MODIFICATION OF THE SPAR-H METHOD TO SUPPORT HRA FOR LEVEL 2 PSA

S. St. Germain[1], R. Boring[1], G. Banaseanu[2], Y. Akl[2], M.Xu[2]

[1]*Idaho National Laboratory, P.O. Box 1625, Idaho Falls, USA 83415-3855,*

shawn.stgermain@inl.gov, ronald.boring@inl.gov

[2]*Canadian Nuclear Safety Commission, 280 Slater St., Ottawa, Canada, K1P 5S9*

georgeta.banaseanu@canada.ca, yolande.akl@canada.ca, michael.xu@canada.ca

Currently, available Human Reliability Analysis (HRA) methods were generally developed to support Level 1 Probabilistic Safety Analysis (PSA) models. There has been an increased emphasis placed on Level 2 PSA in recent years; however, the currently used HRA methods are not ideal for this application, including the SPAR-H method. Challenges that will likely be present during a severe accident such as degraded or hazardous operating conditions, shift in control from the main control room to the technical support center, unavailability of instrumentation, and others are not routinely considered for Level 1 HRA analysis. These factors combine to create a much more uncertain condition to be accounted for in the HRA analysis. While the SPAR-H shaping factors were established to support Level 1 HRA, previous studies have shown it may be used for Level 2 HRA analysis as well. The Canadian Nuclear Safety Commission (CNSC) and Idaho National Laboratory (INL) in a joint project are investigating modifications to the SPAR-H method to create more consistency in applying the performance shaping factors used in the method for Level 2 analysis.

I. INTRODUCTION

Currently available Human Reliability Analysis (HRA) methods were generally developed to support Level 1 Probabilistic Safety Analysis (PSA) models. There has been an increased emphasis placed on Level 2 PSA in recent years; however, the currently used HRA methods are not ideal for this application, including the SPAR-H method.[1] Challenges that will likely be present during a severe accident such as degraded or hazardous operating conditions, shift in control from the main control room to the technical support center, unavailability of instrumentation, and others are not routinely considered for Level 1 HRA analysis. In addition, integration of Emergency Mitigation Equipment (EME) and Severe Accident Management Guides (SAMG) in event mitigation adds another layer of complexity in evaluation of HRA. These factors combine to create much more uncertain conditions to be accounted for in the HRA analysis. While the SPAR-H performance shaping factors (PSFs) were established to support Level 1 HRA, previous studies have shown it may be used for Level 2 HRA analysis as well.

The Canadian Nuclear Safety Commission (CNSC) and Idaho National Laboratory (INL) in a joint project are investigating modifications to the SPAR-H method to create more consistency in applying the PSFs used in the method for Level 2 analysis. This will be accomplished by adapting the SPAR-H guidance and tables for PSF selection for Level 2 PSA and EME/SAMG integration. This paper presents the modifications made to PSF multipliers for diagnosis and actions to better support HRA for Level 2 PSA and EME/SAMG integration as well as recommended guidance for selecting PSF values for Level 2 HRA events.

While the SPAR-H method has previously been used for Level 2 analysis, this paper provides a recommendation for a Level 2 SPAR-H table that accounts for some of the expected conditions unique to accident conditions. Additionally, guidance is provided for selection of PSF values based on considerations for Level 2 PSA needs. The recommended changes do not involve new or changed PSF values, and the base research that supports SPAR-H remains valid. The changes should result in improved consistency, and slightly more conservative results that should be expected given the increased uncertainty in conditions created by severe accidents.

