

INTERNATIONAL STANDARD

IEEE Std 1082™

Guide for incorporating human reliability analysis into probabilistic risk assessments for nuclear power generating stations and other nuclear facilities

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Guide for Incorporating Human Reliability Analysis into Probabilistic Risk Assessments for Nuclear Power Generating Stations and Other Nuclear Facilities

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IEEE Guide for Incorporating Human Reliability Analysis into Probabilistic Risk Assessments for Nuclear Power Generating Stations and Other Nuclear Facilities

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Abstract: A structured framework for the incorporation of human reliability analysis (HRA) into probabilistic risk assessments (PRAs) is provided in this guide. To enhance the analysis of human/system interactions in PRAs, to help ensure reproducible conclusions, and to standardize the documentation of such assessments are the purposes of this guide. To do this, a specific HRA framework is developed from standard practices. The HRA framework is neutral with respect to specific HRA methods.

Keywords: HRA, human reliability analysis, IEEE 1082™, PRA, probabilistic risk assessment

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IEEE Introduction

This introduction is not part of IEEE Std 1082-2017, Guide for Incorporating Human Reliability Analysis into Probabilistic Risk Assessments for Nuclear Power Generating Stations and Other Nuclear Facilities.

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 performance and human reliability methods to form a reasonable reliability estimate.

The initial risk assessment made in the nuclear power plant industry, WASH-1400 [B17], recognized the need for a discipline of human reliability analysis (HRA) to be systematically incorporated within the PRA enterprise.¹ But the methodology—both 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 were vividly demonstrated by the accident at Three Mile Island (TMI). Following TMI, the United States 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.² This conference has subsequently become a series. Parallel to the initiation of the conference, Subcommittee 7, Human Factors and Control Facilities of the IEEE Nuclear Power Engineering Committee began discussing the standardization of 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. The guide was revised in 1997.

This guide outlines the steps necessary to include human reliability in risk assessments. The intent of the guide is not to discuss the details of specific HRA methods, but rather to affirm a method-neutral framework for using a diverse range of HRA methods to support PRA. 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.

Since the 1997 revision of IEEE Std 1082TM, there have been significant developments in HRA methods, theories, and practices. A working group (WG) was convened in 2012 to reaffirm the guide. This WG found numerous cases where the 1997 standard contained outdated references or failed to consider now-commonplace aspects of HRA. The WG, however, confirmed the underlying practice of HRA espoused in IEEE Std 1082-1997 is still contemporary and relevant to HRA practice. The WG has updated the guide, to the extent necessary to reflect important advances in HRA. Thus, the framework for conducting HRA found in IEEE Std 1082-1997 remains intact in this revision but has been augmented with references to contemporary issues and practices.

IEEE Std 1082 remains a unique, concise guide for specifying the framework for conducting HRA as part of PRA. Additional standard guidance documents are available beyond IEEE Std 1082. For example, the Electric Power Research Institute (EPRI) released the Systematic Human Action Reliability Procedure (SHARP) and revised SHARP1 approach [B4], which describes a detailed process of integrating quantitative HRA into PRA, mirroring parts of IEEE Std 1082.³ The American Society of Mechanical Engineers (ASME) has created the Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications [B1], which outlines high level requirements for HRAs to be included in PRAs. The NRC published Good Practices for Implementing Human Reliability Analysis [B13], which serves as a reference for desirable, but not required aspects of HRA. These three guidelines and numerous recommended practices found in specific HRA methods and texts, complement, but do not replace, IEEE Std 1082. For example, SHARP1 [B4] elaborates on quantifying the HRA for inclusion in PRA but does not include the entire HRA

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

²NUREG publications are available from the U.S. Nuclear Regulatory Commission (<http://www.nrc.gov>).

³EPRI publications are available from the Electric Power Research Institute (<http://epri.com>).

process of IEEE Std 1082. The ASME PRA standard [B1] articulates quality requirements for HRA but does not specify how the HRA should be conducted.⁴ NRC's good practices [B13] parallel many aspects of IEEE Std 1082 but does not provide an overall process flow for conducting HRA. IEEE Std 1082 remains relevant as an overarching standard framework for conducting HRA.

