BNL-NUREG-63256

CONF-960912--40

KNOWLEDGE-BASE FOR THE NEW HUMAN RELIABILITY ANALYSIS METHOD, "A TECHNIQUE FOR HUMAN ERROR ANALYSIS" (ATHEANA)

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ABSTRACT

This paper describes the knowledge-base for the application of the new human reliability analysis (HRA) method, "A Technique for Human Error Analysis" (ATHEANA). Since application of ATHEANA requires the identification of previously unmodeled human failure events, especially errors of commission, and associated error-forcing contexts (i.e., combinations of plant conditions and performance shaping factors (PSFs)), this knowledge-base is an essential aid for the HRA analyst.

I. INTRODUCTION

This paper describes the knowledge-base needed to apply ATHEANA, a new HRA method which is introduced in NUREG/CR-6350.[1] The knowledge-base contains:

1) discussion of the underlying principles of ATHEANA,
2) general description of the ATHEANA method,
3) discussion of relevant and recent developments in behavioral science,
4) discussion of operational event analyses, and
5) presentation and discussion of search aids for identifying, modeling, and quantifying human failure events (HFEs).

The knowledge-base is currently under development[2] and will be documented in the ATHEANA Frame-of-Reference Manual. The frame-of-reference manual is one of two tools being developed for applying ATHEANA. The other tool is the ATHEANA Implementation Guidelines which will provide instructions on how to apply ATHEANA and use the frame-of-reference manual. Two companion papers[3,4] in this conference describe the basic process[5] for applying ATHEANA and a simple demonstration of ATHEANA.

II. BACKGROUND OF ATHEANA

ATHEANA has been developed to address deficiencies in current HRA approaches for post-initiator operator actions, by:

* addressing errors of commission and dependencies
* representing more realistically the human-system interactions that have played important roles in accident response, as evidenced by operating experience, and
* integrating recent advances in psychology with engineering, human factors, and PRA disciplines.

In previous work, a multidisciplinary framework for HRA was developed[6] to integrate relevant concepts from the disciplines of behavioral science, engineering, human factors, and PRA. Also, in order to base the development of ATHEANA on real operational experience and confirm its underlying principles, analyses of historical events[1,6,7] have been performed and a more comprehensive data analysis approach and database have been developed[8].

ATHEANA is based upon a fundamental shift in the traditional perspective of operator performance and how HRA is performed. Current HRA methods typically assume that operator errors occur randomly (but usually influenced by certain performance shaping factors (PSFs)) under nominal accident conditions. ATHEANA's premise is different; it is assumed that operators behave rationally and perform very reliably except under certain combinations of plant conditions (typically unusual or unfamiliar accident conditions) and PSFs which virtually guarantee operator failure (i.e., error-forcing contexts). In addition, ATHEANA's focus is upon the identification of previously unmodeled errors of commission (EOCs), such as those which have played important roles in serious nuclear power plant accidents (e.g., Three Mile Island 2, Chernobyl) and incidents (e.g., the 14 events identified in a Office of Analysis and Evaluation of Operation Data (AEOD) report entitled "Operating Events with Inappropriate Bypass or Defeat of Engineered Safety Features"[9]). Finally, the record of operational experience and observations of simulated events[10] show that real events often involve cognitive errors on the part of operators.

The objectives and underlying principles of ATHEANA require new HRA activities which have not previously been performed: 1) the search for and definition of previously unmodeled HFEs (e.g., EOCs) and associated unsafe actions (i.e., the specific ways operators can fail plant or system functions), 2) search for error-forcing contexts (EFCs), and 3) estimation of the frequencies or probabilities of EFC elements. In the ATHEANA method, the identification of an EFC for a candidate HFE serves to both justify its inclusion in a PRA and direct the quantification effort.

The information provided in the frame-of-reference manual assists the ATHEANA user in the searches for HFEs and associated EFCs. The ATHEANA frame-of-reference manual provides search aids which are generalized from the understanding of human behavior derived from behavioral science and the insights from operational event analyses, and illustrative examples from event analyses (e.g., ways in which operators failed plant or system functions, specific EFC elements).

