6 HUMAN RELIABILITY ANALYSIS

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6 HUMAN RELIABILITY ANALYSIS

6.1 INTRODUCTION AND SCOPE

The purpose of this section is to document the Human Reliability Analysis (HRA) performed as part of the ESBWR PRA. The inputs for this analysis are the system models included in Chapter 4 of this ESBWR PRA and the accident sequences developed in Chapter 3.

The basic purpose of human reliability analysis, in a PRA, is to ensure that the main human actions of operators are incorporated adequately, systematically, and in a reproducible manner into the global analysis, appropriately documenting the hypotheses, expert judgments, analysis methods, and information sources taken into account. To this effect, the ESBWR HRA is aimed at determining the type of analysis to be performed within the human reliability task for the definition and identification of human actions, selection of actions for the detailed analysis and the assigning of estimates to the human-related basic events for the quantification of systems and accident sequences.

Three types of human actions are described in this chapter: actions that take place prior to the initiating event, actions that cause an initiating event, and actions that are taken to mitigate an initiating event. Section 6.2 describes the methods used in the analysis. Section 6.3 describes the specific calculations for the Human Error Probabilities (HEPs) used in the ESBWR PRA and how dependencies are treated. Section 6.4 outlines COL action items related to refinement of HEPs.

6.2 METHODOLOGY

This section describes the methodology applied in evaluating the human interactions with the plant systems both during normal operation and during accidents, herein referred to as ”human actions.”

There are several types of human actions during normal plant operation:

- Those related with the failure to restore equipment to its normal condition following a test and/or maintenance action,
- Those that detect the wrong positions, and
- Those causing an initiating event.

On the other hand, human actions during an accident are:

- Those performed by operators following established procedures for mitigating the consequences of an accident;
- Those performed in the mistaken belief that they are the appropriate actions as indicated in the procedures, but which in reality can worsen the conditions of the accident, thereby complicating the mitigation process; and
- Those that are not explicitly included in the procedures and which tend to recover the operability of failed equipment or use alternative means.

Adequate treatment of the human actions in a PRA is one of the keys to a realistic understanding of accident sequences and their relative importance to overall risk.

By virtue of its capacity to combine human reliability with systems and component reliability, the probabilistic safety analysis provides an unsurpassable way of studying the interrelationships between operators, equipment and the evolution of accident sequences.

However, to perform an adequate human reliability analysis it is necessary to have a structured framework which allows the different parts of the analysis to be developed in an orderly fashion while taking into account the general boundary of the PRA.

The methodology used in the present study is in accordance with the Systematic Human Action Reliability Procedure (SHARP) (EPRI NP-3583) (Ref. 6-1).

Human Actions analyzed in the ESBWR PRA have been categorized into the following types:

Type A: Pre-Initiating Event Human Actions

Before an initiating event, plant personnel can affect availability of standby systems by inadvertently disabling equipment or failing to restore to the correct position during the performance of operational activities in the plant. These actions are Type 1 actions of the SHARP.

Human errors associated with miscalibration are considered probabilistically insignificant in ESBWR. The design of the DCIS incorporates self detection of miscalibration for the logical part of the instrumentation channels. For the primary element a specific procedure for miscalibration error detection, including inter-channel cross-checking while calibrating the sensors, will be applied.

Type B: Initiating Event Induced by Human Actions

Plant personnel can initiate an event through various interactions with plant equipment. These would typically occur due to a mispositioning or incorrect operation of equipment that inadvertently trips equipment or inserts false control signals. These actions are Type 2 actions of the SHARP.

Type C: Post-Initiating Event Human Actions

The nature of the passive ESBWR is such that post-initiator operator actions should not be strong contributors to the risk profile as they are in current LWRs.

Two major subsets are identified as follows within this group:

- CP - These are actions that are specifically directed by plant operating and emergency procedures. By following procedures during the course of an accident, plant personnel can operate standby equipment that will either terminate or aggravate the accident. These actions are Type 3 and Type 4 actions of the SHARP

  The part of this group of actions that could aggravate the accident--a "commission error," i.e., an error that, when it occurs, gives rise to a situation in the plant worse than the one than would have happened if the error were of the no-action type (i.e., an omission error)--is considered insignificant when the plant has EOPs (emergency operation procedures) that have a symptom-based orientation and the EOP covers all the possible scenarios drawn in the accident sequences analysis. This was what was considered for the ESBWR PRA.

  Furthermore, the screening values of the HEPs (human error probabilities) used at this stage are sufficiently conservative for the impact of any hypothetical commission error that may occur to be considered adequately treated.

- CR - These are actions that have traditionally been called recovery actions. Plant personnel can recover and operate initially unavailable equipment to terminate an accident. These actions are Type 5 actions of the SHARP

Finally, in accordance with the SHARP (EPRI NP-3583) (Ref. 6-1), the ESWBR HRA framework was divided into the following parts:

- Definition and identification of human actions for the initial dependency analysis
- Initial estimation of the probabilities for the human-related basic events
- Process for the dependency analysis
- Selection criteria for the human actions which will undergo detailed analysis
- Documentation of the results of the human reliability analysis

6.2.1 IDENTIFICATION OF HUMAN-INDUCED BASIC EVENTS IN THE PRA

6.2.1.1 Human-Induced Basic Events in Systems Fault Trees

The general guidelines for identifying individual human actions in the fault trees are based on:

Type A Human Actions

A review of procedures relating to tests, maintenance, calibrations and operating realignments, paying special attention to those components whose normal state of response to an accident changes (change of position, disconnection or set point) in the process of these activities. Furthermore, it will be necessary to verify if, in the event of incorrect positioning, the aforementioned components receive an automatic return-to-operating-position signal after activities that do not require them to be disconnected, even if this disconnection has an alarm. It will also be necessary to identify surveillance procedures and their frequencies for verifying the position and state of these components, locally or in the control room.