IEEE Std 1082 is a method-neutral approach. It is beyond the scope of this guide to enumerate how the guidance can be tied into different HRA methods. Recent reviews of HRA methods may be found in [B1], [B3], [B14], [B15], and [B16]. HRA method development has been extensive, with new approaches that address cognition, context, errors of commission, as well as approaches that span simplified HRA quantification, to dynamic models of human performance. The framework for integrating HRA into PRA as outlined in this guide should apply across HRA methods, although some adaptations may be necessary to meet the unique requirements of specific methods. Such adaptations, especially when using simplified HRA methods, should not come as efficiencies at the expense of performing an integrated and complete HRA process.

⁴ASME publications are available from the American Society of Mechanical Engineers (<http://www.asme.org/>).

IEEE Guide for Incorporating Human Reliability Analysis into Probabilistic Risk Assessments for Nuclear Power Generating Stations and Other Nuclear Facilities

1. Overview

1.1 Scope

This guide provides a structured framework for the incorporation of human reliability analysis (HRA) 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 HRA framework is developed from standard practices to serve as a benchmark to assess alternative ways of incorporating HRA into PRA.

2. Definitions, acronyms, and abbreviations

2.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁵

NOTE—Several terms used in this guide and in the field of HRA are important, yet are ambiguous in common usage or not used frequently enough to be well known. They are defined in this clause for the use in understanding and following this guide.⁶

basic event: An element of the probabilistic risk assessment model for which no further decomposition is performed because it is at the limit of resolution consistent with available data.

⁵*IEEE Standards Dictionary Online* subscription is available at: <http://dictionary.ieee.org>.

⁶Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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

cutset: A group of events that, if all occur, would cause occurrence of the top event (the outcome of interest such as that investigated by means of a fault tree).

dependence: The relationship between two or more human failure events, which may result in an adjustment to the model or the human error probability.

design-basis accident: A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to help ensure public health and safety.

dominant sequence: A sequence of events that constitutes a dominant contributor to overall risk.

event: (A) Any change in conditions or performance of interest. (B) An occurrence at a specific point in time.⁷

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.

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.

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

human error: Failure of human task performance to meet specified criteria of accuracy, completeness, correctness, appropriateness, or timeliness.

human error probability (HEP): The quantitative estimation of the likelihood of a human error.

human failure event (HFE): A basic event that pertains to a human error.

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

human reliability analysis (HRA): Any number of formal approaches and methods used to identify sources of human error and quantify their accompanying human error probabilities.

initiating event: An event either internal or external to the plant that perturbs the steady state operation of the plant by challenging plant control and safety systems whose failure could potentially lead to core damage or release of airborne fission products.

operating crew: Plant personnel working on shift to operate the plant. They include control room personnel and those support personnel who directly support the control room personnel in operating the plant.

performance shaping factor (PSF): A factor that influences human reliability through its effects on performance. These include factors such as environmental conditions, human-system interface design, procedures, training, and supervision.

probabilistic risk assessment (PRA): A qualitative and quantitative assessment of the risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics, such as

⁷This definition differs from the one(s) found in previous IEEE guidance. The current definition has been tailored to match the specific use in human reliability analysis.

core damage or a radioactive material release and its effects on the health of the public [also referred to as a probabilistic safety assessment (PSA)].

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

risk: Probability and consequences of an event, as expressed by the answer to the following three questions: (1) What can go wrong?, (2) How likely is it?, and (3) What are the consequences if it occurs?

screening: A type of analysis aimed at eliminating from further consideration factors that are less significant for protection or safety in order to concentrate on the more significant factors.

screening value: A rough but conservative point estimate of the probability of a specific human failure event.

uncertainty interval: The confidence in the human error probability estimate as expressed in a confidence bound around the single-point estimate.

walkthrough: A systematic process by which the actions required of operators are checked against the real plant or against a model, mock-up, or simulation of the real plant. A walkthrough is typically used to identify performance shaping factors.

