IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations

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Abstract: A structured framework for the incorporation of human/system interactions into probabilistic risk assessments is provided.
Keywords: human reliability analysis (HRA), probabilistic risk assessment (PRA)

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Introduction

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Any process that requires manual control to minimize public risk will require a high level of human reliability. This reliability can be evaluated through the systematic application of a probabilistic risk assessment (PRA). However, such an assessment requires a detailed understanding of human factors to form a complete reliability estimate.

The initial risk assessment made in the nuclear power plant industry, WASH-1400, recognized the need for a discipline of human reliability analysis (HRA), systematically incorporated within the PRA enterprise. But the methodology—both of analyzing human failure events and identifying and incorporating them appropriately in the PRA—was new, incomplete, and in several ways inadequate.

The limitations of the understanding of human reliability in the mid-1970s was vividly demonstrated by the accident at Three Mile Island (TMI). Following TMI, the Nuclear Regulatory Commission (NRC), in conjunction with the Institute of Electrical and Electronics Engineers (IEEE), immediately called for a conference on the human factor issues raised by TMI. This conference has become a series, the fifth of which was held in Monterey, California, in 1992. Parallel to this activity, Subcommittee 7, Human Factors and Control Facilities, of the Nuclear Power Engineering Committee, began discussing the standardization of the HRA technology. The PRA/HRA interface of incorporating and performing an HRA in the context of a PRA was recognized as the most mature of the efforts of HRA. A guide, the least mandating of the IEEE standards documents, was approved as an IEEE standards project in 1984.

In recent years, some convergence in the ideas and methods of HRA has occurred. Most PRAs perform HRA in a standard way, even when using approaches as diverse as the Systematic Human Action Reliability Procedure of the Electric Power Research Institute (EPRI) and the Accident Sequence Evaluation Program HRA method of the NRC.

This guide outlines the steps necessary to include human reliability in risk assessments. It is not its intent to discuss the details of HRA methods, since this technology is evolving and cannot be addressed in the needed depth in this guide. The reader is urged to review bibliography entries [B1], [B2], [B5], [B12], and [B22] for this information. Since human error has been found to be an important contributor to risk, this guide underscores the systematic integration of the HRA at the earliest stages and throughout the PRA.

It is anticipated that human reliability technology will not escape controversy in the near future. This is especially true regarding the quantification of Human Error Probabilities, which is not specifically addressed in this guide. In one sense this is a blessing, since it may ensure that the industries do not become complacent to the contribution of people and their actions to the risk spectrum of the technology they work.

Participants

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IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations

1. Overview

1.1 Scope

This guide provides a structured framework for the incorporation of human/system interactions into probabilistic risk assessments (PRAs).

1.2 Purpose

The purpose of this guide is to enhance the analysis of human/system interactions in PRAs, to help ensure reproducible conclusions, and to standardize the documentation of such assessments. To do this, a specific human reliability analysis (HRA) framework is developed from standard practices to serve as a benchmark to assess alternative ways of incorporating HRA into PRA.

2. Definitions

Several terms used in this guide are important, yet are ambiguous in common usage or not used frequently enough to be well known. They are defined in this clause.

2.1 cognitive process: An internal human activity that receives, manipulates, and stores knowledge or information, or that controls actions according to this knowledge.

2.2 consequences: The result(s) of (i.e., events that follow and depend upon) a specified event.

2.3 diagnosis: A cognitive assessment of the state of the system.

2.4 event: (A) Any change in conditions or performance of interest. **(B)** An occurrence at a specific point in time.

2.5 event tree: A graphical representation of the logical progression of the possible scenarios through a multiple series of events that may, or may not occur.

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2.6 fault tree: A graphical representation of an analytical technique whereby an undesired state of a system is specified and the patterns leading to that state can be evaluated to determine how the undesirable system failure can occur.

2.7 framework: A conceptual system of tasks or activities used in a specified type of analysis.

2.8 human action: The observable result (often a bodily movement) of a person's intention.

2.9 human interaction: A human action or set of actions that affects equipment, response of systems, or other human actions.

2.10 model: An analog representation, which may be conceptual, qualitative, or quantitative.

2.11 recovery: A set of interactions intended to restore failed equipment or to find alternatives to achieve its function.

2.12 reliability unit: That portion of a system for which a single reliability model is valid, i.e., for which there is a single mechanism of failure.

2.13 rule: (A) A series of steps or activities with a single known or anticipated result. **(B)** A guideline for acting or planning action.

2.14 skill: A cognitive and/or physical control process so highly practiced as to require little or no conscious supervision.

2.15 system: An integration of parts or constituents, their relationships, their mutual behavior or possible states, and the laws or rules that determine their behavior.

2.16 taxonomy: A classification scheme, or its results.

