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Implications of an HRA Framework for Quantifying Human Acts of Commission and Dependency: Development of a Methodology for Conducting an Integrated HRA/PRA*

M.T. Barriere,[1] W.J. Luckas,[1] S.E. Cooper,[2] J.Wreathall,[3] D.C. Bley,[4] and W.S. Brown[1]

[1]Brookhaven National Laboratory
Upton, NY
[2]Science Applications International Corporation
Reston, VA
[3]John Wreathall & Co.
Dublin, OH
[4]PLG, Inc.
Newport Beach, CA

ABSTRACT

To support the development of a refined human reliability analysis (HRA) framework, to address identified HRA user needs and improve HRA modeling, unique aspects of human performance have been identified from an analysis of actual plant-specific events. Through the use of the refined framework, relationships between the following HRA, human factors and probabilistic risk assessment (PRA) elements were described: the PRA model, plant states, plant conditions, PRA basic events, unsafe human actions, error mechanisms, and performance shaping factors (PSFs). The event analyses performed in the context of the refined HRA framework, identified the need for new HRA methods that are capable of: evaluating a range of different error mechanisms (e.g., slips as well as mistakes); addressing errors of commission (EOCs) and dependencies between human actions; and incorporating the influence of plant conditions and multiple PSFs on human actions. This report discusses the results of the assessment of user needs, the refinement of the existing HRA framework, as well as, the current status on EOCs, and human dependencies.

1.0 INTRODUCTION

As part of an NRC sponsored program evolving from an assessment of human reliability issues in Low Power and Shutdown (LP&S) operations in nuclear power plants (NPPs), an improved approach to human reliability analysis (HRA) is currently being developed. This approach will be consistent with and reflect human behavior based on detailed analysis of actual events that have been encoded into the Human Action Classification Scheme (HACS). It is intended to be fully integrated with probabilistic risk assessment (PRA) methodology and to enable a better assessment of the human contribution to plant risk, both during LP&S and at-power operations.

Weaknesses in existing HRA methods and specific areas for concentrated development were identified based on the insights gained from the study of human reliability issues in actual events and from experience in applying existing HRA methods. A detailed program plan outline for producing an integrated HRA/PRA methodology that addresses these weaknesses has been developed. NUREG/CR-6093 provides details on the human reliability issues and the associated program plan outline.

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This report details progress to date beyond that presented at the 20th Water Reactor Safety Meeting (October 1992) with respect to each program plan task. Specifically, this report discusses an assessment of user needs, the refinement of an existing HRA framework, the characterization and representation of errors of commission (EOCs), and the development of an approach to deal with dependency between human actions. This report also identifies anticipated follow-on efforts including the development of a quantification process and implementation guidelines as well as, a demonstration of the guidelines and methodology.

2.0 ASSESSMENT OF USER NEEDS

Through the assessment of user needs, several findings that the integrated HRA/PRA methodology should address were identified. These findings included the need for:

- Developing a more realistic representation of the dynamic nature of the human-system interaction, especially during response to accidents;
- Facilitating realistic evaluation of multiple factors influencing human performance; and
- Providing consistent and repeatable results that minimize resource requirements.

3.0 APPROACH FOR DEVELOPING AN HRA FRAMEWORK

In support of developing a new HRA framework to address the user needs described above and improve HRA modeling, it was recognized that the unique aspects of human performance must be identified.. Review and analyses of actual LP&S and at-power events provided the best vehicle for obtaining a general understanding of the dynamic nature of the human-system interaction.

The strategy of using actual plant-specific events as a basis for the development of the new HRA framework and improved HRA methods, was to provide a realism which has been missing in the treatment of human performance in PRA models. In addition, these analyses also provided the basis for identifying more specific requirements of HRA methods such as which classes of human actions (e.g., initiators, pre-accident errors, recoveries) and performance shaping factors (PSFs) are important. Significant differences between human performance during LP&S and that during at-power operations also were identified.

3.1 Data Analysis Strategy

The following steps were implemented for analyzing actual plant-specific events: (1) selection of data sources, (2) development of an analysis tool, (3) event analyses, and (4) review and verification of analysis results. The data sources used for the analysis of LP&S events were full-text LERs identified as significant in NUREG-1449, NRC Augmented Inspection Team (AIT) and Incident Investigation Team (IIT) reports, and AEOD Human Performance reports. NRC event-based reports (i.e., AITs and IITs) and AEOD reports were the source of data for at-power events. The analysis tool developed is called the Human Action Classification Scheme (HACS) which is described in detail in NUREG/CR-6093.

