recommendations, and the FSAR. (See Table 58)

Table 58

Responses to Question 1 of Phase II Survey – Timing Information

Response
• Engineering Analysis.. Thermal Hydraulic models such as MAAP would be used for time to core melt calculations; engineering calculations would be used for items such as time to drain a tank; manufacturer recommendation/judgment may be used for items such as the time a pump can operate in a degraded condition (i.e., insufficient NPSH [Net Positive Suction Head]) before damage occurs.
• I would calculate T_{sw} from the time that the event occurs to the latest time at which an action must be completed in order to prevent an irreversible state, which is not always equivalent to core damage. For example, if core damage occurs in 6 hours but the pumps that are required to prevent core damage cavitate at 2 hours, our value of T_{sw} would be 2 hours (not 6 hours).
• T-H [Thermal-hydraulics] analysis using MAAP or other simplified scoping analysis based on information from FSAR [Final Safety Analysis Report] or accident analysis done for success criteria determination.
• The reference sources or calculation methods for T_{sw} are determined by the action and its success criteria. Sometimes that means that thermal hydraulic analyses are the appropriate bases while in other cases hand calculations may be more appropriate. In certain cases, there is no easy way to determine T_{sw} and judgment is required. In those cases, I have tried to obtain system engineer input, but sometimes, it is up to the HRA analyst to estimate it based on his or her judgment (last resort).
• By plant specific analysis whenever possible (preferred). Otherwise, analysis from a similar design, or finally best estimate, provided that timing is not critical. If timing is critical, one had better use analysis (otherwise the NRC will use 1E-01).
• It depends on the system failure criteria set for the task. T_{SW} is the time lapse between the initiating event and the system failure state reached assuming that there is no operators' intervention on the system state.
• Use of Code MAAP4, use of owners' group analyses, interview operators or ops training personnel
• Most of them by MAAP analyses. Some based from the WCAP [Westinghouse Topical Report], plant specific calculation results. If none of them available, would use operator inputs or simulator times.
• The time window is usually defined by carrying out transient analyses. Even a simulator could be used for these purposes if the plant models are reasonably accurate.
• Typically from thermal-hydraulic calculations
• MAAP Calculations, hand calcs, or estimates.

Question 2

Question 2: “How would you calculate/determine T_M?”

From these responses (See Table 59) it is observed that there are three general ways in which analysts obtain this data: Interviews of either operators or simulator instructors, Job Performance Measurements (JPM), and actual observation of the action. If none of these sources are available, then the analyst could use data provided by THERP or ASEP, but these are used with caution because they tend to be overly conservative.

Table 59

Responses to Question 2 of Phase II Survey – Timing Information

Responses
• Timing information from Operation's records. Individual execution tasks are periodically trained on... these tasks are timed and recorded (Job Performance Measures).
• Maybe from JPM or from simulator exercises.
• I would estimate T_m as the time required to complete the action as measured from the start of the response.
• Observations of crew during simulator scenarios, estimates from observations of similar actions.
• Discussion with simulator instructor or actual simulator runs if available; some bounding values based on judgment.
• The means of obtaining an action’s manipulation time is also dependent on the action itself. If it is one that is practiced in a simulator and time permits a simulator observation, then the action can be timed. Walk-downs are also a means of determining manipulation times. Job Performance Measures are guidelines that plants keep as part of the operator training program and they are sometimes helpful in obtaining times. Operator interviews can be used, but THERP suggests double any operator estimate, which can yield overly conservative results. As a last resort, the time can be estimated by the HRA analyst using a consistent set of rules such as those provided in ASEP.
• Observation of actual action. Interviews and table tops are not reliable.
• From experiments (e.g., simulator exercises) or field data
• Conservative estimate + interview Ops Training personnel
• Almost all of these manipulation timing are from the operator inputs. Very little from calculation results or assumptions.
• T_m can be estimated by experts or just run the simulator.

Question 3

Question 3: "How would you calculate/determine $T_{1/2}$?"

The responses to this question were similar to Question 2 and the same conclusions about Question 2 apply. (See Table 60)

Table 60

Responses to Question 3 of Phase II Survey – Timing Information

Response
• Operator interviews or simulator data
• Simulator exercises if available, but only if forced to use the HCR. I would avoid it.
• I would determine $T_{1/2}$ as the time to begin the response starting from the time the cue is received. In terms of where to get this information, simulator exercises would be the preferable choice. However, since it is not always practical or possible to get these times from simulator exercises, other options would be talk-throughs with operators or training personnel, walk-throughs of the procedures or walkdowns of the actions.
• For some actions actual simulator timing data is available. For others, estimates based on some timing observations of how long it takes to process through EOPS.
• Discussion with simulator instructor or actual simulator runs if available; some bounding values based on judgment.
• I calculate the diagnosis time by taking the time from the cue to the irreversible end state and subtracting the manipulation time from it. I think this is not technically the same as the median response time.
• I calculate the diagnosis time by taking the time from the cue to the irreversible end state and subtracting the manipulation time from it. I think this is not technically the same as the median response time.
• T_{SW} - (T_{delay} + T_M). The critical determination is when diagnosis stops and manipulation begins. Our practice defines this as the point in the procedure where the Operator has arrived at the most critical step.
• From experiments (e.g., simulator exercises) or field data.
• Conservative estimate + interview Ops Training personnel
• Again, almost all of these median response timing are from the operator inputs. Very little from calculation results or assumptions.
• $T_{1/2}$ can be obtained from simulator results and this is easy if the simulator group keeps good records, otherwise one can use expert judgment.

Question 4

Question 4: "Do you believe that it is necessary to document all timing information (See Fig. C-5) even if the method you are using for your HEP calculation does not require this information? For example, the CBDTM method only requires the analyst to determine if there is enough time available to complete the action, or the Annunciator Response Model is independent of timing."

Two participants responded with a simple no response. Eight others responded that all information should be gathered regardless of what is input into the calculations, because it is important for documentation, and it is necessary to understand all aspects of the action modeled. (See Table 61) It is concluded that all timing information asked for by the HRA Calculator should be input regardless of which methodology is used.

Table 61

Responses to Question 4 of Phase II Survey – Timing Information

Response
• No [2 Responses}
• It is very important to have estimates of the system time window, the time of the cues, an estimate of the time it takes to get through the procedure to the appropriate step(s), and an estimate of the time to completion for the CBDTM, as this is necessary to determine (a) whether the action is feasible, and (b) whether there is time for recovery.
• I believe that the timing information (T_{sw}, T_m and $T_{1/2}$) should be documented as part of the HRA.
• It is important to evaluate both cause-based and time-based method for all actions unless there is a large amount of time available for simple actions (Ie. Clearly not time-based)
• Yes; they seem to represent key information that may provide a good benchmark of factors affecting the HEP. For us, since we are using the maximum of the two or three applicable methods, the questions is moot; we have to compile these for TRC/HRE by default
• Including the timing information as part of an action's definition and if time permits, it should be done. Given that resources are not always available to document issues that are not used in the quantification, it does not have to be done to allow a reviewer to reproduce the results.

Table 61 Continued

• Absolutely! The credibility and validity of the analysis will depend on the scrutability of each HRA.
• I don't think it is necessary. Such detailed classification on timing window provides the things need to be considered for assessing time sufficiency. Collecting each segment of time for all tasks is only useful for certain type of tasks.
• YEA!. A traceable record is documented.
• Yes, many of the successful actions depended on the operator response timing. Proper documentation will ensure the bases for the critical time response action are justified.

Question 5

Question 5: "Is your decision about how to collect timing affected by your choice of methodology?"

Five participants responded with a simple yes, and three participants responded with a simple no. The others (with one exception), agree that under certain circumstances the method by which the timing information is collected is affected by their methodology choice. Although there is some disagreement in the responses to this question, most state that there is a correlation between judgments on how timing information is collected and methodology choice. (See Table 62)

Table 62

Responses to Question 5 of Phase II Survey – Timing Information

Response
• No [3 responses]
• Yes [5 responses]
• Yes. While we may effectively discuss $T_{1/2}$ and T_m in our HRA, we do not actually separate the two for quantification.
• Yes. At the risk of not doing what I am preaching in question 17 above; we may not collect certain timing information if it is simply a rule-based or THERP is used.
• Not really. The timing is to ensure that how much time the operators have to successfully complete the action.

Conclusions

Engineering judgment on where to collect timing information are based on the specific information identified within the method. Analysts collect T_{sw} by first considering thermal-hydraulic calculations, then additional sources. T_M is collected by one of the following: operator interviews, observation of the actions, or JPM. If none of these are available, a more conservative approach is used by consulting THERP or ASEP. The same is true for $T_{1/2}$. Analysts are in agreement that all information should be documented regardless of which methodology is used. In addition, engineering judgments about choice of methodology are affected by the timing information.

TABULATED THERP PROBABILITIES

NOTE: Only seven out of the eleven respondents stated that they routinely use THERP.

Question 1

Question 1: "The CPSES analyst has interpreted Table 20-7 of the THERP as follows:

> "In determining the EOM p_{exe} values, if the operator action takes place within ten procedural steps from the start of the accident sequence, Item 20-7(1) [short list, with checkoff provisions] from THERP is used. If the operator action takes place > 10 steps into the sequence, Item 20-7(2) [long list, with checkoff provisions] is used. Items 20-7(3) and 20-7(4) [no checkoff provisions] are usually used when the procedure is not an Emergency Operating Procedure."[16]

Is this how you would use Table 20-7 for errors of omission? i.e. How do you use Table 20-7 in your HEP calculations?"

This question was asked in response to disagreement generated within the Pilot Survey, and Table 63 shows that there is agreement on how to apply THERP Table 20-7. Analysts agree with the CPSES interpretation of how to apply THERP Table 20-7. While most analysts agree on how to count steps/tasks in procedures, there is some discussion about how to credit check-off provisions. If there are questions about check-off provisions, most analysts would directly identify them within the questionable procedure.

Table 63

Responses to Question 1 of Phase II Survey – Tabulated THERP Probabilities

Response
• For this type of Westinghouse procedure, yes, though I would check whether they actually check off the step on the procedure before giving them credit for checkoff.
• The interpretation I use for Table 20-7 is virtually identical. That is, I would assign a short list to those actions performed in procedures that have less than or equal to 10 steps or, for longer procedure, for actions taken within the first 10 steps. Even if the EOPs do not officially have check-off provisions, I would treat the steps in EOPs as such since the operators are trained to use placekeeping aids such as checking off or circling steps that have been completed.
• Long list only if action requires 10 steps or more. There can be multiple tasks in one procedure step.
• I use the CBDTM Method's mechanism to treat step omission and do not count it again for execution. I usually assume that the CBDTM Method's step omission component applies to each subtask within an action, so if there are 10 subtasks, I multiply the initial step omission mechanism's contribution by 10. The use of Table 20-7 from the example seems like a reasonable approach and I would feel comfortable applying that interpretation of THERP.
• Yes. I suspect that there may be some differences in interpreting the long list / short list criteria. At Seabrook, we are considering all steps of the procedure to determine which value to use. As I read the later questions, I get the impression that some may only be counting steps in a specific step / action. I believe that this is incorrect, particularly w/ regard to errors of omission.

Table 63 Continued

• Yes for short vs. long list. However, for checkoff vs. no checkoff, I use the procedure that documents the actual step performed by the operator i.e. no guessing about this important aspect since it heavily influences the results. In fact, I produced several recommendations to improve various procedures by adding Checkoffs. This has lowered the plant CDF [Core Damage Frequency]
• Similar to CPSES.

Question 2

Question 2: “Other than THERP Table 20-7, are there any other THERP Tables you use for Errors of Omission on a regular basis? Under what circumstances do you use the other tables?”

The responses (See Table 64) show that for errors of omission THERP Table 20-7 is used almost exclusively. It should also be noted that seven out of the 11 respondents stated that they routinely use THERP.

Table 64

Responses to Question 2 of Phase II Survey – Tabulated THERP Probabilities

Response
• Occasionally use 20-6 , though more likely to be used for pre-initiators.
• I do not typically use other omission tables.
• We stick to the HRA calculator, i.e. no longer delve into THERP outside the context of the Calculator. [The HRA Calculator provides an electronic version of the tabulated THERP values.]
• Table 20-7b with RNO, procedure with RNO column.
• No [Three responses]

Question 3

Question 3: “Besides THERP Table 20-12, what other THERP Tables do you use for Errors of Commission for control room actions (excluding recovery actions.)? Under what circumstances do you use the other tables?”

In general, most analysts use THERP Table 20-12 for errors of commission for control room actions, and on occasion THERP Tables 20-10 and 20-11 are used. (See Table 65). All three of the tables are available for use within the HRA Calculator.

Table 65

Responses to Question 3 of Phase II Survey – Tabulated THERP Probabilities

Response
• 20-13 if the procedure calls for local operation.
• Table 20-12 is the most commonly used table, but there are additional tables that are used as well, depending on the actions involved. For control room actions, Tables 20-10 and 20-11 are also used. In addition, for actions performed outside the control room (e.g., local valve manipulation), Table 20-13 would also be used.
• I have, on occasion, used Tables 20-10 and 20-11 when a specific reading is important to the completion of an action on a gauge that is not one of the primary reactor parameters. I do not have a specific set of conditions for myself that trigger the use of these tables, which, is probably a weakness.
• We stick to the HRA calculator, i.e. no longer delve into THERP outside the context of the Calculator. [The HRA Calculator provides an electronic version of the tabulated THERP values.]
• Also use Table 20-11 for control room actions of reading displays, checking indicators, etc.

Question 4

Question 4: “Under what circumstances do you use data sources other than the tabulated THERP values for Errors of Omission and Errors of Commission?”

Table 66 shows that when rendering judgments about what failure probabilities to use within an HEP Calculation, one should use THERP as the primary database. The one participant who observes simulator training exercises as potential data sources has spent many years collecting this data. For most HRA analysts this is not within the scope of their analysis.

Table 66

Responses to Question 4 of Phase II Survey – Tabulated THERP Probabilities

Response
• In general, I only use values from THERP for errors of omission or commission. An exception could be for immediate action steps (i.e., actions that occur during the first few steps of a procedure that are supposed to be committed to memory), for which an error probability can be obtained from NUREG/CR-4772.
• Never
• I can almost always find a way to use a THERP table value that is appropriate for the circumstances. However, for multi-step actions that are highly trained, practiced, and used in actual plant operations (such as initiation of SPC [Suppression Pool Cooling] in a BWR), the THERP data can provide overly conservative results. In those cases, I may modify some values and make a note identifying the reason for the change. There is no set of guidelines for this and it is done based on experience and interaction with the PRA model. For example, it would becomes apparent during cutset review that the HEP for SPC initiation is too high when the loss of DHR [Decay Heat Removal] CDF dominates the risk profile due to an HEP of 1E-4 with 24 hours available for action.
• None (with the usual disclaimers). There can always be a time when a specific source could be considered more pertinent.
• Errors of Omission (EOOs) are typically due to failures of operator's attention and memory (slip and lapse types of error correspondingly) in this context. Poor procedure format is the likely cause of attention failure. Unexpected interruption of the task is likely causing memory failure. Taking a short cut is typical Errors of Commission (EOCs) in this context. The causes are likely that the operator links current plant symptoms to a scenario familiar to the operator (e.g., by training).
• Always use THERP
• The operator comments.
• For most of my work I use either data or information derived from simulators or expert judgment.

Question 5

Question 5: “Fig. C-3. is a page from EOP 0.0. and Step 6a has been identified as a critical action. Can you determine an Error of Omission and an Error of Commission using only procedures? If not, what other information is need?”

The responses show (See Table 67) that judgments about errors of omission and errors of commission are based on more than procedure identifications. Most analysts base these judgments on understanding of the scenario and observation of the control room layout (especially indicators).

Table 67

Responses to Question 5 of Phase II Survey – Tabulated THERP Probabilities

Response
• The EOM could probably be derived based on looking at the procedure only. However, in order to correctly calculate the ECOM, knowledge of the control room panel layout should also be included since this impacts whether the ECOM for selecting the wrong control would use item (2), (3) or (4) in Table 20-12. In addition, other performance shaping factors (PSFs) would need to be known (in particular, stress level).
• No. I need to know the scenario- Is MSAFW pump failed so that RNO action is needed. Did both (all) AFW pumps fail; Have the operators been instructed preciously to try to restart? I also need to know crew protocol-Do they use checkoffs with each step, do the use formal communications, etc.
• No. In addition to the preceding steps of the procedure (to determine where it is in the procedure (the step numbers themselves are not adequate)), I would need to see the instrument display for the relevant equipment to determine the appropriate EOCs for P_{exe}. I think it would also be necessary to know about the accident sequence in which that action would be taken to help define the performance shaping factors that might be important (stress level, instrument availability (maybe an alternate gauge is required to be used), environmental conditions, etc.).
• The evolving accident/initiating event is also important to determine PSFs, workload, stress, number of alarms, and others.
• Omission – Table 20-7b with RNO, Procedure with RNO column. Commission - Table 20-11.

Table 67 Continued

•	I agree that the EOP 0.0 might be a critical step in the response to the accident by the crew, but I cannot evaluate the impact without examining the context. The accident determines the context within which the crews work. The displays of the information in the MCR determine what the operators see and this may obscure the ability of the crews to select the correct procedure. Training maybe such that the operators do not carryout the response as well as they could do! So context matters!
•	Control room panel layout.

Question 6

Question 6: “Besides procedures, are there other methods you use to determine Errors of Omission and Errors of Commission? For example, do you do a walk-through of the control panel, or conduct operator interviews?”

The responses to this question are in agreement with Question 5. (See Table 68) When rendering engineering judgments about errors of omission and errors of commission, analysts find it helpful to do both a walk-through of the control room and conduct operator interviews. It is expected that in an ideal world this would be done for every action modeled; however, in reality due to time constraints this may not be possible.

Table 68

Responses to Question 6 of Phase II Survey – Tabulated THERP Probabilities

Response
• The former is necessary, the latter helpful.
• I would want to either walkdown the control panels or look at a drawing of the control room panel layout.
• For local actions, walk through may be important. Operator interviews and simulator observations are always invaluable.
• Walk-through and conducting operator interview are great. The drawbacks are level of effort requirement and accessibility.
• A control panel walkdown is highly desirable and all efforts should be made to perform a walkdown of the panels and take pictures. Operator interviews can provide some insights, but the actual panels are the most helpful.
• Also use the operator inputs. Do both walk-through and conduct operator interviews.
• In addition to procedures: the accident scenario, training, man-machine interface, workload, communications protocol, and leadership. Interviews of NPP operators, and instructors. Reviews of procedures and control boards. Observations of simulator sessions of operators responding to various accidents, etc.

Conclusions

In general, there is good agreement among HRA analysts (who use THERP) on how to interpret the tabulated THERP probabilities. Analysts used Table 20-7 almost exclusively as a database for probabilities of Errors of Omission. When interpreting Table 20-7 of THERP analysts begin counting procedure steps from the beginning of the accident sequence procedures. For Errors of Commission analysts tend to use THERP table 20-12 for control room actions[6] and occasionally use THERP[6] Tables 20-10 and 20-11.

LOWER BOUNDS

Question 1

Question 1: "In your opinion should there be a lower bound for HEP calculations? If so what value do you use and how did you determine that value?"

The responses show (See Table 69) that analysts unanimously agree that there should be a lower bound for HEP calculations. In addition most agree that this should be in the range of 1E-6 to 1E-4; however, there is a lack justification for this range.

Table 69

Responses to Question 1 of Phase II Survey – Lower Bounds

• Yes, 1E-4 Based on engineering judgment [2 responses]
• Yes, an HEP should not be lower than the lowest value in the Annunciator Response Model Table.
• I believe that the lower bound value for the overall mean HEP for a given action should be no lower than 1E-5 and for most actions should not be lower than 1E-4. I also believe the combined HEP (i.e., multiple operator action failures) should not be lower than 1E-6.
• Yes. as low as just above truncation if may still be of practical significance under certain conditions.
• Yes. We use 1E-04 as a lower bound. This value is based on 25 year of PRA discussion w/ NRC and personal opinion. It is difficult to imagine that a complex activity can be considered more reliable than 1 in 10000, regardless of instructions and training. Beyond this value, one is likely to have missed dependencies that have significant impact.
• <1.0E-05
• No, should be based on the HRA calculator results. [The HRA Calculator does apply a lower limit of 1E-6 for the overall HEP]
• Yes, there should be a lower bound for HEPs and combinations of HEPs. I usually use a floor of 1E-6 for individual HEPs and combinations of HEPs that are required within 24 hours of an event. This is consistent with previous PSAs and HRA documentation

Question 2

Question 2: “In your opinion should there be a lower bound on P_{cog} values? If so, what value do you use, and how did you determine that value?”

The responses (See Table 70) show that analysts are equally split about whether to apply a lower bound for P_{cog} values. From these responses, an argument could be made that a lower limit does not need to be applied, because exceptionally low values for P_{cog} will have little or no influence on the final results.

Table 70

Responses to Question 2 of Phase II Survey – Lower Bounds

Response
• Yes, an HEP should not be lower than the lowest value in the Annunciator Response Model Table.
• I do not believe there should necessarily be a lower bound value for either the cognitive error or execution error….. I do believe there should be a lower bound value for the overall HEP.
• I am not sure about an absolute lower bound, but our results tend to be greater than 1E-4
• Yes. as low as just above truncation if may still be of practical significance under certain conditions.
• I wouldn’t apply a floor limit separately to the cognitive and execution components, just the total HEP.
• Yes. We use and overall HEP lower bound of 1E-04. We are equally suspicious of individual contributions w/ values less than these values.
• 1E-5
• No [2 responses]

Question 3

Question 3: “In your opinion should these lower bounds be consistent between methods?”

With one exception, HRA analysts agree that there should be consistent lower bounds between methods. (See Table 71)

Table 71

Responses to Question 3 of Phase II Survey – Lower Bounds

Response
• Yes (8 responses)
• The ERPRI doc (TR-100259) clearly says to use the CBDTM Method as the lower bound. We do that by using the Max(HEP_{CBDTM}, $HEP_{HCR/ORE}$)
• It probably doesn't make a lot of difference if the methods use slightly different HEP floor values. If they are very high floors, then the method will be unusable because it will mask potentially important hardware vulnerabilities. Very low floors could also mask potentially important contributors and would not be accepted by the PSA community. In summary, small variations can be tolerated while large variations would not be useable or accepted by the industry.

Conclusions

Unanimously, all analysts agree that there should be some lower limit to HEP calculations and that this limit should be the same regardless of the methodology used. Most analysts agree that this limit should be in the range of 1E-6 to 1E-4 with a tendency towards the higher end. Engineering judgments about what a lower bound limit should be based not on measurements or method used. Instead they are based on what is a practical and meaningful result.

CHOICE OF METHODOLOGY

Questions 1

Question 1: "How do you determine which methodology to use for an HEP calculation?"

The response in Table 72 show that analysts determine which method to use by a combination of the following: precedents, guidance provided in respective method description or the use of more than one method. (Question 4 further addresses this topic.)

Table 72

Responses to Question 1 of Phase II Survey – Choice of Methodology

Response
• We have used both the CBDTM and HCR for each HEP and chosen the greater failure probability between the two methods
• On the nature of the action, whether it is automatic (instinctive), procedure driven, or a recovery action.
• We only use one methodology throughout the entire HRA. I believe it is more important to use one methodology consistently throughout the analysis than it is to use a particular method.
• Use CBDTM Method and HCR/ORE Correlation for almost all actions. We do not use the Annunciator Response Model.
• Based on the guidance from the HRA Calculator training workshop and previous examples from the HRA experts. When in doubt, use two or three methods and see how they compare.
• I want one that allows for flexibility and thoroughness and one that accounts for major contributors to cognitive and execution errors (like ASEP and CBDTM Method for cognitive and THERP for execution error).
• Since the industry has no guidance or consensus, we generally calculate HEPS using both CBDTM and HCR/ORE, and select the largest HEP. We have occasionally limited our calculations to a given method if the action is clearly (overwhelmingly, etc) time limited (HCR/ORE) or clearly a cognitive / diagnostic problem (CBDTM).
• Each method has its strength in predicting the HEP of certain types of tasks. Selection of the appropriate method is dependent on the type of task of analysis.
• Pre-determined by using EPRI & HRA Calculator guidelines, availability and importance of timing is also an important factor.

Question 2

Question 2 “Is it better to use the same methodology for an entire analysis or to use a method that is appropriate for each individual action?”

The responses to Question 2 are shown in Table 73. Six participants would apply one method and four participants would apply more than one method. (See Table 73) It should be noted that typical actions modeled within a complete analysis are either skill-based or rule-based proceduralized actions, and more than likely the same methodology is appropriate to use for every action. To justify both view points presented in Table 73, when rendering engineering judgments about methodology choice an analyst considers the type of action being modeled and chooses an appropriate method for each action, and often the same method is used for every action within an entire analysis.

Table 73

Responses to Question 2 of Phase II Survey – Choice of Methodology

Response
• We have used both the CBDTM Method and HCR/ORE Correlation for each HEP and chosen the greater failure probability between the two method.
• I would use the same method for each action within the same type
• I believe it is more important to use one method consistently throughout the analysis.
• We apply both methods (CBDTM Method and HCR/ORE Correlation) to all actions except where long times are available.
• I believe is more appropriate to use a method that is appropriate for each individual action; however, on certain cases, it may be useful to compare different methodology if they present significantly different results.
• Picking a specific methodology for specific types of actions implies that the analyst believes the numbers the calculations produce are accurate, which is questionable. In HRA, a consistent application of a methodology that provides a means of developing a relative ranking of the difficulty of the actions is about the best that one could hope for, quantitatively. One would hope that the results are close to "correct", but there is no real way of knowing. By mixing methods, a major benefit of the quantitative portions of the HRA is eliminated (consistency in the evaluations) and I consider it detrimental to the analysis. There may be a small, specific set of operator actions that cannot be quantified using the methods applied the majority of plant actions, but I have not encountered them yet (at least not those that should be quantified using HRA techniques).
• It would be preferable to use the method that is appropriate for the action, however there is no consensus guidance on this topic.
• Use the method appropriate for a specific action as long as the HEP assessment is consistent.
• Yes it is better. Change of methodology to achieve a more favorable answer is like cheating. Only timing consideration may force you into a different method.
• I would suggest using one method but changes in context would affect the HEP values.