3. Overview of an integrated HRA

The risk associated with a nuclear power plant is highly dependent on the reliability of people and their interactions with the equipment and controls in the plant. An HRA is an integral part of a Level 1 PRA. In higher level PRAs, Levels 2 and 3, the quality of the analysis, i.e., quantification of human error, is dependent on the analyst's ability to specify scenarios and the expected human actions. This guide provides a specific approach that, if applied, will standardize the integration of HRA into the PRA process. The breakdown and order of the steps presented are not so important; all of the steps and their activities, however, should be found within any HRA.

3.1 Overall evaluation issues

The focus of this guide is restricted to the incorporation of the HRA integrally into a PRA. This includes the following issues:

a) The compatibility of an HRA with the PRA of which it is a part;
b) The relationship between the way in which an HRA is performed, its philosophy, and the results or insights that may be obtained;
c) The flexibility required in the use of behavioral science technologies associated with HRA; and
d) The limits of an HRA or its results.

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3.1.1 PRA compatibility

The HRA process proposed is suitable to all levels of a PRA given defined scenarios and procedure-based human actions. If these are not defined, then guidance cannot be applied successfully. The guidelines and basic requirements of the HRA follow from those of the PRA. The risk perspective of a PRA requires the quantitative results of an HRA to be probabilistic in nature. The risk applications of PRA require the HRA process to specify human interaction events in qualitative detail sufficient to guide the risk management efforts from a human factors perspective. PRA is a large enterprise, the objectives of which may not be completely identified prior to the assessment. The HRA process should be flexible enough to anticipate some of the likely applications of the results of the HRA. For example, this may include design changes, procedure changes, training development, safety evaluations, or technical specification modification.

3.1.2 The relationship of approach to results

Assumptions made by HRA analysts about the importance of various activities will influence the breadth and detail of models developed for the HRA. The data or chosen method of quantifying human interactions will influence the specific estimates or ranges of uncertainty obtained. It is thus possible to obtain different, even disparate, estimates of human reliability using different quantification methods. Additionally, if results point to the need to improve the reliability of selected human interactions, these improvements should either be readily identifiable from the documented HRA or should be the subject of further or different analytical methods that will allow improvements to be identified as described in IEEE Std 845-1988 [B9].[1] The HRA analyst should bear this in mind when considering the specific approach to be taken.

3.1.3 Flexibility

A wide variety of HRA-related methods are available and being developed (e.g., expert data methods versus plant data, and cognitive versus task-action models). The HRA is a relatively immature technique; however, it is based on the scientific disciplines established in the behavioral sciences with their inherent uncertainties. The HRA should be flexible enough to accommodate new findings and model developments, while structured enough to be repeatable and tractable.

3.1.4 Limits

The results of an HRA should be documented in a format that is understandable to the general user of a PRA. The results should be traceable to their basic assumptions, models, and data sources. The PRA-induced requirement on an HRA is to provide a realistic-as-possible interpretation of the role of plant personnel in accident prevention and mitigation. The HRA also provides input to the PRA analysis and estimates the contribution of this role to plant risk.

3.2 HRA process

A specific HRA process is depicted in Figure 1. It parallels the typical PRA process, but is not organizationally related to it. It should be used so as to be compatible with the PRA. The chosen HRA process is an adaptation of a process that has been used in many PRAs (see [B7]). The general structure is described in 3.2.1, the specific steps are described in 3.2.2 and detailed in Clause 4, and the outputs at each step are described in 3.2.3. The specific timing and level of detail of the HRA must match the PRA. Therefore, the HRA structure discussed in this guide should be applied with modification as needed. In its general form, Figure 1 can also show the initial portions of the PRA process, so that both efforts are truly integrated to form a homogeneous team.

[1]The numbers in brackets correspond to those of the bibliography in Annex B.