HACS is based, in part, upon a variety of previously defined schemes and was developed in conjunction with the review of full-text licensee event reports (LERs). The resultant scheme is capable of documenting the relevant, available plant-specific information, such as that provided in full-text LERs. For example, HACS documents the following: the number of human actions involved in a particular event and, for each human action, the action class (e.g., initiator, recovery), error mode (i.e., errors of omission or commission), error mechanisms (e.g., slip, mistake), location (i.e., in-control room or ex-control room), activity being performed (e.g., maintenance, operation, testing), and the effect of the action (i.e, active or latent). For recovery actions, the location and time for performing recovery actions is also recorded.

Additional HACS fields which contribute to the concise but descriptive record of each event include: unit status, event time, noteworthy plant conditions (e.g., unusual plant configurations, important equipment out-of-service), system and component involved, automatic equipment response to event, the uniqueness to LP&S or at-power, an assessment of event significance, and the corrective actions taken. Table 1 provides a listing of all the HACS database fields.

Table 1. HACS Database Fields

Field 1-Event or Document Identification	Field 15-Human Action Descriptor
Field 2-Event Description Summary	Field 16-Error Mode
Field 3-Event Date and Time	Field 17-Error Type
Field 4-Plant Type/Vendor	Field 18-Active/Latent Effect
Field 5-Unit Status	Field 19-Performance Shaping Factors
Field 6-Noteworthy Plant Conditions	Field 20-Recovery Time
Field 7-Other Unit(s) Status	Field 21-Recovery Locus
Field 8-Human Action Number & Description	Field 22-Recovery Origin
Field 9-Responsible Personnel Type	Field 23-Related Automatic Equipment Response
Field 10-Event Activity	Field 24-Fission Products Barrier Breached/ Threatened
Field 11-Human Action Location	Field 25-Other Effects
Field 12-System Identification	Field 26-Event Initiator
Field 13-Component Identification	Field 27-Unique to Operating State
Field 14-Displays/Controls/Instruments Identification	Field 28-Corrective Action Taken

Using the HACS information fields, three data bases have been created for recording the analysis results of the analyses for LP&S PWR, LP&S BWR, and at-power events, respectiveiy. Although relatively few events (i.e., 32 PWR LP&S events, 32 BWR LP&S events, 14 at-power events) have been analyzed so far, the data sources selected, especially event-based NRC reports, have been chosen for the unique depth and breadtl f detail that they provide. In addition, work is continuing to add events and associated human performance information to the data bases.

Because of the number and variety of information fields contained in the HACS, analysis results encoded in the three data bases can be "sliced" or combined in numerous ways. The results and accompanying discussion given below specifically identify the insights that can be derived by viewing the data analyses in the context of the new HRA framework.

4.0 HRA FRAMEWORK

In PRAs for NPP, HRAs require consideration of a variety of factors, including the plant state (as represented in the PRA), the equipment being operated or maintained, human system interface aspects associated with the task(s) being performed as well as situation specific PSFs. While these factors have been implicitly incorporated in HRA studies performed to date, they have never been formally specified in any of the existing HRA methods. In order to address these HRA limitations and accommodate previously identified concerns associated with modeling EOCs and human dependencies (NUREG/CR-6093), it was necessary to develop an explicit framework of how HRA and PRA modeling are related.

The purpose of the HRA framework is to provide a logical and explicit basis for the development of rules for incorporating human failure events into PRAs that are consistent with knowledge about the consequences and rates of occurrence of different types of human errors. In order for the framework to best describe the relationships between human errors as considered in the behavioral sciences and human failure events as considered in the PRA systems-analysis tasks, an existing framework was selected and refined. The refinement is based on, and has been initiated by, the review of significant operational events as described above and the desire to make any new developments in HRA more representative of real-world events.

Once refined, this framework provided a basis for incorporating different kinds of human errors into the evaluation of various human failure events. It further provided an indication of the kinds of data relationships that will be required to produce a working HRA/PRA methodology. This framework, therefore, is essential for tasks involving the representation of EOCs and dependency as well as the quantification process which are discussed in Sections 5.0, 6.0, and 7.0 respectively. The following discusses the existing HRA framework and its development into the refined HRA framework.