Question 3

Question 3: “Do you believe that any method can be used to analyze any action?”

The responses are shown in Table 74. Analysts agree that there is no one method appropriate for every action, and this further supports the conclusions from Question 2.

Table 74

Responses to Question 3 of Phase II Survey- Choice of Methodology

Response
• No. HCR method may be important to use when timing is a critical component but it may not give the best result when timing is not a key component.
• Different methods can be used within their realm of applicability.
• I believe it should be up to the HR analyst as to which HRA method to use.
• No, both methods (CBDTM Method and HCR/ORE Correlation) should be used on almost all actions.
• Not necessarily. Some methods do not make sense for some circumstances.
• I would say the answer is yes (for a goof methodology) and that while the method might not represent what the “real” answer is believed to be as well as another, it will be close enough. And if it I not, then something should be able to be done within the framework of the methodology to make it work. Take the example of BWR SPC initiation. The EPRI HRA Calculator would yield a result that is too high for long term loss of DHR cases, but there are override options that would allow for a correction to be made.
• No. I don’t believe the Annunciator Response Model is appropriate given CBDTM and HCR/ORE.
• No, none of the existed HRA methods covers the whole scope of possible actions.
• No
• If the methods are consistent, the answer should be “Yes”

Question 4

Question 4: “Under what circumstances do you calculate an HEP value using more than one method and compare the numerical results?”

The responses are shown in Table 75. Generally, analysts do use multiple methods, and usually it is done to compare the results of different methods numerically.

Table 75

Responses to Question 4 of Phase II Survey –Choice of Methodology

Response
• Always
• Only to get an idea of where the range of opinions lies. None of the methods is calibrated, therefore it is useful to have some idea of what the range of values is.
• I cannot say that I would ever use more than one methodology to calculate an HEP other than to compare the results.
• Always use the larger HEP from both methods (CBDTM Method and HCR/ORE Correlation.
• I will check numbers against other industry `examples, but I do not use multiple methods and perform multiple cross-method calculations myself.
• Since the industry has no guidance or consensus, we generally calculate HEPS using both CBDTM and HCR/ORE, and select the largest HEP. We have occasionally limited our calcs to a given method if the action is clearly (overwhelmingly, etc) time limited (HCR/ORE) or clearly a cognitive diagnostic problem (CBDTM).
• When I feel the method has great variability in determining the HEP of a task.
• When the result is unreonable (too low or too high) such that the applicability of the adopted method becomes suspect.
• To present a case for why the selected method is better.

Conclusions

Several of the users of the HRA Calculator calculate HEPs using both the CBDTM Method and the HCR/ORE Correlation and then take the higher of the two values. Using older, non-computerized methodologies, it would be time consuming and difficult to perform two independent analysis for the same action. Using the HRA Calculator this is a simple task, and the second calculation can be done in a matter of minutes. Assuming that the analyst is familiar with the methodology. Many analysts do not perform more than one analysis for the same action, because they calculate HEPs by non-computerized methods.

The responses also show that most HRA analysts are applying some variation of THERP, CBDTM Method and the HCR/ORE Correlation for their analysis. This is important to identify, because it shows that the methods employed by the HRA

Calculator are what current analysts are using even if the HRA Calculator is not being used.

When rendering engineering judgments about which methodology to use, analysts should follow internal guidance for recommendations on methodology choice and if using an electronic method should repeat the calculation using multiple methods for comparison, then chose the higher HEP.

ANNUNCIATOR RESPONSE MODEL

Only a few responses to questions about the Annunciator Response Model were received. It is believed that this is because few HRA analysts apply this method.

When applying this model one must keep in mind that the probabilities provided by THERP were based entirely on engineering judgments. Therefore, it was anticipated that current analysts may want to modify theses probabilities. However, responses to Questions 2 and 3 show this not to be the case. The documentation of the Annunciator Response Model provided in THERP clearly states that the HEP values provided in THERP Table 11-3 are based on a single control room operator. However, responses to these questions indicate it is common practice to interpret them to be for a control room crew even though THERP provides instructions to modify the HEPs in THERP Table 11-3 for a crew. This practice is stated to be conservative.

Question 1

Question 1: "How do you determine the number of annunciators present in the control room for a specific action?"

The analysts agree that there is no ideal way to collect this data. Therefore, it is concluded that there are three different ways in which an analyst can render judgments about how to collect data on the number of annunciators. He can ask operating staff, use alarm response procedures, or observe simulator exercises.(See Table 76). All three of these tasks are time consuming, and it is difficult to obtain the exact numbers of annunciators.

Table 76

Responses to Question 1 of Phase II Survey – Annunciator Response Model

Response
• Ask operating staff.
• For this reason, I would be reluctant to use the annunciator response model in the first place. However, if it is to be used, the best way would be to either observe the scenario in the simulator or talk-through the scenario with an experienced operator or trainer. There may be cases where expert judgment by the HRA analyst could be used. For example, if the alarm is caused by the initiating event or if the alarm occurs well out in time such that other alarms would not be expected.
• Use simulator or discuss with simulator instructor for the scenarios of interest to come up with an estimate.
• Use of Alarm Response Procedures. Interview operators.

Question 2

Question 2: "In your opinion, is it appropriate to use the values shown in Table 11-3 of THERP when there is more than one person present in the control room? These values were derived for single operators, but CPSES always has at least 3 or more people present in the control room."

The responses (See Table 77) clearly show that respondents apply the tabulated values to crew behavior. This is acknowledged by some to provide conservative results. However, numerical values of HEP results from the Annunciator Response Model using the modifications for crew presence given in THERP agree more closely with the CBDTM Method (See Chapter V).

Table 77

Responses to Question 2 of Phase II Survey – Annunciator Response Model

Response
• Yes, if more crew members are focused on the same annunciators they are less likely to miss it, but typically one operator has the responsibility for sections of the control room.
• Yes, I believe that Table C-1 should apply to the entire crew.
• I believe it may be slightly conservative; however, given the dependency of the crew (i.e. similar training and perception), and also, one person may be dedicated to reading the procedure or other task, the applicability of one person for a three-person crew is still reasonable.
• Diagnostic values in NUREG 1278 are for control room crew, not per person or for one person. I do not apply recovery of one's error for diagnostic failures.
• The approach does model crew's response.

Question 3

Question 3: "If you were to model crew behavior using the values in THERP Table 11-3 would you modify any of these values to take credit for additional people?"

The responses (See Table 78) show that the respondents interpreted this question as applying to the initial HFE. Therefore, the responses are essentially the same as those to Question 2.

Table 78

Responses to Question 3 of Phase II Survey – Annunciator Response Model.

Response
• No
• No, I would not modify the HEPs in Table 1 to take credit for additional personnel. However, there could still be opportunity to take credit for recovery by either the same person or additional personnel if additional cues are present.
• Not really. Unless there is significant more independent and available resources and timing is not a critical issue.
• Only if time for second crew.
• Yes I would change the values. I do not use the Annunciator Response Model, I do not think that operators function the way that the model implies, i.e. the more annunciators the higher unreliability of crews! Operators select a number of key annunciators to determine the accident and use EOPs to confirm the accident and then proceed. The Swain model of how operators respond to accidents is based upon a state of knowledge of plant operation around about 1980, limited exposure to simulators and event based procedures. Does not correspond to current operating conditions!

Conclusions

HRA analysts who apply the Annunciator Response model acknowledge that this model is conservative, but they do not attempt to apply additional engineering judgments on how to modify the tabulated probabilities to obtain more realistic HEPs.

HCR/ORE CORRELATION

Questions 1

Questions 1: “List all the sources you use for collecting timing information.” Table 79 shows the responses and Question 2 further addresses this topic.

Table 79

Responses to Question 1 of Phase II Survey – HCR/ORE Correlation

Response
• Simulator exercises, Operator estimates, Job Performance Measures
• Three potential sources would be simulator data, operator interviews or expert judgment, with the third option being a last resort.
• Simulator data for the action, walk through, simulator data for similar actions.
• MAAP runs, T-H calculation, FSAR, NUREGs, Operator interviews, Simulator runs, Simulator instructor interviews,
• Field observations, simulator observations, estimates (very cautiously).
• Field observation, event analysis, and experiment s (e.g., simulator exercise)
• Engineering calcs, MAAP4, owners' group analyses, operators' estimates
• Most of them by MAAP analyses. Some based from the WCAP/WOG, plant specific thermal hydraulic calculation results. If none of them available, would use operator inputs or simulator times.
• Timings from simulators, expert judgment, walkthroughs with plant personnel and transient analyses

Question 2

Question 2: "From your list of timing sources, under what circumstances do you use each source in your HEP calculation? Are all the sources equally considered when choosing which source to use in a calculation?"

The responses to Question 2 are shown in Table 80. It is concluded from both Tables 79 and 80 that all sources of timing information should be considered, and then the best source should be identified based on the specific action. In addition, analysts would prefer to collect timing information from simulator or actual observation of the action.

Within the HCR/ORE Correlation the timing information includes both T_w (cognitive response time) and $T_{1/2}$ (mean crew response time, both cognitive and execution). However, the HRA Calculator determines T_w based on T_{sw}. The responses to questions on timing indicate experts determine T_{sw} primarily based on thermal-hydraulic calculations. But $T_{1/2}$ must be determined from other data. The HRA Calculator determines T_w by T_{sw}-T_m-T_{delay}. Therefore, analysts must check T_w determined by the HRA Calculator against T_w determined by observation to verify sufficient cognitive time is available.

Table 80

Responses to Question 2 of Phase II Survey – HCR/ORE Correlation

Response
• Information from simulator exercises and job performance measures is used when available. Otherwise, operator estimates are used.
• The first choice would be simulator data or actual plant experience. The second choice would be operator interviews. The last resort would be expert judgment.
• Simulator data for the action (with at least three crews) is the best source.
• I would consider all sources and then depending on the purposes of the application choose either a best estimate or conservative values.
• Field observations, simulator observations, and estimates (very cautiously).
• All sources should be considered as long as they are available. Weight factors may be applied to these sources.
• Usually one source is available and usually one source dominates when multiple sources are available.
• Direct evidence is better than expert judgment. The quality of the information depends on the chosen expert. I would use the above to test the quality of the information received

Question 3

Question 3: “Do you consider the accuracy of the timing information when using the HCR/ORE? If so, how does this affect your calculations?”

This question was intended to determine if analysts consider the sensitivity of the HCR/ORE Correlation to small variations in time when rendering judgments about which timing source to use. Table 81 shows that analysts are equally divided. Those who do consider this tend to adjust the information rather than choose a different data source. It is concluded that an analyst may wish to render additional judgments about the accuracy of the timing by adjusting the timing information; however, the accuracy of the information does not influence which timing source to use.

Table 81

Responses to Question 3 of Phase II Survey - HCR/ORE Correlation

Response
• No
• Regardless of where the timing information is derived, consideration should be given as to whether the response times need to be adjusted. For example, if operator interviews are used to obtain response times, the estimates could be on the optimistic side. Even when simulator exercises are used to obtain response times, care should be taken that the simulator scenarios from which the response times are collected are applicable to the scenarios for which the action is credited in the PSA.
• If I do not have strong simulator data, I consider increasing sigma
• No. I use point estimate .
• To the extent possible, we calculate a median based on multiple observations. Otherwise you use what you have. Accuracy is not a term one should associate w/ HEP calculations.
• Yes, I would and have done so in the past. I would consider using different sources to give me some sense of the uncertainty range to be considered

Question 4

Question 4: “In your opinion, should the stress level chosen in the decision tree used to determine sigma be the same as the stress level to calculate P_{exe}?”

Within the HRA Calculator the user determines a stress level for both P_{exe} and P_{cog} portions. The two stress levels do not necessary have to match. Furthermore, within P_{exe} the choices for stress level are low, moderate or high, but in the HCR/ORE Correlation the choices are low or high. There is no choice for moderate stress. This question was intended to address this discrepancy and to identify if analysts use the same judgments to determine stress levels in both P_{exe} and P_{cog}.

The responses (See Table 82) show that the analysts are equally divided on whether to match the stress level between P_{cog} and P_{exe}. Those who do match stress levels acknowledge this is not possible for moderate stress within the HRA Calculator. Therefore, it is concluded that if a perfect model were available and an ideal situation were being modeled, the stress levels between P_{cog} and P_{exe} should be the same. In reality many models (including the HCR/ORE Correlation) are not designed so that the stress level in P_{cog} and P_{exe} can match, and HRA analysts rarely model ideal situations. Therefore, the stress levels will usually vary.

Table 82

Responses to Question 4 of Phase II Survey – HCR/ORE Correlation

Response
• Not necessarily, since the person completing the cognitive and the person completing the execution may be doing so under different conditions.
• Ideally, yes. However, there are only two stress levels (high or low) in the HCR/ORE Correlation Decision Tree, but there are three stress levels (nominal, high and extreme) in calculating P_{exe}.
• Yes, we use high in the sigma decision tree for moderate and high.
• They should be considered in context, and thus separately; however, they may not be totally independent.
• No. There are three choices for the value (Low, Moderate, High). The decision tree is too simplistic.
• Yes, PSFs' effects should be counted

Question 5

Question 5: "What do you consider a lower bound for the calculation of P_{cog}?"

It is well established that the HCR/ORE Correlation can give exceptionally low values for P_{cog} if there is a long time available (greater than 1 hour) to complete the actions. This question was intended to address the issue of what analysts considers a lower bound to be for the HCR/ORE Correlation and to determine if the responses are consistent with the responses in the lower bound section.

Table 83

Responses to Question 5 of Phase II Survey – HCR/ORE Correlation.

Response
• I would not place a lower bound on either P_{cog} or P_{exe} but, rather, the overall mean HEP. There are some instances where one could argue that the cognitive error is negligible compared to the execution error (and vice versa), in which case it would not be appropriate to arbitrarily assign a lower bound value to either the cognitive or execution error.
• CBDTM Method is the lower bound for the HCR/ORE Correlation.
• In IPE days, epsilon basically is zero; but currently with the peer review and increased use of HRA, 1.0E-7 or so.
• We use 1E-04 as a lower bound. This value is based on 25 year of PRA discussion w/ NRC and personal opinion. It is difficult to imagine that a complex activity can be considered more reliable than 1 in 10000, regardless of instructions and training. Beyond this value, one is likely to have missed dependencies that have significant impact.
• 1.0E-05
• 1.0 E-04, but it depends on my overall assessment of the plant operations in the MCR

Table 83 shows that most analysts (with one exception) use a lower bound in the range of 1E-7 to 1E-4. While this is a large range, it does suggest that there should be some lower limit for $P_{cog,}$ and this is in agreement with the responses to the questions asked in the Lower Bound section. Therefore, the conclusions from the Lower Bound section apply specifically to the HCR/ORE Correlation.

Question 6

Question 6: “Consider the following sample calculation of P_{cog} using the HCR/ORE Correlation: [The complete sample calculation is shown in Appendix C. This is a calculation of P_{cog} using the HCR/ORE Correlation to model the action Loss of

Recirculation Capability. The calculated P_{cog} value was 3.1 E-10.] From the above information, would you use the HCR/ORE correlation to calculate P_{cog}?"

This question was attempting to identify if analysts render judgments on the methodology choice based on the results of the calculations. The responses show (See Table 84) that several analysts would use both the HCR/ORE Correlation and the CBDTM Method and then use the largest value. In this example the CBDTM Method would produce a larger P_{cog}. Two experts would not use this method, because the actions are not time dependent. Therefore, analysts do chose the HRA methodology considering the numerical results produced by different methods. Most analysts would apply both the HCR/ORE Correlation and the CBDTM for the same action.

Table 84

Responses to Question 6 of Phase II Survey – HCR/ORE Correlation

Response
• Yes, and we would use the CBDTM method, too.
• I would personally use the CBDTM to calculate Pcog in general. However, one could use the HCR/ORE correlation. Another approach would be to calculate Pcog using both the CBDTM and HCR/ORE correlation and then use the higher of the two values to determine Pcog.
• Yes
• Yes, as a rule, we would try both HCR/ORE and CBDTM
• Our general practice is to use both HCR/ORE and CBDTM to calculate HEPs and use the largest value. I see no reason to deviate from that our practice for this action.
• No, the time window is about two hours. Subtracting the time of delay, the operator still has about 30 minutes response time window. With such long response time window the predictions of HCR/ORE are not good.
• No

Question 7

Question 7: "Using the input stated above [Same example as Question 6], the P_{cog} value determined by the HRA Calculator was 3.1E-10. Do you feel that is a realistic value?"

The experts unanimously agree that the calculated value is unrealistic, and this is in agreement with the response to Question 4. Table 85 shows the complete set of responses, and the same conclusions from the Lower Bound section apply here.

Table 85

Responses to Question 7 of Phase II Survey – HCR/ORE Correlation

Response
• No [3 responses]
• No, too small. This is where our method of using two correlations and selecting the highest is useful.
• No, 3.1E-10 is not a realistic value for this action. However, I would argue that the basis of the calculation for P_{cog} is not correct. The starting point for this action (t=0) should be considered as the time the Refueling Water Storage Tank (RWST) is depleted (75 minutes). The total system time window (T_{sw}) would then be 35 minutes (versus 110 minutes). Using the same values for T1/2 (5 minutes) and Tm (3 minutes) still results in an HEP of 3.1E-10. However, I also disagree with the premise that the stress level would be low. I would consider stress to remain high following a LOCA [Loss Of Coolant Accident] until ECCS [Emergency Core Cooling System] recirculation was successfully established. Therefore, I would use a sigma of 0.4 versus 0.3, which results in a value for Pcog of 1.7E-6. To assess whether this value is too low would require an estimation of the execution error. For this case, I believe the cognitive error would be negligible compared with the execution error.
• It is not a meaningful HEP. All it says it that this action is not sensitive to time. The CBDTM Method is always the lower bound. I do not see the $T_{1/2}$ data but this should be a challenging cognitive action because the operators must do some diagnosis –put together the low RWST level with loss of water outside containment. The loss outside containment may not be obvious. It may require local verification which adds time.
• No. Anything below 1.0E-7 probably is too low.
• No. If you accept 3E-10, you are saying that you believe that a human error prob is 1 in 3 billion. How credible is that. Shoe laces can't be reliably tied much better than 1E-02. Values less than 1E-04 are difficult to justify. Unlikely events do happen, typically because of dependencies that were unforeseen by the "experts".
• 3.1 E-10 this is not a realistic figure, I would estimate that a figure nearer 1.0E-02 might be closer

Question 8

Question 8: "If you encounter an unrealistic P_{cog} valve (such as the example above), what would you do to correct this? Why?"

Table 86 shows that most analysts would apply another method (primarily the CBDTM Method). Only one analyst would calculate P_{exe} and determine if P_{cog} is even relevant to this calculation. Again the responses to this question are in agreement with the conclusions from the Lower Bound Section.

Table 86

Responses to Question 8 of Phase II Survey – HCR/ORE Correlation

Response
• We would calculate the failure probability using CBDTM and would use that value since it would be greater.
• Even if I was a fan of HCR, and used it, the EPRI document introduced the CBDTM to develop a floor for p_{cog}.
• I would calculate Pexe to see whether a low value for Pcog is even relevant
• Always use CBDTM Method then use Max(HEP_{CBDTM}, $HEP_{HCR/ORE}$).
• I would try CBDTM and see the difference.
• The usual; Review the information, Review the HRA Calculator inputs and assumptions. Compare the value to the CBDTM value. If still very low, we would bound at 1E-04. This should be a fairly reliable action since diagnosis is not difficult and there is plenty of time to complete the action. One could argue that the T_{delay} shouldn't really count because the operator will be well aware that the action is coming and will need to be completed.
• Use another method or apply the residual HEP. There are different residual HEPs mentioned. THERP is at 1E-3 level. The newer HRA method such as SPAR-H uses 1E-5. However, real data suggest that 1E-7 might be a reasonable value.
• Use Figure 12-4 of NUREG 1278
• Use expert judgment with the experts being the instructors not operators or manager.

Conclusions

Within this section several different areas of engineering judgments were surveyed. In addition to further supporting the conclusions from other survey sections, the following additional conclusions can be drawn about engineering judgments rendered within the HCR/ORE Correlation.

- Analysts would prefer to collect timing information from simulator or actual observation of the action. In addition, analysts must check T_w determined by the HRA Calculator against T_w determined by observation to verify sufficient cognitive time is available.
- Analysts may wish to render additional judgments about the accuracy of the timing by adjusting the timing information; however, the accuracy of the information does not influence which timing source to use.
- Engineering judgments on which methodology to use are based on consideration of the results produced by different methods.

CBDTM METHOD

Questions 1 and 2 of this section were based upon reading the recommendations in EPRI Report TR-100259. The report recommends revisiting the decision trees on a case-by-case bases. It was suspected that very few analysts follow this recommendation, and Questions 1 and 2 test that theory.

Question 1

Question 1: “The original report on the CBDTM method recommends that the HRA analysts revisit the numerical values used in the decisions trees and modify or adjust as necessary. Do you consider doing this in regular practice? If so what are you looking to adjust?"

The responses are shown in Table 87. As expected, generally, most analysts do not modify the original decision trees.

Table 87

Responses to Question 1 of Phase II Survey – CBDTM Method

Response
• No
• The report also suggested revisiting the structure of the trees. This was included to indicate that the values used were the writers' best assessment at the time, in the hope that more work would be done to improve the pedigree. No-one ever did to my knowledge, except in the Temelin (Czech Republic) PRA the trees were modified to reflect the fact that the control room had computer guided procedure following software linked to the plant process computer, eliminating some of the reading errors.
• No, in my opinion it is not necessary to revisit the numerical values used in the decision trees.
• No, that is difficult to do for an individual analyst. That is like changing the rules. It would be appropriate for an expert panel to change values (or even add new branches or new trees.
• No. If I do, I probably would make a judgment call on the branches and compare with various HFE to see whether they are consistent.
• We do not adjust values. We don't have the time or expertise to both research a different value AND be able to justify it's use to the NRC. The practical bottom line is that the NRC would probably override your carefully crafted value if you were using the results to fight a violation.
• Yes!. To look for obvious inconsistencies
• Yes, operator self review, STA review and extra crew.
• I find it strange that the authors of EPRI TR-100259 recommend that HRA users should change the values given by the calculator. What is the basis for so doing? If you believe that the CBDT values are the best, why change them? If the authors suggest that might be possible to change the values there ought to be a recommended process for so doing. Further, I thought that the basis for the calculator was to produce HEPs that can be used to compare one plant with a similar plant. Allowing variability as a matter of course defeats this objective!

Question 2

Question 2: "Are there any entire decisions trees that you feel are no longer relevant to consider in HEP Calculations for U.S Nuclear Power Plants? If so how do you determine this and which trees do you feel are no longer relevant? The original report was written in 1992 and has not been updated to reflect current operations."

The responses are shown in Table 88. With the exception of the decision tree "deliberate violation" analysts feel all other decisions trees are relevant to current analysis.

Table 88

Responses to Question 2 of Phase II Survey – CBDTM Method

Response
• No
• Tree a could be dealt with more explicitly in the scenario definitions perhaps.
• I do not have any problem with using all the decision trees in the CBDTM, although in practice only a few of the decision trees yield non-zero probabilities for most actions.
• We do not ever use the deliberate violation tree.
• I think it is still at a high level such that the structure/framework is still applicable; judgment still need to be made; the only differences may be the use of HRA calculator may have popularize the uses and improve somewhat the consistency of the applications.
• We use all the trees, but, given our procedure format and usage, the values from a few trees dominate the calculation.
• Yes, deliberate violation tree seems irrelevant. All trained operators are instructed to stop or consult with TSC if they believe the instruction is incorrect.
• I cannot determine which are acceptable and which are not. In my mind since the whole process depends on Swain in the first place the CBDT method is questionable! Yes the report was written in 1992, but it was just a rehash of THERP written in 1980 or even earlier!

Question 3

Question 3: "When using the decision tree pca- Availability of Information [See Fig. C-7.] the CPSES HRA analyst made the following assumption

> "Control room indication is provided for equipment status with visual and audible alarms indicators of equipment failures or parameter deviations. The control room indication is assumed to be available, and accurate unless affected by the initiating event."[16]

This assumption was used for every action in the CPSES database and resulted in the Pca tree always giving a negligible value. Are there any actions for which you would consider doing an HEP calculation when this assumption is not valid and/or the Pca tree would result in a non negligible value?"

The responses (See Table 89) show that most analysts tend to agree with the CPSES assumption. However, some specific examples of when this assumption is not valid include fire in the control room and prolonged station blackout. Therefore, the assumption that control room indication is available unless affected by the initiating event is appropriate with rare exceptions.

Table 89

Responses to Question 3 of Phase II Survey – CBDTM Method

Response
• No [2 responses]
• You'd have to work harder to find indirect indications of the need for the action.
• In practice, like CPSES I do not believe that there are any cases in our HRA where this probability is not negligible. However, it is conceivable that there could be situations where indication is available in the control room but the indication may not be accurate.
• A rare occasion that I can think of is prolonged Station Blackout after battery depletion, there may not be any indication in the control room.
• It is a good general assumption. There are some subtle instrumentation failures that would be difficult for an Operator to recognize. These failures are also difficult for the analyst to recognize, and are fortunately very unlikely.
• Yes. Initiating event is very important for the HRA development.
• When there is a fire in or near the control room. I would pick CR [Control Room] indication inaccurate.
• The question is not if the indications are accurate but rather how are they perceived by the operators. Is the quality of the MMI high or otherwise for the specific accident? When taken together with all the other influences the result may lead to a high or low HEP. Again, the result depends on the context. The pathway selected by the CPSES HRA person is not the problem really, but rather that the other influences of procedures, etc. are not considered along with instrument accuracy.

