Evaluation of the Economic Simplified Boiling Water Reactor Human Reliability Analysis Using the SHARP Framework

by

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ABSTRACT

General Electric plans to complete a design certification document for the Economic Simplified Boiling Water Reactor to have the new reactor design certified by the United States Nuclear Regulatory Commission. As part of the design process, the design control document was produced in 2006, and it includes a description of the human reliability analysis performed as part of the reactor's probabilistic risk analysis. The problem is to verify the claim that the human reliability analysis was performed according to the Systematic Human Action Reliability Procedure (SHARP). The seven step method was compared directly to the actions documented by General Electric. Each step was identified and the actions within the steps were identified and evaluated to verify that no rules of SHARP were in contention with the analysis. The reason for using the SHARP method instead of revisions and improvements of the SHARP method was determined and more detailed analysis will be performed in later phases of the reactor design, but the human reliability analysis quantified with general human error probabilities was still a conservative estimate of the human reliability. The results showed that General Electric performed a human reliability analysis in agreement with the SHARP method. The Economic Simplified Boiling Water Reactor human reliability analysis is ready for more detailed analysis and quantification of human interactions in the next phase of development.

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Table of Contents

Acronyms

ABWR	Advanced Boiling Water Reactor
BWR	Boiling Water Reactor
CP	Type-C Procedural action
CR	Type-C Recovery action
EPRI	Electric Power Research Institute
ESBWR	Economic Simplified Boiling Water Reactor
GE	General Electric
HEP	Human Error Probability
HI	Human Interaction
HRA	Human Reliability Analysis
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk Analysis
SHARP	Systematic Human Action Reliability Procedure
SHARP1	Updated SHARP methodology published in 1993
THERP	Technique for Human Error Rate Prediction
US NRC	United States Nuclear Regulatory Commission

1 Introduction

Human reliability has been a concern for nuclear reactor safety since its conception, and the field has progressed as reactor design has evolved. General Electric is designing the Economic Simplified Boiling Water Reactor[1] (ESBWR), the latest in its line of BWRs. As part of the Probabilistic Risk Assessment (PRA) for the new design, a Human Reliability Analysis (HRA) is conducted to quantify the human error contribution to the likelihood of an accident scenario.

The Systematic Human Action Reliability Procedure[2] (SHARP), developed by the Electric Power Research Institute (EPRI), provides a framework to help make HRA more consistent and reproducible. The method was developed in 1984 and revised nine years later, but both the original and revised methodologies are used. The method has seven steps including an iterative process that allows some of the steps to be repeated when necessary.

The ESBWR HRA[3] claims to be consistent with the SHARP method, and this claim will be investigated with the documentation of the GE reactor.

2 ESBWR- *a brief introduction and overview of the HRA*

The ESBWR is the newest reactor design from General Electric (GE), which began its Boiling Water Reactor (BWR) program in the 1950s. The predecessor to the ESBWR is the Advanced Boiling Water Reactor (ABWR), the world's first operational Generation III reactor.

2.1 Background Information

GE wanted to provide a simplified reactor design to help improve safety, economics, and security. The design incorporates many passive systems to reduce and eliminate systems from previous BWR designs. Many of these design features are highlighted in Table 1.

The ESBWR design certification application was submitted to the United States Nuclear Regulatory Commission (NRC) in August 2005 with the intent to have the safety evaluation report completed by 2007.[4] U.S. utilities plan to submit combined construction and operating license applications under the new NRC licensing process in 2007 and 2008, and GE expects the ESBWR to receive final design approval in late 2008. The focus of this thesis is the treatment of human reliability analysis completed as portion of the ESBWR design certification application.

Many innovative features of the reactor are part of the safety system design. The higher power levels achieved by the ESBWR over the ABWR can be partially attributed to the modular design approach of emergency safety systems. Passive containment cooling and the addition of isolation condensers can meet increased cooling demands of higher power operation by increasing the size of the heat exchangers. The cooling system is gravity fed and contains enough water to keep the core submerged in the event of a loss of coolant accident (LOCA) for 72 hours. Six low pressure loops external to the reactor containment can cool the containment to remove decay heat in the case of an accident.[1] GE claims the ESBWR has a core damage frequency of 3E-8, which is one to two orders of magnitude lower than current operating reactors, but one source of accidents is operator error, which is discussed in the HRA of the reactor.