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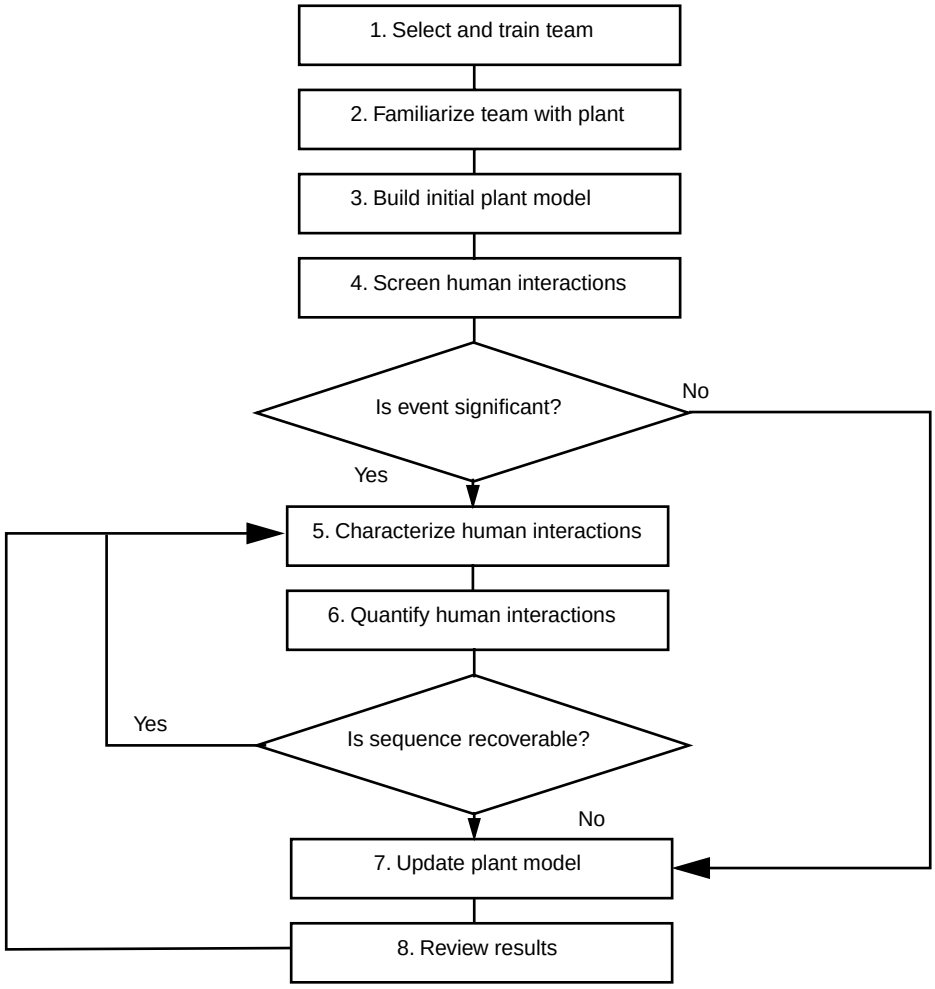


Figure 1—The HRA process

3.2.1 HRA structure

The HRA should be incorporated within the PRA in a stepwise manner. The PRA analysis should begin at a level that is broad enough to ensure completeness without including unnecessary details. As the analysis moves forward, the focus on risk-significant aspects of the plant that affect the core damage frequency becomes possible and breadth can be traded for depth in the analysis. This narrowing of the analysis requires evaluation and judgment. This focusing of the analysis is referred to as *screening* by PRA practitioners.

In this screening step, the resources of the PRA team should be concentrated on those events, including human interactions, that are likely candidates to contribute significantly to the assessed plant risk. This allows the HRA team to minimize the time and resources that are needed to arrive at the risk contribution of human interactions.

This screening step, as shown in Step 4 of Figure 1, is one of the tasks in the flow path of the HRA process. When the PRA process screens events for risk significance, the HRA process should support this screening by providing

— Reasons for ignoring human interactions, or
— Human interactions in the event descriptions (scenarios), or
— Conservative estimates of the probabilities of human error to be used in the screening.

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These conservative estimates are called *screening values.*

The HRA should support the PRA analyst during plant failure model construction by giving guidance regarding which human interactions can be left out of the model, either because they are not likely to be risk-significant or because they can be best introduced when the PRA models have more definition. For example, events that PRA practitioners have called *recovery events* are often not included early in the analysis. These events are logically associated with hardware models that have to be included. The omission of the human interactions is typically conservative with respect to risk because during the initial stages of the PRA the analyst does not take credit for human intervention to restore equipment or, more likely, to find a functional alternative. Hence, the overall likelihood of equipment failure increases. Note that this would not be the case with cognitive errors that lead to system propagations worsening the situation. However, such failure events should not be identified until sequence details are understood and the recovery analysis is performed. The HRA should support the recovery analysis as it does other parts of the PRA.

3.2.2 Summary of HRA steps

The HRA process depicted in Figure 1 is a process of eight tasks and two major decisions. These steps are detailed in Clause 4. These steps form a basis for auditable documentation of the HRA. If the team chooses to deviate from this process, then the deviations from this framework can also be documented for auditability.

The HRA process begins with the selection and training of the PRA team. The team should familiarize itself with the plant and its system, functions, and procedures. The first models of the plant are developed jointly by the team. This model identifies the major human interaction events in functional terms. The results form a list of interactions that are screened by restricting the analysis to candidate-dominant sequences. The HRA supports the screening by providing rough but conservative point estimates of the probabilities of all the human interaction events called screening values, into the models at this stage.

Human actions whose failures are found to be significant contributors to risk are then characterized in detail to support some quantification technique and to support application of the PRA results. Each human interaction is then quantified. The result of the quantification step often changes the event description or adds a more detailed representation of the event; the result should be incorporated into the update of the model. If recovery events are identified at the final stage of the PRA analysis, then the models of these events, including the models of the human interactions, are incorporated into the updated models.

The final review step ends the familiarization activity and, if the PRA team includes people from plant operations, should only be confirmatory. However, numbers or even details could change as a result of this auditing process.

Finally, the documentation of the HRA, like the rest of the PRA, is a crucial step that is ongoing throughout the HRA. This step is not shown on the flow chart in Figure 1, but is detailed separately in Clause 6.

3.2.3 Outputs

The HRA process is structured so as to be able to yield useful results at each step of its production. Table 1 lists the kinds of information produced at each step. Generally, all steps of the HRA process will be performed, since they together represent the steps needed to support a PRA of any level.