Question 4

Question 4: **“**In the decision tree pcb-Failure of attention, how do you differentiate between high vs. low workload?”

Table 90 shows that there is no one parameter used to describe the workload. Instead, analysts tend to base this decision on a combination of the following parameters: 1) number of steps listed in the procedures, 2) number of crew members compared to number of tasks, 3) number of procedures being used in hand, and 4) total number of procedures in use.

Table 90

Responses to Question 4 of Phase II Survey- CBDTM Method

Response
• Operator interview; and as a general rule we have found that high work load occurs early in the event, wheresas low workload occurs later in the event.
• Based on what is going on in the control room in terms of number of alarms and whether they are reinforcing or distracting, and on the number of required responses.
• In general, high workload is considered to represent situations where the operator may be using two or more procedures concurrently, is involved with performing two or more actions, or is required to keep track of several parameters.
• Judgmental based on the number of alarms expected.
• Number of the operators in the crew, and actual actions stipulated in the procedural steps.
• We consider the context of the event. What is happening in the control room, what indications are available, how rapidly conditions are changing, etc. Still, this is a subjective decision.
• More than one event taking place. More than 10 tasks to perform.
• When the operator only use the EOP to response the general transients (without any LOCAs, SBO [Station Black Out], total loss of heat sink etc), I would considered it as “Low”. Any actions that required the operator to mitigate the consequence of accident initiating events would consider “High”.
• Go back to a definition of workload. The analyst should have definitions of the quality of workload for each workload level; high, medium or low. The standards ought to be set ahead of the analysis task. The same goes for the other influences.

Question 5

Question 5: **"**The decision tree pcc-Misread/miscommunication asks the analyst to determine if the indicator is easy to locate. For control room actions, is it reasonable to assume that all indicators are easy to locate? Can you give an example when you would determine this not to be the case?"

There are two parts to this question. First, most analysts tend to agree that control room indications are easy to locate but realize that there are will be exceptions. Second, examples of hard-to-locate indicators tend to be located on back panels or out of sight of the operators. (See Table 91) Therefore, engineering judgments about how to determine if an indicator is easy to locate should be based on determining if the indicator is out of sight (i.e., on the back panel) of the operating crew.

Table 91

Responses to Question 5 of Phase II Survey – CBDTM Method

Response
• Yes; several years ago our Control rooms were modified to consider human factors for location of indications and controls.
• For some actions, indicators are found on back panels, though I think these are mainly confirmatory. I can't give explicit examples.
• No, I don't think it is always reasonable to assume that all indicators are easy to locate. It depends on the layout of the control room. Some control rooms may have indications that are not within site of the operator or are close to the floor.
• At our station, good control room mimics are used. So I would say all control rooms are easy. Some remote actions may be other than easy.
• This is a reasonable assumption for actions required by Emergency Operating Procedures. We have not found a situation where we thought an indicator was difficult to locate.
• Some indicators necessary for the situation may be located at the back of a control panel. The operator need to move physically in order to obtain the readings.
• Indicators are easy to locate at the control room of the plant where I work.
• All of the controls and indicators on the control board and on the front panels are consider easy to locate. The ones that I consider not easy to locate are located on the back panel or not on the control board.

Table 91 Continued

•	The terms easy and not easy to locate is not readily understandable in a human factors or human reliability sense. Currently, in the world of human factors as applied to Human System Interfaces (HSI) there are numbers of people undertaking studies in usability analyses. The process is not exact but people realize that it is necessary to test various HSIs in order to arrive at the 'best' arrangement for a specific application. A similar approach has to be taken with the NPP users!
•	Not enough experience to recall one.

Question 6

Question 6: "The HRA Calculator asks the following question to determine if the indicators are Good or Bad. Does the required indicator have human engineering deficiencies that are conducive to errors in reading the display?[9] In your opinion, are there any groups or types of indicators that have human engineering deficiencies that have not been corrected in most control rooms?"

The analysts agree that most human engineering deficiencies have been corrected, and no analyst can identify any specific deficiency that still exists. (See Table 92) This suggests that it would be a rare expectation for an HRA analyst to determine that an indicator has engineering deficiencies.

Table 92

Responses to Question 6 of Phase II Survey – CBDTM Method

Response
• No [3 responses]
• I am not aware of any ergonomic deficiencies which have not been corrected.
• It would be an exception – maybe local indications.
• Not enough experience to recall one.
• No opinion on 'most' controls rooms. Suspect it greatly depends on the vintage of the plant. The Seabrook control room indicators have been "human factored" since initial design.
• I do not know what HFEs still exit in any current MCRs. Some are good and possibly not very good. But it could be that for accidents the arrangements are good and poor for others. This depended on the skills of the HF personnel involved in the upgrade process. I have seen some excellent MCRs and poor MCRs. The devil is in the details.

Question 7

Question 7: "List the circumstances under which you would consider an indictor to have deficiencies that could lead to human error?" This question further address engineering deficiencies, and again the same conclusions apply. When rendering judgments about indicator deficiencies, analysts may consider the examples shown in Table 93.

Table 93

Responses to Question 7 of Phase II Survey – CBDTM Method

Response
• This is a human factors problem and I would refer you to that literature.
• The following examples are just theoretical. One example could be an analog indicator where the range of indication is large but a precise measurement is needed, making it difficult to obtain an accurate value. Another example is where the actual parameter value reads off-scale. A third example could be in instances where the labeling on the indicator is poor or difficult to read. Again, however, I am not aware of any actual cases of the above examples.
• Units not clear; or analog readings that require close-up readings; out-of sequence display or location.
• It would be an exception - maybe local indications.
• Units or style significantly different than other similar indicators. Different response than similar indicators, e.g. top to bottom, left to right, right to left, etc.
• 1. shifted or incorrect calibration; 2. being an indirect indication rather than a direct indication of a measurement; 3. reading is affected by glare or low illumination; 4. low capacity or capability in visual accommodation.
• One example, if the operators have to interpolate or extrapolate to get their reading.
• Equipment manufacturers light LEDs, they have low power consumption and can be reasonably visible when viewed from the correct position, but they cause misreadings. Indicators located in too high or low positions can cause problems. Mixed solutions involving computer displays and old fashion indicators can cause confusion for operators. The old board arrangements were good in some ways since operators could view displays in parallel, but computer displays are serial in nature, so the crews can have problems if the computer architecture is poor. This is one reason the operators like dense displays, which are frowned on by the HF [Human Factors] community! So the best way to see what works is to test the crews by running accident scenarios on simulators!

Questions 8

Questions 8: “Using the CBDTM method decision trees, how do you determine if a procedure has standard or ambiguous wording?”

The responses are shown in Table 94 and Question 9 further addresses this topic.

Table 94

Responses to Question 8 of Phase II Survey – CBDTM Method

Response
• We assume training and resulting critiques have resulted in ambiguous wording being eliminated from procedures. In addition, we have a writer's guide that helps to ensure standardization of procedure wording
• Based on whether the language is clear or not.
• EPRI-TR-100259 and follow-on reports describing the EPRI CBDTM provide ample guidance in determining whether the procedure has ambiguous wording. In general, the lower branch is seldom, if ever, used.
• Judgment – Look for odd wording. We have a case where the operator must determine whether level is less than (-) 85”. The presence of a double negative (Less than, negative elevation) would qualify as ambiguous.
• General versus specific; scenarios can be easily distinguished versus not easily distinguishable; no double negative, etc.
• If there are any doubts about standard wording, we do a simple poll of people in the general office area. If there are a number of different interpretations or questions, it’s ambiguous.
• The qualitative statements that allow operator’s judgment are ambiguous wording. For example, “if RCS [Reactor Cooling System] pressure is too high then …). “Too high” is qualitative statement. Changing it to a quantitative statement such as “if RCS pressure exceeds 2200 psi then…).
• I get the required operator manual tasks from the procedure. If they are clear to me without required training (not a licensed operator), they are considered unambiguous to licensed operators.
• Since the procedures are written in accordance with the industry standard, I often pick “Standard”
• Best ask the crews and even better run a number crews responding to similar scenarios.

Question 9

Question 9: “In Fig.C-11 are there any examples of what you would consider ambiguous wording? Justify using your response to question 8.”

Questions 8 and 9 are both directed at understanding how analysts determine if a procedure is ambiguously worded. The responses in both Tables 94 and 95 show there are multiple approaches even when all analysts are given the same input. (See Fig C-3). It is concluded that engineering judgments concerning procedure ambiguity should be based on multiple simultaneous approaches and evaluated on a case-by-case bases.

Table 95

Responses to Question 9 of Phase II Survey – CBDTM Method

Response
• No
• Yes, but because of the word verify. It would seem that it would have been better written as a Check whether containment spray is required, then the response not obtained would be to start it. It is complicated by the AND and NOT statements and would be picked up in pcg
• I would not consider the wording to be ambiguous.
• Proper Alignment, If necessary are ambiguous words.
• CBDTM would penalize you for this wording. There are several examples of AND, IF, NOT, THEN, all in proximity and combination, and in both the expected response and the RNO.
• The procedure in Fig. C-4. provides more information than in Fig. C-3. Fig. C-4. not only provide instruction on which component to act on but also indicate the location of the controller. As a result, the procedure of Fig. 11. has longer wording than in Fig. 10. As long as the operators are training and feel comfortable of such instructions, I don't think they would make much difference.
• Three preconditions may confuse a newly trained operator. Overall, not ambiguous.
• Step 7a HAS REMAINED. I would considered ambiguous, because as long as the containment pressure is over 18.0 psig, containment spray is required.
• This seems to me to be the problem with poorly designed procedures from a human factors point of view. Westinghouse EOPs are full of poorly designed statements. The negative statements leading to actions are almost always a problem!

Question 10

Question 10: "Using the CBDTM method, the analyst is asked to determine if the steps are hidden or obvious. What do you consider to be a "hidden" step?"

Table 96 shows that there is no consistent approach for determining hidden steps among experts. It further suggests that some analysts are applying very optimistic assumptions within their analysis, while other apply detailed analysis. The responses do give various suggestions and approaches to addressing hidden steps, and it is believed that if analysts were to consider a combination of the suggestions, then consistent results could be achieved.

Table 96

Responses to Question 10 of Phase II Survey – CBDTM Method

Response
• We don't have any examples of hidden steps.
• See page 4-7 of the EPRI report TR-100259
• I would generally not consider any critical steps to be hidden. As such, I do not recall any cases where the lower branch (hidden) was used.
• Unusual to be hidden.
• An action or decision point embedded in another step or action.
• An action step that is buried in the middle of a lot of text, e.g. a "do" step in the middle of a note or caution.
• Is there operator's training on the essential and supplement instructions in performing an activity not explicitly written in the procedure steps?
• As an example: If you are referred to other procedure that may not be easily located or, if they take the operators to perform contingencies to contingencies.
• If there is a specific procedure available for system or component restoration, but EOP RNO did not specifically identified this procedure number. I would consider this as hidden.
• Nothing is obvious to the central office analyst hence you are forced to consult domain experts rather than knowledge experts. A hidden step is an action identified by the training process or by experience. Many times procedures are found to be defective in some area, even now. It often is discovered by operators/instructors running through different scenarios.

Question 11

Question 11: "Using the CBDTM method, the analyst is asked to determine if steps are graphically distinct. How do you determine if a step is graphically distinct?"

The responses are shown in Table 97 and Question 12 further addressees this topic.

Table 97

Responses to Question 11 of Phase II Survey _CBDTM Method

Response
• We do not take credit for “graphically distinct” steps.
• See EPRI Report TR-100259
• Using WOG EOPs as an example, I would consider the first step in a procedure to be graphically distinct, as I would a step that follows a note or caution or is by itself on a page.
• Several action verbs in the same step.
• Not easily mixed-up for example, if a dyslexic can read the distinction, it is distinct.
• Steps that are boxed, or the only step on a page.
• Not easy to be overlooked. It’s subjective judgment.
• If there is an easy selection from a graph or table
• I assume that graphically distinct means that an influence is either clearly good or bad. If the states are not clear then the analyst has to consider where both branches lead to and then decide if a better HEP might be given by an average or a weighted value of some kind. So for example the first branch is between Easy and Not Easy and the other branches are Bad and Good. The Easy branch would lead to 1.0E-03 and the Not Easy branch would yield 4.0E-03. An average number would yield 2.5E-03!

Question 12

Question 12: “Below is a page from EOP 0.0. (Fig. C-3.) Step 6a has been identified as a critical action, and the analyst has determined that step 6a is “obvious” and graphically distinct from other actions on the page. Would you agree or disagree with these decisions? Discuss how you made your decision.”

The responses are shown in Table 98, and most analysts agree with the CPSES HRA analyst in identifying this step as an obvious, graphically distinct step. Questions 11 and 12 were directed at determining how an analyst determines if a procedure step is graphically distinct.

The responses show that each analyst defines the term differently. Furthermore, some analysts apply a vague or rather subjective definition such as “not easily mixed up”, and others apply a concrete definition like “the only step on the page.” No conclusions can be drawn on which set of definitions is more appropriate, but if an analyst wants to render consistent, justifiable, and well-documented results, the best approach would be to follow some combination of the concrete definitions.

Table 98

Responses to Question 12 of Phase II Survey – CBDTM Method

Response
• I agree that it is “obvious” but I do not agree that it is “graphically distinct.” The step is not more conspicuous than the surrounding steps.
• In the sense that the step has a distinct address, yes. As a historical note, this was originally thought of more in the context of flowchart procedures, typical of BWRs, and some PWRs.
• Step 6 is the only procedure on the page. Therefore, Step 6a, being the first step in Step 6, could be considered graphically distinct. However, because the critical step (Step 6a) is not the only step on the page, I would not consider Step 6a to be graphically distinct. Having said that, I would not object strongly to designating the step as graphically distinct.
• Yes, it is clear or obvious.
• I would call the step obvious because it is a simple action / RNO. I do not consider it graphically distinct because it looks like every other step on the page.
• Agree. Some properties are concise wording, statement layout, distinct bullets, and consistent format through out the procedures.
• I agree. The step is clear, there is no room for misinterpretations.
• The procedure step, RNO are clear and simple. Therefore, I agree with these decisions.
• I do not agree with the assessment. From a designers point of view the TDFW is the most effective pump having a much greater capacity. The combination of the pumps fulfills the diversity requirement, which is extremely important. Not so obvious!

Question 13

Question 13 “Describe your methodology on how you apply recoveries and dependencies using the CBDTM method.”

The scope of this question was rather large, and the responses (See Table 99) address a variety of different areas. In general analysts follow some type of available guidance when rendering judgments about dependences. It is more important to apply a consistent method that to seek an exact method.

Table 99

Response to Question 13 of Phase II Survey – CBDTM Method

Response
• Table 4-1 in TR-100259 outlines the nature of any recovery that may be credited for each of the eight failure mechanisms. The dependence characteristics are derived from the model presented in Table 20-17 of NUREG/CR-1278.
• I use the EPRI report TR-100259
• The following table [Shown in Table 27] summarizes the dependency we would use. It should be noted that this dependency level differs from that used in the current EPRI HRA Method, which assigns zero dependence after 1 hour. It was judged that based on the same crew being involved in the response until the next shift turnover (6 hours on average), some dependency will most likely still be present. Therefore, zero dependence (ZD) was not assumed until 6 hours.
• Use the HRA Calculator recommended dependency level unless off-normal PSFs are present.
• If there are recurring steps that provide opportunity I would assign a multiplier which accounts for dependencies. The dependency would be relatively high, say 0.5 or quite independent if there is a second person with more experience and freshness in the crew.
• Review the steps for succeeding steps that would aid in discovering an error or omission. Review the preceding steps to determine if there are steps that if incorrectly executed, would cause an operator to bypass or miss the critical step.
• Recoveries are allowed if timing allows for it. No complete independency between people, at best use low dependency. I often use medium dependency (all based on NUREG 1278 guidelines).
• Operator will conduct self-review while continuing through the procedure, extra crew will provide peer check, or STA could use diagnostic status tree to notify operator of required action. Both recovery and dependency are based on time available to implement procedure steps.

Conclusions

Within this section several different areas of engineering judgments were surveyed. In addition to further supporting the conclusions from other survey sections, the following additional conclusions can be drawn about engineering judgments rendered within the CBDTM Method.

- Since most analysts do not modify, remove or diverge from the original CBDTM decision trees, there is little engineering judgment applied to modification of the CBDTM method to produce more realistic results.
- HRA analysts tend to agree that with rare exceptions it is appropriate to assume that control room indicators are available unless affected by the initiating event.
- Engineering judgments to differentiate between high and low workload are based on the follow four items: Number of steps in the procedures, number of crew members, number of procedures being used in hand, and total number of procedures in use.
- Engineering judgments about how to determine if an indicator is easy to locate should be based on determining if the indicator is out sight of the operating crew.
- Engineering judgments about procedure ambiguity should be based on multiple simultaneous approaches and evaluated on a case-by-case bases.
- In order to determine if a step is graphically distinct an analyst should follow some concrete, consistent, and well-documented approach.
- It is more important to render engineering judgments about recoveries and dependences using a consistent method than to seek an exact method.

CHAPTER VIII

RECOMMENDATIONS ON THE USE OF ENGINEERING JUDGMENTS WITHIN HRA CALCULATIONS

Regardless of which methodology an HRA analyst is using for quantification, the same judgments will be made within the definition stage. It is recommended that an HRA analyst review the "Good Practice For Implementing Human Reliability Analysis (HRA)," NUREG 1792 and follow these recommendations when rendering judgments within the following areas.[17]

1. Identification and definition of actions to modeled within the HRA Calculator
2. Categorization of actions as pre or post-initiators
3. Definition of critical actions
4. Definition of cognitive portion of the actions

SHARP1 also provides recommendations within this area. but it has not been updated to match current practice. At this time, NUREG 1792 is the most up-to-date and complete high level guidance for performing HRA.

The first step of an HRA is to identify and to define explicitly which human actions are to be modeled using the HRA Calculator. In order to accomplish this, an HRA analyst should complete the following three steps in order to render all the judgments within the definition stage.

1. Review available information to gain an understanding of the PRA model and the systems and equipment involved. NUREG 1792 Sections 5.1.3.1-5.1.3.3 provide recommendations for good practice on what to do in this review. Users of the

HRA Calculator should be aware that the following pieces of information will be needed for every action modeled with in the HRA Calculator, and documenting this information in this stage will help the user later in the quantification stage.

- Procedure and tasks numbers
- Types and number of annunciators the operating crew many encounter
- Locations of the crew – Control room/ex-control actions.
- Potential cues that will alert the crew to perform certain tasks
- Related human interactions that could act as recoveries

2. Define each action such that it can be modeled as a basic event. Each definition should include identifying what the initiating event is and what the possible out comes of the action are. NUREG 1792 Sections 5.2.3.1 and 5.2.3.2 provide specific recommendations.

3. Conceptualize post-initiators actions as two parts: the cognitive portion and the execution portion. For the cognitive portion describe in as much detail as possible how the crew will know to perform the action and take note of when in the sequence of events the crew will receive a cue to perform the action. For the execution portion it is important to identify individual critical actions and potential performance shaping factors that would impact the crew’s performance.

JUDGMENTS WITHIN THE QUANTIFICATION STAGE

Once the action has been defined the HRA analyst must employ the use of engineering judgment several more times in order to quantity each HEP value. The following recommendations are intended to be used as good practice guidance for quantification using the HRA Calculator and have been compiled from the following sources: results of two surveys of HRA experts, review of the original methodologies, review the CPSES complete HRA using the HRA Calculator, and mathematical comparison among methods applied by the HRA Calculator. These recommendations are not intended to be used as cook-book formula for the HRA Calculator but instead provide guidance for inexperienced HRA analysts on how current HRA analysts render these same judgments.

Choice of methodology

There are several different approaches to selecting a method by which to calculate $P_{cog.}$ Appendix D describes the parameters recommended by SHARP1 in identifying which methodology to use[3]. While the HRA Calculator is not a single method, it can be evaluated using the same parameters as the individual methods. The SHARP1 report[3] identifies which methods were available for quantification in 1990, but it does not give guidance on how to interpret and to complete any analysis using an identified method. At the time of the SHARP1 publication, the HRA Calculator had not yet been developed. SHARP1 provides the user with an overview of mechanics of each method but gives little insight into strengths and weaknesses of the mathematical modeling of each method. The user of the HRA Calculator may wish to consult this table if previous analyses are available for comparison and they wish to gain insight on why one method was chosen over another.

Table 100 shows the strengths and weaknesses of each methodology as used within the HRA Calculator. If the HRA analyst has identified that one parameter should be a dominating influence on the HEP calculation, it is important to ensure that the method accounts for that parameter accordingly.

Table 100

Strength and Weakness of Each Method Employed by the HRA Calculator

Method	Strength	Weakness
Annunciator Response Model	Requires little input Simple to understand	Not widely used by industry Does not explicitly account for time, stress, procedures, training or crew work load Derived from engineering judgments
HCR/ORE Correlation	Explicitly accounts for time dependence Derived from simulator data	For actions where there is a long time (several hours) available the correlation gives unrealistically low P_{cog} values. For actions where there is a short time(5 minutes or less) available the correlation give unrealistically high P_{cog} values.
CBDTM Method	Explicitly addresses the use of procedures during accident sequences. Address a variety of different parameters that have the potential to influence the probability of failure. Derived from both engineering judgments and practical experience.	Requires detailed information about the action, which is not always available Knowledge-based actions may be difficult to model because method focuses on how operators use procedures. For knowledge based actions typically no procedures are used. Widely used in industry

Once the HRA analyst has an understanding of the strengths and weakness of each method, the choice of which method to use may become clear. If the user is still not certain which method is best suited for an action, the following steps are recommended.

1) Complete the analysis using the CBDTM method. The CBDTM method addresses the most parameters and requires the user to gather the most information. Using this method will ensure that analyst has considered and documented all possible parameters.
2) Recalculate the HEP using the HCR/ORE Correlation. Using the HRA Calculator this is a simple task, and all the information can be imported from the CBDTM calculation. The user must be sure to complete the window labeled P_{cog}. The HRA Calculation will import default values into this window, not the data used in the CBDTM method. For most actions, one can expect that the two methods will give results to within the same order of magnitude. Two large exceptions are:
    a. For actions that are high stress and $T_{1/2}$ is less than five minutes the HCR/ORE Correlation will produce a consistently higher probability.
    b. For actions in which the P_{exe} value is exceptionally low (below 5E-4) the two methods will diverge. If this is encountered, it is best to reconsider the recoveries applied to the P_{exe} value.
3) As a conservative approach the higher final probability of the two calculations should be used. Special consideration must be taken if there is a very short time available to complete the action (less than five minutes), because the HCR/ORE

Correlation tends to give exceptionally high values. In some situations the analyst can justify this high value, but sometimes it seems unrealistic, and the HRA analyst may wish to defer back to the CBDTM method.

4) Document and save both calculations for reference.

The Annunciator Response model is difficult to justify because it is only influenced by the number of annunciators an operator receives in the control room. If this is the dominating influence, then this model is acceptable. Otherwise, the HCR/ORE Correlation or the CBDTM Method should be used. On the positive side, the Annunciator Response Model and the CBDTM Method do give results which agree to within the same order of magnitude, and approximately 62% of actions will agree to within one significant digit. Using the Annunciator Response Model may lead a reviewer to question why other parameters were not explicitly considered in the calculation of P_{cog}.

Stress

Within the calculation of $P_{exe,}$ the stress parameter is based upon THERP. If an analyst is familiar with the THERP methodology and new to the HRA Calculator, the following differences should be noted. THERP defines stress as four levels [6]:

- Very Low – Insufficient arousal to keep alert – PSF = 2
- Optimum – Facilitative level - PSF =1
- Moderately High – Slightly to moderately disruptive – PSF = 2
- Extremely High – Very disruptive – PSF = 5

The tabulated probabilities in THERP presume an optimum level of stress. It is important to understand these definitions, because the HRA Calculator only allows the user to choose among the following three options with no definitions to accompany the choices:[9]

- Low/Optimum – PSF =1
- Moderate – PSF = 2
- High – PSF = 5

Furthermore, every tabulated failure probability referenced within the HRA Calculator was derived assuming optimum stress as defined within THERP. Because THERP uses four levels and the HRA Calculator only uses three levels, is more important to choose a PSF value rather than a specific level designation. The responses from the surveys show that different analysts use different stress level classifications for the same PSF. Therefore, it is important to document both the stress level classification and the PSF (See Chapter VII – Stress Level). From this point forward, it will be assumed that stress levels are defined as used within the HRA Calculator.

Very low stress as defined by THERP does not fit within the three definitions of the HRA Calculator. If an analyst would like to apply this term within the HRA Calculator, one option would be to choose moderate stress to match the PSF of 2. Then, in the comments section make careful and clear comments that this is a very low stress action. The PSF value is what is important; the classification is for documentation.

Low/optimum stress can be considered the same as optimum level stress as defined by THERP. This type of stress is characterized by active interaction between the operating crew and the environment at a pace that they manage comfortably. Low stress actions are typically actions that crews complete on a routine bases, and they can anticipate how the plant is going to respond. The crew is comfortable in performing this action either because it is routine, or they have received extensive training on this action. For optimum stress level actions, the plant is not in imminent danger of core damage, and the crew will not feel pressure to complete the actions within time constraints.