Table 1: Key Attributes of the ESBWR Design[1]

Key Attribute	Elements of Attribute	Example Design Features
Simplification	• Reduced systems and structures • Simpler operation	• Passive safety systems • Natural circulation and elimination of recirculation pumps • Passive isolation condensers
Standardized design	• Standardized construction design	• Seismic design envelops all site conditions • Standardized components
Operational flexibility	• Increased operating margins	• Large vessel with large masses of water and steam • No regions of thermal hydraulic instability
Improved economics	• Low plant cost • Low development cost • Reduced licensing and first-of-a-kind plant cost • Reduced operation and maintenance costs	• Reduced materials and buildings • ABWR/SBWR features used • Tested new components and systems • Reduced and simpler systems • Reduced construction time

2.2 HRA Methodology

Chapter 6 of NEDO-33201[3] documents the HRA performed for the ESBWR PRA. The methodology of the HRA is described including specific calculations for human error probabilities (HEPs). The last section of the report outlines possible items to refine the HEPs for more detailed analysis to be performed beyond the design control documentation.

2.3 Definition of Human Interactions and Agreement with SHARP

The methodology described in NEDO-33201 covers the evaluation of human interactions (HIs) with plant systems in two states: normal operation and during accident scenarios. The normal operation HIs are defined as causing an initiating event or failing to restore equipment to operational condition following maintenance or testing, and HIs during accidents are HIs that take place after an initiating event.

The methodology states that it is in agreement with the Systematic Human Action Reliability Procedure (SHARP). The consistency of the NEDO-33201 methodology with SHARP and improvements that can be made will be discussed in detail in later sections of this document.

2.4 Quantification of the HEPs

Human error probabilities (HEPs) were taken from EPRI NP-3583,[2] NUREG/CR-1278,[5] and NUREG/CR-4772[6] for the ESBWR HRA. The values represent conservative estimates of human failure and for the level of analysis required. For detailed HRA analysis to be performed for the ESBWR, the histories of operating BWRs can be used to provide experience based values.

2.5 Categories of HIs

The HRA utilizes three distinct types of HIs defined as Type A, B, and C, differentiated by the timing of the HI.

2.5.1 Type A: Pre-Initiating Event HI

These HIs are associated with normal operation. Activities associated with maintenance, tests, calibrations, and evolutions of the plant are all Type A HIs. Before the initiating event, an HI can affect the availability of systems.

2.5.2 Type B: Initiating Event Related HI

In this case, a worker initiates an event by misaligning a system or through malfunction of equipment that trips or inserts false control signals. These HIs are not represented in the HRA because they are implicitly included in the PRA as part of the frequency of generic initiating events.

2.5.3 Type C: Post-Initiating Event HI

With the passive ESBWR, these HIs are not as important as they are with LWRs, but to err conservatively, generic values are included in the HRA. Two kinds of Type C HIs are CP and CR, which are procedural actuation of systems and recovery actions, respectively. The former includes actions directed by procedures that will terminate the accident, and the latter includes recovery actions, and for the ESBWR, only recovery actions for Type A HIs are included.

3 SHARP Model[2]

The Electric Power Research Institute recognized the importance of human-machine interactions to the reliability and safety of industrial facilities and funded research that resulted in the formulation of the Systematic Human Action Reliability Procedure (SHARP) to help create a more systematic process for incorporating human interactions into PRA reports.

3.1 Development of SHARP

In the late 1970's, the importance of human factors was recognized as a major contributor to plant safety. Until this point, increasing equipment reliability had been the focus of improving reliability, but with the accident at Three Mile Island in 1979, human interactions could no longer be ignored. Additionally, the Reactor Safety Study reported that human factors contribute to between 50-85% of failures during accident sequences.[2] EPRI and the US NRC began efforts to improve HI modeling in response to new concern regarding the contributions of HIs to safety.