4.1 Existing Framework

Figure 1 presents a description of the relationships between HRA and PRA activities as typically performed today. The building blocks of the PRA model are the basic events. These basic events include different failure modes of components and subcomponents that, in combination, lead to failures of systems. The basic events are combined in the fault trees according to the definitions of system and functional failures. Combinations of fault trees are represented in the PRA event trees according to the plant state being analyzed (such as a LOCA or other accident scenario) to describe combinations that lead to unacceptable accident conditions such as core damage.

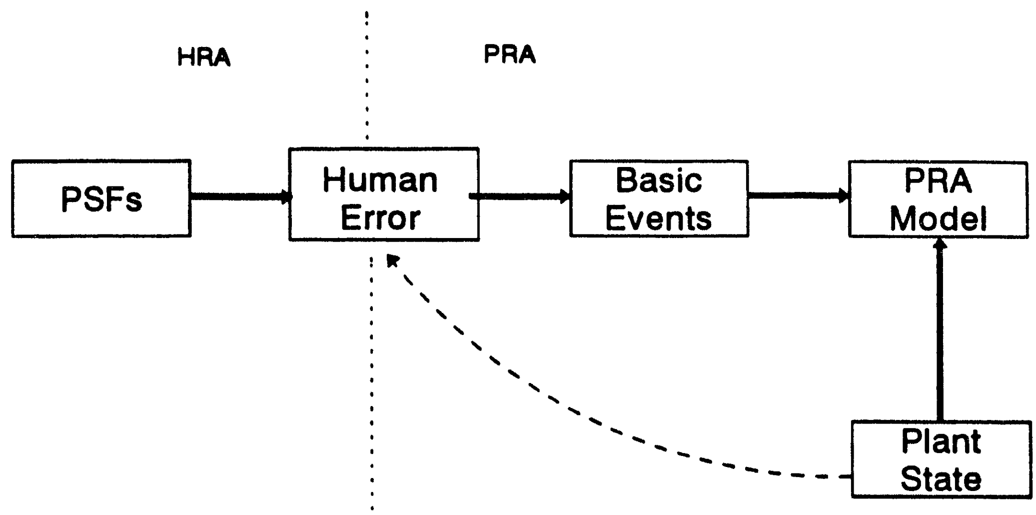

Figure 1. Existing HRA framework

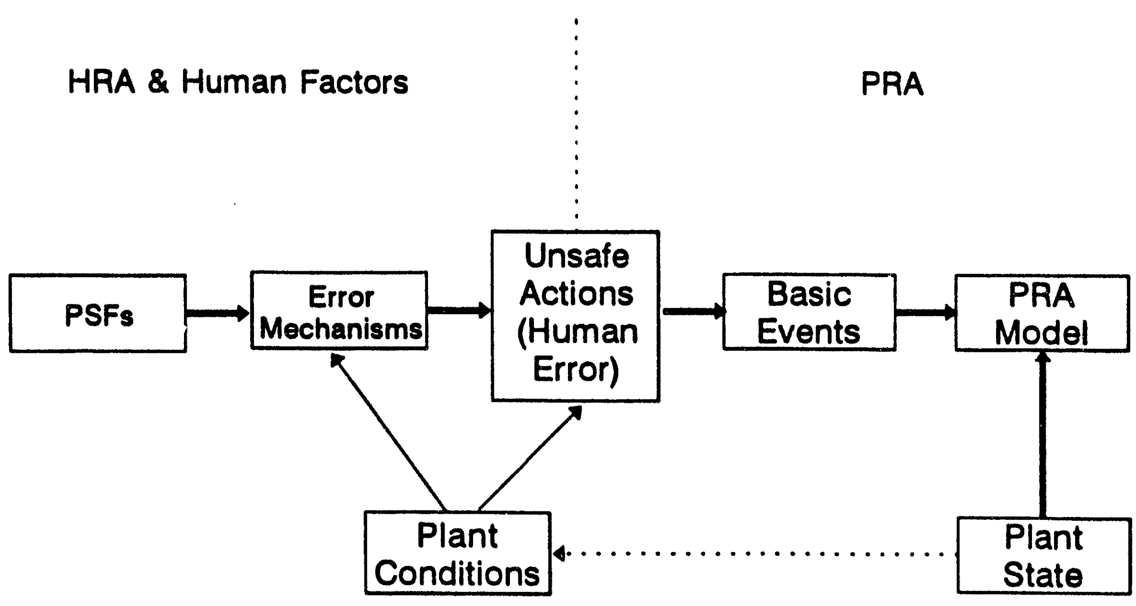

Figure 2. Refined HRA framework

In this framework, human errors are one of the constituents of basic events that lead to system or functional failures, as in "Operator fails to open recirculation suction valve" leading to failure of recirculation flow in a small-break LOCA.

