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Representing Cognitive Activities and Errors in HRA Trees^a

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ABSTRACT

A graphic representation method is presented herein for adapting an existing technology--human reliability analysis (HRA) event trees, used to support event sequence logic structures and calculations--to include a representation of the underlying cognitive activity and corresponding errors associated with human performance. The analyst is presented with three potential means of representing human activity: the NUREG/CR-1278 HRA event tree approach (Swain and Guttman 1983); the skill-, rule- and knowledge-based paradigm (Rasmussen 1979); and the slips, lapses, and mistakes paradigm (Norman 1979, Reason 1984). The above approaches for representing human activity are integrated in order to produce an enriched HRA event tree -- the cognitive event tree system (COGENT)-- which, in turn, can be used to increase the analyst's understanding of the basic behavioral mechanisms underlying human error and the representation of that error in probabilistic risk assessment. Issues pertaining to the implementation of COGENT are also discussed.

INTRODUCTION

The descriptions found in probabilistic risk assessments (PRAs) regarding the demands upon, and the resulting performance of, nuclear power plant (NPP) crews often vary with the analyst performing the human reliability analysis (HRA). One of the techniques in use today, the *technique for human error rate prediction* (THERP),¹ provides a mechanism for presenting the analyst's conceptualization of the activities underlying performance and the errors associated with that performance. THERP also provides a means to determine where the analyst has come from in his or her thinking and a corresponding means by which to perform the calculations needed to support event sequence analysis. Also, THERP easily identifies and

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allows for quantification of dependencies and a variety of performance shaping factor (PSF) information.

However, for a variety of reasons, analysts have chosen to use the HRA event tree presented in THERP to put forth a more behavioristic description of performance than perhaps is warranted. This is due to the fact that there has yet to be a concerted effort to take cognitive psychology, and wed it to the logic structure of the HRA event tree.

Cognitive psychology has, in part, approached the problem of accounting for performance in advanced sociotechnical systems such as nuclear power plants by looking at fundamental error mechanisms such as slips, lapses, or mistakes (see Norman,² Reason³). Recently, books have been devoted to the topic of understanding accidents and human error from a *cognitive perspective*.^{4,5,6} . The cognitive approach deserves merit because it provides the means to understand underlying behavioral mechanisms and to discuss the underlying intellectual activities associated with crew performance. The means for implementing a cognitively-oriented approach to systems engineering and task analysis methods may be found in Hollnagel and Woods⁷ and in Woods and Hollnagel⁸.

In the nuclear industry, the work of Rasmussen⁹ in conceptualizing demands of the task situation as placing operators in skill-based, rule-based, or knowledge-based realms has provided engineers and HRA practitioners a means to describe and discuss human performance. There is, however, a logical relationship between the somewhat behavior-oriented descriptions of human error and performance contained in HRA event trees, and the more cognitively based means of discussing human performance noted above. Cognition underlies performance and error. As a means of reviewing and understanding performance, each has its advantages .

The combination of THERP with more cognitively-oriented approaches may provide a superior product. A method for achieving a merger of the two is presented below.

STANDARD APPROACH TO HRA EVENT TREES

HRA event trees are often used to represent human failures which may, in turn, result in system failure or unavailability. Instruction for constructing HRA event trees is documented in NUREG/CR-1278^{1,10} and in NUREG/CR-4277¹¹. A full system description and an event sequence description should accompany the HRA event tree analysis. In many instances, this will already be available as part of the PRA. The procedures for event tree construction includes modeling of the relevant interfaces, communications, and task and inter-person dependencies. Supervisory activity or activity of a second operator is usually modeled as a

recovery factor. The information for the event tree is determined from the following: task analysis; review of operating limits, training materials, and as-built drawings; and walkdowns of plant procedures and processes. Information available from control room design reviews may be reviewed as well.

As a matter of course, practitioners must decompose behavior into discrete units suitable for assigning HEPs; depending on the needs of a particular PRA some modeling of human performance will be more detailed than others. (Decomposing behavior within the cognitive domain presents similar, if not greater, challenge for the risk analyst). Once the level of detail appropriate to the PRA is determined, it is important that the level of decomposition within a tree be uniform. Non-uniform representation of tasks will result in data skewing.