4. Details of the HRA process

The HRA process, as summarized in Clause 3, is detailed below and includes each step and a statement of purpose, a description of the step, and a statement of output. A strong technical interface between the HRA practitioners and the rest of the PRA team performing the equipment reliability modeling is required.

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Table 1—Products of the HRA process steps

Step	Product
1. Select and train team	Set of skills embodied in an integrated team.
2. Familiarize team with plant	Initial identification of human functions and activities. Problems can be spotted although without much risk context yet.
3. Build initial plant model	All major systems modeled; System interactions identified; A measure of the defense barriers against major classes of off-normal events; Most key human interactions identified.
4. Screen human interactions	Key human interactions identified, screening values chosen, and initial quantification performed.
5. Characterize human interactions	Failure modes, mechanisms, causes, effects, and influences of the key human interactions are determined.
6. Quantify human interactions	Importance ranking, likelihood and uncertainties of key human interactions.
7. Update plant model	Recovery models and interactions added to model.
8. Review results	Confidence that results make sense and can be used by plant staff in risk applications.

4.1 Select and train team

The HRA process requires contributions from a wide range of skills in engineering, plant performance, and behavioral science. It is important that the team that performs the HRA possess a correct mix of these skills. The number of people on the team and their formal backgrounds are relatively unimportant, so long as the aggregate represents the skills listed in 4.1.2. The required training should include methods for cooperation and communication across disciplines (Figure 1, Step 1).

4.1.1 Purpose

The purpose of this step is to assemble a highly qualified team that works well together and integrates several important skills and disciplines. The quality of the HRA portion of a PRA depends, in large part, on the quality and training of this team and its ability to communicate. This teamwork, early in the PRA, will further ensure the identification and analysis of human interaction that can impact the results of the PRA.

4.1.2 Description

The human reliability analysis and expertise in human factors engineering is assumed to encompass the techniques of data collection for the analysis as described in IEEE Std 845-1988 [B9].

Human factors/personnel subsystem analysis provides an evaluation of humans in terms of the role they play as a subsystem that works or operates in the broader context of the system under examination. This type of analysis focuses on producing a systems analysis of human interaction, which can be overlaid on the systems analysis of the plant processes and equipment to identify the areas of match and mismatch between human capabilities and requirements for operation of the plant. This includes control team makeup, shift work, training, etc.

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The expertise required for HRA includes areas a) through d) below. These experts interface with other experts on the PRA team as described in areas e) through g) below. This list does not imply that individuals in each of the specific areas are required. Individuals may have multiple areas of expertise. HRA expertise should be part of the PRA team throughout the analysis. For a detailed alternative description of an HRA/PRA approach, refer to [B24].

a) *Plant operations personnel* provide experienced insight into the way(s) in which people conduct their jobs/tasks in light of training, procedures, and operating experience. As such, they provide added reality to the analysis of human-system interaction and can identify information about task requirements that may not be apparent from system operating descriptions and procedures.

b) *Human factors engineering personnel* provide information about optimal design characteristics to maximize performance in light of human capabilities and limitations. The human factors engineer augments the team by identifying potential areas of human engineering discrepancies (HEDs), which need to be taken into account when evaluating performance shaping factors that contribute to the reliability or risk of an operation.

c) *Human reliability analysts* develop or work with the developed detailed qualitative models of the human systems analysis to provide both qualitative and quantitative estimations of human reliability. The human reliability analysts work with a variety of quantitative techniques to address performance shaping factors, time, and training constraints, and their impact on the reliability of human performance.

d) *Nuclear power plant systems engineering personnel* bring a broad range of knowledge of how the systems examined are designed, operated, and maintained. These personnel are knowledgeable of general operating practices and the details of equipment capacities, operating envelopes, and equipment performance, and they support the analysis of human-system interaction.

e) *Systems safety analysts* provide evaluations of system performance and human performance requirements for situations in which systems conditions transition from normal to abnormal and beyond technical specification operating envelopes. The systems safety analysis may include thermal-hydraulic, fuel, and fission product behavior, and other phenomenological assessment methods to identify realistic functional requirements and success criteria for the human.

f) *Probabilistic risk assessment personnel,* who develop equipment reliability models and data, provide the detailed information on failure rates (or probabilities) for hardware caused by internally and externally initiated events. Output of the PRA usually consists of fault trees, cut sets, or event trees to which the HRA analyst provides input to model the role of the human in system operations for the events under consideration.

g) *Instrumentation and control (I&C) engineers* provide knowledge about the functioning of controls and other instrumentation used by operating personnel to control the process(es) of the systems under examination. Since the types of control and safety systems employed in the plant generally influence the ability of the operating personnel to operate a system, information about I&C is necessary to identify potential problems with system operation.

The HRA team training should be aimed at the development of integrated working relationships among team members and at definition of responsibilities for each member. This training should also provide opportunities for each member to become familiar with the vocabulary of the HRA process and of the skills represented by the other members. The use of sample problem sets, worked on by the entire team, is one effective way of accomplishing these goals.