EPRI sponsored the SHARP project with the intent to expedite the methods to incorporate human reliability into PRA studies. This new method also aimed to incorporate HIs in a way that would be dependent on resources available and would be reproducible.[2] The scope of HIs covered would include the three types mentioned in section 2.5: Type A, B, and C.

Many disparate techniques for modeling HIs were developed, but there was no systematic method that could be used widely. Each method had its use and there was no consistency or relationship between the methods. Sandia National Laboratories developed the Technique for Human Error Rate Prediction (THERP) used by the Reactor Safety Study.[2] In the early 1980's there was new interest in modeling human error and a host of techniques were developed independently, constantly changing the way HRA was conducted. In attempts to make HRA more complete, new models would be developed to fill needs not addressed by current methods, adding complication and cost to PRA studies.

The SHARP process was developed to formalize a process to identify the important HIs of the system, to create a logic structure to help quantify and allocate resources appropriately, and to create a consistent methodology for assessing the human factors of a system. The EPRI experts developed a framework that was divided into seven steps that are independent from the techniques used to quantify HIs in order to create a universal method for incorporating HIs into a PRA. This framework was developed by the Nuclear Utility Services Corporation and reviewed by EPRI staff and independent reviewers. The SHARP method was finally published in 1984.

3.2 Later Revisions of SHARP

Three years after publishing SHARP, EPRI sponsored the Benchmark of SHARP[7] report to evaluate the usefulness of the method. The Nuclear Utility Services Corporation reviewed SHARP and created an accident scenario and benchmark process. The benchmark study identified ten improvements that could be made to improve the SHARP process.

Out of the ten listed, the most significant improvements will be summarized. The SHARP process concentrates on the HRA as a self-contained study, and the experts found that SHARP should emphasize the integration of the HRA into the overall PRA methodology. Instead of breaking the steps of the SHARP method apart as being completed by human reliability or systems analysts, another suggestion was to form an integrated team to follow the entire process through. Additional findings concentrated on clarifying or providing more guidance when selecting events, breaking tasks into subtasks, and identifying iterative processes.

Six years after the benchmark, SHARP1 was published, and despite the similar name, the process is much changed from the original SHARP of 1984. The evolution to SHARP1 included a new approach, emphasizing the integration of the HRA with modeling the plant. The new method also includes only four steps, now called stages that are iterative instead of sequential as the original seven step SHARP. This remains the latest iteration of SHARP.

3.3 Seven Steps of the SHARP Method

The details of the seven steps of the SHARP methodology will be discussed in this section. The steps consist of inputs, activities, rules, and outputs. The inputs come from preceding steps, reports, or other reliable sources. Activities are guided by the rules and include all of the actions of the analysts. The output provides the results of the activities in a useful form for additional steps or the PRA study.

3.3.1 Step 1: Definition

The goal of this step is to make certain that all of the necessary HIs are included in the system analysis. All of the logic structures such as event trees and fault trees are included during the activities portion of this step.

The inputs are the initiating events and the logic structures developed for the analysis of the initiating events. Procedures, incident reports, and past PRA studies may be used. Information and procedures that operators use may also be necessary depending on the HIs.

The activities of step one can be broken down into three groups. First, all of the functions that humans perform must be identified within the logic structures. To help determine all of the key HIs, three methods of investigation are suggested:

- Identification of human activities associated with equipment identified in the event and fault trees
- Examination of the event and fault trees with a classification scheme of how the human enters into an accident sequence to ensure that all possible types of human action are considered
- Examination of related past events and emergency procedures

The next group of activities requires a classification system for the HIs to be chosen. This system should help ensure that all of the important HIs are included in the analysis by evaluating the fault tress for each class of HIs. The final activity of this step is to perform additional checks by examining His through reviews of inputs other than the logic structures such as procedures, incident reports, and past PRA studies.