II. WHY LEVEL 2 SPAR-H IS NEEDED

II.A. SPAR-H Background

The Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method[1] was developed as a simple-to-use approach for risk analysts to compute human error probabilities (HEPs). One way in which SPAR-H achieves simplicity is through the use of eight PSFs. A PSF is an aspect of the human's individual characteristics, environment, organization, or task that specifically decrements or improves human performance, thus respectively increasing or decreasing the likelihood of human error. Many early HRA methods focused on the error likelihood of particular scenarios, whereby the risk analyst would map novel scenarios back to pre-defined scenarios to extract an HEP. This scenario-based HRA approach (also called *holistic HRA*[2]) proved inflexible in application and was prone to mismatches. The Technique for Human Error Rate Prediction (THERP) method[3] is the prototypical HRA method that uses scenarios. A different approach (also called *atomistic HRA*[2]) emerged in SPAR-H and other HRA methods in which the risk analyst focused not on mapping whole scenarios but rather on mapping the applicable PSFs within those scenarios. The advent of PSFs brought greater generalizability of HRA and greater inter-analyst reliability through simplified HEP estimation processes.

SPAR-H is documented extensively in NUREG/CR-6883, *The SPAR-H Human Reliability Analysis Method*.[3] NUREG/CR-6883 contains a wealth of theoretical background and useful application information about SPAR-H. Additional guidance has been released under the *SPAR-H Step-by-Step Guidance* report[4] which augmented the NUREG/CR guidance with additional documentation on determining diagnosis or action for the nominal HEP, defining the PSFs, accounting for dependence, and establishing a lower bound. A 2007 paper by Boring and Blackman[5] documents the origins of the SPAR-H PSF multipliers, which can be linked in most cases back to THERP. The SPAR-H method effectively generalizes the scenario-based quantification in THERP to a more flexible PSF-based approach.

II.B. Level 2 HRA Needs

A Level 2 HRA concerns human actions that may contribute to radioactive release after the loss of core structural integrity. Whereas Level 1 HRA will generally be concerned with the evolution of an event from full-power up to the point of core damage, the situation for Level 2 is fundamentally different. The plant is no longer at power, it is no longer fully functional, and it may challenge operator experience and training. Cooper et al.[6] identifies several key differences in the context being analysed between Level 1 and Levels 2 or 3.

- Use of different procedures (including Severe Accident Management Guidelines [SAMGs]) that differ from [emergency operating procedures] in a number of ways, including format, level of detail, and requirements for decision-making

- Shift of decision-making responsibilities from control room operators to the Technical Support Center (TSC) with likely influences from outside organizations

- Less information and less accurate information on plant conditions that would be expected to be important inputs to decision-making (e.g., ambiguities with respect to extent of fuel damage, loss of instrument precision or function when exposed to extreme environmental conditions, loss of critical instrumentation after battery depletion during station blackout)

- Decision-making that involves making tradeoffs between choices with no equivalent of a "success path" (in the traditional [PSA] sense) and no obvious "better path"

- Ex-control room operator actions under a variety of or combinations of environmental hazards (including radiation)

- Staffing and equipment that may be inadequate for multiple site hazards (e.g., a combination of reactor and spent fuel pool concerns), especially if plant or equipment damage result in second or third resort measures to be attempted

An additional difference that is not specifically called out in the paper is the addition of new EME (also known as the Diverse and Flexible Coping Strategies [FLEX] in the U.S.[7] This equipment affords new opportunities for recovery but may also require additional staff resources to activate.

As noted in Boring and St. Germain,[8,9] the majority of HRA methods have been developed to support Level 1 analysis. THERP,[3] the original and still most widely used HRA method, did not explicitly refer to differences between these analyses. While the THERP method may have predated the advent of Level 1, 2, and 3 discussions in the PSA community, the distinction between levels is also not critical to the integrity of the method. THERP and other HRA methods study human actions and decompose those actions into human behavioural primitives. In the case of THERP, those primitives are found in lookup tables that can, in theory, be applied equally to any level of analysis. In practice, the lookup tables in THERP do not align to many of the types of situations found in Level 2 analysis. To use THERP for Level 2 analysis is quite likely overgeneralizing the method to contexts for which it was not intended.