4.1.3 Output

The quality of the HRA will depend on the quality and integration of the HRA expertise within the PRA team. The quality of the HRA will, in turn, influence the quality of the associated PRA. The results of the team selection and training step should be a well-qualified team that brings together the needed skills in a coordinated and integrated effort.

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4.2 Familiarize team with plant

The HRA requires considerable general and specific knowledge about a plant, including the following:

a) Plant systems and equipment (how it works, its location, and its interconnections)
b) Procedures and operating practices
c) Technical specifications
d) Control facilities including control room, peripheral control facilities, and control and instrumentation
e) Training
f) Crew structure

The HRA is now at the stage indicated in Figure 1, Step 2.

4.2.1 Purpose

The purpose of this step is to provide the team with knowledge of the plant and its operations. The familiarization proceeds throughout the duration of the project.

4.2.2 Description

The team members should become familiar with the plant at the onset of the analysis. The team should understand the plant layout, its systems, its procedures, its instruments and controls, and the structure of the operating crews. This familiarization should include visits to and reviews of the plant and its areas where human interaction takes place. This should include interviews with personnel that perform these interactions to understand their expectations, knowledge, and typical response to plant actions. Where practical, the use of plant training simulators to aid in understanding the response of the control room crew to selected scenarios may prove beneficial.

4.2.3 Output

The output of this step is a team that has a knowledge base to adequately support the project. This knowledge should directly lead to an ability to identify the following:

a) Safety-significant human functions and activities
b) Success criteria for these human actions
c) Potential problem areas in human performance

4.3 Build initial plant model

The HRA expertise, input, etc. should be integrated into the development of the initial plant PRA model to ensure the completeness of the study (Figure 1, Step 3).

4.3.1 Purpose

The purpose of this step is to model the plant's performance in response to selected initiators, events that produce off-normal conditions. The HRA specialists work with the system modelers to ensure that the plant model properly incorporates the human role in the response and makes sense from an integrated perspective. The human failures that could produce initiating events or affect the plant's performance in response to postulated off-normal conditions should also be identified.

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4.3.2 Description

The specific techniques selected and used in the HRA will directly affect the results of the project. The philosophy of human performance and the techniques used in the HRA impose constraints on the PRA models. Similarly, the style and methods of the PRA chosen direct the HRA toward the types of events to be identified.

Human interaction events that are represented as failures to be consistent with the PRA perspective should be classified into one of the following main categories:

a) *Pre-initiator events.* Failures in human activities conducted during normal plant operation that lead to inoperable equipment without causing an off-normal condition in the plant. These events have often been called latent events, since their effects are to leave faulted equipment in an undetected, unavailable condition for response during a transient. These errors should be included in the PRA as a contributor to demand-related unavailability of equipment. An example is leaving a vital system or component inoperable after maintenance that, in turn, fails a system when it is called upon.

b) *Human-induced initiators.* Failures in human activities conducted during normal plant operation that lead directly to off-normal plant conditions and thus initiate a transient. An error that directly causes a high- or low-pressure boundary loss of coolant accident (LOCA) is an example of such an event.

c) *Post-initiator events.* Failures in human activities in response to an off-normal condition. One typical kind of post-initiator event is the failure of personnel to actuate a needed, manually actuated system. Failures in contingency actions are often referred to as *recovery events* and are failures in activities related to restoration of inoperable equipment or finding of alternatives to the use of failed equipment.

These categories correspond to the terminology of the PRA and its logic models. The philosophy of human performance directly affects the location and description of human interaction events at this stage of the HRA. Depending on the category and its importance, the errors may be included for analysis in the fault trees or event trees.

4.3.3 Output

This step produces an initial list of human actions whose failure can influence the outcome of scenarios in the PRA. Each event is characterized functionally and is correlated to the current plant model. During this step, the HRA specialists should consistently and sensibly identify the boundary conditions under which the actions will be performed and their success criteria, e.g., under LOCA conditions, within first 10 min.

4.4 Screen human interactions

Since the evaluation of the PRA models to assess core melt frequencies and their consequences may require extensive computer time and high costs, the models are screened for risk importance to ensure an efficient focusing of the remaining study (Figure 1, Step 4). This step may require iteration, depending on the status of the PRA when the screening is performed.

4.4.1 Purpose

The purpose of this step is to support the PRA screening stage by assisting the PRA team to identify those actions whose failure can have significant impact on plant risk.

4.4.2 Description

The identified human interaction events are roughly quantified at this point. Minimal analysis is performed on the events at this stage. The values that the human reliability analyses provide the PRA at this stage are called screening values. These screening values are deliberately assigned conservatively so as not to inad-

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vertently omit important parts of the plant model. The assignment of screening values may be supported by a particular HRA technique or may require judgment on the part of the team. Many events that are identified in the early modeling activity do not have to be analyzed in detail. This conserves HRA resources and directs the focus of the HRA toward the events that are assumed by the PRA model most likely to be risk significant. However, the screening values chosen should be consistent with anticipated further uses of the study.