The output of this step is a logic structure that includes all of the critical HIs that the HRA needs to consider. System analysts are expected to complete this step of SHARP, but the expectation of which group, the system or human reliability analysts, performs a step will be deemphasized in light of the benchmarking of SHARP that suggested a single team go through the entire process.

3.3.2 Step 2: Screening

The goal of screening is to reduce the number of HIs that need detailed investigation. Screening follows step one, which aims to include every possible HI, to create a useful output that includes the HIs that need to be examined in detail. Screening allows the analysts to concentrate resources on the HIs that matter most in regards to the PRA study.

The input is the inclusive logic structure developed in step one. The screening method needs to be compatible with the event trees, fault trees, or other structure that is used. The activities are to apply a chosen screening method to identify interactions that meet specified parameters dependent on the chosen method. The output is a list of only the key HIs that need to undergo more detailed analysis.

SHARP identifies three screening techniques: judgmental, coarse screening, and fine screening. Judgmental screening relies on the qualitative evaluation of an HI on the safety of plant operation. The logic of the event and impact on the top event are used to determine which HIs are important with this screening method. Coarse screening only removes HIs that are dominated by equipment reliability. This method assumes a unity value for all HIs and generic or actual data for equipment failures. None of the HIs are differentiated form each other. HIs are only eliminated based on their interactions with equipment. The last screening method discussed is fine screening, which takes coarse screening another step forward by applying estimates of human reliability to HIs. At the time SHARP was published, there was not an established method for determining HI probabilities, so it is stated that the reasoning behind the values needs to be clearly stated.

The rules for the screening step focus on consistency to help prevent HIs from being screened out that should be included. The screening technique needs to be applied consistently, double counting should be avoided, and the technique chosen needs to be one that will not rule out significant HIs for the specific analysis being conducted.

3.3.3 Step 3: Breakdown

The purpose of the breakdown is to group HIs into tasks and subtasks. This information should help analysts represent and quantify the HIs. A task in this context is a goal, such as quarterly maintenance, and a subtask is a step taken to complete part of the task. The input is the list of key HIs identified by the screening of step two, and the output is a representation of tasks and influence parameters. A matrix can be used to represent which influence parameters affect which tasks or subtasks. Table 2 provides an example of a matrix as the output of the breakdown of internal flooding of a BWR.

Table 2: BWR Internal Flooding Case, an Example of Matrix Output[2]

Task	Subtask	Behavior	Environment	Procedure	Indications	Comments
1. Rack out of breakers to isolate valve from electric power	1A. Failure to follow procedure to rack out breaker	Follows procedure	Auxiliary control room	Adequate	Lights in main control room	Problem with observing labels
	1B. Inadvertent rack in of breaker	Follows procedure	Auxiliary control room	Adequate	Lights in main control room	Problem with observing labels
2. Remote manual activation of isolation valve	2A. Inadvertent activation (valve bumped accidentally by operator)	Follows procedure	Control room	Not applicable	Lights in main control room	Problem with observing labels
	2B. Inadvertent opening of valve-problem with labels	Follows procedure	Control room	Adequate	Lights in main control room	Problem with observing labels

The activities of dividing the HIs into tasks and subtasks and recognizing the respective influence factors for each division are suggested to be completed in four steps. It is recognized that alternative methods may differ, but the review of HIs should be able to cover at least some of the four steps listed:

1. Review procedures for each HI to identify major tasks, subtasks, and operations that may initiate an accident sequence.
2. Review operating logs and the plant history for any operator errors and also corrective actions taken by operators to possibly discover modes of HIs that can initiate new sequences.

3. Analysts should arrange interviews and walk-throughs with operators to help determine which subtasks that operators and maintenance personal take that can affect performance.
4. The analyst will specify requirements to help select the model for the output based on details of the set of actions for each accident sequence.

The rules for these activities are suggestions for the actions that help the analyst gain a complete understanding of the plant. A couple examples include estimating the impact of the event on the operator's behavior, identifying communication links between operators and maintenance personnel, and assessing time periods for the plant to change state.