Newer methods like SPAR-H handle human behaviour in terms of PSFs, but the basic treatment of these PSFs does not change as the level of analysis changes. The generalizability of the PSFs is a strength of this type of approach, but there is a need to consider the assumptions and quantitative outcomes of SPAR-H for Level 2 applications, since the current standard guidance on the method does not address Level 2 analysis.

Wang performed the only publically documented Level 2 HRA for existing plants using SPAR-H.[10] This work centered on support of Level 2 PSA models for the Chinese nuclear industry. Wang reiterates two primary differences between Level 1 and Level 2 HRA:

- The shift from main control room operations to emergency organization such as the TSC, and
- The use of SAMGs instead of emergency operating procedures.

The SPAR-H method was selected for application in Level 2 HRA because other HRA methods currently used for Level 1 HRA did not generalize well to the Level 2 areas of emphasis cited above. The THERP method was found, due its very limited repertoire of PSFs, to be unable to characterize the complex context of human actions during a severe accident. The eight PSFs in SPAR-H were found to provide good coverage of the PSFs that come into play during a severe accident. SPAR-H proved an effective method for Wang's Level 2 HRA application.[10] While Wang documented using the SPAR-H method for Level 2 analysis, this paper provides recommendations for modification of the SPAR-H PSF tables to specifically support Level 2 analysis and provides guidance for selection of PSF multipliers for various expected Level 2 events.

As demonstrated in an example analysis in St. Germain and Boring,[7] the SPAR-H PSFs may reasonably be used for quantifying Level 2 human actions. The small sample of Level 2 actions evaluated using the SPAR-H method had a similar HEP as the licensees custom Level 2 HRA model. With the limited information available for that evaluation, only three of the SPAR-H shaping factors were adjusted for each event. If the SPAR-H method was used from the beginning, additional information could have been gathered to support evaluation of additional shaping factors. It is likely that with additional evaluation, some of the HEPs from the SPAR-H method may have yielded lower error probabilities. The SPAR-H method is able to reflect the results of operational and organizational influences that are known to improve performance, for example the quality of procedures or training.

While the existing SPAR-H method may be used for Level 2 PSA, it would be extremely difficult to project some of the PSFs into severe accident conditions, and other PSFs should be modified to account for Level 2 factors. Additionally, the guidance provided for use of SPAR-H is focused on a Level 1 PSA, and more consistent application of the method to Level 2 PSA would be achieved through specific guidance that takes into account the differences in Level 1 and Level 2 PSA. As such, St. Germain and Boring[7] recommended a modification of SPAR-H for Level 2 applications, including revising the PSF definitions and multipliers as needed. Just as SPAR-H currently has separate worksheets for At Power and LP/SD applications, it may be appropriate to develop a new SPAR-H worksheet exclusive to Level 2 analyses (see Table I).[11] Because the application of SPAR-H to Level 2 PSA is state of the art, there may be future studies necessary to understand the implications of Level 2 analyses on specific PSFs such as the procedures (e.g., SAMGs), human-machine interfaces (HMIs; e.g., digital HMIs), and work processes (e.g., multiple organizations and associated dynamics). The rest of this paper details the adaptation of the SPAR-H PSF tables for Level 2 application.

TABLE I. SPAR-H PSF Multiplier Levels for At Power, Low Power/Shutdown, and Level 2 Analysis