Type C Human Actions

A review of normal, special, failure or emergency operating procedures and the system design specification to detect any actions that may be carried out by operators concerning the components of a system in response to the requirements specified in the procedures.

The modeling of the identified human-related basic events in fault trees must take into account the following rules:

- Type A Human Actions
  - The model should not include unavailability due to wrong positioning, prior to the accident, of those components whose state (position, power supply, or actuation point) is signaled by a single alarm or indicated and monitored at least every 24 hours
  - The model should not include any human errors that may affect the overall operability of the component arising from maintenance or incorrect testing when these errors have already been implicitly taken into account in the failure probability of the affected components. Thus, only the wrong positioning due to tests, maintenance, operating realignments or calibrations of other components, and wrong calibrations of the component itself, are the only applicable errors
  - The model should not include unavailability due to wrong positioning, prior to the accident, of all those components that receive an effective automatic return-to-operating-position signal, after actuations that do not require their disconnection, in the event of an accident
  - The model should not include unavailability due to wrong positioning, prior to the accident, of all those components whose operation and correct state are tested functionally after they have been changed through testing, maintenance, operating realignments or calibrations
- Type C Human Actions
  - Type C human actions are performed by an operator during an accident but do not include potential recovery actions, i.e., those that may be carried out to improve the conditions of an undesired situation, and which tend to recover the operability of failed equipment or the use of alternative means despite not being expressly included in the procedures

Initial Dependency Analysis

Any human-related basic events included in the modeling should be reviewed to verify that, if desirable, they are combined in models by means of "AND" gates and they represent a common cause failure.

It should also be determined whether or not the event is dependent on time or functional proximity. If it is, a new human-related basic event should be generated in association with the common cause human failure identified unless it can be discarded by any of the first four Type A Human Action rules.

6.2.1.2 Human-Related Basic Events in Initiating Events

Due to the way that the initiating event frequencies were developed in the ESBWR design PRA, generic initiating event frequencies include operator actions that have historically caused plant transients and accidents. Emergency Operation Procedures exist that decouple any dependency between the operator-induced initiating events (Type B) and the subsequent operator response (Type C). Thus, no specific Type B actions are included as basic events in the models.

6.2.1.3 Human-Related Basic Events in Event Trees

The general guidelines for identifying individual human actions are based on the review of emergency, specific, failure and general procedures for identifying actions which the operator may take in response to the contents of these procedures and especially those which, when not executed appropriately, may lead to a core-damaging sequence.

For the modeling of human-related basic events deriving from identified human actions, in event trees and especially in functional headings, potential recovery actions are not included. Such actions refer to alternative means or actions which, though they are not explicitly included in the procedures, may be implemented to improve the conditions of an unwanted situation, and which tend to recover the operability of failed equipment.

Human actions taken in accordance with procedures on a component or system and which, if carried out wrongly, lead to an unwanted situation, will be included in the model of fault trees as a human-related basic event that causes unavailability due to inappropriate action.

When a human action whose error affects sequence development is identified in the functional heading and applies to a single system, it is assumed that it has been modeled for said system and therefore need not be modeled in the functional heading. However, when the identified and modeled human action represents action on components corresponding to different systems, it should be explicitly modeled in the corresponding functional heading, where it will represent the cognitive part of the action, leaving the manual parts in the systems affected.

6.2.1.4 DEFINITIVE INCORPORATION INTO THE MODELS

Applying the general bases for the identification and modeling of human actions in fault and event trees provide analysts with the identified human-related basic events. These events are then reviewed by human reliability analysts so that the information contained in the lists of human-related basic events in each fault tree can be compared with the reference document used, thereby verifying that the general bases have been correctly applied for the identification and modeling of human actions. This allows human-related basic events to be defined and/or eliminated if their likelihood of occurrence is considered negligible according to the most recently available information. Human-related basic events which show clear interdependence among systems are grouped together, and, finally, the new actions are incorporated that have arisen as a consequence of applying some of the previous criteria.

For the basic events in the fault trees, in cases in which more than one single component can give rise to a system train failure, the level of grouping will be at the "train level."

Once the analysts have checked all the human-related basic events identified in the fault trees and event trees, any human actions modeled in both tasks during accidents must be integrated into one single basic event and included in the fault tree, functional heading or event tree, depending on their influence on sequences.

This phase will result in the availability of a global list of human-related basic events in the fault and event trees which will be modeled in the probabilistic safety analysis.

6.2.2 ASSUMPTIONS

(1) The objective and scope of an operator action where a HRA would be required is assumed and conditioned on the availability of operating procedures and necessary data needed.

(2) Currently there is no ESBWR specific HRA related data (performance shaping factors, training data, procedure step timing data, recovery procedure data, walkdown data and cue related data), as such, screened values were used.