3.3.4 Step 4: Representation

The purpose of this step is to create the most usable representation of the HIs from step three. This representation needs to provide a scale showing the influences of HIs on the course of an accident. A few mentioned representations include the HRA tree, operator-action trees, confusion matrix, and operator-action event tree. The input for this step is the output from step three, and the output is a qualitative logic structure that helps attribute HIs to success or failure.

The activities for the selection and usage of the representation help make sure that the appropriate representation for data is chosen. The first step outlined is to select a representation based on the tasks and subtasks identified in step three. The interactions and quality of the data should be considered when finally constructing the final representation that reflects all of the HIs.

3.3.5 *Step 5: Impact Assessment*

This step gives the analyst a chance to assess the impact of newly identified human actions on the system. The input is the representation from step four, and the output is an updated representation that includes the impact of the newly identified HIs.

The activities concentrate on rescreening and identifying new HIs for further analysis. The HIs included in step four are separately analyzed to determine their effects on system unavailability, initiating events, and alternative sequences of events. Screening techniques from step two can be applied here to determine the impacts of the HIs. If no new HIs are discovered, then this step is complete at this point, otherwise, the new HIs need to be grouped for quantification. The last activity is to complete a list of HIs for quantification.

Four rules govern the search for new HIs:

1. Four questions are identified to help identify key HIs. To summarize the four points, they ask if the HI in question changes the reliability of equipment, leads to new initiating events, introduces common-cause links, or creates a need to change the trees.
2. Success and failure branches of the representation need to be grouped for quantification based on inspection or information gained during the rescreening.

3. The logic structures need to sufficiently represent the key HIs. If the analysts determine that this is not the case, then the event-tree and fault-tree logic needs to be changed. Several examples of modification are given to help clarify how this rule should be applied.
4. Lastly, the new event trees should be inspected to get rid of similar sequence end states by combining sequences or eliminating uninteresting end states.

This step can lead to an iterative process incorporating steps two through five until the analysts are satisfied that the key HIs have been incorporated sufficiently. This iteration is shown in Figure 1, which describes the flow of the SHARP method steps.