PSFs	PSF Levels	At Power		Low Power/Shutdown		Level 2 Analysis	
		Multiplier for Diagnosis	Multiplier for Action	Multiplier for Diagnosis	Multiplier for Action	Multiplier for Diagnosis	Multiplier for Action
Available Time	Inadequate time	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0
	Barely adequate time	10	10	10	10	10	10
	Nominal time	1	1	1	1	1	1
	Extra time	0.1	0.1	0.1	0.1	0.1	0.1
	Expansive time	0.01	0.01	0.1 to 0.01	0.01	0.1 to 0.01	0.01
	Insufficient information	1	1	1	1	1	1
Stress/ Stressors	Extreme	5	5	5	5	5	5
	High	2	2	2	2	2	2
	Nominal	1	1	1	1	N/A	N/A
	Insufficient Information	1	1	1	1	2	2
Complexity	Highly complex	5	5	5	5	5	5
	Moderately complex	2	2	2	2	2	2
	Nominal	1	1	1	1	1	1
	Obvious diagnosis	0.1	N/A	0.1	N/A	N/A	N/A
	Insufficient Information	1	1	1	1	1	1
Experience/ Training	Low	10	3	10	3	10	3
	Nominal	1	1	1	1	1	1
	High	0.5	0.5	0.5	0.5	N/A	N/A
	Insufficient Information	1	1	1	1	1	1
Procedures	Not available	50	50	50	50	50	50
	Incomplete	20	20	20	20	20	20
	Available, but poor	5	5	5	5	5	5
	Nominal	1	1	1	1	1	1
	Diagnostic/symptom oriented	0.5	N/A	0.5	N/A	0.5	N/A
	Insufficient Information	1	1	1	1	1	1
Ergonomics / HMI	Missing/Misleading	50	50	50	50	50	50
	Poor	10	10	10	10	10	10
	Nominal	1	1	1	1	1	1
	Good	0.5	0.5	0.5	0.5	N/A	N/A
	Insufficient Information	1	1	1	1	1	1
Fitness for Duty	Unfit	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0	P(failure) = 1.0
	Degraded Fitness	5	5	5	5	5	5
	Nominal	1	1	1	1	1	1
	Insufficient Information	1	1	1	1	1	1
Work Processes	Poor	2	5	2	5	2	5
	Nominal	1	1	1	1	1	1
	Good	0.8	0.5	0.8	0.5	N/A	N/A
	Insufficient Information	1	1	1	1	1	1

III. LEVEL 2 SPAR-H ADAPTATION

III.A. Introduction

While it was shown in St. Germain and Boring[7] that the SPAR-H method could successfully be used to evaluate Level 2 HRA events, it was noted that some of the PSF levels available to analysts using SPAR-H for Level 1 analysis did not make sense for a Level 2 analysis. Additionally, the guidance for selecting a PSF level in the SPAR-H documentation provided little information regarding specific attributes of a Level 2 analysis. The authors have created a new SPAR-H table and guidance specifically to support a Level 2 HRA analysis.[11] Table I shows the existing Level 1 and LP/SD PSF multiplier levels alongside the newly recommended Level 2 PSF multiplier levels. Section III.B provides additional guidance for the analysts in selecting the appropriate PSF levels for Level 2 analysis. The main purpose of this additional guidance is to drive consistency in analysis and improve the reasonableness of Level 2 results.

III.B. Level 2 Performance Shaping Factor Guidance

This work represents an initial concept to solicit additional expert opinion and should not be taken as the definitive solution**.** The following sections provide guidance on each of the SPAR-H PSFs in terms of how the values were selected and how multipliers for each PSF should be selected given the unique characteristics of Level 2 human actions.

III.B.1 Available Time

Similar to Level 1 analysis, time available should be determined by thermal hydraulic analysis. Due to the uncertain nature of severe accidents, several conditions may need to be analyzed to ensure a reasonable time available is used.

For EME/FLEX, detailed task analysis will be necessary to determine the time required. Assumed physical conditions for a severe accident should be accounted for. Additionally, time delays that may be introduced due to slower communication channels when the Technical Support Center is included in the decision making process should be considered. If additional resources are needed to move equipment into place, ensure the time required to notify and mobilize these personnel is accounted for.

For external events, such as flooding, seismic or high winds, the time to move and install EME may need to be significantly adjusted. Factors to consider may include: the distance between the storage location and the installation location, the potential hazards between these locations, the number of alternate routes that may exist, etc.