(3) The accident sequences, both success and failure, are based on current design information.

(4) Operator action progression sequences are not currently explicitly modeled because procedures will not be developed until a later phase of detailed design.

(5) Cognitive and cognitive recovery effort is implicitly imbedded in some screening values, but the majority of it cannot be explicitly quantified currently because procedures will not be developed until a later phase of detailed design.

(6) Detailed timing window analysis is not available currently because procedures will not be developed until a later phase of detailed design.

(7) Execution and execution recovery effort cannot be explicitly quantified currently because procedures will not be developed until a later phase of detailed design.

(8) Integrated evaluation of detailed steps of a given HEP is not available at this early stage of the ESBWR design, when operating procedures becomes available, it is assumed that the current point estimate prior HEP knowledge will be approach updated to reflect the integral process from the cue recognition through execution recovery.

(9) Operator action interdependencies will be analyzed and quantified in detail when detailed ESBWR system design and operating procedures become available.

(10) Under certain conditions, operator actions were assumed as backup function to auto-function failure.

6.2.3 INSIGHTS

Section 11 presents sensitivities, including HRA sensitivities to reveal the risk insights of various operator actions.

The KEY INSIGHT of this section is that, due to absence of operating procedures, HEP values are screened values.

6.3 QUANTIFICATION OF HUMAN ERROR PROBABILITIES

Due to the current status of ESBWR documentation, the analysis of human actions carried out during the design phase is preliminary. Therefore, a conservative assessment of the HEPs is used for the ESBWR design PRA. The generic screening probabilities are estimated from documents SHARP (EPRI NP-3583) (Ref. 6-1), NUREG/CR-1278 (Ref. 6-2), and NUREG/CR-4772 (Ref. 6-3).

A more detailed analysis of the values could be performed; however, since the existing ones are conservative screening values, this would tend only to further reduce the calculated HEP. In this phase of the design, screening values are considered appropriate. The values taken from the references are median values.

The ESBWR PRA model requires mean values. These were calculated by combining the median values with the associated error factors, assuming a lognormal distribution.

6.3.1 Type A Human Actions

For Type A human actions, generic values are used as reported in Table 6.3-1. These HEPs are extracted from documents NUREG/CR-1278 (Ref. 6-2) and NUREG/CR-4772 (Ref. 6-3).

The detection interval in Table 6.3-1 corresponds to the frequency of the error identification anticipated for the system. There are three different levels of Type A actions modeled as follows:

- Skill Based

  Skill based actions include the manipulation of equipment that is performed on a routine basis (for example, every shift) during the operation of the plant. Personnel are trained and well practiced in these manipulations.

  An example is the closure of the associated discharge valve during the maintenance of a pump.

- Rule Based

  Rule based actions include the manipulation of equipment that is performed occasionally. Personnel perform the manipulations under the direction of procedures and following training on those tasks.

  An example is the restoration of isolations following the mixing of a batch of sodium pentaborate SLCS solution.

- Knowledge Based

  Knowledge based actions include the manipulation of equipment that is performed during unique situations.

  An example is the immediate reconfiguration of a system following a failure of an operating pump.

Table 6.3-3a presents the final Type A human error probabilities used in the PRA model given the type of manipulation, the behavior type, and the possible detection interval. For the basic event from restoration errors that are modeled at train level, the assigned value will be the worst of all of the applicable values for the component inside the train, and the value used will be increased based on the number of boundary components required to isolate the train.

6.3.2 Type B Human Actions

Due to the way that the initiating event frequencies were developed in the ESBWR design PRA; generic initiating event frequencies include operator actions that have historically caused plant transients and accidents. Emergency Operation Procedures exist that decouple any dependency between the operator-induced initiating events (Type B) and the subsequent operator response (Type C). Thus, no specific Type B actions are included as basic events in the models.

6.3.3 Type C Human Actions

For Type C ESBWR HRA, generic values are used as reported in Table 6.3-2. These HEPs are extracted from documents SHARP (EPRI NP-3583) (Ref. 6-1), NUREG/CR-1278 (Ref. 6-2) and NUREG/CR-4772 (Ref. 6-3). There are four time frames considered in the ESBWR design PRA, and the Type C HEPs are based on these time frames. The screening probabilities are assigned, in part, according to these time frames. No credit is taken for actions that must be completed very quickly (that is: within a few minutes of the cue).

If Type CR recovery actions must be modeled, the values (median HEPs and associated error factors) indicated in Table 6.3-2 will need to be used, taking into account that said actions will be included in the minimum cutsets of the Core Damage Frequency to be recovered.

If a Type CP action requiring outside Control Room actuation has to be modeled, the values (median HEPs and associated error factors) indicated in Table 6.3-2 for the CR actions will be used for the cognitive and manual parts. If a cognitive part of an action includes local and Control Room actuations, the values indicated in Table 6.3-2 for the CR actions will be used only for the local manual parts.

HEPs are estimated in two parts, the cognitive part (or diagnosis phase) and the manual part (or action phase). The total HEP for an action is the sum of these two parts.

The HEPs for the cognitive parts are assigned based on the following behavior types:

- Skill Based

  The skill based actions are those which are routine and frequently practiced. An example would be for the operators to insert a backup scram signal following an initiating event.