2.2 Acronyms and abbreviations

DOE	U.S. Department of Energy
I&C	instrumentation and control
INPO	Institute of Nuclear Power Operations
LOCA	loss of coolant accident
NRC	U.S. Nuclear Regulatory Commission

3. Overview of an integrated HRA

3.1 General

3.1.1 Importance of human reliability

In assessing the risk associated with a nuclear power plant, the analyst should consider not only the reliability of plant hardware systems but also the reliability of people's interactions with other plant or support personnel and with the plant's equipment and systems. The scope of interactions with plant equipment and systems should include those in the control room and at local control stations and with both manually controlled and automated systems.

3.1.2 Importance of integrated HRA and PRA

An HRA should be an integral part of a PRA. In PRAs, the quality of the analysis (e.g., quantification of human error) is dependent upon the analyst's ability to identify 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. This approach is well established for design-basis PRAs. The approach applies to beyond design-basis analyses such as those used for severe accidents. However, as the uncertainty and variability of the plant state and accident scenario evolution increase, so too does the complexity of

performing the analysis. The steps outlined in this guide should be considered at a minimum; additional steps may be appropriate for certain cases, such as severe accident analyses.

3.2 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) Matching the best suited HRA method to the analysis requirements; and
- d) The limits of an HRA or its results.

3.2.1 PRA compatibility

The HRA process proposed is suitable to all levels of a PRA given defined human failure events. If these are not defined, then this guidance cannot be applied successfully. The risk focus of a PRA requires the quantitative results of an HRA to be probabilistic in nature. Applications of PRAs to risk management efforts require that the HRA documents in sufficient detail the analyst's human factors considerations for the human failure events. The PRA can have a diverse range of applications, 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.

3.2.2 Qualitative HRA

While the approach identified in this guide supports HRA quantification as part of the PRA, it should be noted that there is an increasing emphasis on the importance of qualitative HRA [B15], i.e., HRA that does not produce a human error probability, but rather insights into the human's role and contribution to overall system performance. The HRA approach in this guide supports both qualitative and quantitative aspects of HRA. For PRA, the quantitative approach should be adopted. For non-PRA applications of HRA, steps relevant to quantification should be omitted as appropriate.

3.2.3 The relationship of approach to results

Assumptions made by human reliability analysts about the relative importance of various human activities will influence the breadth and detail of models developed for the HRA. The data and chosen method of quantifying human interactions will influence the specific estimates or ranges of uncertainty obtained, although there is generally good agreement between HRA methods. If results point to the need to improve the reliability of selected systems and accompanying 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 method-specific documents. In addition to method-specific guidance, general guidance on selection of appropriate HRA approaches can be found in cross-method overview documents such as [B2], [B3], and [B14]. The HRA analyst should be mindful of this when considering the specific approach to be taken.

3.2.4 Matching the method to the application

Various HRA-related methods are available and being developed (e.g., cognitive approaches to human error or approaches that address errors of commission). HRAs should be flexible enough to accommodate new findings and model developments, while structured enough to be repeatable and traceable. HRA methods were developed for different purposes, and they feature different strengths [B14]. One emerging practice is

that multiple HRA methods may be used within a single analysis to reflect the strengths of those approaches and the needs of the analysis [B7]. This guide remains method-neutral but encourages analysts to be flexible in considering the best HRA methods for particular applications.

3.2.5 Limits

To be effectively incorporated into a PRA, an HRA should provide a realistic-as-possible interpretation of the role of plant personnel in accident prevention and mitigation. Accordingly, the results of an HRA should be documented in a format such that the basic assumptions, models, and data sources are clearly documented and the limitations of the analysis are understandable to the user (e.g., PRA analyst).