III.B.2 Stress/Stressors

The new minimum value for the stress PSF is now high. Since Level 2 analysis is for post core damage scenarios, there must be some significant external event, serious initiating event, or multiple system failures to bring the plant into this degraded condition. Regardless of the scenario, there will be additional stress placed on the operating crew to comprehend their situation and to prevent further core damage or an offsite release. The understanding of the potential health and economic consequences of the accident will almost certainly increase stress levels.

Extreme stress should be considered for certain external events such as earthquakes that would likely damage plant structures, flooding that would likely inundate the site, damaging winds, or severe plant fires. Each of these external events creates additional physical hazards for plant personnel that would affect the stress level of both the decision makers and the persons performing the actions in the field.

III.B.3 Complexity

The Level 2 SPAR-H diagnosis PSF table no longer allows the Obvious Diagnosis PSF level. Since the analyzed actions are post core damage, with assumed complications that would be required to get into this situation, it is unlikely Obvious Diagnosis situations would exist, or they would have occurred earlier in the scenario. It is expected that not all plant parameter indications will be available or reliable. Certain plant instrumentation may be outside of calibration conditions, and there is a risk that plant personnel may not recognize that indications are providing inaccurate information.

Activation of the Emergency Response Organization (ERO) will likely add additional complexity to the situation. After command and control is transferred from the main control room to the ERO, communication paths may be longer and less practiced. Additional complexity may result from shared ERO responsibilities between the TSC and EOF (Emergency Operations Facility). It was observed during the accident at the Fukushima Daichii station that guidance was also provided by a corporate entity that added to the confusion. There also exists the potential for interference or distraction from local government agencies or regulators. For Multi-Unit accidents, additional complexity may be placed on the ERO trying to manage simultaneous accidents with limited resources. Prioritization of actions between different units will certainly add to decision making complexity. It is recommended that actions likely to occur after the activation of the ERO use the Moderately Complex PSF.

Entry into the SAMGs introduces additional complexity. The actions recommended in the SAMGs are not nearly as prescriptive as those outlined in emergency operating procedures or normal operating procedures. The wide variety of options presented in the SAMGs will require additional evaluation by the staff and increases the complexity of diagnosis. It is recommended that the Moderately Complex PSF be used for actions that will likely take place after entry into the SAMGs.

It is expected that normal indication may not be available for certain severe accident scenarios. For modeled actions that will likely rely on obtaining key plant parameters from remote indications, the Highly Complex PSF should be considered.

III.B.4 Experience/Training

The Level 2 SPAR-H PSF tables no longer allow credit for a High level of experience and training. No site has a high experience level for post core damage human actions. Even for sites that perform frequent ERO drills, these drills cannot be performed with the accompanied stress and hazards that will part of a real event. Additionally, ERO drills usually rely on walk throughs and simulation and do not usually require actual plant manipulations or equipment installation.

Nominal credit may be used for EME if documentation shows all personnel expected to operate EME receive adequate training and practice operating, moving, and installing equipment. Until reasonable levels of training and experience are demonstrated, select Low for this PSF for human actions related to EME equipment. For multi-unit scenarios, even if adequate numbers of equipment are available to support each unit, the ERO may not be practiced in prioritizing the deployment of limited resources.

Post core damage training is not currently well documented as is relates to HRA. Future research may be required to determine the effects on human reliability for severe accidents.

III.B.5 Procedures

The Diagnostic/symptom oriented PSF level should only be selected for actions directed from EOPs early in a Level 2 scenario.

For actions directed from SAMGs, the nominal PSF level should be selected as a minimum, with the Available but Poor level selected for SAMG actions that present many possible actions for a given situation with limited guidance provided. The key parameters that need to be evaluated for each modeled Level 2 actions should also be evaluated to understand the source of the indication. Results of thermal hydraulic analysis may be required to understand the possible plant conditions that the plant may be in for an expected human action to understand the expected interpretation of the SAMGs for the given conditions.