- Rule Based

  The rule based actions are those which are performed in response to a specific set of procedures. An example would be to start FAPCS in SPC mode when the suppression pool water temperature reaches a preset limit.

- Knowledge Based

  The knowledge based actions are those where the operators need to deduce the proper course of action based on indirect indications or a complex combination of individual indications. An example would be injecting SLCS via the boron mixing system following a failure of a SLCS division.

The HEPs for the manual part (action) are assigned based on the following criteria:

- Skill Based

  The skill based actions are those which are routine, frequently practiced, and require a few simple actions. An example would be for the operators to manual initiate depressurization from the control room.

- Rule Based

  The rule based actions are those which are more complex and involve specific sequences of manipulations, however procedures and training are readily available. An example would be starting FAPCS in suppression pool cooling mode (non-automated).

- Knowledge Based

  The knowledge based actions are those that are complex and not routine. Procedures are available, but training and drills are infrequent. An example would be controlling a system from outside the control room.

6.3.4 Human Action Dependencies

Section 6.2.1.1 defined some guidelines for the identification and modeling of human-related dependencies during tests, maintenance, calibrations and operational realignments and also during post initiating event actuations resulting in the generation of specific common cause human-related basic events.

Some of these specific basic events are due to individual human actions which include all types of manipulation; however, special rules are often used to avoid the modeling of a large number of possible combinations. It may be hypothesized that no common cause human basic events can be postulated for maintenance actions on components that are located in models in "AND" gates because they are unlikely to happen concurrently, since the applicable maintenance frequency is far less than the frequency of other types of manipulations, considering the fact that between the two maintenance actions there are verifications and intermediate tests that would minimize the possibility of common cause human related failure due to maintenance actions among components.

Section 6.2.1.3 defined guidelines relating to Type C human actions, grouping all the various actions in a single basic event with the same codification and assuming complete dependence in all maneuvers.

The minimal cut-sets which are not affected by any of these criteria were identified as being dependent and were evaluated on the basis of the levels of dependence indicated in NUREG/CR-1278 , Ref. 6-2, the THERP (Technique for Human Error Rate Prediction) method. Finally, the estimate previously assigned to the dependent basic event was replaced by the value obtained from the evaluation.

For Type C human errors that affect various systems, the logic model includes separate basic events representing the cognitive part of the action and various basic events representing the manipulation of the systems involved. If more than one human action shares a cognitive or manual part, the basic event representing the dependent part is included in both locations in the fault tree model. For the purposes of the design PRA, even partially dependent actions are modeled as fully dependent.

For example, the basic event XXX-XHE-FO-LPMAKEUP (cognitive part of the low pressure injection system initiation when the required low pressure in the RPV exists) is modeled in the FAPCS and in the FPS system. Another example is depressurization using the SRVs, that is modeled using separate cognitive and manual basic events. This is because complete dependence between the basic events XXX-XHE-FO-LPMAKEUP and XXX-XHE-FO-DEPRESS (cognitive part of the need of depressurization upon high pressure injection system failure) was considered when they appeared in the same sequence. Accordingly, the basic event XXX-XHE-FO-DEPRESS is also modeled in the FAPCS and FPS systems.

Finally, it is necessary to evaluate the minimal cut-sets which include the human-related basic events of the different accident sequences which cause failures in various sequence functions. The criteria to be applied are as follows:

- Dependencies which have been explicitly taken into account during the review of fault trees and sequences are discarded, essentially disregarding the manual part of actuations during accidents and actuations prior to the initiating event;
- No dependencies are considered between functions with highly differentiated characteristics; and
- No dependencies are considered for human-related basic events due to Type A and Type C actions in the same minimal cut-set, due to the highly differentiated time frames and the low combined probability.

After quantification, all the human actions that appeared combined in the same minimal cutsets whose accumulated frequencies were, at the most, 99% of the core damage frequency, were reviewed. Based on this review, it was considered unnecessary to model any special new dependencies. This is because either no dependence was identified or the dependencies were already explicitly taken into consideration in the models or, for those cases where a degree of dependence was considered possible, it was determined that the values of the probabilities of the human actions combined in the same minimal cutsets at this stage were sufficiently conservative for the impact of the possible dependency to be considered adequate.

Table 6.3-1
Generic Error Probability Values for
Type A Actions
(NUREG/CR-1278, NUREG/CR4772)

Generic Error Probability Values for Type A Actions Human Action	Detection Interval	Behaviour Type (1)		
		Skill	Rule	Knowledge
Type A (2)	≤ 720 h	$5 \cdot 10^{-4}$ (EF=5)	$2.5 \cdot 10^{-3}$ (EF=5)	$1.25 \cdot 10^{-2}$ (EF=5)
	≤ 2190 h	$1.5 \cdot 10^{-3}$ (EF=5)	$7.5 \cdot 10^{-3}$ (EF=5)	$3.75 \cdot 10^{-2}$ (EF=5)
	≤ 4380 h	$3 \cdot 10^{-3}$ (EF=5)	$1.5 \cdot 10^{-2}$ (EF=5)	$7.5 \cdot 10^{-2}$ (EF=5)
	≥ 8640 h	$6 \cdot 10^{-3}$ (EF=5)	$3 \cdot 10^{-2}$ (EF=5)	$1.5 \cdot 10^{-1}$ (EF=5)