Moderate stress level is comparable to the THERP level of moderately high stress. A moderate stress level is used for actions that require the crew to perform several tasks at a rapid pace. The crew has had both simulator and classroom training on this action but is not required to perform the action on a routine basis. THERP references the following examples as moderate stress actions:

- Single transients (Other than large LOCA), that involve shutdown of the reactor and turbine.[6]
- Tasks preformed during startup and shut down that must be performed with time constraints.[6]

In addition to these types of actions, HRA analysts classify the following events as moderately stressed actions (See Chapter VII – Stress Level):

- The crew currently has the plant under control but the situation is quickly evolving and operator actions are time critical.
- The operators receive multiple instruments and alarms unexpectedly at the same time.

High stress is comparable to extremely high stress as defined by THERP. Other HRA analysts often refer to this type of stress as extreme. THERP defines high stress as a level of stress that “threatens a crews well-being.”[6] For operating crews this would be the threat that the crew has lost control of the situation and without action core damage is imminent. High stress actions are always time dependent. The tasks involved in these actions are skill- or knowledge-based, and inexperienced crew members are hesitant to perform these tasks. Examples of high stress actions include:

- Actions that are necessary because the crew has previously misdiagnosed an event, and now the plant is not responding as expected.
- The consequence of the action has the potential for radiation release not only to the public but also workers.[6]
- Several emergency backup systems have already failed.
- Work preformed within a radiation environment where protective clothing must be worn.[6]

Because each action is complex and unique, the parameters that influence stress will vary among actions, and no formula can be used to determine a stress level. Furthermore, individual analysts tend to create individual approaches to determining a stress level. Therefore, it is not appropriate or justifiable to make a general assumption about stress levels within a complete HRA. For example, an HRA analyst may want to state that optimal stress will be used as a default value, because operators are well trained (See Chapter VI Assumption 1 and Assumption 30). If an independent reviewer disagrees with this assumption, they will specifically question the stress choice in each and every calculation. The analyst will also spend a significant amount of time within each calculation justifying why the assumption was appropriate in each case. If one wishes to state a general assumption at the beginning of an analysis, it is better to comment about the approach by which the stress level will be determined. As in the example above, one could state: To determine a stress level, a moderate stress level was first considered, then adjusted up or downward depending on type of training the crew has received.

To determine a stress level the following steps are recommended for an analyst to follow in order to encompass all the areas that influence stress which current analysts feel are important to consider.

1. Consider all parameters (shown in Table 101) that influence the stress of the operating crew.

2. Using information obtained in step one, assign a stress level with appropriate PSF value used to calculate P_{exe}. While there could be some variation among HRA analysts on a stress level chosen, if the main influences of stress have been identified, the HRA analyst should have little difficultly justifying to reviewers his choice for the stress level.

If all the influences have little or no effect on the stress level then an optimal level of stress should be used. Similarly, if all the influences are considered as high contributors to stress then a high stress level should be used. There will obviously be a gray area at the boundary between the low and moderate stress and moderate and high stress.

If actions are required to be completed in a limited amount of time such that the crew is aware of the time constraints, then either a moderator or a high level of stress should be used. HRA analysts, as well as THERP, agree that if protective clothing is needed because of environmental conditions, then the stress level should be high. One of defining differences between moderate and high stress is that for high stress actions the crew is aware that core damage is imminent, because either several back up systems have failed or they have already failed a different action.

Users of the HRA Calculator have the option of choosing different stress levels for different tasks within an action. Unless specific actions are completed by two different people at independent locations with significant time between the actions, it is difficult to justify using different stress levels between different sub-tasks within a specific action. It is best to apply a stress level to the operating crew as opposed to trying to identify how each member will respond to the action.

Table 101

Parameters to Consider When Identifying a Stress Level

Sequence of events occurring in the plant	This includes identifying what has previously occurred and what the operators anticipate will occur.
Timing	There are two parts to consider in the influence of timing and its impact on stress level; First, how long has the crew already been involved in this sequence of events? Naturally, as the sequence progresses the stress level of the operating crew should also increase. Second, how much time is available to for the crew to diagnose and to respond to the action? If the crew is under shorter-than-normal time constraints to complete the action, then a moderate or high stress level should be used.
Crew's familiarity with the tasks	Training is a separate parameter discussed in latter sections. The crew's familiarity with the action can come from training exercises and by identifying how often the crew performs the same series of tasks on a routine basis. One would expect that the more training a crew receives on action the less stress the crew will feel.
Clarity of procedures	The analyst should take note of how procedures will be followed during an action. For skill-based actions, procedures will be memorized and the use of procedures should have little or no effect on stress level. For rule-or knowledge-based actions, procedures will be used in hand, and if exceptionally clear could aid the crew and potentially lower the stress level. If the procedures are ambiguous or confusing, the stress level of the crew would tend to increase. For knowledge-based actions, procedures will need to be interpreted, and this should lead to a stress level of moderate or high.
Environmental conditions	Because Version 2.01 of the HRA Calculator does not account for environmental conditions explicitly as a PSF, the environmental conditions should be accounted for within the choice of stress level. If the environmental conditions are the same as normal operating conditions, then this parameter should have no influence on the stress level. This is because the tabulated values for errors of omission and errors of commission are normalized to the "normal" conditions in which they were measured. If the crew is working in a high radiation environment, then a high level of stress should be chosen.
Alarms and signals received from plant	It is important to identify what signals the crew expects to receive for the sequence being analyzed. If the signals can be used to diagnose several different accident scenarios and are unclear, this could lead to confusion among crew members thus increasing the stress level. If the alarms, provide clear identification of a specific accident, then the stress level of the crew could decrease. If using the Annunciator Response Model, the analyst must identify how many annunciators are present for diagnosing the event. As the number of annunciators increases, the stress level of the crew will also increase.
Number or tasks required	As the number of tasks increase, the stress level should also slightly increase. This influence should be ranked below other influences because, if the tasks are performed on a routine bases, several tasks should be routine, and the crew could feel comfortable performing these actions.

3. Ask operators what they would estimate the stress level to be. It is common practice for HRA analysts to ask operators for opinions about how stressful certain actions are to perform. When interviewing operators it is critical that the operators understand the context in which the questions are being asked. Before asking questions about stress, it is important to review why you are interested in determining a stress level and the definition of each level as applied to the HRA Calculator. The operators may consider every action to be high stress, but using the HRA Calculator definition of high stress this is not appropriate.

There are situations in which the HRA analyst and the operators will disagree on the stress level. If this arises, the analyst should go back to step 1 and discuss each parameter with the operators and determine whether that the HRA analyst and operators are in agreement. If there is still no agreement after the discussion (assuming the analyst is confident in his evaluation), the HRA analyst's decision should used. This is because the HRA analyst should be most familiar with how this input will influence the HEP calculation.

4. Match the explicit stress choice determined in P_{exe} to the implicit stress level used within P_{cog}. The Annunciator Response Model and the CBDTM Method both have considered stress implicitly in the calculation of $P_{cog.}$ The HCR/ORE Correlation uses stress explicitly, but the only choices the user has available are high or low stress. Once a stress level has been identified for the P_{exe} portion, it is good practice to ensure consistency between P_{exe} and P_{cog}. Consistency does not necessarily mean that the stress levels are the same. The survey responses show that HRA analysts often use a variation

between P_{exe} and P_{cog} in order to best model each individual action. If there is not consistently between the two, the user has three options: First, re-examine the stress level identified for P_{exe} taking careful note of the parameters within the P_{cog} portions. Second, choose a different method to calculate P_{cog} that considers stress more appropriately. Third, simply document the discrepancy and continue the calculation. The third option should be used only when other approaches have been exhausted.

Annunciator Response Model

If using the Annunciator Response Model to calculate P_{cog}, stress level must be a function of the number of annunciators the crew receives to diagnose an event. The HRA analyst must be able to justify that stress level of the operating crew also increases in proportion to the number of annunciators.

HCR/ORE Correlation

Using the HCR/ORE Correlation, the user must judge the stress level as high or low. There is no choice for moderate stress level. Low and high stress are defined the same as in P_{exe}. If an HRA analyst determines a moderate stress level for $P_{exe,}$ then one option to ensure consistently is to interpolate between high and low stress used in $P_{cog.}$ This is possible because stress is the final branch in the decision tree used to calculate sigma, and the HRA Calculator allows the override function to be used. In the documentation section, the user must document why the override function was used.

Another option would be to reconsider the stress level in $P_{exe,}$ and identify if the action could be re-categorized as high or low stress instead of moderate. This approach would be consistent, but changing the stress level used in P_{exe} could influence the end result by a factor of three.

CBDTM Method

Stress is accounted for within the decision trees by identifying the parameters that could influence stress such as training, workload of the operating crew, and clarity of the procedures. In step 1 the analyst will identify all of these parameters, and when doing the P_{cog} calculation needs to consider these decision branches in the same manner as done in step one. It should be noted the decision trees are not affected by timing information, and if the analyst determines that the stress level is dominated by a limited amount of time, then the CBDTM method is a poor methodology choice.

Rule-, skill-, or knowledge-based designation

Rule-based, skill-based, and knowledge-based actions are defined in the HRA Calculator in the same manner as THERP. THERP defines skill-based actions as actions that consist of more or less subconscious routines governed by stored patterns of behavior. Typically, current HRA analysts refer to skill-based actions as actions that are memorized and can be preformed without consulting procedures. While these actions are usually stated in the procedures, the operators are so familiar with the situation that they do not directly consult procedures. Examples of these types of actions include:

Manipulating a single switch in response to an expected annunciator, manually tripping the reactor during ATWS event, or operator uses hand tool to perform routine maintenance.

THERP defines rule-based actions as actions that require a more conscious effort in following stored (or written) rules. Typically, HRA analysts refer to rule-based actions as actions which are proceduralized, and the operating crew is familiar with general procedure guidance. These actions are compliance based, and procedures are always referenced. Most of the failure probabilities provided by THERP and given within the HRA Calculator are for rule-based actions.

Knowledge-based actions, as defined by THERP, are actions in which the tasks are, to some extent, unfamiliar and there is considerable cognition involved in deciding what to do. HRA analysts refer to knowledge-based actions as actions in which the crew must formalize a solution based on symptoms of the plant and no written procedures exist. Within a complete HRA, there are typically very few knowledge-based actions modeled within a PRA. In current plants, there is comprehensive training and procedures for most anticipated operator actions. If an HRA analyst encounters a knowledge-based action, they typically exclude the action from the PRA model because it occurs outside the scope of the PRA, or the probability of failure is set to one. The methods employed by the HRA Calculator poorly model these types of actions because of the extremely complex level of cognition involved.

To determine the classification of each action, it is recommended that the HRA analyst consult Table 102. This table lists the different aspects that characterize each type of action. For each parameter, the HRA analyst should be able to identify which category the actions fit into. After reviewing the complete table, the type of action that is identified most often should be used to classify the action.

Table 102

Parameters Used for Classification of Actions

	Skill-based actions	**Rule-based actions**	**Knowledge-based actions**
How are procedures used within the action?	All procedure are memorized.	Procedures are used in hand even though experienced crew members may have procedure memorized.	There are no specific procedures used for diagnosing the action. Once the crew diagnoses the event, there may or may not be exact procedures suitable for use.
Do crew members have general procedure guidance committed to memory?	Yes	Yes, the crew will know what to expect, but they will not react until directed to do so by the procedures.	No, because event has proceeded beyond procedures' applicability.
Are the actions committed to memory?	Yes	Sometimes	No
What type and how often does the crew receive training on this action?	The crew has received extensive training on these types of actions, and these actions are practiced often.	The crew has received training on these types of actions, but the actions are not practiced regularly.	There is no formal training for these types of actions.
How much communication among crew members is expected?	The crew will respond immediately, and no communication is necessary.	Typically, three-way communication will be employed.	The crew will have extensive discussion on developing a solution.

Once the action has been assigned a classification, the HRA Calculator requires the user to identify the complexity of the both the cognitive and execution portion as simple or complex. While this may be useful in understanding the action being modeled, the user's response has no numerical impact on the results. Thus, the user should attempt to classify the action but should not exhaust time or resources on these sub-classes. If no choice is input, the HRA Calculator assigns the action a default value of complex.

Within the HCR/ORE Correlation, the user must identify the action as rule-based or skill-based. There is no choice for knowledge-based actions. If the analyst identifies the action as knowledge-based, it is recommended that another method be used for quantification of $P_{cog.}$ The CBDTM Method may not be appropriate to model knowledge-based actions, because this model is highly dependent upon the crew's use of procedures. For knowledge-based actions the event has proceeded beyond procedures applicability. If an action is considered to be knowledge-based, the user has two options: 1) choose a different methodology not presented within the HRA Calculator or 2) apply a conservative approach and set the probability of failure to one.

Timing information

Depending upon the methodology used to calculate P_{cog}, timing information influences the calculation of P_{cog} differently. (See judgment section). Taking note of this, it is still recommended that all judgments about timing be rendered following the same set of guidelines. Furthermore, it is recommended that all timing information be collected and documented regardless of what is specifically input into the calculation. This provides complete documentation of the action as well as provides justification for the method selected.

There are several different ways in which an HRA analyst can collect timing information. Table 103 gives a list of possible sources of timing information.

Table 103

Sources of Timing Information Ranked in Order of Importance

	T_w and T_{delay}	T_M	$T_{1/2}$
1	Engineering analysis such as MAAP or other thermal-hydraulic codes	Observation of action in the simulator.	Simulator and training records
2	Manufactures recommendations	Operations records	$T_{1/2} = T_w - (T_{delay} + T_m)$
3	FSAR	Job performance measures	Operator interviews
4	Timings referenced in procedures	Operator interviews	Estimation based on talking through procedures
5	Calculations used in similar PRA models	ASEP recommendations	

To collect timing information the HRA analyst should begin by examining the first method listed in Table 103 and proceed down the table until all information is gathered.

If possible, it is recommended that more than one source be used for comparison of timing information; this would determine consistency between sources or make the HRA analyst aware of potential differences. The times need to be representative of times that would actually occur during the accident sequence and not ideal conditions. An HRA analyst could simply use a stop watch to time T_w during a simulator exercise. In the true scenario, the operators could respond differently because of more confusion, higher stress level, or different environmental conditions. Comparing two sources of information would alert the HRA analyst of any overly optimistic times that may have been obtained.

After the timing information has been collected, the HRA analyst must address the question: Is there enough time available to complete the action? If not, the HRA Calculator will not allow the user to proceed, and the HRA analyst will either have to assume the probability of failure is 1, or re-examine the times being used within the HRA Calculator.

Annunciator Response Model

The probabilities for this method were intended to be interpreted such that as time increases, the severity of the accident will also increase. If this is not the case for the action being modeled, then another method should be used to calculate $P_{cog.}$

HCR/ORE Correlation

Timing is the dominating parameter in the HCR/ORE Correlation, especially $T_{1/2}$ and T_w. P_{cog} is so sensitive to the ratio of $T_w/T_{1/2}$ that a one minute variation in T_w can change the P_{cog} value up to 50% . Because of this, the HRA analyst must recognize this high degree of sensitivity will produce large uncertainty in the calculation of P_{cog}. This is especially true when T_w is very short (less than about 5 minutes); for theses types of actions, the HRA analyst must consider if timing is the dominating influence on P_{cog}. If it is, then the HCR/ORE Correlation is appropriate to use.

CBDTM Method

The CBDTM uses timing information to provide recommendations on considering additional crew who many be available for recovery. The longer the sequence progresses, the more people will become involved; and their presence may be credited in cognitive recovery. It is recommended that the HRA analyst follow the recommendation of the HRA Calculator for determining times at which additional crew can be credited. (See judgments section on timing)

Training

Classification of the type of training as simulator or classroom should be relatively clear to an HRA analyst. It is recommended that HRA analysts consult with training instructors and training records to determine how often and what type of training occurs. The number of times an action is trained has no numeric effect on quantification. It does give the analyst an idea of how comfortable a crew should be at performing an action which would affect the stress level. HRA analysts agree that engineering judgments about training should also impact judgments about stress and action complexity.

HRA analysts tend to agree that most Level 1, post-initiator actions modeled for U.S nuclear power plants are well-trained. If this assumption is applied to a complete HRA analysis by always using the most optimistic values, then the actions are not differentiable by different types and degrees of training. This is problematic, because all analysts agree that different types and degrees of training should be a dominating parameter in determining the HEP. This is considered to be a weakness of the HRA Calculator because training is not explicitly modeled as a PSF within the calculation of P_{exe}. It is recognized within P_{cog} using the CBDTM Method and the HCR/ORE Correlation. Some of the decision trees explicitly differentiate between simulator or classroom training and it is recommended that analysts not choose the most optimistic value but instead take the time extra time to identify differences between classroom and simulator training.

For additional guidance on how to render specific engineering judgments within decision tree nodes for both the CBDTM Method and the HCR/ORE Correction, it is recommended that analysts following the recommendations within the HRA Calculator.

Procedures

The use of procedures by operating crews within U.S nuclear power plants is considered by most to be second nature. In addition to identifying which procedures will be used during the accident scenario, the HRA analyst must also address the high level question: How does the use of procedures affect the probability of failure? This question can be further broken into small questions.

- How will the operating crew know to transfer to another procedure if necessary?
- How are the procedures used by the operating crew? For example, the crew could have the procedures in hand, or they may complete the steps from memory.
- How does the clarity of the procedure affect the actions of the operating crew?
- How accurately does the operator or operating crew follow the procedures?

To answer these questions, it is recommended that the HRA analyst observe at least one action during a simulator exercise. It is not practical for an analyst to observer every action modeled, but observation of similar simulator exercises would provided the analyst with a general understanding of how a crew, specific to the plant being modeled, uses procedures. To further understand the use of procedures it is recommended that the analyst do a talk through of each action with the procedure in hand and ask the operators how they would answer the above questions.

Procedures are used within the calculation of P_{exe} when specifically identifying critical actions and recoveries applied to specific tasks. Version 2.01 of the HRA Calculator requires the user to identify a step number from the procedures for every critical action and recovery. For most actions this is simple task. There are actions in which procedures are not used in hand, and no step number can be identified. In these situations, it is recommended that the user simply place a dummy variable in place of the step number. The user can not leave this input blank. By requiring the user to input a step number the program inadvertently assumes all actions are proceduralized.

NUREG 1792 provides a list of procedure characteristics that could be considered to have negative impacts on the HEP. Most of these specific parameters are identified within the CBDTM Method only. Again, like training, procedures are not addressed as an independent PSF within $P_{exe,}$ and many HRA analysts consider this a weakness of the HRA Calculator.

HCR/ORE Correlation

The HRA Calculator recommends that the decision node about procedures address the extent of procedural guidance and the cues available. For example, whether the procedure, itself, is sufficient to guide the operator or whether he/she also has to monitor meters, position indicators, etc. This can be identified by answering the following two questions:

> 1) "Is the procedural guidance simple/explicit enough; e.g., one step, clearly defined (is it unnecessary to monitor meters/alarms to make the correct decision)?
>
> 2) Are the indications/alarms clear enough to support a decision, or is it necessary to take additional observations to reach a correct decision? Is the diagnostic straightforward without the need for consulting SPDS or bringing in additional crew members?"[9]

The decision tree used to determine sigma was developed as part of the HRA Calculator and these questions and recommendations come directly from the HRA Calculator User's manual

CBDTM Method

Within the CBDTM Method judgments about procedures are made within the following decision trees.

- Pcd – Information Misleading
- Pce –Skip a Step in the Procedure
- Pcf – Misinterpret Instructions
- Pcg – Misinterpret Decision Logic

It is recommended that for most of the decision nodes addressing procedures the analyst answer each question by simple observation of the procedure. Most of the nodes have concrete, obtainable solutions and require little judgment by the analyst. The following nodes have been identified to require sometimes subjective judgments, and further recommendations are provided.

Pce –Skip a Step in the Procedure –The analyst must address the node titled Hidden vs Obvious. Most procedures have been updated to correct for potentially hidden steps, and the hidden branch is seldom used. A hidden step is considered to be one of the following:

- A step that is given within a caution statement,
- A step located on the back of a page,
- More than one step is contained within a single statement,
- The step references another procedure that is difficult to locate.

Also within the Pce tree, the user must address the node titled graphically distinct. There is no common definition of graphically distinct among HRA analysts. Furthermore, they define graphically distinct in vague terms such as, not easily overlooked, or not easy to mix up. EPRI Report TR-100259, gives the following example of graphically distinct:

> "Steps that form the apex of branches in flowchart procedures, steps proceeded by notes or cautions, and steps that are formatted to emphasize logic terms are more eye-catching than simple action steps, and are less likely to be overlooked simply because the look different than surrounding steps. However, this effect is diluted if there are several such steps in view at one time (as on a typical flowchart), and for this reason the only steps on flowcharts that should be credited as being graphically distinct are those at the junction of two branching flow paths."[8]

For non-flow chart procedures, it is recommended bulleted, boxed, or other highlighting techniques be identified as graphically distinct. Also steps listed first in a series of steps or which is the only step given on a page can be considered graphically distinct.

Pcf – Misinterpret Instructions – Within this tree, the analyst must address the node titled, Standard or Ambiguous Wording. Again, HRA analysts tend to agree that most procedures in current plants have been updated to remove ambiguously worded steps. EPRI Report TR-100259, recommends the following three questions be addressed within this decision node:

> 1) "Does the step include unfamiliar nomenclature or an unusual grammatical construction?
>
> 2) Does anything about the wording require explanation in order to arrive at the intended interpretation?
>
> 3) Does the proper interpretation of the step require an inference about the future state of the plant?"[8]

Answering yes to any of the above questions would alert the HRA analyst that the procedure has ambiguous wording. Furthermore, HRA analysts also use some additional criteria.

- Qualitative statements such as pressure is too high, are considered to be ambiguously worded because of the word too.
- The use of double negatives within a procedure step is considered to be ambiguously worded.

Human interactions with hardware

For each critical action identified within P_{exe} the HRA analyst must identify both an error of omission and an error of commission for every critical action and recovery. The HRA Calculator provides the user with tabulated failure probabilities, which were taken from THERP. HRA analysts all agree THERP provides the most complete set of failure data available, and they seldom use other available databases. It is, therefore, recommended that HRA analyst use the provided databank and only under rare circumstances use data from other sources.

The HRA Calculator has modified some of the THERP probabilities based on Swain's recommendations to credit exceptionally well-written procedures. Current HRA Calculator users tend to agree that these modifications from the original methodology are appropriate. But, HRA analysts using other methods feel that these modifications are overly optimistic. In order to obtain consistency among HRA Calculator users, it is recommended that users of the HRA Calculator use the tabulated probabilities provided in the HRA Calculator and not refer back to the original THERP values.

For errors of omission it is recommended that HRA analysts use Table 20-7 exclusively for post-initiator actions. Within this table the HRA analyst must identify where the procedure contains a short list (less than 10 items) or a long list (greater than 10 items). It is recommended that each proceduralized step be considered an item. Also, within THERP Table 20-7 the user must determine if check off provisions are correctly used. It is recommended that the analyst specifically identify if there are check off provisions and the crew actually uses them. This has lead several analyst to produce recommendations for improvements within various procedures by adding check-offs which lowered CDF. It is not appropriate to assume that all EOPs use check off steps without physically identifying them.

For errors of commission it is recommended that HRA analysts do the following: 1) observe the control room layout and if time permits do a walk-through, 2) identify procedures being followed and 3) understand the sequence of events being modeled. Without completing all three items the HRA analyst can not choose an appropriate value. Typically, HRA analysts use THERP Table 20-12 for most post-initiators, and occasionally THERP Tables 20-11, 20-13 will also be used.

Annunciator Response Model

The Annunciator Response Model is only impacted by this parameter. The analyst must determine how many annunciators the operating crew will observe before they can diagnose and correct the problem. This is a difficult problem to address, because THERP defines a single annunciator as a group of alarms or indicators that trained operators regard as a single unit and does not further define single unit. This is a rather subjective decision, and most HRA Calculator users do not apply this method. It is recommended that if an analyst is not able to differentiate clearly between single or groups of annunciators, then the CBDTM Method or the HCR/ORE Correlation be used to calculate P_{cog}.

HRA analysts who do use this model agree that there are three ways in which to collect annunciator data.

1) Use alarm response procedures
2) Operator or training instructor interviews
3) Simulator observation

It is recommended that HRA analysts begin by identifying all potential alarms listed within alarm response procedures. Then discuss the list with training instructors to identify if some annunciators could be grouped together because they are always trained together. These interviews will also provide useful insight into identifying annunciators other than alarms that would aid the crew in diagnosing the response. Observation of simulator exercises would be useful for the analyst to compare his list of annunciators to those that are important during the scenario. However, using simulator observations as the primary source for data would be difficult to justify unless the action being modeled is identical to the simulator exercise. The alarms are highly dependent upon the specific action.

It should be noted that THERP provides a method for taking credit for the presence of additional people, and if an analyst would want to credit additional people for recovery, they would have to modify the result of the calculations external to the HRA Calculator. There is no override function available within the Annunciator Response Model.

CBDTM Method

Pca- Availability of Information- Within this tree the user must determine whether there are indications available to correctly diagnose the accident and then determine if the indicators are accurate. For most Level 1 post-initiator actions the HRA analyst can assume that unless the indicator is malfunctioning because of the initiating event, it is available for correct diagnoses. There are few situations in which the indication is not available and they include:

- Fire in or near the control room.
- Prolonged station blackout after battery depletion

These exceptions are considered rare, but when they do occur, the analyst must then carefully address the rest of the decision tree nodes, because this tree would then become a dominating factor to the overall HEP.

Pcb –Failure of Attention – First, the analysts must determine whether the work load of the crew is high or low. It is recommended that HRA analysts use the following criteria in Table 104 to differentiate between high and low work load.

Table 104

High vs Low Workload

	High Work Load	**Low Work Load**
Number of required steps listed in procedures.	Greater than 10 steps	Less than or equal to 10 steps
Number of operators in crew compared to number tasks.	More tasks than operators available to complete simultaneous tasks.	No single operator is assigned more than one task at a time
Number of procedures being used.	Two or more simultaneously	Only one procedure at a time
Number of parameters crew must keep track of within response.	Greater than two	Less than or equal two

Next, within the Pcb decision tress, the analyst must determine whether the control panel needs to be continuously monitored or checked only once. This is usually specified within the procedure steps.