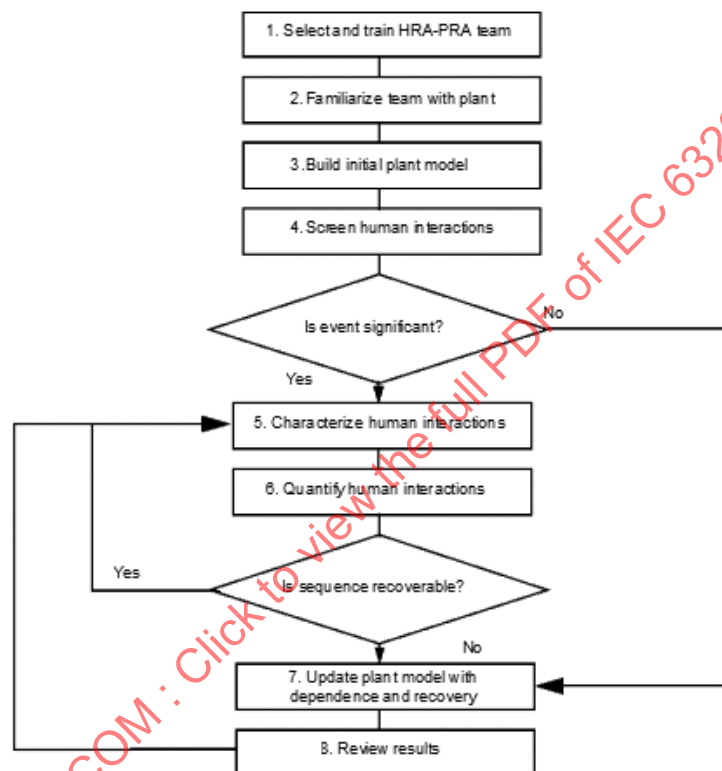


Figure 1—General HRA process

3.3 HRA process

3.3.1 General

A general HRA process is depicted in Figure 1. It parallels the typical PRA process (see [B1] and [B6]), but is not organizationally related to it. The chosen HRA process is an adaptation of a process that has been used in many PRAs (see [B9]). The general structure is described in 3.3.3, the specific steps are described in 3.3.4 and detailed in Clause 4, and the outputs at each step are described in 3.3.5. The timing and level of detail of the HRA should synchronize with the PRA. Therefore, the HRA structure discussed in this guide should be applied with modification as needed.⁸ 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 an integrated analysis.

⁸For example, HRA for external and area initiating events may deviate from the prescribed HRA process. In such a case, typically the analyst takes the initiating event HRA as the basis, checks the feasibility of actions for external and area events, and then modifies the analyses as necessary.

3.3.2 Existing versus new HRA

The process outlined in [Figure 1](#) represents an approach that may be used to create a new HRA. In creating a new HRA, the HRA should be integrated into the PRA process and not viewed as an independent analysis from the PRA. In practice, it is common to start with an existing HRA for a similar system or plant and then reuse and modify it with details specific to the new analysis. The proper documentation of the initial HRA across all steps helps to ensure that reuse is viable. When reusing and modifying an existing HRA, analysts should carefully document any changes in assumptions and their consequences in the new analysis. Steps in [Figure 1](#) may be omitted when feasible as part of the reuse process. The applicability of specific steps will vary according to the types of modifications made to the existing HRA.

3.3.3 HRA structure

The HRA should be incorporated within the PRA in a stepwise manner. The HRA should begin at a level that is broad enough to help 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.

3.3.4 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 as follows:

- a) The HRA process begins with the selection and training of the joint HRA-PRA team.
- b) The team should familiarize itself with the plant and its systems, functions, and procedures.
- c) The first models of the plant should be developed jointly by the team. This model identifies the major human interaction events in functional terms.
- d) The results form a list of interactions that are screened by restricting the analysis to candidate- dominant sequences. The HRA supports 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.
- e) Human actions whose failures are found to be significant contributors to risk are then characterized in detail as human failure events to support quantification and application of the PRA results.
- f) Each human failure event 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.
- g) Dependence between human failure events is considered. If recovery events are identified, then the models of these events, including the models of the human interactions, are incorporated into the updated models.
- h) The final review step ends the activity and, if the HRA-PRA team includes people from plant operations, should only be confirmatory.

Finally, the documentation of the HRA, like the rest of the PRA, is a crucial element that is ongoing throughout the HRA. Documentation is not shown on the flow chart in [Figure 1](#) but is detailed separately in [Clause 5](#).

3.3.5 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.