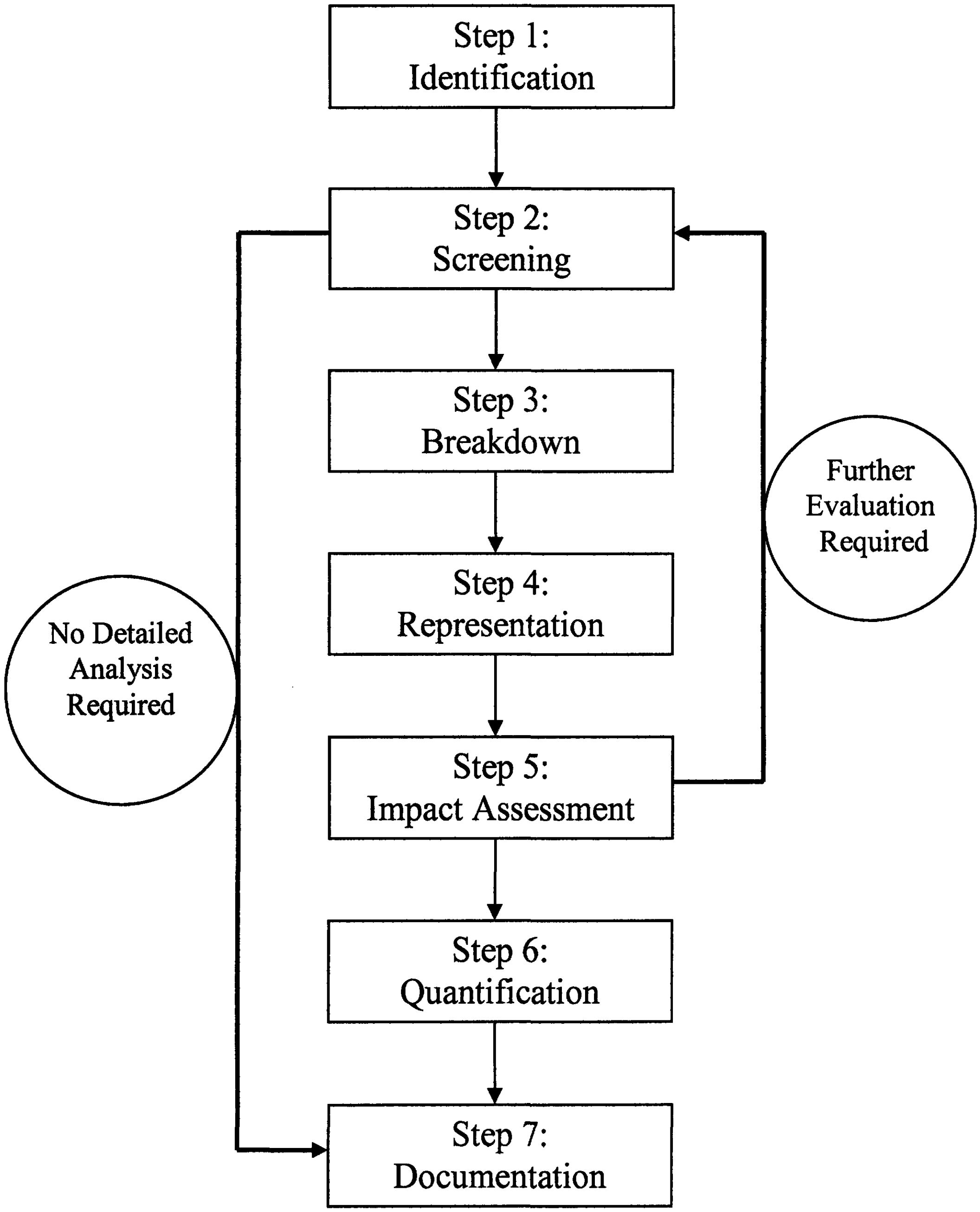

Figure 1: Flow Chart of the 7 steps of SHARP[2]

3.3.6 Step 6: Quantification

The goal for quantification is to assign appropriate probabilities of success and failure to the key HIs. The input comes from the previous step as well as any available data source. These include plant specific experience, generic data, simulator results, expert opinion, and handbooks. The output is the probability and uncertainty assigned for each key HI.

The activities are divided into five steps to help organize the quantification of the HIs. First, the model to be quantified must be examined so the best data for each task can be selected. Sensitivities and uncertainties should be stated if possible, and a sensitivity comparison may be desirable. The results need to be reviewed and incorporated into the PRA study quantification, and lastly, these results need to be carefully documented. The rules associated with the aforementioned activities are based on studies current when SHARP was written and may still be applicable in many cases, but newer works should be consulted.

3.3.7 Step 7: Documentation

The purpose of documentation is to create a record of the process to support the quantitative assessment. A summary of the output from this step can also be useful if incorporated as part of the PRA study. Descriptions of the models, representations, and other sources of information should be included. An analysis of the documentation to confirm its completeness is required and a "reflection of the quantitative impact of the human on the main study issue" is suggested.

The activities are to produce a document completing the objectives of this final step and two guidelines are included in place of rules for the step. These guidelines state that the documentation should create a record of the analysis and that the output of the other steps be included in the documentation of the analysis. The record should also show the original sources of any information used in the SHARP process, including procedures, data sources, models, and interviews.

4 Consistency of ESBWR HRA with SHARP

This section will verify the claim that the ESBWR HRA performed as part of the ESBWR PRA is consistent with the SHARP method. The NEDO-33201 document only includes a summary of the portion of the ESBWR PRA relating to the HRA, and without access to additional documentation it will be difficult to be certain that the SHARP methodology has been applied as intended, especially given that the provided documentation concentrates on quantification of HIs. There is not enough information to know that the steps of SHARP have been applied rigorously, so instead, the approach used a good faith assumption that work not included in the NEDO-33201 document is consistent with the SHARP method.

4.1 Step by Step Comparisons

The steps of the SHARP method will be compared to the actions described in the HRA portion of the ESBWR PRA. The few pages of the report are not enough to be certain that SHARP was followed in its entirety, but the steps will be traced as well as can be determined from NEDO-33201. Examples of some steps and actions will be taken from the accompanying tables and figures of the document.