These human errors, comprising basic events, are broadly undifferentiated; that is, no major differences between various errors are considered. They are, for the most part, identified simply with descriptions such as "Operator fails to _" or "Maintenance technician fails to restore _". In many PRAs they are evaluated on the basis of a small set of common PSFs. These PSFs, for example, have included the timescale for actions, the effectiveness of annunciators, and the ability of a second person checking the first. While some PRA studies have incorporated other PSFs, they have been primarily subjectively developed. In addition, these PSFs have been applied frequently to large groupings of human error events with little consideration as to the specific kinds of errors they cause or influence.

The human performance issues are addressed in the context of the accident scenario defined by the plant state in the PRA. For example, the final HRA quantification is performed on a "cutset-by-cutset" basis, especially where the quantification for post-accident responses is based on a timescale available for action. Cutsets are the boolean logic statements resulting from the event-tree models that define a unique combination of basic failure events that would cause the accident. One cutset may represent a combination of failures associated with a pump in one train and a valve in another train, and failure of the operators to restore operation. The timescale available for operators to recover the valve close to the control room in time to prevent core damage in that cutset (and hence the probability of recovery) may be quite different from a cutset that involved accessing some remote area of the plant. Although current PRAs do attempt to incorporate situation-specific factors that may influence human performance, improvements are necessary to more realistically accommodate the influence of plant state on human performance.

4.2 Refined HRA Framework

Figure 2 presents the elements of the refined framework as presently conceived. The refined HRA framework revises the relationships between human errors, their causes, and the basic events modeled in PRAs. The most important changes lie in the addition of explicit identification of multiple error mechanisms as causes of human errors, and the role that plant conditions play in forcing the occurrence of human errors.

Specifically, the revised framework describes relationships between the following elements: the PRA model (i.e., fault trees, event trees), plant states (i.e., those definitions or constraints on operational modes modeled, model assumptions, initiating events, etc.), plant conditions (e.g., LP&S-specific plant configurations, system unavailabilities), PRA basic events, unsafe acts, human error mechanisms, and PSFs.

The following discusses those framework elements that have been added or revised. These elements will be discussed in terms of: the change in terminology of "human errors" to "unsafe actions," the addition of error mechanisms, the refinement of PSFs and PRA basic event, and the addition of plant conditions, respectively.

4.2.1 Unsafe Actions

The term "human error" has been used interchangeably with "human failure event" by PRA analysts for nearly two decades. The term refers to a basic event involving a lack of action, or an inappropriate action, taken by operations, maintenance, or other staff member, that leads the plant to a less-safe state. However, the term "human error", when used by behavioral scientists, can refer to quite different aspects in human behavior. These aspects can be in conflict with those intended by the PRA analyst. In particular, the PRA concern is only that an unsafe condition results; the reasons why that occurred are of generally limited concern to the PRA. In contrast, from the behavioral perspective, the consequence of the error is generally of limited interest when compared to the underlying causes of such error.

For the purposes of making explicitly clear the concern to the PRA, the refined framework does not refer to human errors, it refers instead to "unsafe actions." Unsafe actions are those actions taken by people that lead the plant into a less-safe state. Unsafe actions also include actions not taken (the so-called errors of omission). Unsafe actions imply nothing about whether the action taken (or not taken) was a "human error", to avoid the inference of blame or that the human was the root cause of the problem. As will be described later, people are often "set up" by circumstances and conditions to take the actions that were unsafe. In those circumstances, the human did not commit an error in the every-day sense of the term; they were doing what was the "correct" thing as it seemed at the time.

4.2.2 Error Mechanisms

The unsafe acts that are contributors to important PRA basic events can be considered the results of specific error mechanisms. The different error mechanisms defined in the refined HRA framework are: slips/lapses, mistakes, and circumventions. These different error mechanisms provide reasons for failing to perform an action, or performing some other unsafe act. Consequently, there are important differences between these error mechanisms, both as to the conditions under which they can occur and their potential impact on risk. The following provides a summary of the distinctions between the classes of error mechanisms, based on work by Reason (1990).