Table 1—Products of the HRA process steps

Step	Product
1. Select and train HRA team	Integrated team with requisite PRA and HRA skills.
2. Familiarize team with plant	Initial identification of human functions and activities. Potential human errors can be spotted although without much risk context yet.
3. Build initial plant model	All major systems modeled. System interactions identified. Defense barriers against off-normal events described. 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. Initial estimates of time required to take action.
6. Quantify human interactions	Importance ranking, likelihood, and uncertainties of key human interactions.
7. Update plant model with dependence and recovery	Model with recovery actions and dependencies included.
8. Review results	Confidence that results make sense and can be used by plant staff in risk reduction efforts.

4. Details of the HRA process

4.1 General

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 human reliability analysts and the rest of the PRA team performing the equipment reliability modeling is needed. This team should be a joint team whenever possible. The HRA-PRA team may be a subset of the overall PRA team, including members specialized in human factors and human reliability.

4.2 Steps in the human reliability analysis (HRA) process

4.2.1 Step 1: Select and train HRA team

4.2.1.1 General

The HRA process requires contributions from a wide range of skills in engineering, plant performance, human factors, and mathematical or statistical analysis. It is important that the team that performs the HRA possesses 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 [4.2.1.3](#). A senior person should be appointed from within the organization to lead the HRA-PRA team and in particular, to lead the integration of the team skills and champion their interaction with the broader PRA team. The required training should include methods for cooperation and communication across disciplines.

4.2.1.2 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 ensuring that the individuals selected as team members possess the necessary technical skills and ability to work and communicate effectively as a team. This teamwork, early in the PRA, will facilitate the development of the HRA and the accuracy of the PRA.

4.2.1.3 Description

The expertise required for the HRA-PRA team includes items a) through g) below. These experts interface with other experts on the PRA team and at the plant as needed. This list does not imply that individuals in each of the specific areas are required. Individuals may have multiple areas of expertise, e.g., a PRA analyst with operations background who is trained in HRA methods. To help ensure proper consideration of human aspects of risk, HRA expertise should be part of the PRA team throughout the analysis. The team should have the following cumulative experience:

- 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 the expected effects of task and workplace characteristics on human performance, given human capabilities and limitations. Human factors engineers augment the team by identifying attributes of tasks and task environments that should 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-system 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 system 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) **System safety analysts** provide evaluations of system performance and human performance requirements for situations in which system conditions transition from normal to abnormal and beyond technical specification operating envelopes. The system 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 can consist of fault trees, cut sets, event trees, Bayesian networks, dynamic event trees, system dynamics models, or Petri nets, to which the human reliability analyst provides input to model the role of the human in system operations for the events under consideration.
- g) **Engineering personnel** 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 instrumentation and control (I&C) is necessary to identify potential problems with system operation.

4.2.1.4 Team training

The HRA-PRA team training should be aimed at the development of integrated working relationships among team members, and at shared understanding of the responsibilities for each member. This training should also provide opportunities for each member to become familiar with the vocabulary of the HRA process and with 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.

4.2.1.5 Output

The quality of the HRA will depend on the quality and integration of the expertise within the HRA-PRA team. The quality of the HRA will, in turn, influence the quality of the associated PRA. The result 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.

4.2.2 Step 2: Familiarize the team with the plant

4.2.2.1 General

4.2.2.1.1 Existing plants

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

- a) Plant systems and equipment (i.e., 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) Plant-type reference events and plant-specific initiating events (within or beyond design-basis, as required)
- f) Training
- g) Crew structure

4.2.2.1.2 New plants

For new plant builds, some of this information may not be fully defined during the initial HRA development. This information should be filled in, and the HRA should be refined, as plant and operational details become available.

4.2.2.2 Purpose

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

4.2.2.3 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 I&C, 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 possible, the use of plant training simulators to aid in understanding the response of the control room crew to selected scenarios may prove

beneficial. As noted previously, HRA for initial licensing of new plants may not be able to make use of all desired sources of information.

4.2.2.4 Output

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

- a) Human functions and activities that are important to safety
- b) Success criteria for these human actions
- c) Potential problem areas in human performance

4.2.3 Step 3: Build the initial plant model

4.2.3.1 General

HRA expertise should be integrated into the development of the initial plant PRA model to help ensure the completeness of the study.

4.2.3.2 Purpose

The purpose of this step is to model the plant's performance in response to initiators that produce off-normal events. The HRA specialists should work with the system modelers to help ensure that the plant model properly incorporates the human roles 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.