4.4.3 Output

The initial conservative estimates of human failure probabilities are used during the initial quantification of the plant model. The result of the screening step is a list of human interaction events (except possibly for some recovery events) that will be the focus of the remainder of the HRA.

After screening, the candidate dominant sequences that survive this screening as potential risk contributors are known. The human interactions that are not associated with these sequences do not require a detailed analysis. Only the human interactions in the dominant sequences are carried through the rest of the HRA process. The human actions that have survived the screening process will be evaluated in greater detail in Step 5. All the human actions that have been screened out shall be documented in an initial report to ensure completeness of the work. At this point, a detailed HRA begins.

4.5 Characterize human interactions

The PRA should have identified sequences that are the likely candidates for the plant's dominant risk sequences. In this step, the HRA specialists analyze the human interactions that remain in sufficient detail to quantify them in the next step (Figure 1, Step 5).

4.5.1 Purpose

The purpose of this step is to develop enough information to characterize each human interaction so that it may be quantified.

4.5.2 Description

The initial identification of the events in Step 3 was in functional terms. The events that have been retained in the analysis (posing a high risk of core melt) require additional detailed analysis to determine specific failure modes, mechanisms, causes, and effects. The information that is gathered should be sufficient to account for all important influences (sometimes called performance shaping factors) on the probability that the operating crew will fail to accomplish the required action. This information is model/quantification method dependent and requires insights into behavioral science methods, such as task sequences, time lines, operator burden, and environmental conditions.

A number of performance-shaping factors should be considered for deriving the probability of failure for the actions considered in an HRA. The performance-shaping factors explicitly incorporated into the models should include the following, as a minimum:

a) Type, location, and design of controls/displays.
b) Type, sensory mode employed, delay, and frequency of feedback.
c) Characteristics of procedures used.
d) Task organization and task loading of control-room personnel when handling a transient or accident under worst-case conditions.
e) Management organization and the supervision of personnel and procedures for carrying out maintenance tasks.
f) Training quality and content, frequency of training, and training specificity.
g) Worker competency level in relationship to tasks germane to the event.

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4.5.3 Output

This step produces a characterization of the original screened human interaction in its likely failure mode. This representation may be descriptive or graphical. For each failure mode, one or more failure mechanisms are identified, as well as the likely failure causes. It then identifies all influences on the particular failure mode's occurrence probability.

4.6 Quantify human interactions

This step follows the identification and characterization of the human interaction events and is composed of the quantification of those human actions identified in the predefined accident sequences in the plant model and the evaluation of the PRA. The HRA process is now at the point indicated in Figure 1, Step 6. (See [B3], [B5] and [B25].)

4.6.1 Purpose

The purpose of this step is to provide a numerical estimate (as described in 4.6.2) for each human interaction event in candidate dominant sequences. The estimates should be consistent with the numerical accuracy requirements of the PRA. This allows the quantification of the dominant sequences and thus, risk, as well as its numerical uncertainty by the PRA analyst.

4.6.2 Description

The numerical estimation of human interaction events would be best obtained from a database of appropriate events. The data used in adjusting probability values, as well as in model development, can be obtained from a general review of the Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR) data; from interviews with operators and maintenance personnel; and from physical examinations, walk-throughs, and talk-throughs of specific controls and control actions. Plant-specific historical data and Licensee Event Reports (LERs) should also be thoroughly reviewed. Surrogates to data can also be used. Simulators are a potential source of surrogate data and work sponsored by EPRI and the Oak Ridge National Laboratory have provided usable data. Interviews and walk-throughs are also valuable tools to collect data that will help in the quantification process. Plant-specific data should be used whenever available. In many cases, especially when quantifying errors not related to well understood plant procedures, data will be unavailable. In these human actions of commission and recovery, quantification must be based on the best available information and in many cases expert opinion. The analyst is cautioned that these types of errors can many times dominate the risk calculations and therefore must be well described and treated accordingly. Due to the inherent uncertainty of this quantification process, point estimates without a statement of uncertainty should be unacceptable to the HRA. (See IEEE Std 845-1988 [B9] and [B13] through [B16].)

4.6.3 Output

This step adds a numerical estimate, including error bounds, to each significant human interaction and its qualitative characterization.

4.7 Evaluate additional recoverability

Once the sequences have been quantified, the PRA team should evaluate whether additional recovery actions are possible. Some recovery actions may have been included in the initial development of human interactions for the PRA model.

4.7.1 Purpose

This task evaluates the potential for including the recovery of failed systems and additional human actions and/or systems into the model.