Table 105 gives commonly-used terms which can be applied to differentiate between monitor and check. In addition to identifying these key words listed in the procedures, operator interviews would also be of great benefit to the HRA analyst.

Table 105

Terms Used to Differentiate Between Monitor and Check

Check	**Monitor**
Verify	PERFORM ……. UNTIL set point is reached.
Ensure	MAINTAIN level BETWEEN …….
	CONTROL level BETWEEN ……..
	WAIT UNITL ………….

Pcc – Misread/miscommunication – In the first node the user must address the following question:

> "Is the layout, demarcation, and labeling of the control boards such that it is easy to locate the required indicator?"[9]

HRA analysts tend to agree that most indicators are easy to locate for control room actions directed by EOPs. An indicator would be considered difficult to locate if it is located on the back panel and out of general sight of the operators. For ex-control room actions, this node is more difficult to address and would require the HRA analyst to go physically into the plant and watch an operator perform this task.

Next, the HRA analyst must address the question asked by the HRA Calculator:

> "Does the required indicator have human engineering deficiencies that are conducive to errors in reading the display?[9]

HRA analysts agree that most control rooms have been updated to correct any human engineering deficiencies. When HRA analysts were asked if they could identify any groups or types of indicators that may be considered deficient the following suggestions were provided.

- Indicators that required interpolation or extrapolation.
- Indicators where the range of indication is large, but a precise measurement is needed.
- Units or styles are different than similar indicators.
- Reading is off the scale.
- Reading is affected by glare or low illumination.

Recoveries within an action

The HRA Calculator does not address the issue of recovery actions between individual actions. As a general rule of thumb, most HRA analysts only credit recoveries directed within the procedures. Furthermore, it is difficult to justify taking credit for site policies such as self-review for every action.

Most HRA analysts agree that justifiable HEP values are above 1E-5. The most prevalent mechanism to obtain probabilities lower than 1E-5 is to apply multiple recoveries. It is, therefore, recommended that recoveries not be applied if they lower the final HEP below 1E-5.

To address dependency levels between actions and recoveries within P_{exe}, it is recommended that the HRA analyst use the recommendations provided within the HRA Calculator. THERP can also be consulted for further guidance if necessary. The HRA Calculator's recommendations are based upon the stress level identified and the time available to complete the action. It is difficult to provide further recommendations on how to assign a dependency level, because there is large disagreement among HRA analysts. Users of the HRA Calculator tend to follow the HRA Calculator recommendations, but HRA analysts using different methods all created unique and individual approaches.

CBDTM Method

After completing each decision tree, the HRA Calculator asks the user to account for recoveries made by the presence of additional people. The more time available to complete the action, the more people may become available for recovery. While there is a minimum amount of time available to allow additional crew, the user is not required to take credit for any recovery. It is recommended that HRA analysts follow the recommendations of the HRA Calculator to apply recoveries to decision trees. These recommendations were based on ERPI Report TR-100259. In addition, it is recommended that HRA analysts not take credit for self-review unless a requirement for it is explicitly stated in the procedures. Self-review is already credited within the decision trees.

Review of final HEP

Once an HEP value is obtained, the analyst must review the results to ensure that the value has physical meaning. This is done by addressing the following questions:

1) Is the final value realistic?

2) Does the final value appear to be consistent among other actions within the same analysis?

It is recommended that the analyst look at similar calculations using different methods and previous analysis. Analysts use previous calculations to identify an estimate of what the final value may be. However, this should be done with caution because in many cases the analyses have either been completed using a different method, or that plant conditions have been updated.

The second question can be addressed by comparing actions within the model. For example, analysts tend to agree that as more time is available the lower the failure probability, and this can be verified after each calculation. A second example is that as stress increases the probability of failure also increases.

HRA analysts tend to use a lower bound for HEP values in the range of 1E-6 and 1E-4 with a tendency towards the higher end. This range of values can be used to identify the results that may be unrealistically low. For results that may be unrealistically low it is recommended that the analyst review the entire calculation especially engineering judgments rendered about recoveries. It is also recommended that prior to beginning a complete analysis that an analyst set a consistent lower bound regardless of which methodology is applied.

Regardless of which methodology is used to calculate P_{cog}, it is recommended that analysts review P_{cog} in relation to the final HEP value. In some cases P_{cog} will be exceptionally low (below 1E-6) and, therefore, not have any influence on the final results when compared to P_{exe}. However, if the analyst determines prior to completing the calculation that the cognitive portion of the action is a contributor to the failure probability, then the analyst may wish to apply another method for P_{cog}.

During the review stage it is also recommended the engineering judgments made about timing and recoveries be reviewed, because these judgments specifically have major influences on the numerical results.

CHAPTER IX

CONCLUSION

This study has identified thirteen areas of judgments (See Table 106) that an HRA analyst would have to render when completing an HEP calculation using the HRA Calculator. In addition, recommendations on how to render each of theses judgments have been proposed. The recommendations represent current HRA practice and identify what constitutes a complete, justifiable, well-documented calculation. In some instances, there were multiple approaches to rendering the same judgment, and the study's recommendations try to incorporate theses different approaches into a single recommendation. For example, see Chapter VIII , Stress Level.

Table 106

Areas of Judgments That an HRA Analyst Will Render for a HEP Calculation Using the HRA Calculator.

1	Identification and definition of actions to be modeled within the HRA Calculator
2	Categorization of actions as pre- or post-initiators
3	Definition of critical actions
4	Definition of cognitive portion of the action
5	Choice of methodology
6	Stress
7	Rule-, skill- or knowledge-based designation
8	Timing information
9	Training
10	Procedures
11	Human interactions with hardware
12	Recoveries and dependencies within an action.
13	Review of final HEP

As part of this study, the results of the three methods employed by the HRA Calculator were compared for a complete set of post-initiator actions from a PRA. It is concluded that for the same input, the three methods generally produce HEP values on the same order of magnitude with two large exceptions:

1) Actions that are high stress and $T_{1/2}$ is less than 5 minutes, and

2) Actions in which the P_{exe} value is exceptionally low (below about 5E-4).

If this study were to be continued, the next step would be to have an HRA analyst follow these recommendations for a complete analysis. While these recommendations were created by surveying current HRA analysts, it is expected that once an analyst tries to apply them, minor adjustments will need to be considered.

These recommendations have been created specifically for Version 2.0 of the HRA Calculator. It is expected that as newer versions of the HRA Calculator become available, the specific recommendations will need to be reconsidered, but the areas of the judgments will remain constant. (Assuming the methods are still the same.) This is because the areas of judgment were created by consideration of the original methodologies as well as how the parameters are used within the HRA Calculator.

The field of HRA is still in its infancy, and there is a lack of databases of human failure probabilities. Therefore, engineering judgments are critical to all HEP calculations regardless of which method is being applied. As the field of HRA continues to develop, it is expected that more failure probabilities will be collected, and hopefully this will reduce the number of subjective judgments an HRA analyst needs to render for HEP calculations.

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APPENDIX A

SAMPLE P_{cog} CALCULATION USING THE CBDTM METHOD WITHIN THE HRA CALCULATOR

The following figures show the eight decision tress and the choices made for a sample P_{cog} calculation using the CBDTM Method.

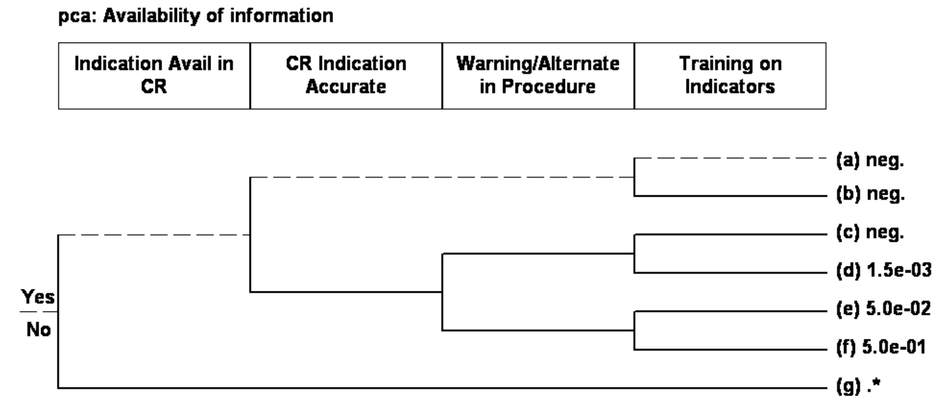

Fig. A-1. Decision Tree Pca: Availability Of Information

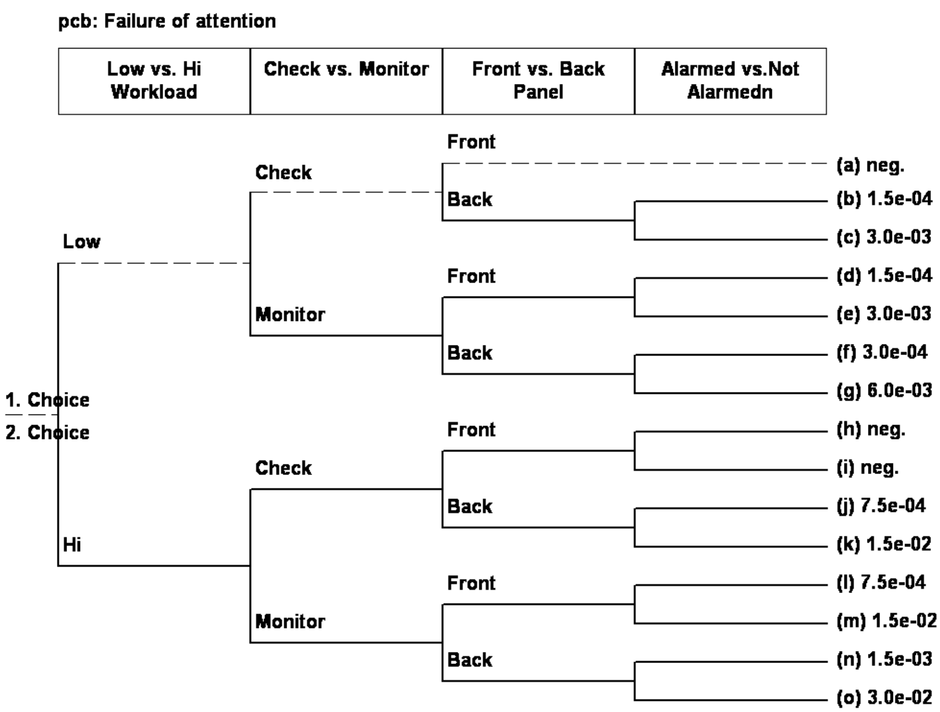

Fig. A-2. Decision Pcb Failure of Attention

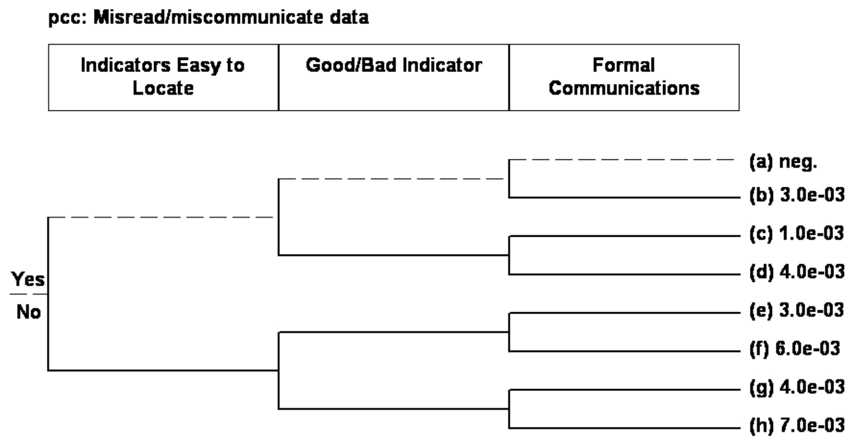

Fig. A-3. Decision Tree Pcc Misread/miscommunicate data

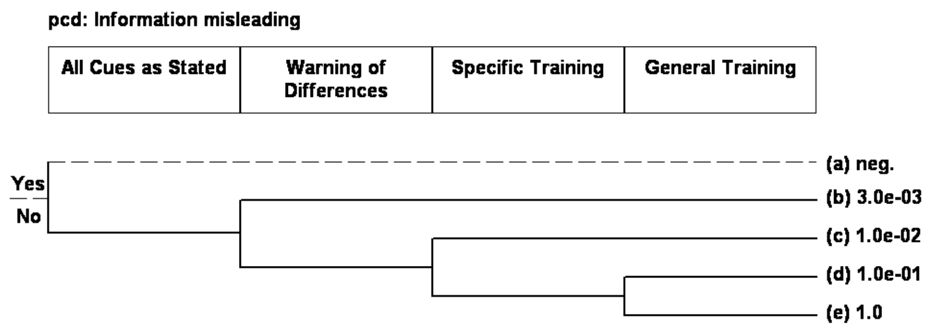

Fig. A-4. Decision Tree Pcd Information Misleading

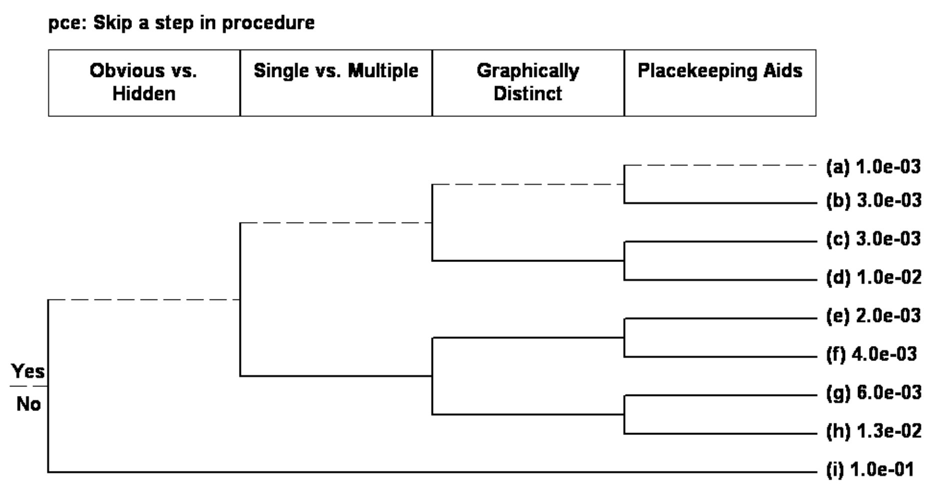

Fig. A-5. Decision Tree Pce Skip a Step in Procedure

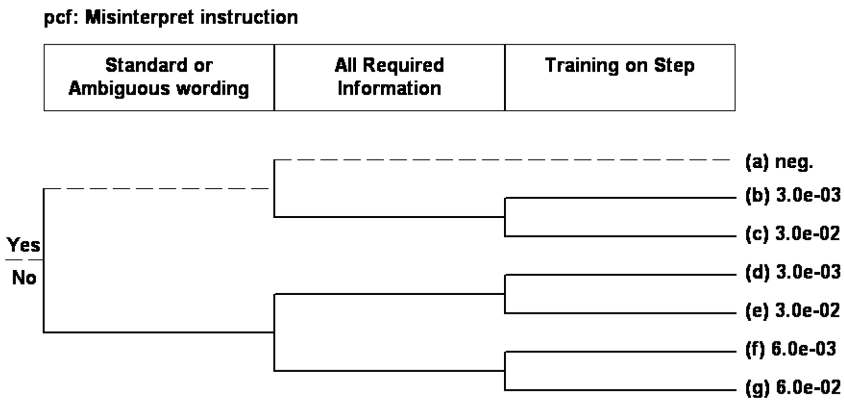

Fig. A-6. Decision Tree Pcf Misinterpret Instruction

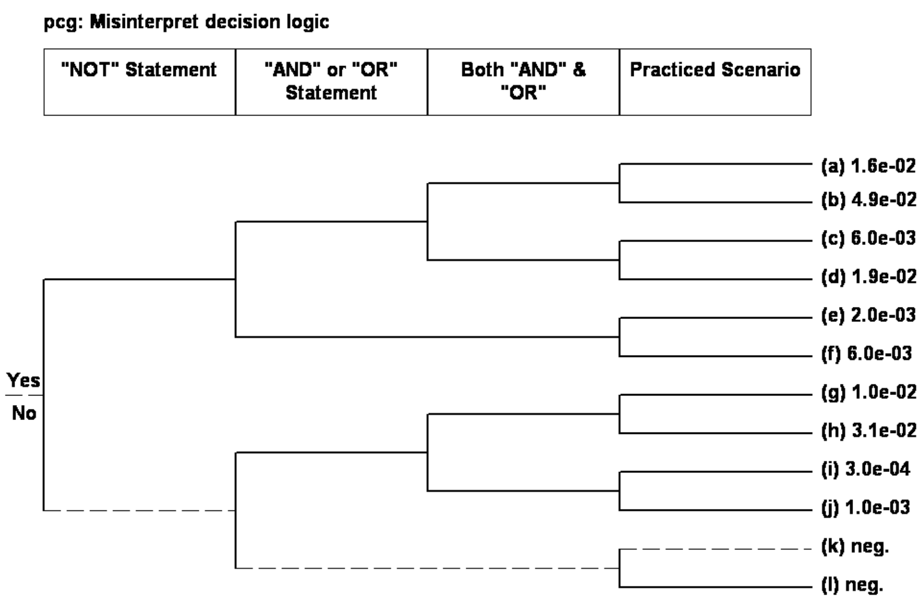

Fig. A-7. Decision Tree Pcg Misinterpret Decision Logic

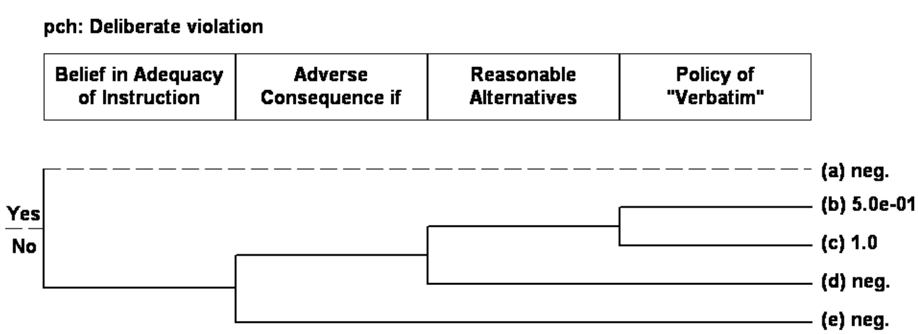

Fig. A-8. Decision Tree Pch Decision Tree Pch Deliberate Violation

TABLE A-I

Sample Calculation Cognitive Unrecovered

Pc Failure Mechanism	**Branch**	**HEP**
Pc_a: Availability of Information	a	neg.
Pc_b: Failure of Attention	a	neg.
Pc_c: Misread/miscommunicate data	a	neg.
Pc_d: Information misleading	a	neg.
Pc_e: Skip a step in procedure	a	1.0e-03
Pc_f: Misinterpret instruction	a	neg.
Pc_g: Misinterpret decision logic	k	neg.
Pc_h: Deliberate violation	a	neg.
Sum of Pc_a through Pc_h = Initial Pc =		1.0e-03

TABLE A-II:

Sample Calculation for Cognitive Recovery

	Initial HEP	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review	Recovery Matrix	DF	Multiply HEP By	Final Value
Pc_a:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_b:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_c:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_d:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_e:	1.0e-03	X	-	-	-	-	1.0e-01	HD	5.0e-01	5.0e-04
Pc_f:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_g:	neg.	-	-	-	-	-	NC	-	1.0	
Pc_h:	neg.	-	-	-	-	-	NC	-	1.0	
Sum of Pc_a through Pc_h = Initial Pc =										5.0 e-4

DF-Dependency Factor
HD –High Dependency
NC- No Credit

APPENDIX B

PILOT SURVEY

PILOT SURVEY FOR THE EVALUATION OF ENGINEERING JUDGMENT APPLIED TO ANALYTICAL HUMAN RELIABILITY ANALYSIS (HRA) METHODS

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INTRODUCTION

Objective

The overall objective of this study is to better understand the subjective use of engineering judgment as applied to analytical human reliablity analysis (HRA) methods. Your responses to this two-part survey will be used to study and identify when, why, and how to apply the use of engineering judgment in HRA. The intended final results of this study will be a set of proposed guidelines on how and when it is appropriate to apply engineering judgment for modification of the results of the HRA Calculator. These guidelines will benefit the probablisitic risk assesment (PRA) industry by providing insight on understanding engineering judgment, and this knowledge can be used to produce more consistent and justifiable human error probabilities (HEP) values.

Comanche Peak Human Reliability Analysis

Comanche Peak Steam Electric Station (CPSES), has graciously provided their HRA for use in this study. CPSES is a two unit, 4 Loop Westinghouse design Pressurized Water Reactors (PWR). In 2004, CPSES updated their HRA analysis using the HRA Calculator. The HRA under consideration for this study is for their Level 1 PRA for internal events during full power operations only.

For the purpose of this study, you should assume that the analysis and data provided comes directly from CPSES. While the format of the information has been adjusted to meet the needs the study, the analysis has not been modified from what CPSES provided to the researcher.

HRA Calculator

All analyses shown in this survey were completed using the Electric Power Research Institute (EPRI) HRA Calculator. The HRA Calculator provides a standardized approach to HRA that promotes uniform methods to achieve comparable results when considering plants that are similar in design, procedures and training. The software is setup to guide the user through and HEP calculation by interactive worksheets.

The user has the ability to choose which HRA method to apply. For post-initiator, the methods available are, Caused Based Decision Tree Method (CBDTM), THERP, and ORE/HRC. For pre-initiators, the methods available are THERP and ASEP. While the HRA Calculator provides many choices for input values, the user also can add their own input values and comments for documentation if desired.

The software also creates detailed reports in a logical easy-to-follow format, making it convenient for a second analyst to understand what has been inputted into any calculations.

SURVEY PART ONE

Instructions

Below is the complete set of general HRA assumptions made by the CPSES HRA analyst during his analysis. Please identify and discuss where you would have made alternative or additional assumptions if you were performing this analysis.

General Assumptions Made Throughout Entire CPSES HRA Analysis

The following are general assumptions used in most of the HEP analysis, but in some circumstances the HRA analyst has chosen not to follow these general assumptions. These assumptions were taken directly from the CPSES Human Reliably (HRA) Notebook. Comments in [ ] have been added by the researcher for additional clarification. A * indicates that this assumption is built into or is the default value used by the HRA Calculator

1. Operators are highly skilled in performing the necessary tasks, each having more than 6 months experience and most with several years experience. In most cases, "optimum stress" is applied due to the level of experience, the nature of the event and lack of an undue challenge in performing the proceduralized tasks. Some events, however, result in a high stress situation. For example, a steam generator tube rupture (SGTR) event would in general result in a high stress situation and the nominal human error rates would be modified as appropriate. . [The HRA Calculator asks the user to choose an operator stress level. The choices available are optimum, moderate and extreme. This assumption says that the optimum stress level will be chosen as a default value. Assumption 30 gives an exception to the default value.]

2. Control room indication is provided for equipment status, with visual and audible alarm indications of equipment failures or parameter deviations. The control room indication is assumed to be available, unless affected by the initiating event.

3. Visual and audible alarms demand (or serve as prompts for) initial operator response. Some events such as Loss of Component Cooling Water and Loss of Safety Chill Water, are diagnosed within their respective Abnormal Operating Procedures. For any other abnormal plant condition resulting in a reactor trip or the need for reactor trip, the operators' activities begin with the proceduralized steps in EOP-0.0, within which diagnosis of the event is conducted. The operators are not led from the alarm indications directly to diagnosis of the event without going through the EOP-0.0 procedure.

4. It is assumed that each operator is responsible for completing specific tasks. In addition to the Control Room Supervisor (CRS), Reactor Operator (RO) and Balance of

Plant Operator (BOP) who are normally in the control room, there is a Shift Supervisor (SS) and a Shift Engineer (SE, who is also the STA) on each operating crew. The RO and BOP operators are familiar with the operations and controls in the entire control room; each is assigned one position for a shift, but can be rotated to the other position on a different shift. For non-time critical actions, where the extra crew members are not specifically assigned to other tasks, a recovery factor for the extra crew member can be credited. Credit for STA actions, generally Critical Safety Function Status Tree related, are not credited until 15 minutes after the initiating event occurs, if credit is taken.

5. Since “self checking” is a site-wide policy that has received high management attention, this is the recovery most often credited. Credit is taken for STA actions for the HRA events that need to be accomplished at a relatively long period of time after the initiating event has occurred

Time critical actions are those which take a long time to diagnose and perform relative to the length of the time window available. The time critical actions are primarily identified either through the operator interview process or via an examination of the relevant procedures, and an examination of the time windows available from thermal-hydraulic analyses (such as RELAP or MAAP) or other engineering calculations. The operator interview process ascertains the cues and steps in the procedure that the operators use to diagnose the event and the time at which this diagnosis takes place. Then, the steps judged to be critical to that particular Human Interactions (HI) are confirmed and the overall time to successfully complete these steps determined. The overall time accounts for potential delays due to additional, non-critical procedural steps that must be executed first, time required for the component to change state (e.g. to start a turbine-driven pump), and limitations that may be present due to crew manning. [Assumptions 26 and 27 gives more detail on timing] If the available time window is less than the diagnosis time plus the time required to successfully complete the action, then the action is assumed to be failed. If the available time window is longer than the diagnosis time plus the time required to successfully complete the actions, then the probability of failure is adjusted through selection of the stress factor and the allowed credit for recovery. For example, if there is a 30-minute time window and the action takes 5 minutes to diagnose and 15-20 minutes to execute, then an optimum to moderately high level of stress is taken and no credit is given for recovery. Alternately, if the time window is 1 hour, and the action is at the end of the success branches on the event tree (e.g. LOCA followed by successful injection, cooldown, and depressurization such that the time window starts several hours after the initiator), and the competition from other actions is low, then the stress is taken as optimum and credit may be given for recovery. In each case the operator actions are examined within the context of the scenario to determine the potential impact of time constraints.