For EME/FLEX equipment procedures, procedures should be of equivalent quality, reviewed, and trained on as procedures for operating plant equipment to warrant the nominal PSF level. Evaluation of the EME procedures should be based on the expected conditions in which this equipment will be operated, not just an administrative validation of requirements. Since most EME is portable, verify that accommodations for providing the procedures at the location of use and ensure adequate conditions exist to actually use the procedures at the intended location under all conditions (e.g., ensure there is adequate lighting).

III.B.6 Ergonomics/HMI

The Level 2 SPAR-H PSF tables no longer allow a Good PSF level selection for either Diagnosis or Action, such that the new minimum level will be Nominal. This is due to the uncertain conditions that will likely exist during a severe accident. There will likely be unforeseen physical challenges as well as degraded instrumentation and lighting that will not be explicitly modeled in the PSA.

For the diagnosis PSF for SAMG actions, if the action is known to rely on portable, remote, or seldom used indications, the HMI should be carefully evaluated for the expected environmental conditions. Environmental conditions that may impede the use of these indications include poor lighting, steam environment, or other physical hazards and challenges. Additionally, the possibility of instrumentation indications displaying incorrect information due to exceeding calibration conditions should be evaluated.

For the action PSF for EME/FLEX equipment, the analyst will need to review the installation locations, storage locations, and connections to ensure required components are well labeled and transportation methods are well established in order to select a Nominal PSF level. For external events that will likely disrupt the equipment installation or transportation such as flooding, heavy snow or seismic events, the Poor PSF level should be selected.

III.B.7 Fitness for Duty

The Level 2 SPAR-H PSF tables remain unchanged for Fitness for Duty. The analyst should consider the timing of Level 2 HRA events with respect to the accident scenario. Actions that are likely to take place late in the scenario may be impacted by crew fatigue. Crew fatigue will be impacted by minimum crew staffing, ERO processes, or impacts from external events that hamper replacement crew members from reaching the facility. The geography and distance travelled by expected support staff should be considered. Extreme stress can manifest physiologically and may degrade fitness further. Consideration should be made for potential multi-unit accidents as well: Does the ERO plan provide enough staff to support multiple accidents concurrently?

III.B.8 Work Processes

The Level 2 SPAR-H PSF tables no longer allow a Good PSF level selection for either Diagnosis or Action; the new minimum level will be Nominal. It would be hard to justify credit above nominal for processes related to emergency response. Given the differences that exist between accident conditions and drill conditions, even ERO organizations that are well defined and drill frequently are not likely going to reduce the human error probability simply through processes. The analyst should review the ERO, emergency plans, emergency facilities and drill history to determine if a Poor PSF level should be selected instead of Nominal.

III.B.9 Overall Guidance

The analyst should be aware that certain characteristics in Level 2 HEP event analysis could fit in multiple PSFs, therefore the analyst should avoid excessive penalties by applying negative PSF multipliers to several PSFs for the same challenge. The analyst should document the assumptions and reasons for choosing each PSF multiplier. Future work may focus on improving Level 2 HRA guidance as additional focus is put into accident management and analysis, for example the Training PSF criteria may change if more post accident training becomes available. Additionally, some PSFs are certainly more important in a level 2 analysis and will be the dominant drivers. It may be reasonable to reduce the number of PSFs that are evaluated for a Level 2 analysis. Use of the SPAR-H method for Level 2 analysis may point out weak areas in a plant’s accident plan if very low HEPs result from very high multipliers in certain PSFs that propagate through the PSA and become significant large release contributors. This analysis may point to a need for improved post accident indications, procedures or training.

IV. EXAMPLE ANALYSES

An existing plant PSA from the Canadian nuclear industry was reviewed to identify Level 2 human failure events. A subset of these human failure events was selected for review of the HRA. This subset included events with a low or high overall HEP. The existing events analyzed by the utility made use of a custom Level 2 HRA method. The quality of these HRA analyses was reviewed in terms of the utility of the methods to address contemporary HRA needs and expectations. The events were then reanalyzed using the SPAR-H HRA method and the results compared.