Slips and lapses lead to unsafe actions where the outcome of the action was not what was intended. Skipping a step in a procedure or reversing the numbers in an identification label are examples of lapses and slips, respectively. Both are errors associated with what has been termed skill-based level of performance. This level of performance is associated with the predominantly automatic control of routine and highly-practiced actions. The significance to risk of these error mechanisms seems to be quite small for the simple fact that these actions, not being as intended, are easily recognized by the person involved and (in most circumstances) easily corrected. HRA methods like the Technique for Human Error Rate Prediction (THERP) (NUREG/CR-1278) address slips and lapses as their primary focus.

For unsafe actions where the action was as intended, there are two broad classes of error mechanisms. The first is where, while the action was as intended, the intention was wrong. For example, the operator may have misdiagnosed the plant condition and is following the procedure for the wrong condition. The consequential actions are mistakes. The second is where a person decides to break some rule (even though the rule is known to them) for what seems to be a good (or at least benign) reason, such as reversing the steps in a procedure to simplify the task. Unsafe actions in this last category are circumventions. It should be noted that acts of sabotage are distinct from circumventions in terms of the intended consequence.

Mistakes can be considered rule-based or knowledge-based depending on whether the task is demanding rule-based or knowledge-based performance; that is, whether documented or trained instructions are being followed (as in almost all NPP activities important to safety) or whether the person involved is relying on technical and specialist knowledge (as in generalized troubleshooting). Rule-based mistakes are further subdivided as to whether the wrong rules are being followed (e.g., following misdiagnosis), or the rules are the "correct" ones but contain omissions or errors.

Mistakes are perhaps the most significant to risk because they are being followed purposefully by the user, who has limited cues that there is a problem. Indications contradicting the erroneous diagnosis are often dismissed as for instance, "instrument errors." Often it takes an outsider to the situation to identify the nature of the problem as happened at Three Mile Island. Existing HRA methods address slips/lapses and, to a lesser extent, mistakes. However, mistakes are the dominant error mechanism for LP&S conditions, as documented in both the PWR and the BWR LP&S HACS data bases.

Circumventions are potentially significant contributors to risk in that unanalyzed conditions can result from unexpected combinations of errors and circumventions. However, two conditions seem to mitigate this potential. First, the person committing the circumvention is (usually) aware that the action has occurred and can bring any significant consequence to the attention of other staff (attitudes to punishment can heavily influence this self-reporting, however). Second, in the current environment in the nuclear industry, circumventions seem to be a relatively rare occurrence.

4.2.3 Performance Shaping Factors

As previously stated, existing HRA methods recognize, usually implicitly, a relatively small set of influences on human performance, i.e., PSFs. In addition, current HRA quantification methods are typically driven by a single, dominant PSF (e.g., time available for response).

Given the differences between the possible error mechanisms that could be the cause of one unsafe action, the use of a single set of PSFs for all mechanisms is inappropriate. Each error mechanism has its primary set of PSFs. A salient feature in the refined HRA framework is the recognition that different PSFs may apply to different error mechanisms. For example, based on the analysis of actual events, important PSFs for slips and lapses, included workload and fatigue, the format of job aids, the availability of appropriate memory helpers (checklists, mnemonics, etc.) and calculators. For rule-based mistakes involving inadequate procedures, PSFs associated with the technical validity and completeness of procedures or work orders, and coordination of multiple work groups, were found to be important. The rate and location of circumventions was found to be strongly influenced by the task design, the occurrence of incompatible goals or requirements, and the rewards/penalties system for compliance.

The important point from the event analyses is that no single set of PSFs apply to all error mechanisms, and that using a single set of PSFs would only be appropriate if that error mechanism was the most risk-significant. The refined framework provides for an expanded list of PSFs and the explicit consideration of multiple PSFs. As observed in the LP&S PWR event analyses, the majority of EOCs, both slips and mistakes, were found to be influenced by multiple PSFs.