Notes:
(1) Values given are the Median HEP and the associated (Error Factor)
(2) Source: NUREG/CR-1278 and NUREG/CR 4772

Table 6.3-2

Generic Error Probability Values for

Type C Actions

(SHARP (EPRI NP-3583), NUREG/CR-1278, NUREG/CR 4772)

Generic Error Probability Values for Type C Human Action	Cognitive Part (Time)	Behaviour Type (1)		
		Skill	Rule	Knowledge
Type CP (2)	30 minutes	10^{-2} (EF=5)	10^{-1} (EF=5)	1
	60 minutes	10^{-3} (EF=5)	10^{-2} (EF=5)	10^{-1} (EF=5)
	24 hours	10^{-4}(EF=5)	10^{-3} (EF=5)	10^{-2} (EF=5)
	Manual Part	10^{-3} (EF=5)	10^{-2} (EF=5)	10^{-1} (EF=5)
	72 hours	10^{-5} (EF=10)	10^{-4} (EF=10)	10^{-3} (EF=10)
	Manual Part	10^{-4} (EF=5)	10^{-3} (EF=5)	10^{-2} (EF=5)
Type CR (2)	30 minutes	10^{-2} (EF=10)	10^{-1} (EF=10)	1
	24 hours	10^{-3} (EF=10)	10^{-2} (EF=10)	10^{-1} (EF=10)
	Manual Part	10^{-3} (EF=10)	10^{-2} (EF=10)	10^{-1} (EF=10)
	72 hours	10^{-4} (EF=10)	10^{-3} (EF=10)	10^{-2} (EF=10)
	Manual Part	10^{-4} (EF=10)	10^{-3} (EF=10)	10^{-3} (EF=10)
Notes:	(1) Values given are the Median HEP and the associated Error Factor (2) Source: SHARP (EPRI NP-3583), NUREG/CR-1278 and NUREG/CR-4772			

Table 6.3-3a

Human Action Probabilities with a

Preliminary Analysis Type A

Identification	Description	Behavior Type	Detection Interval (hr)	Value	Mean Value
C12-BV_-RE-F003A	MISPOSITION OF VALVE F003A	Rule	≤ 2190	7.50E-03	1.21E-02
C12-BV_-RE-F003B	MISPOSITION OF VALVE F003B	Rule	≤ 2190	7.50E-03	1.21E-02
C12-BV_-RE-F013A	MISPOSITION OF VALVE F013A	Rule	≥ 8640	3.00E-02	4.84E-02
C12-BV_-RE-F013B	MISPOSITION OF VALVE F013B	Rule	> 8640	3.00E-02	4.84E-02
C12-BV_-RE-F015A	MISPOSITION OF VALVE F015A	Rule	≥ 8640	3.00E-02	4.84E-02
C12-BV_-RE-F015B	MISPOSITION OF VALVE F015B	Rule	≥ 8640	3.00E-02	4.84E-02
C12-BV_-RE-F021A	MISPOSITION OF VALVE F021A	Rule	≤ 2190	7.50E-03	1.21E-02
C12-BV_-RE-F021B	MISPOSITION OF VALVE F021B	Rule	≤ 2190	7.50E-03	1.21E-02
C12-BV_-RE-F064	MISPOSITION OF VALVE F064	Rule	≥ 8640	3.00E-02	4.84E-02
C12-BV_-RE-F065	MISPOSITION OF LOCKED OPEN VALVE F065	Rule	≥ 8640	3.00E-02	4.84E-02
G21-BV_-RE-F308	MISPOSITION OF VALVE F308	Rule	≥ 8640	3.00E-02	4.84E-02
G21-BV_-RE-F334	MISPOSITION OF VALVE F334	Rule	≥ 8640	3.00E-02	4.84E-02
G31-TRN-RE-TRAINA	RESTORATION ERRORS RWCU/SDC TRAIN A	Rule	≤ 720	5.00E-03	8.07E-03
G31-TRN-RE-TRAINB	RESTORATION ERRORS RWCU/SDC TRAIN B	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-CONDA	FAILURE TO RESTORE CONDENSATE TRAIN A	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-CONDB	FAILURE TO RESTORE CONDENSATE TRAIN B	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-CONDC	FAILURE TO RESTORE CONDENSATE TRAIN C	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-CONDD	FAILURE TO RESTORE CONDENSATE TRAIN D	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-FWA	FAILURE TO RESTORE FEEDWATER TRAIN A	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-FWB	FAILURE TO RESTORE FEEDWATER TRAIN B	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-FWC	FAILURE TO RESTORE FEEDWATER TRAIN C	Rule	≤ 720	5.00E-03	8.07E-03
N21-TRN-RE-FWD	FAILURE TO RESTORE FEEDWATER TRAIN D	Rule	≤ 720	5.00E-03	8.07E-03
P21-BV_-RE-F049A	MISPOSITION OF RCCW INLET TO CRD HEAT EXCHANGER	Rule	≤ 2190	7.50E-03	1.21E-02
P21-BV_-RE-F049B	MISPOSITION OF RCCW INLET TO CRD HEAT EXCHANGER	Rule	≤ 2190	7.50E-03	1.21E-02
P21-BV_-RE-F050A	MISPOSITION OF RCCW OUTLET FROM CRD HEAT EXCHANGER	Rule	≤ 2190	7.50E-03	1.21E-02