Typically, the branches of the HRA event tree represent a binary decision/action path in which correct performance and incorrect performance are the two choices. Based upon review of the existing evidence, the analyst selects a failure rate associated with incorrect or deviant performance and places that value on the right-hand side of the tree, the left-hand side always reflects the correct action pathway. Recovery actions are modeled by a diagonal line that comes back from the failure on the right to the next correct action located on the left, (see Figure 1).

Tree construction becomes somewhat involved when one considers actions which are to be taken in parallel rather than serially. Typically, task flows involving multiple important subtasks (usually more than 20) present problems for analyzing all the combinations of pathways leading to success for a particular task. Key to the quantification of these trees is that each of the branches on the right hand side has a human error probability (HEP) associated with it. For the most part, analysts make use of THERP data tables to select the HEP values associated with a particular type of error. Three types of HEPs from THERP are available: (a) a nominal HEP -- HEP for which performance shaping factor (PSFs) have not been accounted for; (b) a basic HEP (BHEP) -- an HEP with PSFs considered; and (c) a conditional HEP (CHEP)--represents the modification of the BHEP to take into account the influence of other tasks. This is a convention. *The HRA tree logic structures will support the representation of various subtask types, error modes, and failure rate estimates available in sources other than THERP.* Additionally, values may be imported from other THERP trees.

For example, analysts may wish to use the nominal group technique (NGT) to estimate an HEP for decision making activities conducted during beyond-design-basis accidents. Procedures for employing the NGT technique may be found in Seaver and Stillwell.¹¹ Subject matter experts (SMEs) participating in these sessions should receive training on probability and statistics. The scenarios presented to the SMEs should be well defined and thought out. For a critical review of methods for eliciting and using expert opinion in risk assessment see

Mosleh et al.¹³ Once data have been obtained from NGT sessions they may then be placed in the HRA event tree. In general, the importance of decision-based errors has been recognized in PRA and in HRA but rarely are these errors represented in HRA event trees.

APPROACH FOR COGNITIVELY-BASED HRA EVENT TREES

Introduction to the COGENT Modeling Scheme

The COGENT modeling scheme adds two taxonomies to the HRA event tree proposed by Swain and Guttman. The first of these, the Rasmussen taxonomy, provides description regarding the skill-based, rule-based, or knowledge-based behavior underlying the execution of tasks. It is not apparent and must be deduced from the pattern of errors exhibited by personnel. The second taxonomy, the one proposed by Norman² and Reason³, describes the type of error committed (which is easily observed as a slip, lapse or as a mistake) and implies something about the underlying cognition as well. Both theories allow for external cues such as system feedback via information systems to play a role in determining performance. In the case of the Rasmussen taxonomy, good system feedback gives us more certainty that crews are using conventional rules for operations and diagnosis. On the other hand, the presence of poor systems feedback, makes us less certain regarding operator performance. Given poor feedback, crews may be forced to use rules of which we know very little about (these are the rules related to personal experience and individual weighting of previous evidence). In the case of the Norman and Reason taxonomy, improved system feedback may not prevent lapses, but may serve as signposts to reduce slips, improve recovery from slips, or to aid in reducing mistakes in diagnosis by presenting the right information at precisely the right time. The COGENT system nomenclature; $S_{s,l,sm}$, $R_{l,m}$, and $K_{l,m}$, for combining the two systems is presented below.

The nomenclature is based on a primary letter with subscripts which follow. The primary letters are S , R , and K and are the primary factors of the Rasmussen taxonomy where:

S =Skill-based behavior

R = rule based behavior. and

K = knowledge-based behavior.