6. In general, if the success of a task requires the success of “OR”ed operator actions, the

dependency modeling is applied. This assumption is based on the belief that if the operator fails the first step in a series or group of "OR"ed actions, it is more likely that he will fail subsequent steps in the group. In that regard, the nominal human error probability (HEP), multiplied by the applicable performance shaping factor (PSF), is applied to the first step; then a dependency is applied to the HEP of the first step to derive the HEP of the second and subsequent steps. Dependencies are calculated using the formulas in Table 20-17 of Reference 5.

*7. Execution errors are calculated using the THERP tables in Reference 5. Values from these tables for errors of omission are divided by three based on Swain's notes in Chapter 15 of Reference 5. These notes describe adjustments to the nominal Swain values, in particular to credit the layout of the procedures into a "response/response not obtained" format. Additional details on the application of this method are outlined in the quantification description of Section 4.3.

8. A procedure step is considered graphically distinct, as used in decision tree "e" of the cognitive error calculation (p_c–e), if it is preceded by a boxed CAUTION or NOTE or is the only step on the page.

9. The Emergency Response Facility (ERF) Review recovery factor is not applied if the operator action took place less than one hour into the sequence, or if the time available for the operator action is less than one hour. The Technical Support Center (TSC) and Operations Support Center (OSC) are typically manned within one hour of an emergency plan declaration.

10. The immediate action steps in Emergency Operating Procedures are steps performed from memory without reference to the written procedures. However, immediate action steps are reviewed after the actions are performed to ensure all required actions are taken. Recovery credit is typically not applied in this analysis of the final cognitive error (p_c) estimation even though reading the procedure serves as a check/recovery of the operator's immediate actions. This is conservatively held as a potential future recovery.

11. There are a few instances where the EPRI Cause Based Decision Tree Methodology (CBDTM) may be inappropriate for estimating the cognitive human error probability (p_c). Operator response to events indicated by a Main Control Board alarm(s) rather than a reactor trip are often skill-based in nature and do not require a decision or diagnosis. Initial operator guidance is typically provided in the appropriate Alarm Response Procedure(s), rather than in the Emergency Operating Procedures. For this type case, p_c is validated by comparison to the THERP Annunciator Response Model (Table 20-23 of Reference 5).

12. The Emergency Operating Procedures are written in a columnar “response/response not obtained” format. They incorporate checkoffs and have provisions for place keeping. Use of both of these aids is practiced during operator training on the simulator. These assumptions are important to the EPRI CBDTM assessment of procedure usage performance shaping factors.

13. For Control Room actions, only proceduralized recoveries are credited.

14. The application of recovery is included when it is judged that there is enough time for re-visitation, based on the sequence timing and time available for the operator action provided in the PRA Accident Sequences and Success Criteria analyses (References 2 and 7-9). See assumption #20 for additional details on the impact of timing on dependencies.

15. In applying recovery, moderate dependence is usually assumed when the instruction that provides the recovery mechanism for an action is on the same page of the procedure as the instructions to perform the action, the rationale being that one way to miss a procedural step is to skip a page. The equation for conditional probability for moderate dependence from THERP Table 20-17 (Reference 5) is used.

16. If the recovery instruction is on a different procedural page, the recovery factor used is usually the Error of Omission (EOM) (from Table 20-7 of Reference 5) for the procedure step.

17. In determining the EOM p_e values, if the operator action takes place within ten procedural steps from the start of the accident sequence, Item 20-7(1) [short list, with checkoff provisions] from THERP is used. If the operator action takes place > 10 steps into the sequence, Item 20-7(2) [long list, with checkoff provisions] is used. Items 20-7(3) and 20-7(4) [no checkoff provisions] are usually used when the procedure is not an Emergency Operating Procedure.

18. Table 20-13 from THERP is for local manual valve operation. This table is also applied to operation of other local components such as switchgear breakers and room doors.

19. Application of stress factors in quantifying human error probabilities tends to be quite subjective, and can vary considerably between analyses and analysts. For the CPSES HRA, stress is considered objectively in the following manner:

    a. Stress is implicitly included in the EPRI TR-100259 (Reference 6) determination of cognitive errors (p_c) through some of the selections in the decision trees such as workload and the recovery credit; stress is explicitly modeled in the determination of the execution errors (p_e) (Reference 5) as outlined below;

* b. Optimum stress (x1) is usually used for the p_e portion of operator actions directed by the "base" emergency procedures. In some cases, such as steam generator tube rupture, the stress level is judged to be higher and a moderately high stress (x2) is applied;

* c. For those operator actions where the operators are following instructions in the Function Restoration (FR) procedures or the Emergency Contingency Action (ECA) procedures, moderately high stress (x2) is applied to p_e to reflect the increased stress caused by the failure(s) that put the operators in those procedures; and

*d. If operator action is required as a result of subsequent equipment failure while in a FR or ECA, extremely high stress (x5) is applied to the p_e for the additional action.

20 . The dependence between elemental human error probabilities in the subtasks that
make up each p_e are handled using the dependency rules in THERP (Table 20-17 of Reference 5). For example:

If an operator action required 2 of 2 manipulations for success within one HEP calculation, p_e includes HEPs for EOC(1)+ EOC(2). [EOC - Error Of Commission] If an operator action required 1 manipulation, with 2 switches available, failure to manipulate the first switch can be recovered by operating the second switch: EOC(1) * EOC(2). Consideration must be given that EOC(2) may have a link or dependence with EOC(1) based on the time available.

A similar consideration exists for core damage sequences containing multiple operator action failure events. In this case the degree of dependence between the events representing different functions (no common elements) is determined using the following guidelines:

a. Two operator action failures separated in time by an essential successful action are regarded as independent.

***** b. The time available for most operator actions varies from minutes to hours. The degree of dependence between operator actions is varied accordingly:

Time Separation (min.)	Dependence
0 < t < 15	High
15 < t < 30	Moderate
30 < t < 60	Low
60 < t	Zero

c. Events initiated by the same cue and on parallel success paths are treated as having a common p_c element.

d. Responses to memorized IMMEDIATE ACTION steps are independent of actions taken later in the procedure. Similarly, the IMMEDIATE ACTION steps are independent if they are performed by different crew members.

e. For cases where an operator action failure significantly reduces the time window for a subsequent operator action, high dependence would be assessed on the second operator action.

f. For cases where an operator action failure guarantees failure of a subsequent operator action, complete dependence would be assessed.

21. The HRA was conducted using the Emergency Response Guidelines and Abnormal Procedures from Unit 1. Discussions with the operators indicate the procedures are close enough for Unit 2 that they can be assumed to be identical.

* 23. In the quantification of human error probabilities, a lower bound of 1E-5 was used as the minimum allowed value for single, or combinations of multiple, human interactions.

24. All post initiator Human Failure Events (HFE) in the PRA model had their Risk Achievement Worth (RAW) calculated using the PRA current model of record (Reference 45). To ensure that the risk significant HFEs were included in this recalculation, several risk significant systems had one train removed and then the HFE RAWs were calculated. The HFEs were ranked and the top 30 were recalculated using the HRA calculator. Many HFEs were based on the same calculations so they were recalculated even though they may not have been in the top 30. The list is shown in Attachment G.

25. All latent HFEs were recalculated. The latent HFE equations, section 4.4, were used as basis for the input to the HRA Calculator. The latent HFEs were recalculated with all of the pertinent information documented using the HRA Calculator. The results from the HRA calculator may not agree with the values shown with the equations since the HRA calculator analyzes the HFE in more more detail. The equations are shown for historical purposes and should not be used in the HFE analysis.

26. The default value for time required to manipulate a switch on the control board is 3 minutes. This value is used as the minimum time, even if the operator stated a shorter time in the operator interviews, required by the operator to find and manipulate the switch.

27. The default value for time required to recognize and respond to an inidication/annuciator in the control room is 5 minutes. This value is used as the minimum time even if the operator stated a shorter time in the operator interviews, required by the operator to respond to an inidication/annuciator in the control room.

*28. The value used for the dependency in the recovery of an execution error was the value determined by the HRA Calculator (i.e. zero, low, medium, and high), this is in lieu of any comments made during operator interviews.

29. The procedures in the reference section do not contain the revision number. The revision number for the procedures used will be documented on the operator interview sheets.

30. The stress level (optimal, medium, high) was determined during the operator interviews and are not annotated in each HFE detailed calculation. The stress level was based on time and actions required to complete the task. [This assumption is an exception to the default stress level chosen in assumption 1]

References Cited in Assumptions

[5] Swain, A.D and Guttmann, H.E, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, (THERP) NUREG/CR-1278, Sandia National Laboratories, August 1983.

[6] EPRI TR-100259, “An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment”, June 1992.

[45] R&R –PN-022,”Accident Sequence Quantification”

SURVEY PART TWO

Instructions

Please read the following analysis prepared by CPSES and answer the questions presented at the end.

HEP Given Information

Human Failure Event (HFE) Scenario Description

1. Initial Conditions: Steady state, full power operations
2. Initiating Event: General Transient
3. Accident sequence: Transient sequences shown below.

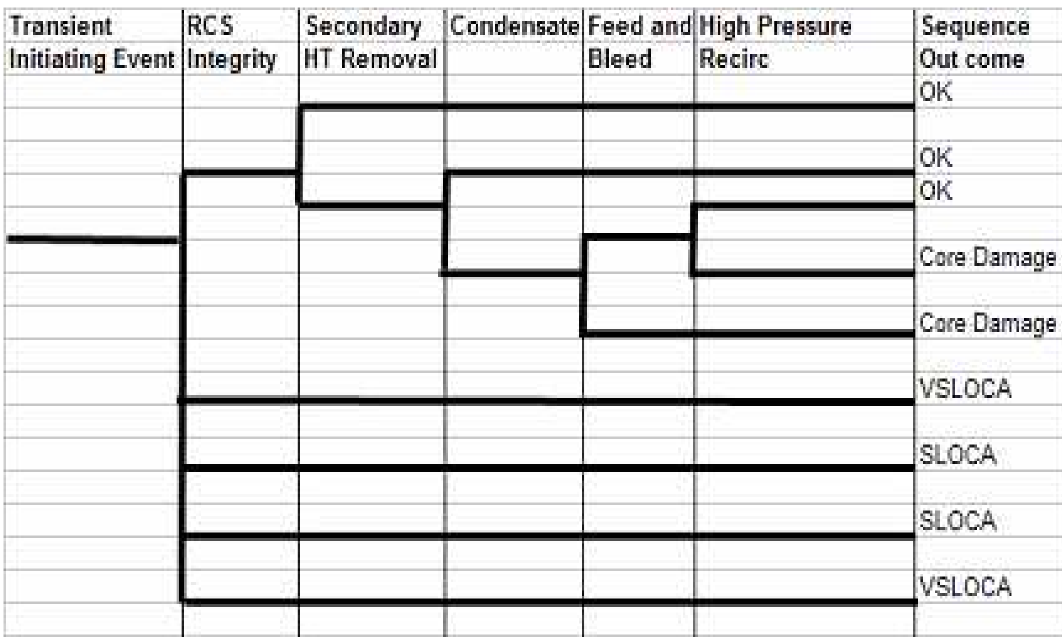

Fig. B-1. Transient Event Tree

4. Preceding operator error or success in sequence: N/A
5. Operator action success criterion: Start of Bleed and Feed
6. Consequence of failure: Core damage
7. Key assumptions: The stopping of the reactor coolant pumps, resetting SI [Safety Injection] sequencers, and resetting containment spray are non-critical actions

During the accident scenarios listed above, the operator is required to establish Feed and Bleed if a loss of auxiliary feedwater occurs. Upon the loss of all AFW, the operators are instructed by the Critical Safety Function Status Trees in the Emergency Response Guidelines to enter FRH-0.1, "Response to Loss of Secondary Heat Sink". This procedure first instructs the operator to attempt to restore secondary cooling via AFW and MFW, with condensate not questioned. If this is not possible, the procedure requires the operator to use the pressurizer PORVs to provide the bleed path from the RCS and high pressure safety injection to provide the feed to the RCS. High pressure safety injection is assumed to require initiation via generating a safety injection signal (S Signal).

All of these tasks can be accomplished from the control room and the operators are well trained on this task.

[Unlike other PWR plants 2 PORVs on the primary side are required for successful completion of this action. Opening only 1 PORV will not provide sufficient flow.]

Operator Interviews

Two operators were present in this discussion and their combined responses are shown below.

What are cues that operator would observe?
    No secondary heat sink
How much time is required for operator to see the cue and diagnose the problem?
    1-2 minute
How much time is required for control room manipulation?
    2 minute
How many times is this action trained in the classroom?
    Once every 2 years
How many time is this action trained in the simulator?
    Once every 2 years
What type of response would you classify this as?
a) Simple, intuitive, or memorized action (skilled)
b) Procedure-directed (Rule)
c) Requires a lot of diagnosis or is non-proceduralized (knowledge-based)

    The operator responded with answer B
Would you classify this action as simple or complex?
    Simple
What is the operators workload during this scenario?
    High
What is operators stress level relative to normal operations?
    High

Discussions with the operators indicate there will be no hesitation on the part of the operator to initiate bleed and feed when the procedure dictates it.

Application

These operator actions apply to the Transient initiating event category (General Transient, Inadvertent Safety Injection Actuation, Steam/Feedwater Line Break, Loss of Main Feedwater, Loss of Cooling Water (component cooling water, station service water, and safety chill water)), and Loss of various electrical buses. Each of these basic events models failure to start Primary Feed and Bleed cooling following a transient initiating event where it is conservatively assumed there is no S signal.

Procedure

The procedure used for this task is FRH-0.1, "Response to Loss of Secondary Heat Sink". FRH-0.1 is entered from the Critical Safety Function Status Tree or EOP-0.0, "Reactor Trip or Safety Injection".

Timing Information

The time available for this action (beginning state to end state) comes from the review of MAPP calculation RXE-LA-CP1/0-062. The success criteria determined in the calculation are based on the operator opening the PORVs. Based on the above T_{sw} is 1200 seconds (20 minutes).

Cue

At least 3 Steam Generators less than 27%

or

Pressurizer pressure greater than 2335 psig due to loss of secondary heat sink

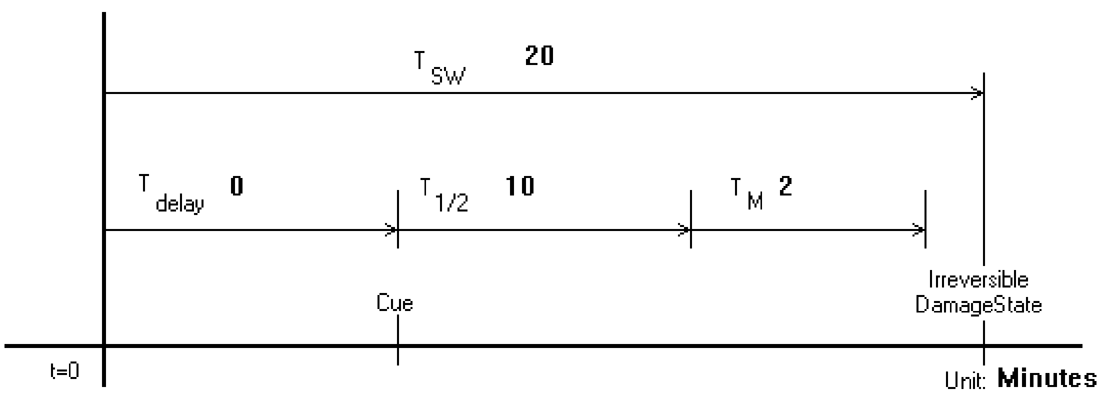

Fig. B-2. Feed and Bleed Timing Information

The above terms are defined as follows:

Reference (Start) Time (T_0)- The starting point of an HRA timeline. This is defined at the time at which the initiating event begins.

System Time Window (Tsw) - Time available for action before an undesired end state is reached

Manipulation Time (T_M) - The time required to complete the execution portion of a human interaction

Delay Time (T_{delay}) - The time from T_o until the cue is reached.

Median Response Time ($T_{1/2}$) – The time available to diagnose the problem.

Miscellaneous Information Provided By CPSES HRA Analyst

The HRA Calculator asks the analyst for the following environmental conditions for documentation purposes. However, the results are not used in the mathematical computation of the HEP.

Degree of Clarity of Cues & Indications:

X - Very Good
- Average
- Poor

Human-Machine Interface:

X - Control Room Panels
- Local Control Panels
- Local Equipment

Environment:

Lighting		**Heat/Humidity**	
X	Normal	**X**	Normal
	Emergency		Hot / Humid
	Portable		Cold

Radiation		**Atmosphere**	
X	Background	**X**	Normal
	Green		Steam
	Yellow		Smoke
	Red		Respirator required

Equipment Accessibility:

	Location	**Accessibility**
X	**Control Room Front Panels**	Accessible
	Control Room Back Panels	
	Hot Shutdown Panels	

HEP Calculation

Method Approach

HRA Calculator using Caused Based Methodology

Critical Actions

1. Diagnose the need for Feed and Bleed
2. Actuate injection via an S signal
3. Reset the Safety Injection and Containment Isolation Signals, and open the air supply
4. Open the 2/2 PORVs.

Calculation Of Pc

Dotted lines shows chosen path.

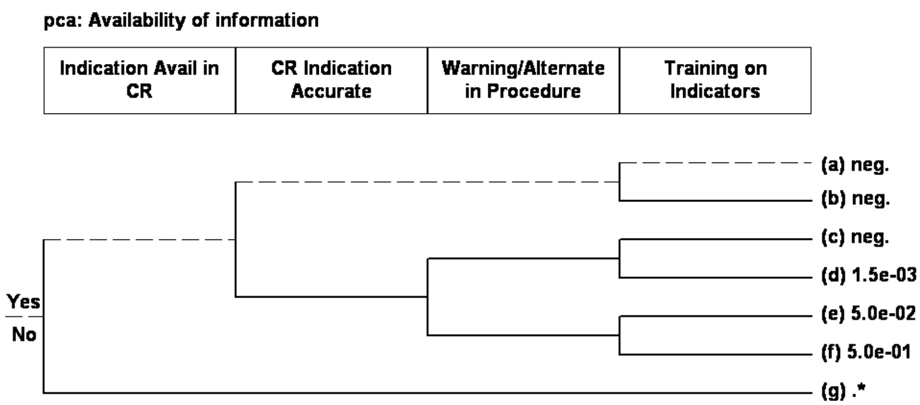

Fig. B-3. Pca: Availability of Information

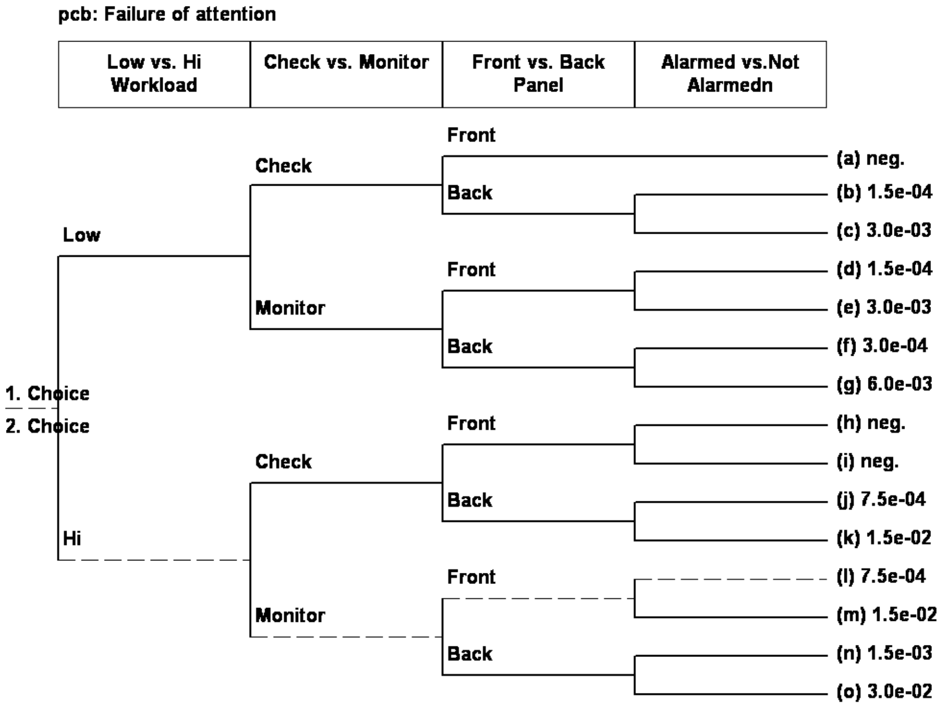

Fig. B-4. Pcb: Failure of Attention

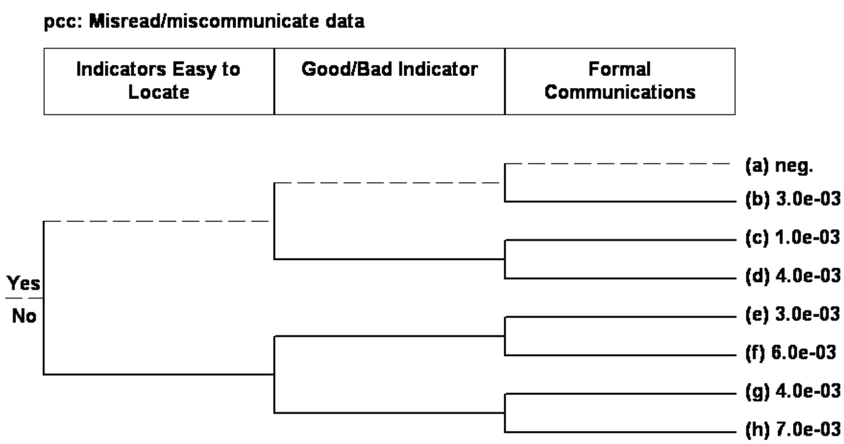

Fig. B-5. Pcc: Misread/miscommunicate Data

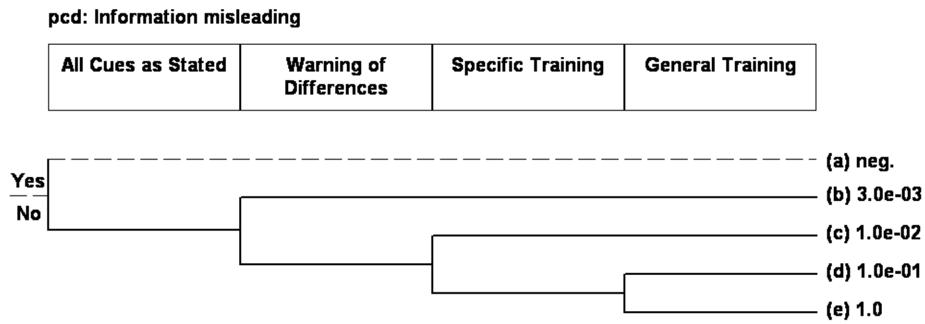

Fig. B-6. Pcd: Information Misleading

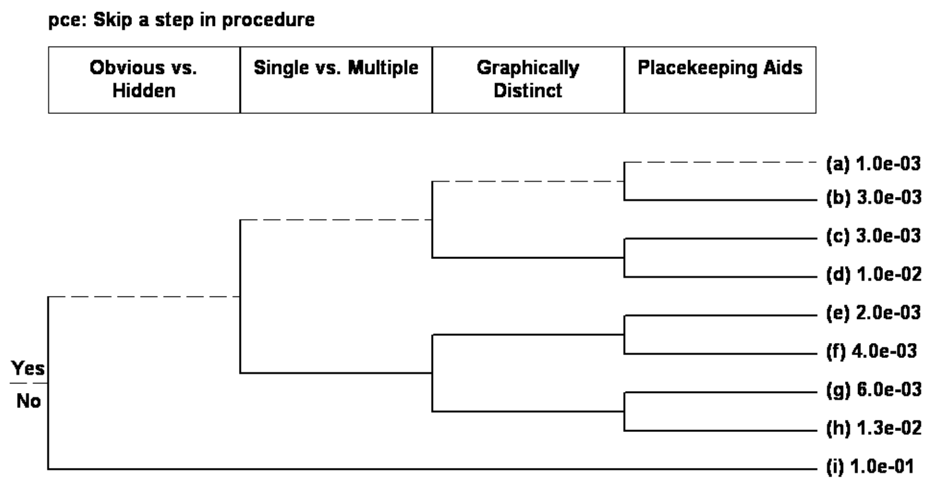

Fig. B-7. Pce: Skip a Step In Procedure

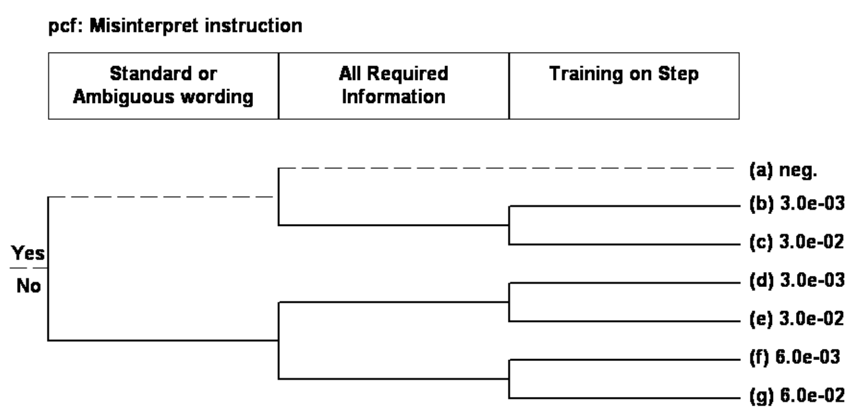

Fig. B-8. Pcf: Misinterpret Instruction

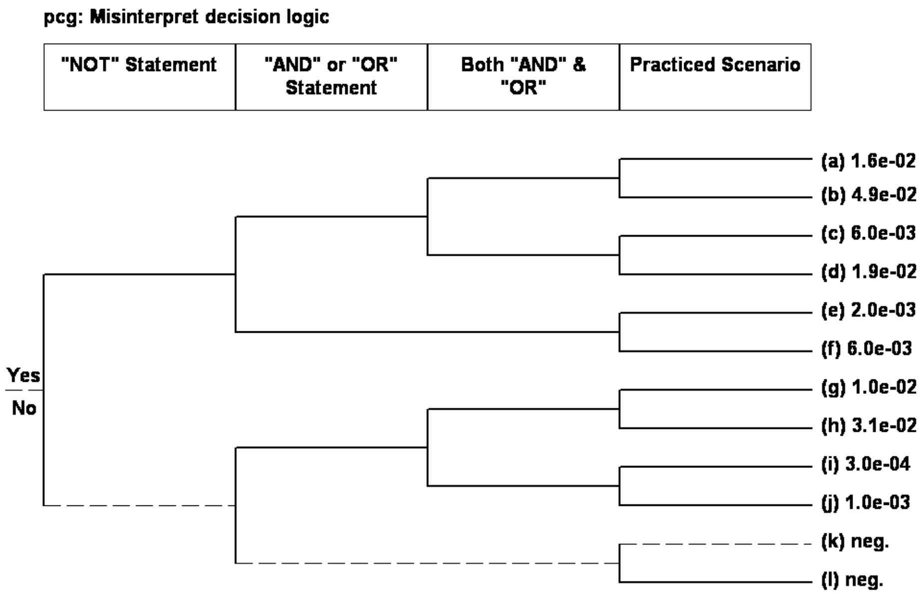

Fig. B-9. Pcg: Misinterpret Decision Logic

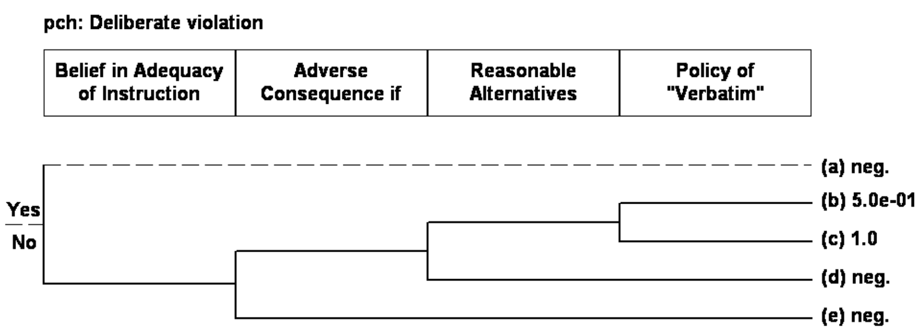

Fig. B-10. Pch: Deliberate Violation

TABLE B-I

Summary of Event Tress and Unrecovered Pc Calculation

Pc Failure Mechanism	**Branch**	**HEP**
Pc_a: Availability of Information	a	neg.
Pc_b: Failure of Attention	l	7.5e-04
Pc_c: Misread/miscommunicate data	a	neg.
Pc_d: Information misleading	a	neg.
Pc_e: Skip a step in procedure	a	1.0e-03
Pc_f: Misinterpret instruction	a	neg.
Pc_g: Misinterpret decision logic	k	neg.
Pc_h: Deliberate violation	a	neg.
Sum of Pc_a through Pc_h = Initial Pc =		1.8e-03