Table 6.3-3a

Human Action Probabilities with a

Preliminary Analysis Type A

Identification	Description	Behavior Type	Detection Interval (hr)	Value	Mean Value
P21-BV_-RE-F050B	MISPOSITION OF RCCW OUTLET FROM CRD HEAT EXCHANGER	Rule	≤ 2190	7.50E-03	1.21E-02
P21-TRN-RE-HX1A	FAILURE TO RESTORE RCCW TRAIN 1A HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-HX1B	FAILURE TO RESTORE RCCW TRAIN 1B HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-HX2A	FAILURE TO RESTORE RCCW TRAIN 2A HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-HX2B	FAILURE TO RESTORE RCCW TRAIN 2B HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-HX3A	FAILURE TO RESTORE RCCW TRAIN 3A HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-HX3B	FAILURE TO RESTORE RCCW TRAIN 3B HX	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP1A	FAILURE TO RESTORE RCCW TRAIN 1A PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP1B	FAILURE TO RESTORE RCCW TRAIN 1B PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP2A	FAILURE TO RESTORE RCCW TRAIN 2A PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP2B	FAILURE TO RESTORE RCCW TRAIN 2B PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP3A	FAILURE TO RESTORE RCCW TRAIN 3A PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P21-TRN-RE-PUMP3B	FAILURE TO RESTORE RCCW TRAIN 3B PUMP	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-HX1A	FAILURE TO RESTORE TCCW HX1A	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-HX1B	FAILURE TO RESTORE TCCW HX1B	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-HX2A	FAILURE TO RESTORE TCCW HX2A	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-HX2B	FAILURE TO RESTORE TCCW HX2B	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-PUMP1A	FAILURE TO RESTORE TCCW PUMP 1A	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-PUMP1B	FAILURE TO RESTORE TCCW PUMP 1B	Rule	≤ 720	5.00E-03	8.07E-03
P22-TRN-RE-PUMP1C	FAILURE TO RESTORE TCCW PUMP 1C	Rule	≤ 720	5.00E-03	8.07E-03
P41-TRN-RE-PUMP1A	FAILURE TO RESTORE PSW PUMP 1A	Rule	≤ 720	5.00E-03	8.07E-03
P41-TRN-RE-PUMP1B	FAILURE TO RESTORE PSW PUMP 1B	Rule	≤ 720	5.00E-03	8.07E-03
P41-TRN-RE-PUMP2A	FAILURE TO RESTORE PSW PUMP 2A	Rule	≤ 720	5.00E-03	8.07E-03
P41-TRN-RE-PUMP2B	FAILURE TO RESTORE PSW PUMP 2B	Rule	≤ 720	5.00E-03	8.07E-03

Table 6.3-3a
Human Action Probabilities with a
Preliminary Analysis Type A

Identification	Description	Behavior Type	Detection Interval (hr)	Value	Mean Value
P51-CMP-RE-C001B	SERVICE AIR SYSTEM COMPRESSOR RESTORATION ERROR	Rule	≤ 720	5.00E-03	8.07E-03
P52-CMP-RE-C001B	INSTRUMENT AIR SYSTEM COMPRESSOR RESTORATION ERROR	Rule	≤ 720	5.00E-03	8.07E-03
P54-BV_-RE-F013A	RESTORATION ERROR OF F013A	Rule	≤ 720	2.50E-03	4.04E-03
R21-TRN-RE-FODG1A	FAILURE TO RESTORE FUEL OIL TRANSFER TRAIN 1 FOR DG-A	Rule	≤ 2190	1.50E-02	2.42E-02
R21-TRN-RE-FODG1B	FAILURE TO RESTORE FUEL OIL TRANSFER TRAIN 1 FOR DG-B	Rule	≤ 2190	1.50E-02	2.42E-02
R21-TRN-RE-FODG2A	FAILURE TO RESTORE FUEL OIL TRANSFER TRAIN 2 FOR DG-A	Rule	≤ 2190	1.50E-02	2.42E-02
R21-TRN-RE-FODG2B	FAILURE TO RESTORE FUEL OIL TRANSFER TRAIN 2 FOR DG-B	Rule	≤ 2190	1.50E-02	2.42E-02

Table 6.3-3b

Human Action Probabilities with a

Preliminary Analysis Type C (CP and CR)