The subscripts s , l , sm and m represent factors of the Norman and Reason taxonomy where:

s =slips

l =lapse

sm =small mistakes and

m =mistakes

S_{s,l,sm} Skill-based behavior proposed by Rasmussen⁹ is normally under only a small degree of cognitive control, the behavior is almost reflexive. Slips, lapses and small mistakes may occur in the skill-based realm. Slips are those instances where the intention is incorrect and the execution is improper, or where the execution is improper because the sequence is wrong; lapses are similar to omissions and refer to instances where *inattention* or *interruption* result in failure to perform. Simple mistakes refer to instances where there is a history of making the right decision or recognition, but something happens to interrupt or to derail the process. This is to be contrasted with the general conception of a mistake wherein there exists a fundamental error in *interpretation* or *understanding*, or where formerly good rules are improper when applied to a new situation. Skill-based tasks are so well rehearsed or memorized that they seem automatic, the phrase "skill of the craft" is used to describe this sort of behavior. Reading is an example of a skill that, for most of us, is automatic. When we wish to read, we do so. We are not aware of saccadic jumps performed by our eyes or light falling on the fovea, or even simple rules of reading: read left to right, next read top to bottom, etc. *We simply read.*

R_{s,l,m} Rule-based behavior is under greater cognitive control. Reading and following a procedure is an example of rule-based behavior. Slipses, lapses, and mistakes may occur in the rule-based realm. Following signs on the highway is an example of rule-based behavior. In contrast, knowing how to turn the wheel of the car and integrating information related to the rate of speed and feel of the car when driving on ice are examples of skill-based behavior. Rule-based slips include less-than-adequate execution of proper rules. For example, carefull reading of the instructions on a fire extinguisher prior to use is a sound rule. By merely skimming the instructions, one could mistakenly attempt to use an extinguisher for combustibles on a fire comprised of flammables. A rule-based slip (and a larger fire) is the result. A rule-based lapse may occur when one is distracted and forgets to execute a task, a prime example of which is unintentionally skipping a step in an approved procedure. In everyday life, people sometimes complain of simply drawing a blank. Rules may be misapplied in a variety of situations, one of which is diagnosis. A rule-based mistake occurs when one applies the wrong rule, or applies a correct rule but at the wrong time. For example, the practice of exiting a freeway ramp at more than 25 miles per hour (which may be a personal habit that violates a posted rule) fails miserably when applied to icy conditions. A further example of a rule-based mistake may be a misdiagnosis (although misdiagnosis may also occur in the knowledge-based realm).

K_{l,m} Knowledge-based behavior occurs when our immediate environment lacks supporting external cues such as procedures, signs and other types of displays that aid us in

making decisions. Lapses and mistakes may occur in the knowledge-based realm. As a result, we are forced to act from a basis of individual expertise. Cognitive operations conducted in the knowledge-based realms include attempting to solve problems by use of analogy, generating and testing new hypotheses, and dealing with beyond-design-bases and other unprecedented events. Factors that can easily place us within a knowledge-based realm (where our internal rules may fail us) include: unclear or misleading systems feedback; lack of control indication; false or misleading procedures; inexperience; or unavailability of systems. Knowledge-based lapses include failure to remember solutions to problems encountered previously. For example, inexperienced NPP crews may forget that cycling closed the power operated relief (PORV) blockvalves is a potential means to compensate for a drop in pressurizer inventory. Knowledge-based mistakes are quite another matter. Imprecise knowledge of system relationships or dealing with events for the first time are examples of situations that invite knowledge-based mistakes. Attempting to manually close a valve against a known pressure of 600 PSI would be an example of a knowledge-based mistake; the physics of the task make it just about impossible.

Determining the appropriate cognitive category from those listed above requires the HRA analyst to be familiar with control room equipment, procedures, crew knowledge and experience, and to have an understanding of plant response to off-normal or emergency events and how the unfolding of a particular scenario will most likely be presented to and responded to by a control room crew.

Sample Application: Failure to respond to an SFAS actuation event

Postulated Sequence of Events. The postulated scenario for this hypothetical B&W plant begins as the reactor operator (RO) fails to recognize the safety features actuation system (SFAS) trip from one of two annunciated sources, either the reactor coolant (RC) pressure less than 1500 pounds per square inch (PSI); or the containment (CT) pressure reading less than 20 PSIA. In both instances, the annunciation consists of the following: a flashing annunciator tile, a computer alarm presented on a CRT located in a wraparound console in the control room, and a very loud, highly recognizable audible alarm. The crew is trained and procedures which provide the proper response for the above annunciation are available and are used by the crew. A temperature/saturation (TSAT) meter is present in the control room and is easily readable. A pressure/temperature display is also available and, with just a minor amount of interpretation, the operator can come to the same conclusion as if he or she had been reading the TSAT meter.