4.2.3.3 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. This guide is intentionally method-neutral, and appropriate method selection guidance may be found in other sources (e.g., [B2], [B3], [B14], [B15], and [B16]). A screening analysis (described in 4.2.4) helps ensure that the human failure events are meaningful when later analyzed using specific HRA methods.

In order to be consistent with the PRA, human failure events should be classified into one of the following main categories:

- a) **Pre-initiator events.** Failures in human activities conducted during normal plant operations 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 or indirectly, to off-normal plant conditions and thus initiate a transient. A human error that directly or indirectly causes a high- or low-pressure boundary loss of coolant accident (LOCA) is an example of such an event. Errors of commission, such as disabling required automation, may be another type of human-induced initiator.
- 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 failure events and are failures in activities related to restoration of inoperable equipment or finding of alternatives to the use of failed equipment.

4.2.3.4 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 team 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 the first 10 min.

4.2.4 Step 4: Screen human interactions

4.2.4.1 General

Since the evaluation of the PRA models to assess core melt frequencies and their consequences may require extensive analyst and computer time and high costs, the models are screened for risk importance to help ensure an efficient focus of the remaining analysis. This step may require iteration, depending on the status of the PRA when the screening is performed.

4.2.4.2 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.

4.2.4.3 Description

4.2.4.3.1 General screening approach

In this screening step, the resources of the HRA-PRA team should be concentrated on those events, including human interactions, which are likely candidates to contribute significantly to the assessed plant risk. This allows the HRA-PRA team to minimize the time and resources that are needed to arrive at the risk contribution of human interactions. When the PRA team screens events for risk significance, the HRA process should support this screening by providing the following:

- a) Criteria for ignoring human interactions,
- b) Descriptions of human interactions in the event (scenarios), or
- c) Conservative estimates of the probabilities of human error to be used in the screening.

These conservative estimates are called screening values.

4.2.4.3.2 Screening for recovery

The HRA should support the PRA 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 analysts 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.

4.2.4.3.3 Screening quantification

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 HRA provides the PRA at this stage are called screening values. These screening values are deliberately assigned conservatively so as not to inadvertently 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 prove to be risk significant and subsequently 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 analysis.

4.2.4.3.4 Screening for errors of commission

It is important to note that while the typical role of screening is to exclude human interactions that do not have a significant impact on overall risk, screening may also serve to identify errors of commission that would not be part of the initial selection of human failure events in the PRA. For example, a critical plant function that is maintained by an automated system may not normally include human interactions, simply because no human control input is necessary for the successful operation of the system. However, in identifying opportunities for automation failure in the PRA, it may be revealed that one cause is inadvertent or intentional disabling of the automation by a human operator. A screening analysis can reveal this commission to be a significant contributor to overall risk.

4.2.4.4 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 failure 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 next in Step 5 (4.2.5). All the human actions that have been screened out should be documented in an initial report to help ensure completeness of the work. At this point, a detailed HRA begins.

4.2.5 Step 5: Characterize human interactions

4.2.5.1 General

The PRA should have identified sequences that are the likely candidates for the plant's dominant risk sequences. In this step, the human reliability analyst reviews the candidate human failure events that remain in sufficient detail to quantify them in the next step.

4.2.5.2 Purpose

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

4.2.5.3 Description

The initial identification of the human failure events in Step 3 (4.2.3) was in functional terms from the plant model. The events that have been retained in the analysis (e.g., those events that pose 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 [commonly called performance shaping factors (PSFs)] on the probability that the operating crew will fail to accomplish the required action. This information is method-dependent and requires knowledge of human factors methods

such as task analysis and functional requirements analysis, coupled with insights into psychological factors affecting operator performance.