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4.7.2 Description

Once the candidate dominant sequences are identified, those additional human recovery actions and/or systems that can prevent the undesired outcome can be incorporated into the model. The human interactions identified should be characterized and quantified on a scenario-specific basis, since the likelihood of operators' success is heavily contingent on the plant conditions presented to them. This action is the source of the feedback indicated in the HRA process in Figure 1. By incorporating alternate means of mitigating risk-significant events, the risk profile may be changed. As a result of these recovery actions, the overall risk profile may be decreased and the list of dominant sequences may be altered. Certain sequences that were previously identified as risk-significant may be of less importance to overall plant risk when recovery actions are factored into the risk profile. This may be especially important in cases where the results of the PRA are being used to justify costly modifications to the plant.

4.7.3 Output

The output of this step is a set of human interactions that is needed to reflect additional, heretofore unmodeled, recovery into the plant model. These human interactions have been qualitatively and numerically characterized by an analysis that accounts for the specific plant conditions that exist at the time the recovery is attempted.

4.8 Update plant model

This step occurs when the sequence solution has been reviewed and the recovery analysis is performed for the significant sequences. Then the plant model is updated to reflect the final human interaction events and their numerical characteristics (Figure 1, Step 7).

4.8.1 Purpose

The purpose of this step is to update the model of the plant that includes recoveries and all significant human failure events identified over the course of the HRA.

4.8.2 Description

All aspects of the contributions to risk should be included in the updated plant model. Dependencies among human failure events or between human failure events and other events should be clearly identified in the models. Each human failure event in the model should be identified as to whether it is quantified with a screening probability or a detailed analysis.

4.8.3 Output

The output of this step is a plant model that includes all reasonable sources of human failure events that affect the dominant sequences and the recovery contributors to plant risk.

4.9 Review results

A PRA integrates diverse information about the plant. Its results depend on the accuracy of this information, and the adequacy of the plant logic model to combine this information into clear and realistic delineation of the scenarios that lead to the undesired events. A final review of the HRA analysis by qualified people external to the PRA team is required as identified in Figure 1, Step 8.

4.9.1 Purpose

This step verifies that the results of the HRA and PRA are reasonable relative to the plant, its equipment, and its operation.

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4.9.2 Description

The results of the HRA and PRA are ensured to be credible by one or more means. The HRA results should be reviewed against station tests and by maintenance and operations personnel. Talk-throughs or walk-throughs of the dominant sequences should be used to validate the decision-making and diagnostic strategies assumed by the HRA for each sequence. When available, simulator exercises are a preferable but more costly means to validate this kind of information. Sequence reviews should be conducted before the final quantification stage of the PRA. The HRA review team should include a member familiar with plant operations. Other plant operations and maintenance personnel should be solicited at the end of the analysis to review the HRA results for credibility and informational accuracy. The HRA part of the analysis should be reviewed by independent HRA experts.

4.9.3 Output

The output of this step is a human reliability analysis that reasonably reflects the contribution of human actions to plant risk that can be used in the utility's risk reduction efforts. This provides a tool to focus on contributors to risk and help justify modifying plant performance, thereby making the plant and its operations safer.

5. Documentation

The objective of HRA documentation is to produce a traceable description of the process used to develop the quantitative assessments of human interactions. In this step, both the system and human reliability analysts provide the descriptions of data, assumptions, models, and representations used. In addition, important dependencies and sensitivities that impact the representation or models should be identified for integration into the uncertainty and common cause analyses.

The analysis documentation should be organized to ensure that the information and data are clearly presented; that the assumptions, data sources, models selected, and criteria for elimination and retention of human interactions are recorded; and the human impact on fault trees, event trees, sensitivities, and initiating events is stated. The output is a report documenting these aspects.

Each step of the HRA process should be documented and include the following:

a) The origin of source data and reasons for selection.
b) The nature of the operating history review.
c) The operation history reviews applied.
d) The methodology used.
e) The reasons for selection of methodologies used.
f) The specific operation actions explicitly modeled.
g) The nature of operator interaction analysis performed.
h) The types of operator actions modeled implicitly.
i) The method of screening and quantitative values, if used.
j) A list of the important actions carried out for more detailed analysis.
k) The nature of plant staff interviews.
l) The type of control room reviews.
m) The limitation (boundary conditions) on use of each value; i.e., just for LOCA, just for low level, etc.

The net results of the HRA documentation should fit the PRA needs and provide a reviewer or user of the PRA with a usable, auditable paper trail for the HRA results. An example and description of a data table for recording and documenting HRA data is in Annex A.

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Annex A

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An example for documenting HRA data

A suggested data table is presented along with a description of each item, A through T. Each of these elements should be recorded to ensure that the HRA process is repeatable, verifiable, internally consistent, and understandable to the regulator, utility management, and other HRA professionals.

Table A.1 displays the minimum data categories that should be recorded and stored.

Each of the items/columns must be addressed so that a traceable record is generated for each human error probability (HEP), along with the appropriate performance shaping factor (PSF). The elements of the table are defined as follows:

A. Sequence no. Enter the relative task sequence of a series of important tasks taken from the event tree and/or fault tree node designator (item P of Table A.1) e.g.:

task 1.1.
task 1.2.
task 1.2.1.
task 1.2.1.2.

If a task analysis has already been conducted at the plant, the HRA team may choose to select those task items from the task analysis sheets and include only those task sequences of interest in the HRA data file.