III. UNDERSTANDING FROM BEHAVIORAL SCIENCE AND OPERATIONAL EVENT ANALYSES

Summaries of the understanding from behavioral science and insights from analyses of operational events which are relevant to ATHEANA are provided below.

A. Understanding from Behavioral Science

Behavioral models can be used to help explain why nuclear power plant operators may commit errors during accident response. In particular, the information processing model includes four major cognitive activities that match up with the activities typically performed during accident response:

1) situation assessment,
2) monitoring and detection,
3) response planning, and
4) response implementation.

In responding to an actual accident, these activities are performed iteratively. Each of these cognitive activities (or information processing stages) are described briefly.

Situation assessment is the process of constructing an explanation for operator observations. The result of this process is a "situation model" which represents the operators' understanding of the current plant state and their expectations for plant behavior as the accident progresses. The situation model is also based upon the operators' general understanding (e.g., training) of how the plant behaves (e.g., reactor physics, thermal-hydraulics, system design). The operators constantly update their situation model based upon new information, obtained through monitoring activities and resulting from changes in the plant state or behavior (which result from either the accident progression or operator actions). The operators' situation model guides their monitoring activities and their development of response plans.

In turn, monitoring activities are directed by either procedures (i.e., response plans) and the operators' situation model or alarms and other signals which get the operators attention. For the purposes of this project, detection refers only to the operator's recognition that an accident or incident has occurred that requires operator response.

Response planning is the process of deciding what actions to take. The operators' situation model and available procedures are used in this process but the operators also must decide if the procedure steps are appropriate or adequate for an specific accident (which may require omission of procedure steps or addition of unproceduralized actions). After a response plan is selected and implemented (i.e., response implementation), operators typically evaluate the effectiveness of their plan and actions through monitoring.

Because failures in situation assessment can cause or lead to failures in all of the other cognitive activities, the

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initial focus of the ATHEANA frame-of-reference manual is on failures in situation assessment. Analyses of operational events[1,2,8] and simulated events[10] confirm the importance of situation assessment as the root of many operator errors.

The primary failure mode during situation assessment activities is the failure to correctly interpret the information provided. Interpretation failures can be: 1) the failure to recognize "abnormal" conditions, 2) the discounting or rejecting of information because the indication is thought to be spurious, 3) the misinterpretation of the indication to fit a wrong situation model, or 4) the development of a wrong explanation for the indication (i.e., wrong situation model). In some cases, such as when operators match plant symptoms with the most frequently occurring accident with similar characteristics, the behavior is not necessarily a failure, except in the wrong context. In other cases, the behavior is appropriate and allows operators to respond more quickly.

The ATHEANA frame-of-reference manual identifies the important failure modes for each of these four cognitive activities and some of the factors that can contribute to cognitive failures. For example, failures in situation assessment may be caused by failure in memory retrieval (e.g., only the most recent or most frequently occurring events can be recalled), bias toward the first diagnosis made (despite accumulating evidence to the contrary), processing of partial information (due to, for example, the competing demands of other operator tasks), or incomplete or incorrect plant knowledge.

B. Insights from Operational Event Analyses

Analyses of five operational events were performed to provide examples of operator unsafe actions, associated error-forcing contexts, and failures in cognitive activities. The five events analyzed, three at-power events and two shutdown events, respectively, were:

* Crystal River 3 (12/8/91)
* Dresden 2 (8/2/90)
* Ft. Calhoun (7/3/92)
* Prairie Island 2 (2/20/92)
* Oconee 3 (3/8/91)

The three at-power events were selected for analysis due to their similarity to the small-break loss-of-coolant accident chosen for the trial application of ATHEANA documented in NUREG/CR-6350. The shutdown events had been analyzed in previous project work and were known to contain many examples of factors which adversely effected operator performance.