4.2.5.4 Performance shaping factors

A number of PSFs may be considered when estimating the probability of failure for the actions considered in an HRA. The PSFs explicitly incorporated into the models should include as a minimum, the following [B13]:⁹

- a) Training and experience
- b) Quality of procedures
- c) Availability of instrumentation
- d) Time available
- e) Complexity
- f) Workload, time pressure, and stress
- g) Team and crew dynamics
- h) Available staffing and resources
- i) Ergonomic quality of the human-system interface
- j) Environmental factors
- k) Accessibility and operability of equipment
- l) Need for any special tools
- m) Communications
- n) Special fitness needs

Not all HRA methods model all PSFs. The use of a particular HRA method should not limit the scope of the analysis; rather, the analysis should guide the selection of the appropriate HRA method to treat the human interactions adequately.

4.2.5.5 Output

This step produces a characterization of the original screened human failure event 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.

4.2.6 Step 6: Quantify human interactions

4.2.6.1 General

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.

⁹This list focuses on post-initiator performance shaping factors. Additional factors may be needed to model pre-initiating events. This list is illustrative but not exhaustive of those factors driving performance. An analyst should determine the appropriate set of factors to support different applications.

4.2.6.2 Purpose

The purpose of this step is to provide a numerical estimate for each human failure 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.

4.2.6.3 Description

4.2.6.3.1 Operational data

The numerical estimation of human failure events would be best obtained from a database of appropriate events. In the absence of empirical data, insights into human error probabilities can be derived through interviews with operators, simulator training instructors, and maintenance personnel; and from physical examinations, walkthroughs, and talkthroughs of specific controls and control actions. Plant-specific historical data and operating experience should also be thoroughly reviewed when available. Surrogates to data can also be used. Simulators are a potential source of surrogate data, and work sponsored by various research institutes and laboratories has provided usable data. Interviews and walkthroughs are also valuable tools to collect data that will help in the quantification process. Plant-specific data should be used whenever available.

4.2.6.3.2 Estimation using HRA methods

In many cases, data will be unavailable, and it is necessary to use an HRA quantification technique. The majority of HRA methods offer approaches to estimating human error. These approaches include techniques such as matching analysis scenarios to pre-analyzed and quantified error types, adjusting nominal human error probabilities through modifiers such as PSFs, selecting appropriate pre-quantified decision tree paths, or using expert estimation techniques. Due to the inherent uncertainty of this quantification process, point estimates without a statement of uncertainty should not be accepted for use in the HRA.

4.2.6.3.3 Human error probability range

The human error probability should generally fall within the range of 1.0 to 1E-5 (i.e., 1×10^{-5} or 0.00001) [B13]. This lower bound of 1E-5 serves as an approximation of best possible human performance under any circumstances. While many HRA methods do not set a lower bound, analysts should always consider the reasonableness of their human error probability estimates and set realistic bounds on these values. It is possible, of course, that lower values may be achieved for human failure events when these events consider multiple second-checkers and/or hardware safety systems. Lower-than-lower-bound human error probabilities are the product of modeling-redundant safety systems and personnel; it is unlikely that a single-point failure (a human failure event attributable to a single human action) could reasonably produce a human error probability lower than 1E-5.

4.2.6.4 Output

This step adds a numerical estimate in the form of a human error probability, including uncertainty such as error bounds or probability distribution, to each human failure event and its qualitative characterization.

4.2.7 Step 7: Update plant model with dependence and recovery

4.2.7.1 General

Once the sequences have been quantified, the HRA-PRA team should evaluate whether dependence should be considered and whether additional recovery actions are possible. Some recovery actions may have been included in the initial development of human failure events for the PRA model. The output of this step is a set of human interactions that is needed to reflect additional, heretofore unmodeled, dependence and recovery in the plant model. These human interactions have been qualitatively and numerically characterized by an analysis that accounts for the specific plant conditions that exist to propagate human error through dependence

or minimize its effects through recovery. This step occurs when the sequence solution has been reviewed and the dependence and recovery analysis is performed for the significant sequences. The plant model is then updated to reflect the final human failure events and their numerical characteristics.

4.2.7.2 Purpose

This task evaluates the potential for including the dependence between human failure events and the recovery of failed systems and additional human actions and/or systems into the model. The purpose of this step is to update the model of the plant to include dependence and recovery for all significant human failure events identified over the course of the HRA.