B. Task description. Describe each task in the sequence of interest. It should start with who does the task, what is done, and how it is accomplished, e.g.:

The operator	opens valve	V612	by turning a J handle	to the right.
WHO	ACTION	OBJECT	HOW	WHERE

The task description may be derived from the emergency operating procedures or from a task analysis that may have been performed at the plant before the HRA team was assembled. If the data for this item is not available, then a limited-scope task analysis or recorded walk-through should be conducted.

C. Task purpose. State the reason for each task action. This information (items B and C in the HRA data file) may be obtained from the operating procedures, operations staff, or shift supervisor.

D. Task initiator. List the task initiator. A task can be initiated by an alarm, a person (supervisor request), or a procedure step, or the task may be self-initiated by the operator. Initiators are typically listed as SYSTEM-PROCEDURE-PERSON- or SELF-.

E. Plant system affected. Describe the plant system or subsystem that is affected by the execution of the task (e.g., turning a pump on or off would impact the safety cooling subsystem or cooling fluid inventory).

F. Task time required. Record the time required to perform this task and compare it with the time it actually takes to complete. Typically the time is listed in minutes.

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G. Important PSFs and weight. Record only the important PSFs related to the task and the appropriate weight assigned.

H. Realistic human error description. Describe, in detail, the important human errors that could propagate into possible core damage.

I. Rationale for human error. For each human error described in item H, provide a rationale (e.g., the operator may fail to activate the correct pump because the pump is not called out by name in the procedure and the pump labeling designator is obscured by a maintenance tag hanging above it. In addition, the training program does not specifically address this action related to the task and the operator who provided the walk-through was unable to find the correct switch. The operator had to ask the shift supervisor where it was located).

J. Human engineering discrepancies (HEDs). List any HEDs that may impede the task or make it difficult to find or operate, (e.g., the lighting on this panel is below the value specified in NUREG 0700 and MILSTD 1472-D, and the instrument is physically located outside the optimal range of viewing).

K. Training module & quality. Complete this item after reviewing the applicable training modules associated with each important operator task. Summarize the findings concerning discrepancies noted during the assessment of training materials and course content, along with the relevant criteria used during the review. The criteria for this assessment may be drawn from several sources including the NRC, the Department of Energy (DOE), EPRI, and Institute of Nuclear Power Operations (INPO).

L. Procedure no., name, and rated quality. Record the procedure number if any associated with the task under review, the name of the procedure, and the criteria used for the assessment.

M. Operator experience & background. Record information concerning the least-experienced operator at the plant who will be expected to perform this task. Any background factors such as vision, hearing, general health, etc. should also be listed. During the HRA, it should be assumed that the weakest human link (regarding prior experience) will be called to execute the task under a worst-case scenario. The reason for this approach is to provide a conservative (from a safety perspective) human error estimate.

N. Environmental factors. List the relevant factors and quantitative measures for items such as heat, noise, illuminance, radiation level, and humidity if it is felt that these factors may influence the execution of the task both in terms of completion times and probability of error.

O. List of past errors related to this task. Describe any past human errors that have occurred regarding this task and event scenario. Data sources such as LERs, unusual occurrence reports (UORs), or other internal plant records may be used for this purpose if the information exists. If there are no written records available, then attempt to interview a cross-section of operators to obtain their opinions and experiences. Include “near miss” information if it is available.

P. Event tree and/or fault tree node designator. Record the event and/or fault tree node designator/description associated with the task under study so that others may quickly trace the task back to the appropriate document and element on the event tree.

Q. Previous event outcome. Past events should be reviewed and recorded in order to ascertain expected occurrence frequency and expected consequence. Any problems in task execution should be noted along with the frequency of occurrence. This information will be valuable in determining past events likelihood and their possible influence in sharpening operator skills under pressure. If this information is unavailable, try to assess the frequency with which drills are performed that simulate this event.

R. Management/organization control factors. Record conclusions and criteria used to assess the impact of various management /supervisor controls over the task from a safety perspective.

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S. Human error probability (HEP) with upper and lower bounds. List the actual calculated HEP along with the upper and lower bounds.

T. HEP Rationale summary. Record assumptions used and a quantitative summary of the rational behind the HEP calculation and document the PSF weights used for the calculation. The purpose here is to ensure that the numbers used are verifiable, repeatable, and open to public scrutiny (understandable).

Table A.1—HRA data elements

(Include title of event)

A	B	C	D	E	F	G	H	I	J
Sequence no.	Task description	Task purpose	Task initiator	Plant system affected	Task time required	Important PSFs and weight	Realistic human error description	Rationale for human error	HED discrepancies

K	L	M	N	O	P	Q	R	S	T
Training module & quality	Procedure no., name, & rated quality	Operator experience & background	Environmental factors	List of past errors related to this task	Event tree and/or fault tree node designator	Previous event outcome	Mgmt./Org. control factors	HEP with upper & lower bounds	HEP rationale summary

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Annex B

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