ROs are assumed to be trained well enough that they trip the reactor coolant pumps (RCPs) almost reflexively; the written procedure is present for confirmation but the action has been memorized. The last step modeled in Figure 1 presents the verification step, required by procedures, wherein the RO verifies that the high pressure injection (HPI) is proper in regard to plant conditions. The type of errors possible for this step are somewhat limited and include: failing to read the rules properly (i.e., a simple misreading of the rule) or making a *misinterpretation* of the rule from the stress of being in a LOCA situation. All these actions and potential errors associated with these actions may be modeled in a conventional THERP HRA event tree. Corresponding failure rates are also available, with exception of the last fault modeled, from NUREG/CR-1278. Misinterpreting a rule or making a judgment outside of a procedure may be calculated by expert estimation methods such as the NGT technique. Note that the conventional approach to HRA event tree notation presents: the proper performance designated by a lower case letter; aspects of recovery designated by a dashed line and lower case letter; and potential failures indicated by an upper case letter followed by failure mode information detailing whether the error committed was one of omission or of commission. By expanding our modeling of crew behavior to include aspects of cognition as well, it would become possible to give a more complete picture of performance and thus help us to determine why, in the context of a particular situation, personnel might be prone to err.

Review of Figure 1. Figure 1 presents a conventional HRA event tree flow for control room crew actions related to improper response to a safety features actuating systems (SFAS) event which, in turn, is related to a loss of coolant accident (LOCA) resulting in inadequate subcooling margin. The LOCA postulated is a pipe break (as opposed to an alternate condition such as a pump seal rupture). The event and actions taken by the crew are for a hypothetical scenario occurring at a hypothetical plant. Only important actions have been modeled. For example, procedural requirements that the crew close two power operated relief valves (PORVs) have not been modeled; closing these two block valves has no effect on recovering from the pipe rupture postulated in this scenario. The type of errors modeled in this HRA event tree are the typical errors of omission and commission described in NUREG/CR-1278¹. Recovery paths are indicated and would be included in part of the normal calculation of the failure rate estimate for recognition and action related to SFAS actuation. While overt behavior is described and some cognitive activity such as failure to correctly read rules for comparison and failure to interpret rules correctly, is described, (see items "F" and "G") no information is provided regarding the analyst's assumptions for the realm in which the cognitive activity is occurring (the Rasmussen schema) or the level of cognitive activity and type of error, i.e., do slips, lapses, or mistakes predominate for the scenario? The failure rates associated with the human actions

related to SFAS actuation have not been depicted as they are the same for the HRA tree presented in Figure 1 as they are for the intermediate and final "COGENT" tree which follows later as Figures 2 and 3, respectively.

Figure 1. HRA Event Tree for RO failure for an SFAS Trip Response to LOCA a,b,c

a Event Results in Inadequate Subcooling Margin
b Symptom Based Procedures In Effect
c THERP based scheme In effect OM=Omission, COM=Commission

Review of Figure 2. Figure 2 presents an intermediate step in the COGENT process, the HRA event tree presented in Figure 1 has now been updated to depict the analysts assumptions regarding application of the Rasmussen approach. All failures presented are acknowledged as as indicative of either skill-based, rule-based, or knowledge-based behavior.

Figure 2. RO fails to Respond to SFAS Actuation for LOCA^{a,b,c}

a Event Results in Inadequate Subcooling Margin
b Symptom Based Procedures In Effect
c Rasmussen-based scheme In effect S=Skill-based, R=rule-based, K=knowledge-based behaviors

Figure 3. Figure 3 presents the same HRA event tree shown as Figure 1 with the exception that all failures presented in Figure 1 are now acknowledged as either slips, lapses, simple mistakes, or mistakes, and as either skill-based, rule-based, or knowledge-based behavior. The cognitive scheme proposed in earlier sections of this manuscript has been applied. For example, failures A and B of Figure 3 refer to failures to recognize an event signature for an SFAS trip. In both cases, the annunciation is so strong that the most likely type of error is a simple mistake (SM) not in detection but in recognition. A lapse (failing to detect a rather noxious and piercing sound) is not feasible. Crews are so well-trained that this error is most likely a skill-based, simple mistake. Since symptom-based procedures are assumed to be in use, the crew may very likely be working on a LOCA hypothesis while they follow their procedures. Failures A and B

are similar and modeling indicates that either annunciator is sufficient to recognize entry into SFAS.