Identification	Description	Type	Cognitive Part (1)	Available Time	Median Value	Manual Part	Median Value	Final Mean Value
B21-XHE-FO-6OPEN	OPERATOR FAILS TO OPEN 6/10 SRVS	CP	XXX-XHE-FO-DESPRESS	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
B32-XHE-FO-VENT	OPERATOR FAILS TO OPEN VENT	CP	Knowledge	60 minutes	1.00E-01	Rule	1.00E-02	1.76E-01
C12-XHE-FO-LEVEL2	OPERATOR FAILS TO BACK-UP CRD ACTUATION	CP	Skill	30 minutes	1.00E-02	Rule	1.00E-02	3.21E-02
C41-XHE-FO-EQU	OPERATOR FAILS TO ACTUATE SLCS	CP	Skill	30 minutes	1.00E-02	Skill	1.00E-03	1.77E-02
E50-XHE-FO-EQU	OPERATOR FAILS TO ACTUATE GDCS	CP	XXX-XHE-FO-RPVLDE	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
E50-XHE-FO-GDCS	OPERATOR FAILS TO ACTUATE GDCS	CP	XXX-XHE-FO-RPVLDE	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
G21-XHE-FO-LPCI	OPERATOR FAILS TO ALIGN AND ACTUATE FAPCS IN LPCI MODE	CP	XXX-XHE-FO-DESPRESS	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
G21-XHE-FO-LPCIADS	OPER FAILS TO ALIGN AND ACTUATE FAPCS IN LPCI MODE AFTER DEPRESURIZATION	CP	XXX-XHE-FO-LPMAKEUP	N/A	0.00E+00	Rule	1.00E-02	1.61E-02
G21-XHE-FO-RSPC	OPERATOR FAILS TO RECOG. NEED FOR SPC	CP	Rule	60 minutes	1.00E-02	N/A	0.00E+00	1.61E-02
G21-XHE-FO-SPC	OPERATOR FAILS TO MANUALLY INI. FAPCS IN SPC MODE	CP	G21-XHE-FO-RSPC	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
G21-XHE-FO-SPCADS	OPERATOR FAILS TO MANUALLY INI. FAPCS IN SPC MODE AFTER ADS	CP	G21-XHE-FO-RSPC	N/A	0.00E+00	Rule	1.00E-02	1.61E-02
G31-XHE-FO-SDC	OPERATOR FAILS TO ACTUATE SDC MODE NO MSL LOCA OUSIDE CONTAINMENT NO SLCS	CP	Rule	24 hours	1.00E-03	Rule	1.00E-02	1.77E-02
G31-XHE-FO-SDCATWS	OPERATOR FAILS TO ACTUATE SDC MODE ATWS	CP	Knowledge	24 hours	1.00E-02	Knowledge	1.00E-01	1.76E-01

Table 6.3-3b

Human Action Probabilities with a

Preliminary Analysis Type C (CP and CR)

Identification	Description	Type	Cognitive Part (1)	Available Time	Median Value	Manual Part	Median Value	Final Mean Value
G31-XHE-FO-SDCMSL	OPERATOR FAILS TO ACTUATE SDC MODE MSL LOCA OUTSIDE CONTAINMENT	CP	Knowledge	24 hours	1.00E-02	Rule	1.00E-02	3.21E-02
G31-XHE-FO-MIBOC	OPERATOR FAILS TO ISOLATE RWCU BREAK OUTSIDE CONTAINMENT	CP (2)	Rule	24 hours	1.00E-03	Rule	1.00E-02	1.77E-02
N21-XHE-FO-CONDMU	FAILURE TO MANUALLY OPEN CONDENSER MAKEUP VALVES	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
N21-XHE-FO-CONDPUMP	OPERATOR FAILS TO START CONDENSATE PUMP	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
N21-XHE-FO-FWPUMP	OPERATOR FAILS TO START FEEDWATER PUMP	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
N21-XHE-FO-FWRERUN	OPERATOR FAILS TO RESTART FDW AFTER RUNBACK- ATWS	CP	Rule	30 minutes	1.00E-01	Rule	1.00E-02	1.76E-01
P21-XHE-FO-STDBYPUMP	OP. FAILS MAN. ACT. OF STDBY PUMP WHEN AUT. ACTUATION FAIL	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
P22-XHE-FO-HX	FAILURE TO ALIGN TCCW HX	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
P22-XHE-FO-PUMP	FAILURE TO START STANDBY TCCW PUMP	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
P41-XHE-FO-TCCWHX	FAILURE TO MANUALLY ALIGN STANDBY TCCW HX	CP	Rule	30 minutes	1.00E-01	Skill	1.00E-03	1.63E-01
P51-XHE-FO-CMP	OPERATOR FAIL TO ISOLATE ONE COMPRESSOR TRAIN GIVEN OTHER FAILED	CP	Rule	60 minutes	1.00E-02	Skill	1.00E-03	1.77E-02
P54-XHE-FO-F009	OPERATOR FAIL TO REOPEN F009	CP	P54-XHE-FO-REOPEN	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
P54-XHE-FO-F013B	OPER ALIGN STDBY RACK FAILURE	CR	-------	-------	-------	-----	-----	True
P54-XHE-FO-F014	OPERATOR FAILS TO MANUALLY OPEN VALVE F014	CP	Rule	60 minutes	1.00E-02	Skill	1.00E-03	1.77E-02

Table 6.3-3b

Human Action Probabilities with a

Preliminary Analysis Type C (CP and CR)