4.2.4 PRA Basic Events

Traditionally, there are three types of basic events included in PRA models, which represent human errors: pre-accident (or latent) and post-accident human failure events and non-recovery actions. Although human-induced initiators are recognized as possible initiating event causes, the frequency of human initiators for at-power events has typically been small compared to hardware-caused initiators. Consequently, it has been considered sufficient to capture both human and hardware failures in the initiating event frequency data for at-power PRAs. This review and analysis of actual plant-specific event has indicated that human actions are the dominant contributor to LP&S initiators. Thus basic events should accommodate the unique aspects of human action initiators.

4.2.5 Plant Conditions

Starting with the PRA basic event (involving some unsafe action), events occur with the combinations of an unsafe act ("operator fails to ...", "technician inadvertently ...") and a plant condition in which that unsafe act has risk-significant consequences. For example, operators terminating operation of a heat-removal system in the condition of significant decay-heat levels is an event of importance in a PRA, but under other conditions, or involving other systems, the same unsafe act may not be a PRA basic event. Therefore, unsafe acts must be considered in combination with the plant conditions in which they are risk-significant.

Plant conditions are the specific features of the plant and its operating state that can influence human actions performed and can create opportunities for unsafe actions. For example, draindown operations in a PWR LP&S refueling outage requires many manual actions by operators under conditions of limited instrumentation alarms etc. Conversely, maintaining a reactor at-power requires only a few manual actions (such as performing surveillance tests). To some degree these conditions are implicit in the plant state defined in the PRA. However, the specific human interactions with the plant are not defined traditionally in the PRA, especially for actions that could lead to initiating events or other errors of commission.

A detailed description of plant conditions is necessary to identify the possible situations where people are almost forced into failure. The influence of plant conditions can be seen from the frequent and continuous human interventions with the plant during LP&S operations. For example, combinations of workload, ambiguous task requirements/instructions, and a lack of supervision led a situation where operators overdrained the reactor water level beyond midloop within 8 hours of shutting down the reactor (Prairie Island, Unit 2, in February 1992). This example indicates the level of specification for plant conditions necessary to be identified in order to potentially define the conditions under which humans are more likely to fail. It is this level of plant condition description that enables the important identification of, for instance, EOCs, which primarily result from errors during periods of intervention with the plant (such as changing power levels, performing surveillance testing, or maintaining LP&S conditions).

5.0 ERRORS OF COMMISSION

For purposes of this research project an error of commission is operationally defined as ***an overt unsafe human action that leads to a change in plant configuration with the consequence of a worsened plant state.*** EOCs are identified as a critical area for HRA development. The principal reason for this identification is that the state-of-the-art in HRA does not address EOC modeling. Consequently, EOCs are not currently captured in PRAs. However, the data analyses have shown EOCs to be dominant contributors to risk especially in analysis of actual LP&S events. The fundamental characteristics of EOCs are being examined, in an on-going task in order to develop EOC modeling methods.

Specific examples of EOCs identified in the plant specific event analyses include:

- RCS overdraining resulting in loss of shutdown cooling;
- Erroneous termination of safety injection;
- Other actions performed under conditions not well covered by procedures, training, instrumentation.

The event data represented in the LP&S HACS databases indicated that EOCs are the dominant unsafe action mode. Furthermore, EOC human initiators were found to be more prevalent than EOO human initiators. On the other hand, the majority of EOCs committed during at-power events are non-initiators (i.e., either pre-accident or post-accident). EOCs, in general, and EOC initiators, in particular, should be considered in new HRA methods.

In addition, mistakes have been found to be the predominant error mechanism of EOCs while slips have been found to be the predominant mechanism for EOOs. Since slips are more commonly modeled in at-power PRAs, new HRA methods, which address LP&S, must also include consideration of EOCs that result from mistakes.

6.0 HUMAN DEPENDENCY

Human dependency can be characterized by two or more PRA Basic Events (a,b) involving human actions whose failure probabilities are not independent and therefore causes the probabilistic relationship $P(a,b) \neq P(a) \times P(b)$ to be true. Some examples of human dependencies being examined include:

- direct dependence on some common external process (e.g., procedure-writing or planning);
- multiple tasks dependent on common PSFs such as supervision, training, and procedures;
- multiple actions dependent on a single rule-based mistake (e.g., misdiagnosis);
- task-sequential dependencies where errors in performing task A influences reliability of subsequent task B; and
- direct task interactions, such as failure in Task A causing failure in Task B (e.g., error in calibrating level sensors causing incorrect level measurement, which fails operation of mitigating systems).