Figure 3. Cognitive Event Tree System (COGENT) for RO failure for SFAS Trip Response to LOCA a,b,c

a Event Results in Inadequate Subcooling Margin

b Symptom Based Procedures in Effect

c $S_{s,l,sm}$ = Skill-based slip, Skill-based lapse, Skill-based simple mistake

$R_{s,l,m}$ = Rule-based slip, Rule-based lapse, Rule-based mistake

$K_{l,m}$ = Knowledge-based lapse, Knowledge-based mistake

Failure C, failure to check the TSAT meter, is a step called for in procedures. Failing to complete this step could either be due to distractions caused by commotion present in the control room or by skipping a step in the procedure. The possibility of either error occurring is extremely unlikely. However, the designations of skill-based lapse and skill-based slip, (e.g., reading the wrong device), are useful in describing what may happen. Failure to check the PT

display comprises the same categories of performance. Note also that SFAS training is required and adequate procedures exist and will be used. Therefore, it is most likely that if crews were to fail to perform this action they would have either to be interrupted or be under such pressure that they inadvertently skip this step. Checking the PT display has been modeled as a recovery factor; failure to do so is modeled on Figure 3 as failure D.

Step e, "reactor operator trips the reactor coolant pumps (RCPs)" requires a combination of cognitive awareness of the importance of the RCPs coupled with skill-based psychomotor activity. Failure to do so, see "E", is not likely as an error in execution (a skill-based slip). Proper modeling of this failure is as a skill-based lapse with a very low probability. At most plants, simulator and classroom training on the significance of RCPs helps to ensure that the correct practice is followed. Next, in order for failure to occur, operators must fail to verify HPI to be proper in regard to plant conditions. Two potential failures are associated with this task. In the first, error F, the operator fails to read the look-up tables properly -- a rule-based slip. In the second instance, error G, the operator is subject to a high degree of stress and misinterprets the rule for determining that high pressure injection (HPI) is flowing at a proper rate. This latter error constitutes a knowledge-based mistake. Both of these error types are more interesting than those depicted formerly. Errors F and G contain elements of rule-based and knowledge-based behavior, respectively. They represent slips in the application or execution of rules as well as mistakes in the knowledge-based realm and are modeled accordingly.

Comparison of the first and third tree structures shows that Figure 3, which presents the COGENT tree, extends the omission and commission failure mode information contained in the traditional THERP event tree presented in Figure 1 to include aspects of cognition. The tree present in Figure 3 provides a formalism of two popular taxonomies and provides the analyst with useful information for conducting sensitivity analysis as well. For example, some performance gain, that is, reduction in failure rates, is to be achieved in moving crews from the knowledge-based to the skill-based or rule-based domains. This is true because we have greater uncertainty regarding what crews might do when they are forced to work from individual knowledge and experience (the knowledge-based realm) than we do when they have clearly defined procedures and adequate training (which places them in the rule-based domain). Placing crews in rule-based domain situations (even for relatively novel events) may be possible by increasing the breadth and depth of scenarios covered by simulator training. Similarly, new and improved types of advanced displays and computerized operator support systems may also help to reduce the errors associated with having personnel operate from their unique experience in confronting similar events.

IMPLEMENTATION ISSUES

The COGENT approach presented above provides a forum for discussing the role of cognition in performance, but it brings with it a unique set of challenges for the HRA practitioner, not the least of which is determining the failure rates corresponding to cognitive actions portrayed on the trees. Even highly proceduralized HRA techniques for determining human error probability estimates such as THERP^{1,10} and SLIM-MAUD¹⁴ do not provide the analyst with a cognitive taxonomy or data sufficient to evaluate the simple and complex mistakes which can be represented in the COGENT tree. The taxonomy in THERP places human failures into one of three failure mode categories: omission, commission, or misdiagnosis. Clearly, COGENT, depending upon the context in which it is used, either more finely breaks down the simple commissions identified in many of the THERP 1278¹ data tables, or identifies elements of cognition not present in the data tables.