Identification	Description	Type	Cognitive Part (1)	Available Time	Median Value	Manual Part	Median Value	Final Mean Value
P54-XHE-FO-F026	OPERATOR FAIL TO REOPEN F026	CP	P54-XHE-FO-REOPEN	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
P54-XHE-FO-REOPEN	OPERATOR FAILS TO RECOGNIZE OPENING OF F009 OR F026	CP	Rule	60 minutes	1.00E-02	N/A	0.00E+00	1.61E-02
T10-XHE-FO-CONTVENT	OPERATOR FAILS TO ACTUATE CONTAINMENT VENTING	CP	Rule	60 minutes	1.00E-02	Skill	1.00E-03	1.77E-02
U43-XHE-FO-2ND	OPERATOR FAILS TO ALIGN FPS CROSSTIE	CP	XXX-XHE-FO-DESPRESS XXX-XHE-FO-FPSLINY XXX-XHE-FO-LPMAKEUP	N/A	0.00E+00	Rule	1.00E-02	1.61E-02
U43-XHE-FO-LPCI	OPERATOR FAILS TO ACTUATE U43 IN LPCI MODE	CP	XXX-XHE-FO-DESPRESS	N/A	0.00E+00	Skill	1.00E-03	1.61E-03
			XXX-XHE-FO-FPSLINY					
U43-XHE-FO-LPCIADS	OPER FAILS TO ACTUATE U43 IN LPCI MODE AFTER DEPRESURIZATION	CP	XXX-XHE-FO-LPMAKEUP	N/A	0.00E+00	Rule	1.00E-02	1.61E-02
U43-XHE-FO-MAKEUP	OPERATOR FAILS TO ACTUATE U43 IN MAKE UP MODE	CP	XXX-XHE-FO-ICPCCS	N/A	0.00E+00	Rule	1.00E-02	1.61E-02
U43-XHE-FO-PMPTRK	OPERATOR FAIL TO SUPPLY WATER FROM PUMP TRUCKS	CP (3)	XXX-XHE-FO-ICPCCS	N/A	0.00E+00	Rule	1.00E-02	2.66E-02
XXX-XHE-FO-DEPRESS	OPERATOR FAILS TO RECOGNIZE NEED OF DEPRESSURIZATION	CP	Rule	30 minutes	1.00E-01	N/A	0.00E+00	1.61E-01
XXX-XHE-FO-FPSLINY	OP. FAILS TO RECOG. NEED FOR FPS LATE INYECTION	CP	Rule	24 hours	1.00E-03	N/A	0.00E+00	1.61E-03
XXX-XHE-FO-ICPCCS	OPERATOR FAILS TO RECOGNIZE THE NEED TO MAKEUP ICS/PCCS POOL LEVEL.	CP	Rule	24 hours	1.00E-03	N/A	0.00E+00	1.61E-03

Table 6.3-3b

Human Action Probabilities with a

Preliminary Analysis Type C (CP and CR)

Identification	Description	Type	Cognitive Part (1)	Available Time	Median Value	Manual Part	Median Value	Final Mean Value
XXX-XHE-FO-LPMAKEUP	OP. FAILS TO RECOG. NEED FOR LOW PRESS MAKEUP AFTER DEPRESURIZATION	CP	Rule	30 minutes	1.00E-01	N/A	0.00E+00	1.61E-01
XXX-XHE-FO-RPVLDE	OP. FAILS TO RECOG. OR CHECK THE RPV DECREASING LEVEL	CP	Skill	30 minutes	1.00E-02	N/A	0.00E+00	1.61E-02

(1) When the Identification of the basic event only applies to the manual part of the action in this column the identification of the cognitive part of the action is indicated

(2) Generic CR values are used for the cognitive and the manual part of the action because the manual part should be performed outside of the control room.

(3) Generic CR values are used for this the manual part of the action because should be performed outside of the control room

6.4 REFINEMENT OF HUMAN ERROR PROBABILITIES

In order to reduce the conservative contribution of human actions in the ESBWR PRA, human actions that prove to be important can be analyzed in detail.

The criteria for selecting the human actions for detailed analyses are the following:

- Any Type A human action which could potentially cause a failure of more than one redundant train/division of one or more systems
- Any single Type C human action of an operator which could directly cause damage to the core

The purpose of the detailed analysis is to remove unnecessary conservatism from the PRA results. Because of the way the screening values were chosen, more detailed analysis will reduce the HEPs. As a consequence, detailed analysis is not considered necessary in the DCD phase.

In order to perform a detailed analysis of the human actions modeled in NEDO-33201 Section 6.4, several procedures and data are required. The development and availability of most of these items are expected in the COL phase.

The type of procedures and information necessary to develop detailed analysis are listed below:

- Type A human actions:
  - Tagging procedures;
  - Test and calibration procedures;
  - Periodic Operational equipment realignment procedures;
  - Equipment position checking procedures; and
  - Walk around inspection procedures.
- Type C human actions:
  - Emergency Operating Procedures;
  - Abnormal Operating Procedures;
  - Integrated Operating Procedures;
  - Annunciator Response Procedures;
  - System operation procedures;
  - Plant staff organization procedures; and
  - Any other Plant special or auxiliary procedures.

Finally, to fully assess the final HEPs, it is necessary to evaluate other performance shaping factors (PSF) that could influence steps in each important human action basic event (for example, training, man-machine interface, operator experience, and so forth). Much of this information will not be available prior to the construction phase of the plant. Therefore, during the detailed design and COL phase, PSFs will be estimated based on data from existing BWR PRA models.

6.5 REFERENCES

6-1 EPRI: Systematic Human Action Reliability Procedure (SHARP), NP-3583, June 1984.

6-2 NUREG/CR-1278 "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report", August 1983.

6-3 NUREG/CR-4772 "Accident Sequence Evaluation Program – Human Reliability Analysis Procedure", February 1987.