TABLE B-II

Cognitive Recovery

	Initial HEP	Self-Review	Extra	Recovery Matrix	DF	Multiply HEP By	Final Value
Pc_a:	neg.	-	-		-	1.0	
Pc_b:	7.5e-04	X	-	1.4e-01	MD	1.4e-01	1.0e-04
Pc_c:	neg.	-	-		-	1.0	
Pc_d:	neg.	-	-		-	1.0	
Pc_e:	1.0e-03	X	X	1.0e-01 * 5.0E-1	ND –self review MD- Extra crew	5e-02	5.0e-05
Pc_f:	neg.	-	-		-	1.0	
Pc_g:	neg.	-	-		-	1.0	
Pc_h:	neg.	-	-		-	1.0	
Sum of Pc_a through Pc_h = Initial Pc =1.5e-04							

No credit was taken for STA Review, Shift Change and ERF Review.

DF = Dependence Factor
ND= No dependence
MD =Medium Dependence

TABLE B-III

Execution Unrecovered Calculated Using THERP

Step	Omission				
		Table	Item	Stress	Stress
Step No.	HEP	Ref.	Ref.	E/M/O	Value
11	1.3E-3	20-7b	2	E	5
Actions: Actuate SI					
12	1.3E-3	20-7b	2	M	2
Actions: Verify RCS feed					
14	1.3E-3	20-7b	2	M	2
Actions: Reset both trains of SI					
16	1.3E-3	20-7b	2	M	2
Actions: Reset Containment Spray Isolation phase A and B					
17	1.3E-3	20-7b	2	E	5
Actions: Reset Containment Spray Signal					
18	1.3E-3	20-7b	2	M	2
Actions: Establish N2 and Instrument Air					
19	1.3E-3	20-7b	2	E	5
Actions: Open 2/2 PORVs and Block Valves to establish bleed path					
20	1.3E-3	20-7b	2	M	2
Actions: Verify bleed path					

TABLEB-III Continued

	Commission				Total
	Table	Item	Stress	Stress	Per
	Ref.	Ref.	E/M/O	Value	Step
	20-12	8a	E	5	7.8e-03
	Comments:				
	20-12	3	M	2	5.2e-03
	Comments: Recovers step 11 with medium dependency				
	20-12	8a	M	2	3.1e-03
	Comments:				
	20-12	8a	M	2	3.1e-03
	Comments: Completed with step 14 therefore it is zeroed out				
	20-12	8a	E	5	7.8e-03
	Comments:				
	20-12	3	M	2	5.2e-03
	Comments:				
	20-12	3	E	5	1.3e-02
	Comments:				
	20-12	3	M	2	5.2e-03
	Comments: Recovers step 19 with medium dependency				

The tables referenced are those given in the THERP handbook. The HRA calculator has some of the tables built into the software with some assumptions built in. These tables are attached at the end for reference.

Discussions with the operators indicate there will be no hesitation on the part of the operator to initiate bleed and feed when the procedure dictates it. For these scenarios, there is assumed to be both high stress and a high workload.

E- Extreme Stress – PSF = 5
M- Moderate Stress – PSF = 2
O-Optimum Stress – PSF = 1

TABLE B-IV

Execution Recovery Calculated Using THERP

Critical Step No.	Recovery Step No.	Action	HEP (Crit)
11		**Actuate SI**	**7.8e-03**
	12	Verify RCS feed	
14		**Reset both trains of SI**	**3.1e-03**
	16	Reset Containment Spray Isolation phase A and B	
	18	Establish N2 and Instrument Air	
19		**Open 2/2 PORVs and Block Valves to establish bleed path**	**1.3e-02**
	20	Verify bleed path	
17		**Reset Containment Spray Signal**	**7.8e-03**
		Total Unrecovered:	**3.2e-02**

TABLE B-IV Continued

HEP (Rec)	Dep.	Cond. HEP (Rec)	Total for Step
			3.9e-03
5.2e-03	HD	5.0e-01	
			7.8e-04
3.1e-03	HD	5.0e-01	
5.2e-03	HD	5.0e-01	
			6.5e-03
5.2e-03	HD	5.0e-01	
			7.8e-03
Total Recovered:			**1.9e-02**

TABLE B-V

Summary of Calculation

Analysis Results:	**without Recovery**	**with Recovery**
$\mathbf{P_{cog}}$	1.8e-03	1.5e-04
$\mathbf{P_{exe}}$	3.2e-02	1.9e-02
Total HEP		1.9e-02

<u>Survey Questions</u>

Instructions

Please answer the following questions with either yes or no responses or a brief text response to the question.

1) When completing and HRA analysis do you or your company follow a set of guidelines? If possible, please provide a copy of these guidelines when submitting your responses.

2) If possible, without doing an independent calculation, what would you expect a typical HEP value for this Human Failure Event (HFE)? Based on your intuition do you agree with the model HEP value?

Assumptions (Part Two portion only)

3) Are there assumptions within this specific HFE that you feel are invalid or lacking justification?

4) If asked to complete this HFE analysis independently, would you have chosen to make the same assumptions? Please note your different assumptions and your justifications for making theses.

Choice of Methodology

5a) The methodology chosen for this analysis was Caused Based Methodology. In your opinion, is this the best methodology for this HFE? Other methods available are: HCR/ORE/THERP and THERP.

5b) If you would choose to use a different methodology, what is your reasoning for this?

Critical Actions

6) Do you agree with the critical steps assigned to this HFE?

7) Would you add or subtract any of these steps?

Calculation of Pc

8) The values for the branches of the trees were taken directly from THERP. Do you agree with the choices made in the decision trees and the values assigned to them?

9) CMPSES has a site policy of self checking. Is this enough justification for ALWAYS taking credit for self checking?

Calculation of P_E

10) Do you agree with the choices of THERP values for errors of omission and errors of commission? If you disagree, then why and what value would you use?

11) Do you agree with the stress values and how the stress performance shaping factors are applied?

Acceptability of final HEP results
12a) How would you determine if this HEP value is acceptable in terms of meeting the needs of the PRA model?

12b) What additional information would be needed?

12c) What other people, would need to be included in this discussion?

13a) Can you determine if the HEP is consistent with historical values and/or similar to other NPPs values?

13b) If this value were inconsistent with the historical value, would you question and change this analysis in any way?

14) Do you have any prior knowledge of how a crew may actually behaves during this action (or similar ones)? Is the HFE adequately represented to reflect how the crew actually behaves?

APPENDIX C

PHASE II SURVEY

PHASE II SURVEY FOR THE EVALUATION OF ENGINEERING JUDGMENT APPLIED TO ANALYTICAL HUMAN RELIABILITY ANALYSIS (HRA) METHODS

March 2005

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INTRODUCTION

Objective

The overall objective of this study is to understand better the subjective use of engineering judgment as applied to analytical human reliablity analysis (HRA) methods. This Phase II Questionaire is produced in response to the results and findings from the Phase I Pilot Survey. The Phase I Survey showed that there was very little agreement between HRA experts on the questions asked. The responses to the Phase I Survey were so specific to the example that it was difficult to make general conclusions. Consequently for this survey, more general questions have been asked.

The Phase I Survey also indicated that many respondents were not familar enough with the method used in the pilot survey to answer many of the questions. This questionaire is divided into sections that are specific to different methods. The respondents need to answer only the questions about the methodology which he is are familiar. It is intended and expected that very few participants will answer all the questions.

Comanche Peak Human Reliability Analysis

As in the Phase I Survey, the Comanche Peak Steam Electric Stations HRA [1] will be used as an example. However, in this survey some modifications have been made from the original analysis in order to meet the needs of the study. Since the CPSES analysis was completed using only the Caused Based Deterministic Method (CBDTM), all calculations using different methods were done by the researcher with input from a CPSES HRA analysis. Therefore, the HEP calculations shown in this survey are similar but not identical to what CPSES actually uses in the PRA model.

CPSES has two 4-Loop Westinghouse design Pressurized Water Reactors (PWR). In 2004, CPSES updated its HRA analysis using the HRA Calculator. The HRA under consideration for this study is for Level 1 PRA for internal events during full power operations only.

Overview of HRA Calculator

All analyses shown in this survey were completed using the Electric Power Research Institute (EPRI) HRA Calculator [2]. The HRA Calculator provides a standardized approach to HRA that promotes uniform methods to achieve comparable results when considering plants that are similar in design, procedures and training. The software is setup to guide the user through HEP calculation by interactive worksheets.

The user has the ability to choose which HRA method to apply. For post-initiator, the methods available are (1) Caused Based Decision Tree Method (CBDTM) [3], (2) THERP [4], and (3) ORE/HRC [5]. For pre-initiators, the methods available are THERP and ASEP. However, this survey is concerned only with post-initiator actions. While the

HRA Calculator provides many choices for input values, the user also can add his/her own input values and comments for documentation if desired.

The HRA Calculator breaks every HEP calculation into two parts: (1) failure to execute the action correctly (P_{exe}) and (2) failure to recognize the need for human intervention to determine the correct action to take (P_{cog}). **P_{exe} is calculated using THERP regardless of the method chosen by the user.** Each critical action is assigned an error of omission and an error of commission, and each critical action is adjusted by a stress Performance Shaping Factor (PSF). The user can then apply recoveries and dependencies to P_{exe}.

P_{cog} is where the numerical variation in HEP calculations occurs within the HRA Calculator between different methods. The CBDTM method calculates P_{cog} by the use of a series of decision trees and then applies recovery by the identification of time available for recovery and the use of additional personal present in the control room. Examples of the decisions trees and recoveries will be shown in latter examples.

The THERP approach to P_{cog} is a simpler approach compared to CBDTM. This approach selects P_{cog} from a table of failure probabilities based on the number of annunciator present in the control room. THERP has defined an annunciator as a set of alarms that trained operators regard as a single unit. Table C-I below gives the tabulated values for the choices of P_{cog} using the annunciator response model.

TABLE C- I
Tabulated P_{cog} Values using Annunciator Response Model

# of ANNs	1	2	3	4	5	6	7	8	9	10	Pr[Fj]	EF	Mean
1	0.0001										0.0001	10	0.0003
2	0.0001	0.001									0.0006	10	0.0015
3	0.0001	0.001	0.002								0.001	10	0.003
4	0.0001	0.001	0.002	0.004							0.002	10	0.005
5	0.0001	0.001	0.002	0.004	0.008						0.003	10	0.008
6	0.0001	0.001	0.002	0.004	0.008	0.016					0.005	10	0.014
7	0.0001	0.001	0.002	0.004	0.008	0.016	0.032				0.009	10	0.024
8	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064			0.02	10	0.04
9	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13		0.03	10	0.08
10	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13	0.25	0.05	10	0.14
11 to 15	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13	0.25	0.12	10	0.31
16 to 20	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13	0.25	0.15	10	0.40
21 to 40	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13	0.25	0.20	10	0.53
> 40	0.0001	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.13	0.25	0.25	10	0.67

The third method available for calculating P_{cog} is the HCR/ORE [4] correlation. This method uses the following correlation derived from simulator data to calculate P_{cog}.

$$P_{cog} = 1 - \Phi\left[\frac{\ln\left(\frac{T_w}{T_{1/2}}\right)}{\sigma}\right] \quad [1]$$

σ = logarithmic standard deviation

Φ = standard normal cumulative distribution - $\frac{1}{\sqrt{2z}}\int_{-\infty}^{z} e^{-\frac{u^2}{2}}\,du$

T_w = time window for cognitive response

$T_{1/2}$ = crew median response time

The HRA calculator [1] calculates σ using decision trees based on procedures, operator training and stress level. For the actions used in this project, the CPSES analyst considered all the actions to be proceduraized and well-trained. An example of the decision tree used to calculate σ is shown below.

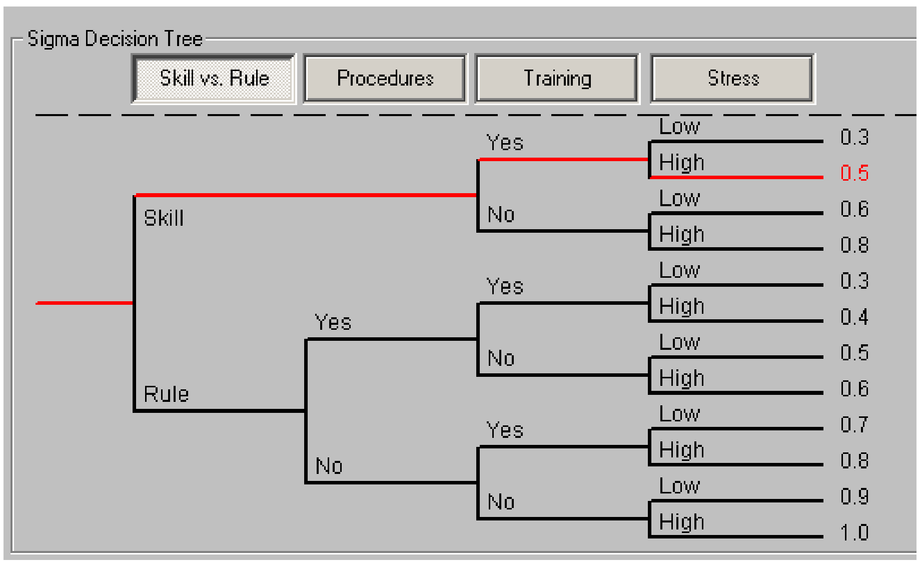


Fig. C-1. Decision Tree Used for Determining Sigma using HCR/ORE

INSTRUCTIONS

Please provide short answer responses to the questions in each section. Only complete the sections with which you are familiar. Very few people will have the background to provide responses to every section. Please consider each question as it would pertain to a Level 1 PRA for internal events during full power operations only.

GENERAL HRA JUDGMENTS

Notes: 1) The questions pertain to post-initiator control room actions only.
2) A color printer is needed to see Figures 6 and 13 in hard copy.

Complexity of Actions

1) How do you judge whether an action is Rule-based, Skill-based or Knowledge based?

2) Do you use this type of designation in your HEP calculations? If so, how is this information used?

3) To what extend do you think the designation between Rule-based, Skill-based, or Knowledge-based actions influences your HEP calculations?

    a. Not at all
    b. Very little
    c. Somewhat
    d. Are a dominating factor

4) Do you think your answer in 3 is different for different methodologies? If so how?

Stress Level

5) How do you determine stress level for an action?

6) Suppose during operator interviews that the operators conclude that the action is low stress but you believe the action is high stress, how do you determine a stress level?

7) To what extend do you think the Stress level choice influences your HEP calculations?

    e. Not at all
    f. Very little
    g. Somewhat
    h. Are a dominating factor

8) Do you think your answer in 7 is different for different methodologies? If so how?

9) When calculating P_{exe} (using the HRA Calculator) is it better to maintain a constant stress level for all critical actions or vary the stress level between actions? Table C- II and C-III show both scenarios for the Feed and Bleed Action used in the Phase I Survey.

TABLE C-II a and C-II b
Pexe Calculated for Feed and Bleed Using Different Stress Levels For Different Critical Actions

Step	Omission				
		Table	Item	Stress	Stress
Step No.	HEP	Ref.	Ref.	E/M/O	Value
11	1.3E-3	20-7b	2	E	5
Actions: Actuate SI					
12	1.3E-3	20-7b	2	M	2
Actions: Verify RCS feed					
14	1.3E-3	20-7b	2	M	2
Actions: Reset both trains of SI					
16	1.3E-3	20-7b	2	M	2
Actions: Reset Containment Spray Isolation phase A and B					
17	1.3E-3	20-7b	2	E	5
Actions: Reset Containment Spray Signal					
18	1.3E-3	20-7b	2	M	2
Actions: Establish N2 and Instrument Air					
19	1.3E-3	20-7b	2	E	5
Actions: Open 2/2 PORVs and Block Valves to establish bleed path					
20	1.3E-3	20-7b	2	M	2
Actions: Verify bleed path					

Commission				
	Table	Item	Stress	Stress
HEP	Ref.	Ref.	E/M/O	Value
2.7E-4	20-12	8a	E	5
1.3E-3	20-12	3	M	2
Comments: Recovers step 11 with medium dependency				
2.7E-4	20-12	8a	M	2
2.7E-4	20-12	8a	M	2
Comments: Completed with step 14 therefore it is zeroed out				
2.7E-4	20-12	8a	E	5
1.3E-3	20-12	3	M	2
1.3E-3	20-12	3	E	5
1.3E-3	20-12	3	M	2
Comments: Recovers step 19 with medium dependency				

E- Extreme Stress – PSF = 5
M- Moderate Stress – PSF = 2
O-Optimum Stress – PSF = 1

Table C-III a and C-III b
Pexe Calculated for Feed and Bleed Using the Same Stress Level For All Critical Actions

Step	Omission				
		Table	Item	Stress	Stress
Step No.	HEP	Ref.	Ref.	E/M/O	Value
11	1.3E-3	20-7b	2	E	5
Actions: Actuate SI					
12	1.3E-3	20-7b	2	E	5
Actions: Verify RCS feed					
14	1.3E-3	20-7b	2	E	5
Actions: Reset both trains of SI					
16	1.3E-3	20-7b	2	E	5
Actions: Reset Containment Spray Isolation phase A and B					
17	1.3E-3	20-7b	2	E	5
Actions: Reset Containment Spray Signal					
18	1.3E-3	20-7b	2	E	5
Actions: Establish N2 and Instrument Air					
19	1.3E-3	20-7b	2	E	5
Actions: Open 2/2 PORVs and Block Valves to establish bleed path					
20	1.3E-3	20-7b	2	E	5
Actions: Verify bleed path					

Commission				
	Table	Item	Stress	Stress
HEP	Ref.	Ref.	E/M/O	Value
2.7E-4	20-12	8a	E	5
1.3E-3	20-12	3	E	5
Comments: Recovers step 11 with medium dependency				
2.7E-4	20-12	8a	E	5
2.7E-4	20-12	8a	E	5
Comments: Completed with step 14 therefore it is zeroed out				
2.7E-4	20-12	8a	E	5
1.3E-3	20-12	3	E	5
1.3E-3	20-12	3	E	5
1.3E-3	20-12	3	E	5
Comments: Recovers step 19 with medium dependency				

E- Extreme Stress – PSF = 5
M- Moderate Stress – PSF = 2
O-Optimum Stress – PSF = 1

Training

10) Do you differentiate between simulator training vs. classroom training in HEP calculations? If so, how is this used in your calculations?

11) For the CPSES analysis, the HRA analyst has determined that every action in the database is WELL trained. Do you consider all training to be equally weighted in HEP calculations? Do you have a consistent system for distinguishing between well trained and poorly trained action?

12) To what extend do you think training influences your HEP calculations?

    i. Not at all
    j. Very little
    k. Somewhat
    l. Is dominating factor

13) Do you think your answer in 12 is different for different methodologies? If so how?

Timing

The HRA Calculator uses Fig. C- 2 to show timing aspects of an HEP calculation. The user is required to identify all timing portions regardless of the method used to calculate P_{cog}.

Reference (Start) Time (T_0)- The starting point of an HRA timeline. This is defined at the time at which the initiating event begins.

System Time Window (Tsw) - Time available for action before an undesired end state is reached.

Manipulation Time (T_M) - The time required to complete the execution portion of a human interaction

Delay Time (T_{delay}) - The time from T_o until the cue is reached.

Median Response Time ($T_{1/2}$) – The time available to diagnose the problem.

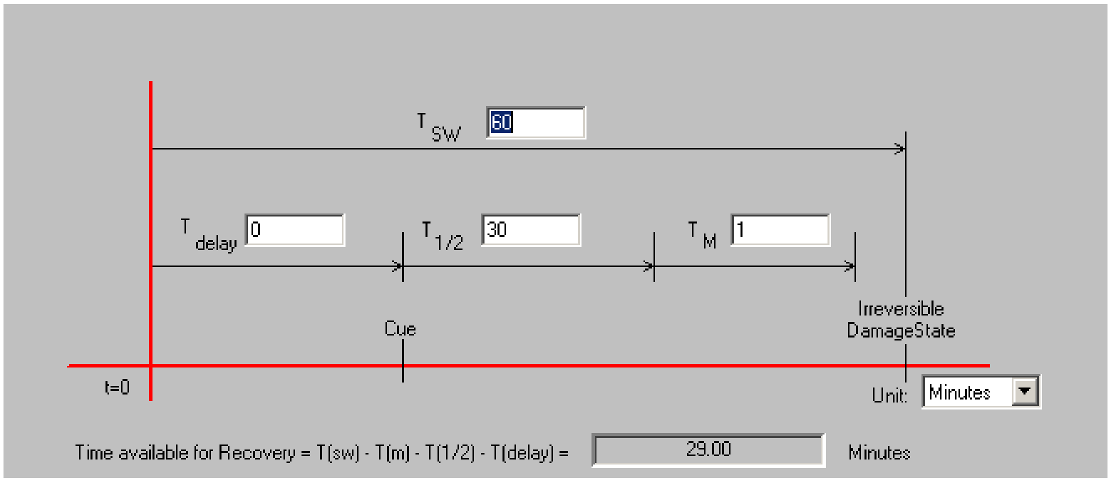


Fig. C-2. Timing Diagram used by HRA Calculator

14) How would you calculate/determine T_{sw}?

15) How would you calculate/determine T_M?

16) How would you calculation/determine $T_{1/2}$?

17) Do you believe that it is necessary to document all of the above timing information even if the method you are using for your HEP calculation does not require this information? For example, the CBDTM method only requires the analyst to determine if there is enough time available to complete the action, or the Annunciator Response Model is independent of timing.

18) Is your decision about how to collect timing affected by your choice of methodology?

<u>THERP Tabulated Values</u>

The CPSES analyst has interpreted Table 20-7 of the THERP Handbook as follows:
In determining the EOM p_{exe} values, if the operator action takes place within ten procedural steps from the start of the accident sequence, Item 20-7(1) [short list, with checkoff provisions] from THERP is used. If the operator action takes place > 10 steps into the sequence, Item 20-7(2) [long list, with checkoff provisions] is used. Items 20-7(3) and 20-7(4) [no checkoff provisions] are usually used when the procedure is not an Emergency Operating Procedure.