SLIM-MAUD methods require that the analyst use calibration values to assist in bounding the analysis (and the final HEP estimate). Selection of appropriate anchor values is key to the success of the method. Where are these bounding estimates to come from, i.e., where are the good data which reflect differences in failure rates based on cognitive activity? Can we use existing failure rate information, and either modify the base HEP estimate or the confidence bounds for that estimate. Would this be sufficient to reflect the fact that we are dealing with cognitive activity? Is there an empirical basis for doing so? Likewise, what are the relevant performance shaping factors for cognitive activities, what is their distribution, and when are they most salient? And what of "context," that is, what role does context play in determining when crews are most likely to make joint cognitive decisions which are incorrect? The list of potential influences upon cognition such as workload, safety culture, and management factors is enormous. These questions apply equally well to other HRA quantification techniques such as the direct and indirect estimation techniques described in Seaver and Stillwell¹². Emerging estimation methods and data sets from such techniques as INTENT¹⁵ are limited by the expertise of the participants and by the domain of decisionbased errors represented in the analysis.

Other approaches, such as those characterized by postulating time reliability curves based on median crew responses during simulator trials, have only a limited resemblance to what we refer to as aspects of cognition. Different curves were distinguished for knowledge-based, rule-based and skill-based behaviors, and Wreathall¹⁶ postulated different error factors based on the presence of certain performance shaping factors. This work was an important step in early HRA methods but begs the question as to why errors occur during

seemingly adequate time frames, or in non-stressful situations, or in situations which are not amenable to study by simulator methods.

Thus, even if the quality of modeling as it exists in PRA can be raised slightly by the application of the COGENT graphic representation method, much research is needed in order to determine meaningful failure rates for cognitive activities represented in the trees. Once these individual rates have been determined, an overall HEP for a cognitively-analyzed task sequence can be calculated in the same manner as existing HRA event trees are calculated.

DISCUSSION AND SUMMARY

A means of enriching HRA event trees by representing cognitive aspects of human error has been introduced. Using this technique, it is possible to bridge an existing gap between the modeling needs of HRA practitioners and the classification schemes of today's cognitive theoreticians. Practitioners will have to decide whether existing quantitative estimation methods such as THERP, HCR, NGT or SLIM-MAUD sessions are an adequate means by which to determine human error probability estimates for placement on cognitive event trees such as COGENT. Upgrades to existing methods and data sets which take into account cognitive factors are sorely needed.

Models of cognitive error mechanisms postulated by theoreticians can be used to increase our understanding of the "why" behind existing failure rates, and to guide our discussions on how to lower these rates or eliminate certain types of conditions. HRA event trees, or fault trees for that matter, are a suitable means for establishing a dialog between HRA and PRA practitioners -- they have served in this regard for almost a decade, and can be used in either a retrospective sense, that is, to model accident scenarios, or in a proactive sense as part of a PRA conducted to assess nuclear power plant risk. The COGENT modeling technique introduced here can not only be used to portray the role of cognition in human error but to assess the risk for select operations, including recovery from emergency events.

As part of the COGENT framework, a convenient means for conceptualizing the legitimate nestings of two popular cognitive approaches has been presented. Note that *skill-based tasks* can carry errors easily categorized as either slips, lapses, or simple mistakes; *rule-based tasks* can carry either slips--recalling the wrong rule, lapses -- not being able to call up any rule, or mistakes -- misjudging the situation and calling up the right rule for the wrong situation. *Knowledge-based tasks* are easily associated with lapses in thought and forgetting previous relevant training and life experience-- knowledge-based lapses. Mistakes that simply produce poor hypotheses or using inappropriate analogy to attempt to solve problems

are also possible and are represented as knowledge-based mistakes. Expansion of the tree into other domains is possible as well. Note that performance shaping factor information is not currently carried forward as part of the tree structure.