Analyses of these events confirmed or complemented the understanding of behavior science discussed in the previous section. For example, the only failure in detection was observed for a shutdown event (i.e., the Prairie Island 2 event) in which limited instrumentation was available. With respect to situation assessment, the event analyses identified the following failures:

1) operators developed wrong situation models of the plant state and behavior,
2) wrong situation models can persist in the face of contrary (but true) evidence,
3) wrong situation models can be strengthened by irrelevant information or the effects of (unknown) hardware failures, and
4) operator actions, or interactions with the plant taken without the operators knowledge, can mask accident symptoms or cause them to be misinterpreted.

The situation assessment failures identified in the event analyses also highlighted the importance of contextual factors (e.g., instrument or equipment failures) which caused or complicated situation assessment failures, in addition to the misinterpretation failures discussed in the previous section.

The frame-of-reference manual presents identified examples of unsafe actions and associated EFC elements for each cognitive activity (with reference to the relevant event). In addition, the frame-of-reference identifies some instances in which more traditional PSFs (e.g., excessive workload, poor lighting) appeared to negatively impact operator performance in the five events and a generalized list of factors which are typically overlooked or dismissed in PRAs but which appeared to be important in these five and previously analyzed events (e.g., instrumentation does fail, operators typically will believe valve position indicators despite contradictory evidence, management decisions regarding maintenance scheduling, entering Limiting Condition for Operation statements, or special configurations can result in defeated plant defenses and additional burdens on operators).

IV. TRANSFORMATION INTO THE PRA/HRA PERSPECTIVE

The information derived directly from behavioral science and event analyses must be transformed for the purposes of HRA and PRA.

For example, the iteration between cognitive activities must be simplified and priorities must be established in order to bound the analysis. In the current frame-of-reference manual, situation assessment failures are considered the highest priority (followed by failures in response planning). Within the set of situation assessment failures, important failures result from the development of an initially, wrong situation model with respect to either the initial plant state or to expectations for accident progression. In both cases, the initial, wrong situation model is not updated (through failures in monitoring, response planning, and additional situation assessment activities). Another alternative, but considered less important, is that the initial situation model is correct, but fails to remain current due to failures to correctly update the model when the plant behavior changes or operator interact with the plant.

Development of the wrong, initial situation model or failure to update is attributed to one or more of the following "reasons": 1) problems in information transmission (e.g., instrumentation failures), 2) problems in information interpretation, or 3) problems in monitoring. In all of these cases, both contextual factors (e.g., plant conditions, hardware failures) and psychological factors can be causes. In fact, all of operational events analyzed involved complicating contextual factors, implying that the behavior science perspective in which operators can fail solely due to inherent cognitive characteristics is probably too pessimistic a view for the purposes of HRA for nuclear power plants (which have many indications, procedures, and other aids for performing cognitive activities).

V. SEARCH CUES FOR HUMAN FAILURE EVENTS, UNSAFE ACTIONS, AND ERROR-FORCING CONTEXTS

The following discussion summarizes the key information currently provided by the ATHEANA frame-of-reference manual to assist in the search for HFEs, unsafe actions, and EFCs. This information is preliminary and is expected to be expanded in future work. In addition, the ATHEANA Implementation Guidelines (to be developed) will provide ATHEANA users with further guidance on how to use the information given in the frame-of-reference manual, as well as guidance on what supplemental plant-specific is needed.

A. Definitions of HFEs and Unsafe Actions

The ATHEANA frame-of-reference manual provides the ATHEANA user with a series of tables which connect typical, generic PRA success criteria and functional failure modes (e.g, equipment fails to initiate) with examples of HFEs and associated unsafe actions. These tables are based solely on generic concepts regarding plant, system, and component design, functions, and failure modes. In other words, plant systems, functions, and equipment have a finite number of failure modes and operators can fail these systems, functions, and equipment only in these same modes. Consequently, while the examples given in the frame-of-reference manual will have to be adapted for plant-specific applications, no understanding of the behavioral science concepts is required for this step.

The current version of the frame-of-reference manual also provides examples of human failure and unsafe actions from analyzed events. For example, the important unsafe action is the Crystal River 3 event was the six-minute bypass of the engineered safety features actuation signals, which prevented the automatic start of the high pressure injection (HPI) system. The associated HFE which would be modeled in the PRA is "HPI inappropriately removed from automatic control". In turn, the functional failure mode and PRA functional success criteria associated with this unsafe action are "HPI fails to initiate" and "HPI automatically actuates and continues to operate for the duration of the mission time".