19) Is this how you would use Table 20-7 for errors of omission? Ie. How do you use Table 20-7 in your HEP calculations?

20) Other than THERP Table 20-7, are there any other THERP Tables you use for Errors of Omission on a regular basis? Under what circumstances do you use the other tables?

21) Besides THERP Table 20-12, what other THERP Tables do you use for Errors of Commission for control room actions (excluding recovery actions.)? Under what circumstances do you use the other tables?

22) Under what circumstances do you use data sources other than the tabulated THERP values for Errors of Omission and Errors of Commission?

23) Fig. C-3 is a page from EOP 0.0. and Step 6a has been identified as a critical action. Can you determine an Error of Omission and an Error of Commission only using procedures? If not, what other information is need?

24) Using the THERP tables, what values of Error of Commission and Error of Omission would you assign to this Step 6a of Fig. C-3? What table numbers did you use in your decisions? Discuss any assumptions that you made in your choices of failure probabilities.

CPSES EMERGENCY RESPONSE GUIDELINES	UNIT 1	PROCEDURE NO. EOP-0.0A
REACTOR TRIP OR SAFETY INJECTION	REVISION NO. 7	PAGE 7 OF 97

STEP	ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED
6	Verify AFW Alignment:	
	a. MDAFW Pumps - RUNNING	a. Manually start pump(s).
	b. Turbine Driven AFW Pump - RUNNING IF NECESSARY	b. Manually open steam supply valve(s).
	c. AFW total flow - GREATER THAN 460 GPM	c. Check narrow range levels and perform the following: <u>IF</u> narrow range level greater than 5%(26% FOR ADVERSE CONTAINMENT) in any SG, <u>THEN</u> control feed flow to maintain narrow range level between 5%(26% FOR ADVERSE CONTAINMENT) and 50% <u>AND</u> go to Step 6d. <u>IF</u> narrow range level less than 5%(26% FOR ADVERSE CONTAINMENT) in all SGs. <u>THEN</u> manually start pumps and align valves as necessary.
	d. AFW valves alignment - PROPER ALIGNMENT	d. Manually align valves as necessary.

Fig. C- 3. Sample Page From EOP 0.0. Use for Question 23 and 24

25) In Fig. C-4 below Step 3a has been identified as a critical action. What THERP tables and values for Errors of Commission and Errors of Omission would you assign this action? Discuss any assumptions that you made in your choices of failure probabilities. (Do you believe there is enough information provided to answer this question?)

CPSES EMERGENCY RESPONSE GUIDELINES	UNIT 1	PROCEDURE NO. EOP-0.0A
REACTOR TRIP OR SAFETY INJECTION	REVISION NO. 7	PAGE 4 OF 97

STEP	ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED
2	Verify Turbine Trip:	
	a. All turbine stop valves - CLOSED	a. Manually trip turbine. <u>IF</u> the turbine will <u>NOT</u> trip, <u>THEN</u> either: • Pull-out the EHC pumps -OR- • Trip the turbine via the Local Trip Valve (830' Turbine Deck).
3	Verify Power To AC Safeguards Busses:	
	a. AC safeguards busses - AT LEAST ONE ENERGIZED • AC safeguards bus voltage- 6900 Volts(6500-7100 Volts)	a. Restore power to at least one AC safeguards bus: • Perform manual emergency start of DG(s). • Perform manual normal start of DG(s) <u>AND</u> manually close supply breaker(s). <u>IF</u> power can <u>NOT</u> be restored to at least one AC safeguards bus, <u>THEN</u> go to ECA-0.0A, LOSS OF ALL AC POWER, Step 1.
	b. AC safeguards busses - BOTH ENERGIZED	b. Restore power to de-energized AC safeguards bus per ABN-601, RESPONSE TO A 138/345 KV SYSTEM MALFUNCTION or ABN-602, RESPONSE TO A 6900/480 VOLT SYSTEM MALFUNCTION when time permits.

Fig. C- 4: Sample Page From EOP 0.0. Use for Question 25

26) Besides procedures, are there other methods you use to determine Errors of Omissions and Errors of Commissions? For example, do you do a walk-through of the control panel, or conduct operator interviews?

<u>Lower Bounds</u>

27) In your opinion should there be a lower bound for HEP calculations? If so what value do you use and how did you determine that value?

28) In your opinion should there be a lower bound on P_{cog} values? If so, what value do you use, and how did you determine that value?

29) In your opinion should these lower bounds be consistent between methods?

Choice of Methodology

30) How do you determine which methodology to use for an HEP calculation?

31) Is it better to use the same methodology for an entire analysis or to use a method that is appropriate for each individual action?

32) Do you believe that any method can be used to analysis any action?

33) Under what circumstances do you calculate an HEP value using more than one method and compare the numerical results?

P_{cog} CALCULATIONS USING ANNUNCIATOR RESPONSE MODEL

1) How do you determine the number of annunciators present in the control room for specific action?

2) In your opinion, is it appropriate to use the values shown in Table C-1 when there is more than one person present in the control room? These values were derived for a single operators but CPSES always has at least 3 or more people present in the control room.

3) If you were to model crew behavior using the values in Table C-1, would you modify any of these values to take credit for additional people?

P_{cog} CALCULATIONS USING HCR/ORE CORRELATION

1) List all the sources you use for collecting timing information.

2) From your list of timing sources, under what circumstances do you use each source in your HEP calculation? Are all the sources equally considered when choosing which source to use in a calculation?

3) Do you consider the accuracy of the timing information when using the HCR/ORE? If so, how does this affect your calculations?

4) In your opinion, should the stress level chosen in the decision tree used to determine sigma (See Fig. C-1) be the same as what is used to calculate P_{exe}?

5) What do you consider a lower bound for the calculation of P_{cog}?

Consider the following sample calculation of P_{cog} using the HCR/ORE Correlation:

Operator fails to use ECA- 1.1 on Loss of Recirc Capability

HFE Scenario Description:
1. Initial Conditions: Steady state, full power operation
2. Initiating Event: All except LBLOCA ans MBLOCA
3. Accident sequence: Loss of RCS inventory
4. Operator action success criterion: Successful implement ECA-1.1A
5. Consequence of failure: Core damage

On loss of recirculation capability, the operators are required to enter ECA-1.1, "Loss of Recirc. Capability." This procedure will instruct them to limit injection flow, and provide makeup to the RWST in order to extend the injection phase. Due to the high flow rates and short time to depletion of the RWST, this action is not credited in the Large and Medium LOCA trees. Success in this recovery will prevent core damage. The length of time to RWST depletion is expected to exceed 2 hours.

The Tsw timing for this Human Action was determined from a review of Calculation RXE-LA-CP1/0-003. MAPP run SB2F1 was selected as the limiting case for this HEP determination.   This MAAP run is a 4 inch SBLOCA (the largest break in the small break range) where all Emergency Core Cooling fails at recirculation. This represents the limiting case for these initiators because the depletion time of the RWST is minimized due to this being the largest break in the small break range. Since the SIPs are not injecting in this run, the time to RWST depletion could be less than the time calculated. However, the time at which the containment spray is actuated is the lower bound for RWST depletion because of the comparatively short time it takes to deplete the RWST after sprays are actuated. If SIP injection was considered core uncovery occurred at approximately 8500 seconds approximately 22 seconds after RWST depletion (6302 seconds). Thus, If SIP injection and injection form both CCPs had been considered, core damage would still occur after 6700 seconds (110 minutes). Based on the above Tsw is 6700 seconds (110 minutes). The Tdelay is 75 minutes based on the RWST depletion time of 4500 seconds.

Procedure and step governing HI:
Cognitive: EOP-1.0A, "Loss of Reactor or Secondary Coolant", EOS-1.3b, "Transfer to Cold Leg Recirculation"
Execution: ECA1-1.1A "Loss of Emergency Coolant Recirculation"

Training:

-    - **None**
- X - **Classroom** Frequency: 1 per year
- X - **Simulator** Frequency: 1 per year

Degree of Clarity of Cues & Indications:

- X - **Very Good**
-    - **Average**
-    - **Poor**

Stress:

- X - **Optimum (Low)**
-    - **Moderate**
-    - **Extreme (High)**

Type of Response: Rule

Human-Machine Interface: Control Room Panels

Environmental Conditions: Normal

Lighting – Normal
Heat/Humidity – Normal
Radiation- Background
Atmosphere – Normal
–No steam smoke or use of respirator required.

Equipment Accessibility: Control Room Front Panels

Cue:
RWST Lo Lo level alarm
Leak outside containment
Radiation monitors
Containment sump level

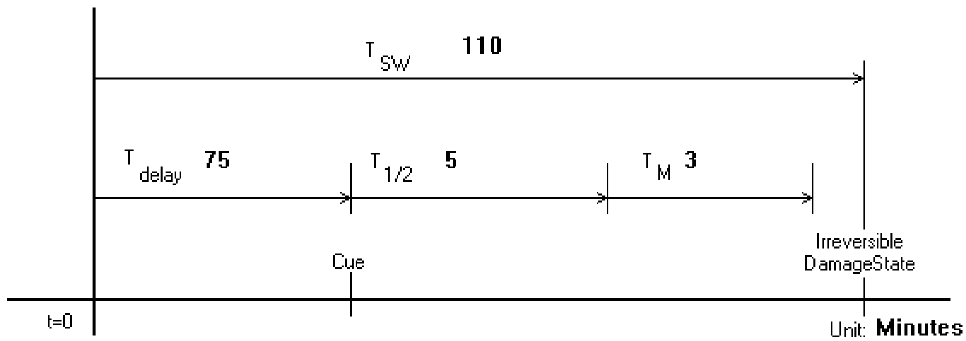


Fig. C- 5 Timing Diagram For Sample P_{cog} Calculation

Reference for Manipulation Time: Operator interviews

Duration of time window available for action (TW): 27.00 Minutes

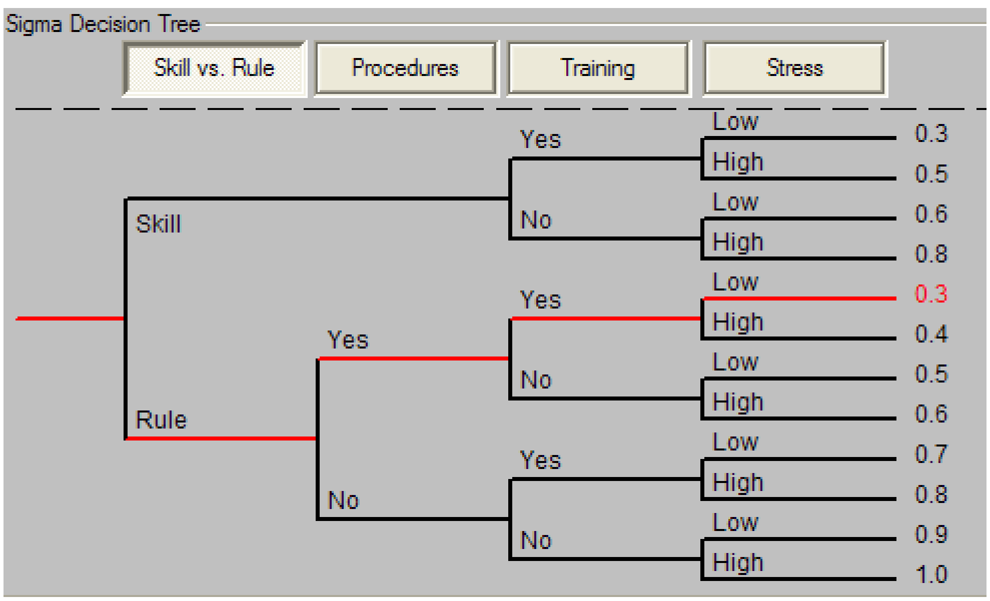


Fig. C-6: Sigma Decision Tree Used in HCR/ORE Correlation

6) From the above information, would you use the HCR/ORE correlation to calculate P_{cog}?

7) Using the input stated above, the P_{cog} value determined by the HRA Calculator was 3.1E-10. Do you feel that is a realistic value?

8) If you encounter an unrealistic P_{cog} valve (such as the example above), what would you do to correct this? Why?

9) In the example above, do you feel the use of operator interviews to gather manipulation timing was appropriate?

P_{cog} CALCULATIONS USING CBDTM METHOD

1) The original report on the CBDTM method recommends that the HRA analysts revisit the numerical values used in the decisions trees and modify or adjust as necessary. Do you consider doing this in regular practice? If so what are you looking to adjust?

2) Are there any entire decisions trees that you feel are no longer relevant to consider in HEP Calculations for U.S Nuclear Power Plants? If so how do you determine this and which trees do you feel are no longer relevant? The original report was written in 1992 and has not been updated to reflect current operations.

3) When using the decision tree presented in Fig. C- 7 the CPSES HRA analyst made the following assumption "*Control room indication is provided for equipment status with visual and audible alarms indicators of equipment failures or parameter deviations. The control room indication is assumed to be available, and accurate unless affected by the initiating event.*" This assumption was used for every action in the CPSES database and resulted in the Pca tree always giving a negligible value. Are there any actions you would consider doing an HEP calculations for when this assumption is not valid and/or the Pca tree would result in a non negligible value?

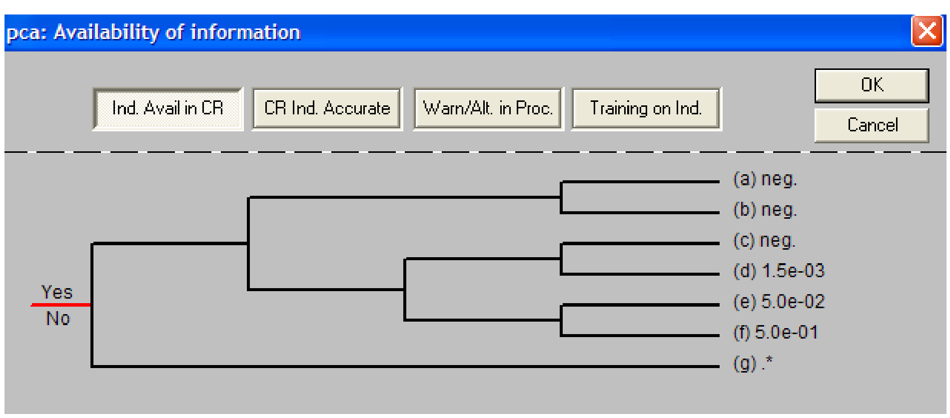
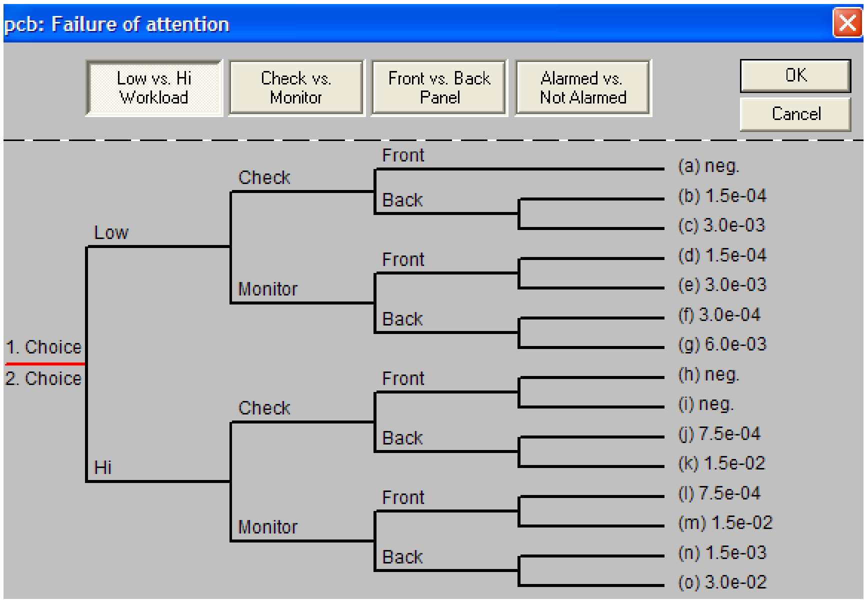


Fig. C- 7. Pca Decision Tree – For use with Question 3

4) In the pcb decision tree shown in Fig. C-8, how do you differentiate between high vs. low workload?



Fig, C- 8. Pcb Decision Tree – For use with Question 4

5) The decision tree shown in Fig. C- 9 asks the analyst to determine if the indicator is easy to locate. For control room actions, is it reasonable to assume that all indicators are easy to locate? Can you give an example when you would determine this not to be the case?

6) The HRA Calculator asks the following question to determine if the indicators are Good or Bad. *"Does the required indicator have human engineering deficiencies that are conducive to errors in reading the display?"* In your opinion, are there any groups or types of indicators that have human engineering deficiencies that have not been corrected in most control rooms?

7) List the circumstances under which you would consider an indictor to have deficiencies that could lead to human error?

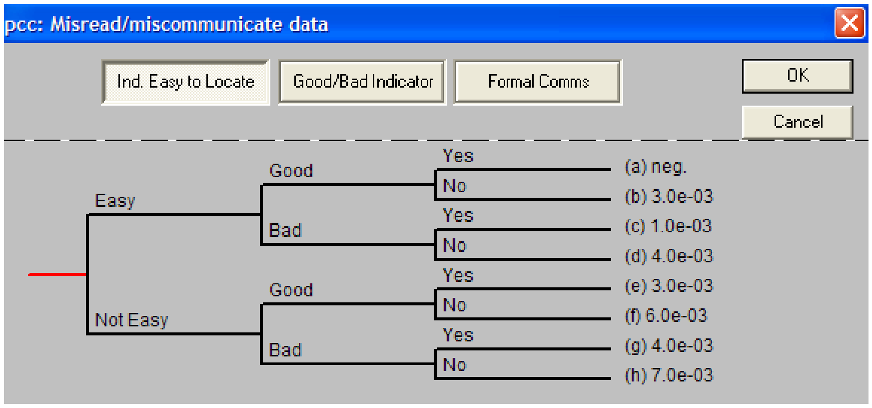


Fig. C-9. Pcc Decision Tree- For use with Questions 5, 6, 7

8) Using the CBDTM method decision trees, how do you determine if a procedure has standard or ambiguous wording?

9) Using the CBDTM method, the analyst is asked to determine if the steps are hidden or obvious. What do you consider to be a “hidden” step?

10) Again using the CBDTM method, the analyst is asked to determine if steps are graphically distinct. How do you determine if a step is graphically distinct?

11) Below is a page from EOP 0.0. (Fig. C-10) Step 6a has been identified as a critical action and the analyst has determined that step 6a is “obvious” and graphically distinct from other actions on the page. Would you agree or disagree with these decisions? Discuss how you made your decision.

12) In Fig. C-11, are there any examples of what you would consider ambiguous wording? Justify using your response to question 8.

13) In Fig. C-11, the analyst has identified that step 7 is a critical action. Using the CBDTM method decision trees the analyst has made the following choices shown in Fig. C-12. Assuming that scenario is well practiced, do you agree with the choices made in the decision tree shown in Fig. C- 13? Justify your answer.

CPSES EMERGENCY RESPONSE GUIDELINES	UNIT 1	PROCEDURE NO. EOP-0.0A
REACTOR TRIP OR SAFETY INJECTION	REVISION NO. 7	PAGE 7 OF 97

STEP	ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED
6	Verify AFW Alignment:	
	a. MDAFW Pumps - RUNNING	a. Manually start pump(s).
	b. Turbine Driven AFW Pump - RUNNING IF NECESSARY	b. Manually open steam supply valve(s).
	c. AFW total flow - GREATER THAN 460 GPM	c. Check narrow range levels and perform the following: IF narrow range level greater than 5%(26% FOR ADVERSE CONTAINMENT) in any SG, THEN control feed flow to maintain narrow range level between 5%(26% FOR ADVERSE CONTAINMENT) and 50% AND go to Step 6d. IF narrow range level less than 5%(26% FOR ADVERSE CONTAINMENT) in all SGs. THEN manually start pumps and align valves as necessary.
	d. AFW valves alignment - PROPER ALIGNMENT	d. Manually align valves as necessary.

Fig. C-10. Sample Page From EOP 0.0. Use for Questions 11

CPSES **EMERGENCY RESPONSE GUIDELINES**	UNIT 1	**PROCEDURE NO.** EOP-0.0A
REACTOR TRIP OR SAFETY INJECTION	REVISION NO. 7	PAGE 8 OF 97

STEP	**ACTION/EXPECTED RESPONSE**	**RESPONSE NOT OBTAINED**
* 7	Verify Containment Spray Not Required:	
	a. Containment pressure - HAS REMAINED LESS THAN 18.0 PSIG • 1-ALB-2B window 1-8, CS ACT - NOT ILLUMINATED -AND- • 1-ALB-2B window 4-11, CNTMT ISOL PHASE B ACT - NOT ILLUMINATED -AND- • Containment Pressure - LESS THAN 18.0 PSIG	a. Perform the following: 1) Verify Containment spray initiated. <u>IF NOT</u>, <u>THEN</u> manually actuate. 2) Verify appropriate MLB indication for CNTMT SPRAY (BLUE WINDOWS) <u>AND</u> PHASE B (ORANGE WINDOWS). <u>IF</u> valves <u>NOT</u> aligned, <u>THEN</u> manually align valve(s) as appropriate. (Refer to Attachment 6 as necessary). 3) Verify containment spray flow. 4) Ensure CHEM ADD TK DISCH VLVs - OPEN • 1-HS-4752 • 1-HS-4753 5) Stop all RCPs.

Fig. C- 11: Sample Page From EOP 0.0. Use for Questions 12 and 13

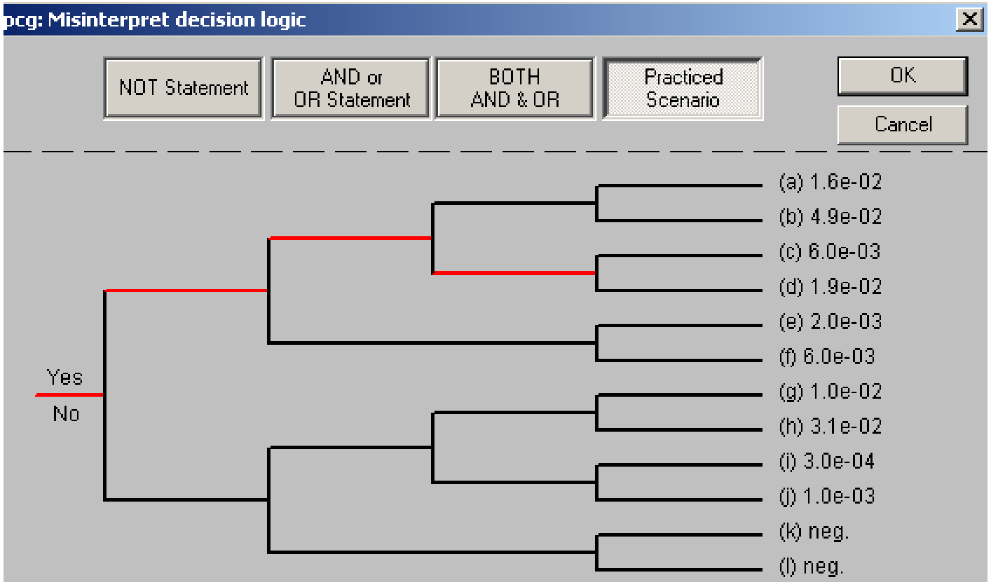


Fig. C- 12. Decision Tree Choices Based Upon Fig. C-11.

14) Describe your methodology on how you apply recoveries and dependencies using the CBDTM method.

REFERENCES

[1] CPSES HRA Notebook 2004

[2] EPRI HRA Calculator, Software user's manual version 2.01, May 2003

[3] EPRI, *Operator Reliability Experiments Using Power Plant Simulators* Volume 2. July 1990.

[4] Swain, A.D and Guttmann, H.E, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, NUREG/CR-1278, Sandia National Laboratories, August 1983.

[5] EPRI, *Operator Reliability Experiments Using Power Plant Simulators* Volume 2. July 1990.

APPENDIX D

SHARP1 COMPARISON OF DIFFERENT HRA METHODS

TABLE D-1

SHARP1 COMPARISON OF DIFFERENT HRA METHODS

Comparison Index	Handbook Method	CBDTM Method	Normalized Correlations	HRA Calculator
	THERP/ASEP		**HRC**	**THERP, ASEP, CBDTM, HCR/ORE**
Ease of use	H	M	M	L
Level of Resources Required	L	L	H/M	M
Traceability	M	L	H/M	H
Applications				
Type of human actions	A Cp	Cp, Cr	Cp Cr	Cp Cr A B C (Excludes control room actions)
Type of error	Slips and Mistakes Treated as EOM and EOC	Errors of Cognition Slips and Mistakes Treated as EOM and EOC	Slips Mistakes and Non-responses Treated Explicitly	Execution Errors, Errors of Cognition
Qualitative Output				
Degree of Knowledge is enhanced through application	L	L	M	M
Analytical Application				
Form of Algorithm	Boolean Expression	Decision Trees	A formula with graphical solutions	Combination of Boolean Expressions, Mathematical formulas, Computerized database
How Performance Shaping Factors are Handled	Judgment	Recoveries	Recommend values provided	Recommendations Only considers stress as a PSF
Degree of integration of engineering knowledge	L	L	Depends on skill of user	L
Data Required				
Communication with Others	L	M	H	M
Availability of data for methods	H	H	M	M –Dependent upon which method is chosen
Quantitative output				
How is uncertainty addressed	By assignment of uncertainty factors	By assignment of uncertainty factors	Not considered	By assignment of uncertainty factors
Capability for sensitivity Analysis	Fixed by elements in Handbook	Fixed by decision trees	Ranges for Key parameters established by evaluations	Can be accomplished by trial and error method.

H-High, M-Medium, L-Low

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