To check for consistency, the individual parts of each step were compared to any documentation provided by the HRA. The inputs and outputs were not provided for many of the steps, but any evidence of activities was compared to the SHARP model. The activities identified in the HRA were also compared to the rules to make sure that they were adhered to as specified by the model.

4.1.1 Step 1: Definition

The types of human actions are clearly defined in the HRA, and they are all accounted for in the PRA study for the ESBWR. Type B HIs are not explicitly modeled as part of the HRA because the generic frequency of initiating events includes operator initiated events. The HRA includes all of the important HIs for the plant.

The output of an enriched logic structure is not incorporated as part of the HRA; however, none of the rules for the definition were found to be violated by the information presented in the HRA. The classification scheme developed is sufficient to ensure complete treatment of HIs. There is no part of the documentation that works contrary to any of the expectations or stated rules for the definition step.

4.1.2 Step 2: Screening

The screening step of SHARP is not explicitly documented by the HRA portion of the ESBWR PRA. The information pertaining to screening is the list of the Type A and Type C interactions that were quantified. This list shows all of the HIs that were not screened out and were quantified by the analysts.

All of Type A actions were valve misalignments, which makes sense for a reactor design with a passive emergency cooling system. The only influence the plant personnel can have on the passive system is the valve lineup since there are no other components in which they interact. All of the valve manipulations are identified as rule based Type A interactions, because they are performed under the direction of procedures that would be followed prior to the initiating event.

The Type C human actions include a more diverse group of operations plant personnel perform. Without detailed explanations of why each action needs to be performed or how it affects the system, these actions do not provide enough information to draw any conclusion on the screening performed.

4.1.3 Step 3: Breakdown

The breakdown was not a visible step of the SHARP process as part of the HRA report. Because the Type A actions are all valve misalignments, the breakdown for all of the Type A HIs will have similar tasks, subtasks, and influence parameters. The Type C HIs will have more variation, but the provided documentation does not provide any details of the breakdown of the HIs completed as part of the HRA.

4.1.4 Step 4: Representation

There is no documentation of the representation used for the HRA in the NEDO-33201 document. The only part of a tree provided is an example of human action dependence and does not provide any indication of how the HIs were represented by the analysts.

4.1.5 Step 5: Impact Assessment

The iterations of the impact assessment are not provided, but the output of this step can be described by the list of Type A and Type C human actions. Even though the structures are not available as part of the HRA, the list of human actions is comprised of the result of the iterations of the rescreening and impact assessment. The list of HIs to quantify in the next step does show that the sixth activity of the impact assessment was explicit followed.

4.1.6 Step 6: Quantification

The analysts decided that for the design control document phase, the HRA does not need to be as rigorous as it would for the final design of the reactor, so the conservative HRA uses generic screening probabilities obtained from the SHARP report, NUREG/CR-1278, and NUREG/CR-4772. The mean values required for the ESBWR PRA were obtained from the median values and associated error factors.

The SHARP method requires all procedures and plant specific documents to be used as part of the analysis for the HRA, but, at the time, when the design control document HRA was being completed, there were no procedures to analyze. For this reason, it was assumed that any failure to restore a valve to the operational configuration would be categorized as a Type A action. The activities of the quantification process according to the SHARP model are followed closely. The sensitivity comparison, activity four of the quantification step, is optional and it may have been completed and not documented, but based on the general approach of the quantification for the ESBWR, it may have been deemed not desirable for the design control document by the analysts.

The Type C actions are more complicated to calculate. The analysts divided the HEPs into two phases: diagnostic and action. The sum of the two probabilities yields the total HEP for a Type C action. Generic HEPs from the same three documents were used for the Type C actions. The summation of two values to obtain an estimate of a HEP is consistent with the SHARP method as part of rule four of step six.