B. "Reasons" for Unsafe Actions

The ATHEANA frame-of-reference manual provides "reasons" for unsafe actions which consist of a synthesis of psychological and plant factors, ultimately represented by specific error-forcing contexts. At the current stage of ATHEANA's development, several levels of "reasons" are used to make the transition from unsafe action definition to specific EFC elements.

Figure 1 shows the different levels of "reasons" being developed for the ATHEANA frame-of-reference manual. These levels of "reasons" should be investigated after candidate HFEs and associated unsafe actions are identified and should be applied to each candidate unsafe action and each information processing stage. (However, priorities established by ATHEANA with respect to information processing stages should be used in order to focus this search. Preliminary priorities were discussed above.)

The different levels are:

* "rules" of information processing
* "rules" of action
* information required to implement "rules"
* plant conditions and/or configurations what can make "rules" appear to be satisfied
* PSFs

The "rules" of information processing come from the understanding of behavioral science which were discussed earlier. These "rules" describe how operators are expected to behave in response to an accident (e.g., match the accident symptoms to similar accidents faced in training or previous events.)

The "rules" of action are both formal (e.g., procedures) and informal (e.g., training or experience) which guide operators in deciding what actions to take. The ATHEANA user will be directed (by the Implementation Guidelines) to review procedures (e.g., emergency operating procedures (EOPs)) to identify what guidance is available to operators for performing the actions associated with the unsafe actions. For example, if the unsafe action is "Inappropriate termination of HPI", then the ATHEANA user should search the EOPs for HPI termination criteria. Also, since the principles of behavior science and operational experience indicate that formal "rules" can be overridden, the ATHEANA user will have to search for informal "rules" which might lead operators into thinking that termination of HPI is appropriate (when, in fact, it is not). Informal "rules" come from training, experience, and operating practices. For example, it is considered good practice to protect operating pumps from being damaged if there is no pump lube oil pressure or cooling, or if the pumps are cylcing, deheaded, or experiencing runout. So, if the operators believe (due to a faulty indication, for example) that the HPI pumps are in danger of being damaged, they might stop them even though their function is required. "Rules" perceived to be relevant to a specific accident by operators also may be in conflict. For example, if operators act upon a "rule" from training that going solid in the pressurizer (for pressurized water reactors) should be avoided, they may place priority on this "rule" and stop HPI pumps. Examples of this kind of conflict have been identified in event analyses performed for this project and in the events identified in the AEOD report.[9]

Once the relevant "rules" have been identified, the information required to implement these "rules" must be identified. Then, the ways in which this information can be faulty (e.g., instrumentation failures, certain plant conditions or configurations) or misportrayed (i.e., ergonomics problems such as broken interfaces or faulty designs) are investigated. These plant or hardware-oriented problems overlay or supplement situation assessment failures in information interpretation already included in the HFE/unsafe action definition. In particular, potentially confusing plant conditions (based upon plant physics) or instrumentation designs are identified. Finally, the impact of additional PSFs is considered.

The current version of frame-of-reference manual provides preliminary tables of examples for each of these levels of "reasons".

VI. FUTURE WORK

Currently, the frame-of-reference manual[2] provides a first approximation to the search aids needed for applying ATHEANA. Plans for future work on ATHEANA includes development of the Implementation Guidelines, expansion of the frame-of-reference manual (especially search cues), expansion of the supporting database of event analyses (i.e., HSECS), and further demonstration of how to apply ATHEANA.

ACKNOWLEDGMENTS

This work has been performed for the USNRC under contract to Brookhaven National Laboratory (BNL). The authors gratefully acknowledge the support of Ann Ramey-Smith, Mark Cunningham, and Joseph Murphy of the USNRC Office of Research, and the technical input provided by James Reason of the University of Manchester on the multidisciplinary framework. However, the opinions expressed in this paper are solely those of the authors, and do not necessarily represent those of the USNRC or BNL.