The enriched HRA event tree, *COGENT*, needs to be validated by means of application to a PRA. Enhancing the way in which we present information is only one strategy for making HRA better; adequate inquiry into the possibility for error must be present as well and should reflect the tools normally brought to task by the HRA analyst. In determining the potential for decision based errors, at least two sources are readily available. The first, SNEAK analysis¹⁷, identifies potential pathways for error whose root cause sources include poor systems conditions and inadequate administrative or physical barriers. The second, the cognitive environment simulation (CES)¹⁸ makes use of a nuclear power plant simulation coupled with an artificial intelligence system containing a rule-based system determined from task analysis of operating crews' experience with plant transients. Running CES can lead to the identification of instances where the rules and expectancies of crews can lead to either correct or incorrect perception and decisions regarding plant status. In addition to defining possible errors, in order for *COGENT* implementation to be successful, a meaningful manner for quantifying cognitively based errors is required. Research is currently under way to test the *COGENT* approach and to pursue the goal of making human factors and cognitive information available to HRA and PRA analysts in a meaningful manner.

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REFERENCES

1. Swain, A. D. and H. Guttman (1983) *Handbook for Human Reliability Analysis with Emphasis on Nuclear Power Plant Operations: Technique for Human Error Rate Prediction*, NUREG/CR-1278, US NRC, Washington DC.
2. Norman, D. A. (1981) "Categorization of action slips." *Psychological Review*, 88, 1-15.
3. Reason, J. (1984) "Lapses of attention." In *Varieties of Attention*, (Parasuraman and D. Davies, Eds), Academic Press, New York: NY.
4. Reason, J. (1990) *Human Error*. Cambridge University Press, Cambridge UK.
5. Norman, D. A. (1988) *On the Psychology of Everyday Things*. Basic Books, New York NY.
6. Perrow, C. (1984) *Normal Accidents: Living With High-Risk Technologies*, Basic Books, Inc., New York NY.
7. Hollnagel, E., and Woods, D. D., (1983) *Cognitive systems engineering: new wine in new bottles*. International Journal of Man-Machine Studies, 18, 583-600.
8. Woods, D. D., and Hollnagel, E. (1986) Cognitive Task Analysis. (Manuscript).
9. Rasmussen, J. (1984) *Skills, rules, knowledge, signals, signs, and symbols, and other distinctions in human performance models*. IEEE Transactions on Systems, Man and Cybernetics, SMC-12, 257-266.
10. Bell, B.J., and Swain, A. D. (1983) *A Procedure for Conducting a Human Reliability Analysis for Nuclear Power Plants*, NUREG/CR-2554, Washington DC.
11. Swain, A. D. (1987) *Accident Sequence Evaluation Procedure (ASEP)*, NUREG/CR-4277, US Nuclear Regulatory Commission, Washington: DC.
12. Seaver, D. and Stillwell, W. G. (1983) *Procedures for Using Expert Judgment to Estimate HEPS in Nuclear Power Plant Operations*, NUREG/CR-2743, Washington: DC.
13. Mosleh, A., Bier, V. M., and Apostolakis, G. (1987) *Methods for the elicitation and use of expert opinion in risk assessment*. NUREG/CR-4962, Volume 1, Washington, DC.
14. Rosa, E. A., Humphreys, P. C., Spittel, C. M. and Embrey, D. E. *Application of SLIM-MAUD: A Test of an Interactive Computer-Based Method for Organizing Expert Assessment of Human Performance and Reliability*, Vol. 1, Main Report, NUREG/CR-4106, Washington DC.
15. Gertman, D. I., Blackman, H. S., Seidler, K., Hancey, L. N., Sullivan, C., and Hahn, H. A. (1991) *INTENT: A method for estimating failure rates for decisionbased errors*, Reliability Engineering and System Safety, 34, 127-137.
16. Wreathall, J. in Hall, R. E., Fragola, J., and Wreathall, J. (1982) *Post-event human decision errors: Operator action trees and the time reliability correlation*, NUREG/CR-3010, Washington DC.
17. Hahn, H. A., Blackman, H. S., and Gertman, D. I. (1991) *Applying SNEAK analysis in the identification of human errors of commission*. Reliability Engineering and System Safety, 33, 289-300.
18. Woods, D. D., Pople, H. E., and Roth, E. M. (1990) *The Cognitive Environment Simulation as a Tool for Modeling Human Performance and Reliability*, Vol 2, Main Report, NUREG/CR-5213, Washington, DC.

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