IV.A. Actions That Have a Low HEP, Directed from Severe Accident Guidelines (OPACT1)

The representative action selected for evaluation for this criterion was: Operator initiates LP ECC with the Emergency Power Supply already operating. This event was assigned a HEP of 2E-3 by the licensee using a custom Level 2 HRA model. The licensee classified the operator action as low difficulty for both diagnosis (1E-3) and execution (1E-3). SPAR-H yielded an HEP of 4E-3 modified by Extra time for the Time Available PSF and High Stress for the Stress PSF. The remaining PSFs were rated as nominal.

IV.B. Actions That Have a Medium HEP, Directed from EOPs or APOPs (OPACT2)

The representative action selected for evaluation for this criterion was: Operator restarts the Shutdown Cooling System. The event was assigned an HEP of 1.1E-2 by the licensee using a custom Level 2 HRA model. The licensee evaluated the operator action as low difficulty for diagnosis (1E-3) and medium difficulty for execution (1E-2). SPAR-H yielded an HEP of 2.4E-2 modified by High Stress for the Stress PSF, Moderate Complexity for the Complexity PSF, and Diagnostic for the Procedures PSF. The remaining PSFs were rated as nominal.

IV.C. Actions that Have a High HEP, Directed From the Severe Challenge Guidelines (OPACT3)

The representative action selected for evaluation for this criterion was: Operator initiates dousing recirculation after 2 failed actions. The event was assigned an HEP of 2E-1 by the licensee using a custom Level 2 HRA model. The licensee classified the operator action as high difficulty for diagnosis (1E-1) and high difficulty for execution (1E-1). SPAR-H yielded an HEP of 1.1E-1 modified by High Stress for the Stress PSF and Highly Complex for the complexity PSF. The remaining PSFs were rated as nominal.

IV.D. Overall Observations

Table II presents a summary of the HEPs from the licensee's PSA report using a custom Level 2 HRA model and values calculated by the authors using SPAR-H.[11] The simplified licensee's method accounts for very few factors, whereas SPAR-H uses eight shaping factors. The SPAR-H evaluation was made solely on provided documentation from the licensee's PSA to be used as example of how the method could be used. Use of the SPAR-H shaping factors provided more information to support an assigned HEP and would remove some subjectivity in an analysis. Some general observations can be made from this comparison. SPAR-H typically produced a value that was slightly higher than the licensee's method, except for the higher HEP event. The results would likely be somewhat different if the analysis were done with complete access to the required information. This analysis did show that the SPAR-H method was well suited for the CANDU reactor design, and could likely be applied to any reactor design PSA.

TABLE II. Comparison of HEPs

Human Error ID	Description	Licensee HEP	SPAR-H HEP
OPACT1	Operator initiates LP ECC with EPS already operating.	2E-3	4E-3
OPACT2	Operator restarts the SDCS.	1.1E-2	2.4E-2
OPACT3	Operator initiates dousing recirculation after 2 failed actions.	2E-01	1.1E-01

V. CONCLUSIONS

In conclusion, the results of this study have demonstrated that SPAR-H may be used for evaluating HEPs in a Level 2 PSA. While the method could be used as currently written, it was initially developed to support Level 1 PSA models. With additional guidance, it is expected that the SPAR-H method would produce more consistent and realistic HEPs between analysts. SPAR-H, like other HRA methods, may be applied to any reactor design, and may be used for new reactor concepts as well as existing reactor designs beyond the light water reactors that the method was originally used. This report presents proposed modifications to the SPAR-H Level 1 At-Power PSF tables to better support Level 2 analyses and includes additional guidance for selecting PSF levels given the unique characteristics of expected Level 2 events. To support this study, SPAR-H was used to reanalyze human actions previously evaluated using a custom Level 2 HRA model. The analysts in this study where able to make reasonable assessments of the SPAR-H shaping factors;

however, better documentation or access to plant staff and information would improve the confidence in the results. SPAR-H produced a result similar to the model used by the licensee; however, the use of shaping factors provides more information and tends to lead to more repeatable results.