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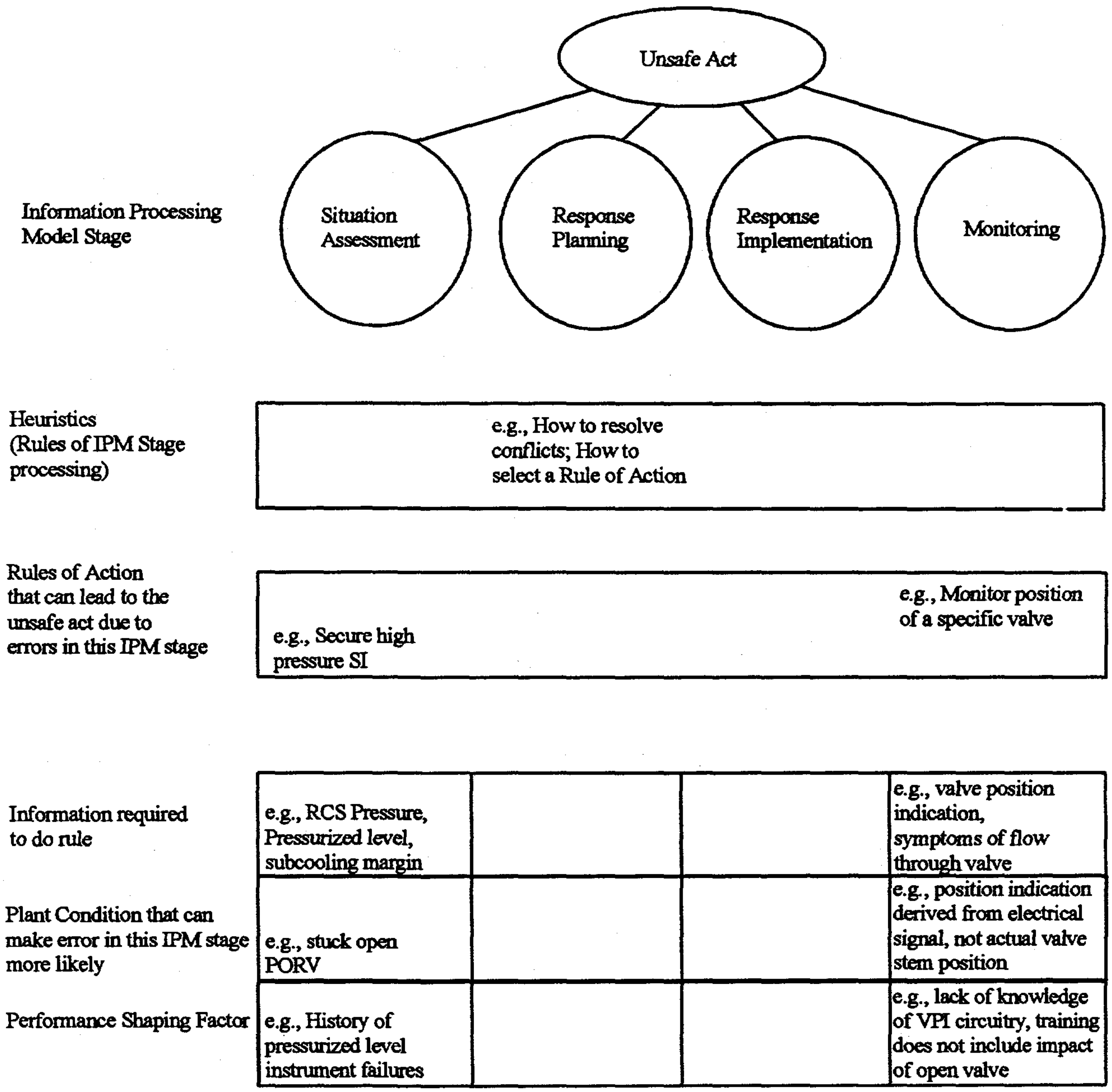

Figure 1 Integrated view of ATHEANA search