4.2.7.3 Description

4.2.7.3.1 Incorporating dependence

All aspects of the contributions to risk should be included in the updated plant model. Dependence is a result of an error increasing the likelihood of a subsequent error. Quantitatively, dependence means that the human error probability of human failure events in sequence may be higher than without dependence. Dependencies among human failure events or between human failure events and other events should be clearly identified, analyzed, and quantified in the models. Justification for dependence or independence should be provided. Each human failure event in the model should be identified as to whether it is quantified with a screening probability or a detailed analysis.

4.2.7.3.2 Incorporating recovery

Once the candidate-dominant sequences are identified, those additional human recovery actions and systems that can prevent the undesired outcome can be incorporated into the model. The human failure events 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. 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 modifications to the plant.

4.2.7.4 Output

The output of this step is a plant model that includes all reasonable sources of dependence between human failure events and recovery contributors to plant risk.

4.2.8 Step 8: Review results

4.2.8.1 General

A PRA integrates diverse information about the plant. A sensitivity analysis should be performed to consider risk factors of human origin, to determine their potential impact, and to rank their importance in relation to all other identified risk factors. 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 by qualified people external to the PRA team is required.

4.2.8.2 Purpose

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

4.2.8.3 Description

The results of the HRA and PRA are confirmed as credible by one or more means. The HRA results should be reviewed against station tests and by maintenance and operations personnel. Talkthroughs or walkthroughs 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-PRA 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 a PRA should be reviewed by independent HRA experts.

4.2.8.4 Output

The output of this step is an HRA that reasonably reflects the contribution of human actions to plant risk and 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.

5. Documentation

5.1 Purpose

The objective of HRA documentation is to produce a traceable description of the process used to develop the quantitative assessments of human interactions. Documentation is overarching across all HRA process steps detailed in [Clause 4](#). The HRA-PRA team provides 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.

5.2 Structure

The analysis documentation should be organized to help ensure that the information and data are clearly presented; that the assumptions, data sources, models selected, and criteria for elimination and retention of human failures are recorded; and that the human quantitative impact on the PRA model 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 composition of the HRA team
- b) The origin of source data and reasons for selection
- c) The nature of the operating history review
- d) The operating history reviews applied
- e) The HRA method(s) used
- f) The reasons for selection of the HRA method(s) used
- g) The specific human failure events explicitly modeled
- h) The nature of operator interaction analysis performed
- i) The types of operator actions modeled implicitly
- j) The method of screening and quantitative values
- k) A list of the important actions carried out for more detailed analysis

- l) Assumptions driving quantification such as performance shaping factors, recovery, and dependence
- m) The nature of plant staff interviews
- n) The type of control room reviews
- o) The limitation (boundary conditions) on use of each value (e.g., just for loss of coolant accidents, just for low level)

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](#). Thorough HRA documentation is also a necessary step for potential HRA reuse.

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Annex A

(informative)

An example for documenting HRA data

An example data table is presented along with a description of each item, A through T. Each of these elements should be recorded to help 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 PSF(s). The elements of the table are defined as follows:

A. *Sequence number*. 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).

Example:

task 1.1.A
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-PRA 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.

Example:

<i>The operator</i>	<i>Opens valve</i>	<i>V612</i>	<i>By turning a J handle</i>	<i>To the right</i>
<i>WHO</i>	<i>ACTION</i>	<i>OBJECT</i>	<i>HOW</i>	<i>WHERE</i>

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 are not available, then a limited-scope task analysis or recorded walkthrough 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, for example, by an alarm, a person (supervisor request), or a procedure step; or, the task may be self-initiated by the operator.

E. *Plant system affected*. List 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.

G. *Important performance shaping factors (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 or 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 walkthrough was unable to find the correct switch. The operator had to ask the shift supervisor where it was located).

J. *Human engineering deficiencies (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 [B12] and MIL-STD 1472G [B8], and the instrument is physically located outside the optimal range of viewing).

K. *Training module and 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 US. Nuclear Regulatory Commission (NRC), the US. Department of Energy (DOE), Electric Power Research Institute (EPRI), and Institute of Nuclear Power Operations (INPO).

L. *Procedure number, 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 and 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, illumination, radiation level, and humidity if these factors may influence the execution of the task in terms of completion times or 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 licensee event reports (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 simulates 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.

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

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

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