ACKNOWLEDGMENTS

This work was supported and funded by the Canadian Nuclear Safety Commission. The opinions expressed in this publication do not necessarily reflect those of the Canadian Nuclear Safety Commission. This project is prepared under an international cooperative agreement for the purpose of exchanging technical information. This study is intended for research purposes only, may be preliminary, and certain procedures described may be untested. The research report is purely for information purposes. The report also includes analysis and views expressed by the research team. The recipients of this material should take their own professional advice before acting on this information.

This work of authorship was prepared as an account of work sponsored to Idaho National Laboratory, an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights. Idaho National Laboratory is a multi-program laboratory operated by Battelle Energy Alliance LLC, for the United States Department of Energy under Contract DE-AC07-05ID14517.

REFERENCES

1. D.I. GERTMAN, H.S. BLACKMAN, J. MARBLE, J. BYERS, and C. SMITH, *The SPAR-H Human Reliability Analysis Method*, NUREG/CR-6883. Washington, DC: U.S. Nuclear Regulatory Commission (2005).
2. R.L. BORING and D.I. GERTMAN, "Atomistic and holistic approaches to human reliability analysis in the US power industry," *Journal of the Safety and Reliability Society*, **25(2)**, 21-37 (2005).
3. A.D. SWAIN and H.E. GUTTMAN, *Handbook of human reliability analysis with emphasis on nuclear power plant applications. Final report. NUREG/CR-1278.* Washington, DC: U.S. Nuclear Regulatory Commission (1983).
4. A.M. WHALEY, D.L. KELLY, R.L. BORING, W.J. GALYEAN, *SPAR-H Step-by-Step Guidance, INL/EXT-10-18533, Rev. 2.* Idaho Falls: Idaho National Laboratory (2011).
5. R.L. BORING and H.S. BLACKMAN, "The Origins of the SPAR-H Method's Performance Shaping Factor Multipliers," *Proc. Joint 8th IEEE Conference on Human Factors and Power Plants and the 13th Annual Workshop on Human Performance/Root Cause/Trending/Operating Experience/Self Assessment*, 177-184 (2007).
6. S. COOPER, J. XING, and Y. CHANG, "What HRA needs to support site-wide, multi-hazard level 2 PRA," *Proc. International Topical Meeting on Probabilistic Safety Assessment and Analysis 2013 (PSA 2013)*, 1686-1696 (2013).
7. S. ST. GERMAIN and R.L. BORING, *Assessment of Human Interactions Credited in Level 2 PSA Including Guidance for Crediting Severe Accident Management Guidance (SAMGs) and Emergency Mitigation Equipment (EME), INL/LTD-14-34734.* Idaho Falls: Idaho National Laboratory (2015).
8. R.L. BORING and S. ST. GERMAIN, *Assessment of Human Interactions Credited in Level 1 PSA, INL/LTD-14-32884.* Idaho Falls: Idaho National Laboratory (2015).
9. R. BORING, S. ST. GERMAIN, G. BANASEANU, H. CHATRI, and Y. AKL, "Applicability of Simplified Human Reliability Analysis Methods for Severe Accidents," *Proc. 7 th International Conference on Modelling and Simulation in Nuclear Science and Engineering (7ICMSNSE)*, 098.1-11 (2015).
10. Y. WANG, "The human reliability analysis in level 2 PSA using SPAR-H method," *Advanced Materials Research,* **608**, 848-853 (2013).
11. S. ST. GERMAIN and R.L. BORING, *SPAR-H Level 2 Human Reliability Analysis, INL/LTD-14-38368.* Idaho Falls: Idaho National Laboratory (2015).