The 'Generic Error Probability Values for Type C Actions" are from the two aforementioned NUREG documents. The appendix of the SHARP[2] methodology provides Rasmussen's model of human behavior, but the suggested ranges for skill, rule, and knowledge based behavior are not used. The typical probabilities for the three behavior types is stated as being an order of magnitude apart, and the generic HEPs provided in the NEDO-33201 tables are all an order of magnitude apart with one exception. For example, the Type CR 24 hour HEPs are 10^{-3}, 10^{-2}, and 10^{-1} for the skill, rule, and knowledge based behaviors, respectively. The Rasmussen model was used only to determine the relative differences between the three behavior types, and the order of magnitude difference is not consistent with the HCR model.[9] The behavior type relationships are a crude estimate compared to more recent work regarding cognitive HEPs.

The skill based behavior HEPs are taken from the NUREG/CR-1278,[5] which includes tables from NUREG/CR-4772.[6] From this single behavior HEP, the other two can be calculated using the relative behavior relationship in the preceding paragraph. Many of the skill based HEPs are taken directly from Table 7-2 in NUREG/CR-4772; however, some are not consistent with that table. For example, the 30 minutes and 60 minute skill based behavior type HEPs are 10^{-2} and 10^{-3} in both the table and in NEDO-33201. The values not consistent with the Table 7-2 may have been calculated using the Swain Handbook,[5] but the factors that were used to produce different HEPs from those in Table 7-2 were not documented in NEDO-33201 and cannot be reproduced without assuming which factors affecting dependency were used to determine the HEP. NEDO-33201 does state that any partial dependency was modeled as fully dependent, but there is no indication of which dependencies were considered for this HRA.

The quantification is consistent with the SHARP method, but the documentation by the ESBWR PRA does not provide enough information to determine how the generic HEPs were calculated. The HEPs are provided in tables for all of the Type A and Type C actions in NEDO-33201, and the way the values are used is clearly stated. This step is more carefully documented because SHARP does not include a quantification method; therefore, the procedure GE used is described to support the HRA and with the exception of explaining how the individual HEPs were calculated, the quantification sufficiently documents how the HEPs are used.

4.1.7 Step 7: Documentation

The HRA document did not include the documentation that is required as part of the SHARP method. If the required documentation had been provided, then determining the compliance of the HRA to the SHARP method would be a clear and straightforward process. The NEDO-33201 document provides only the information previously discussed and lacks many of the requirements of the documentation step that will be assumed to have been completed as a separate document. Parts of the process, notably the quantification, are more comprehensively documented than other steps as indicated by the analysis of steps three, four, and five.

4.2 Later SHARP Revisions in Relation to the ESBWR

Considering the SHARP model was reviewed and SHARP1 came out before the ESBWR PRA was performed, it would make sense that an updated SHARP methodology would be employed for the GE reactor. The reason that an older model was used may be because the analysts were more familiar with the original from past experience.

Another reason the SHARP model may have been used was because the nature of the new passive systems on the ESBWR made the model a better fit. This explanation seems less likely because the improvements on the model are not specific to the plant or system hardware. The improvements were intended to make the HRA process more consistent and reproducible across many facilities.

Lastly, the SHARP1 document does not stand alone. For this reason the engineers may have wanted to use SHARP model. The SHARP1 document does refer analysts back to the original SHARP model for details on some topics.[8] The SHARP1 process also concentrates on documentation and similarly to SHARP does not include a method for quantification. The SHARP method may have been more suitable for the ESBWR design control document phase for these reasons.

5 Conclusion

Before starting the analysis of NEDO-33201 to determine its consistency with the SHARP method, it was clear that all of the documentation was not available as part of the document. Even though it was not possible to determine with certainty that the SHARP method was followed, the analysis was conducted to determine if any of the ESBWR HRA would not be consistent with the SHARP method.

Based on everything included in chapter six of NEDO-33201, the HRA chapter, there is no evidence that any of the actions of the analysts conducting the PRA were contrary to the expectations of SHARP. The last section of chapter six acknowledges that this is a design phase that does not require the most rigorous analysis, implying that detailed analysis will be completed at a later time. With the detailed analysis, there should be comprehensive procedures and records of the HRA work completed.

6 References

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