There are several different kinds of dependence mechanisms that can cause these relationships. For this project the dependence mechanisms being investigated in an on-going task, are those that influence multiple human actions. These include common processes, common PSFs, and other local task dependencies. Each of these dependence mechanisms is discussed below.

Common processes are those that, by their nature, are common-mode influences to whole groups of human actions. These include: management decisions; work organization, planning and scheduling; and other programmatic functions (e.g., procedure development) within the plant. Deficiencies in these processes can lead to poor or erroneous performance simultaneously in many plant departments (e.g., operations, maintenance), and between work teams within departments. One simple example is the case where a lack of work planning led to the simultaneous performance of maintenance of two redundant trains of diesel generators during a refueling outage. A second example is the development of technically inaccurate procedures within the procedure-writing function, that led to errors in performance by both operations and maintenance.

The category of common PSFs relates to the potential effects of such influences as common procedures, common human-systems interfaces (e.g., work environment), and common training programs. Common PSFs can also include poor morale or behavioral norms which, for example, can be important for circumventions. These common PSFs have the potential, if less than adequate, of causing a significant increase in the failures probabilities for those human actions affected by them.

An example of such a common PSF was during the event at Oconee Unit 3, in March of 1991. In that event, a sequence of errors occurred that were largely (though not exclusively) the result of several operators separately being misled by an erroneous label (i.e., poor human-systems interface). That label was not the formal plant label (which was very difficult to observe), but nonetheless misled both the operators installing the blind flange and different operators later checking the installation.

In addition to common processes and common PSFs are the local task dependencies. These are aspects of the job and the task that result in the probabilities of failure no longer being independent. Examples could include the influence of a common supervisor, the work being performed in a common area, or the consequences of timing or interdependencies from one action or failure on another. For example in the Oconee event, the occurrence of the failure to properly check the blind flange installation, led to the opportunity for the subsequent testing crew to fail. If the first task had been performed correctly, the later failure would have become moot. This dependence is common with many redundant tasks.

7.0 CONCLUSIONS

The following subsections discuss the status of this research project with respect to results to date, implications of the refined framework, and follow on efforts.

7.1 Results To-Date

Key findings from the actual plant-specific event analyses include:

- Human actions are significant contributors to risk during LP&S operations;
- Human-induced initiators comprise a significant portion of the observed unsafe actions;
- Mistakes (versus slips) and errors of commission (versus omission) predominate the error mechanisms and modes of unsafe human actions which occur during LP&S (when compared to at-power operations);
- There are frequently dependencies between human actions, which should be addressed in addition to hardware dependencies;
- The most frequently cited PSFs are procedures and human engineering;
- Human actions influenced by multiple PSFs were found to be present in most events of significance;
- PSFs and unsafe actions appear to be very sensitive to the context of the plant conditions; and
- Recovery is frequently aided by situation-appropriate PSFs such as procedures, training, and the technical knowledge of the operations and management personnel.

These results provide the focus for HRA methods development to address the associated deficiencies in current HRA methods which were previously developed and used in PRAs for at-power conditions.

7.2 Implications of Framework for HRA Methods

The insights obtained from the plant-specific event analyses, and in the context of the refined HRA framework, have several implications with respect to the development of new HRA methods. These include:

- HRA methods must be capable of evaluating a range of different error mechanisms, not just those for which data are readily available. For example, many HRA methods provide data for slips and lapses. None provide ways of quantifying rule-based mistakes involving technically deficient procedure, which is perhaps one of the most risk significant mechanisms;
- Both error modes, commission and omission, must be addressed by new HRA methods, especially in order to realistically model LP&S conditions;
- Dependencies between human actions, should be addressed by new HRA methods;
- Plant conditions must be considered in HRA methods: in the determination of what basic events are appropriate to model, in the identification of opportunities for unsafe acts (e.g., EOCs), and in the determination of likely error mechanisms and their associated PSFs;
- New HRA methods must recognize that unsafe acts frequently are influenced by multiple PSFs and that different PSFs may be important to different error mechanisms.

7.3 Follow On Efforts

Once the examination of EOCs and Dependency is completed, the effort for quantification process development will commence followed by the development of implementation guidelines. Finally, a demonstration of the methodology using the guidelines will be conducted by PRA/HRA analysts on appropriately selected events for a BWR and PWR. This demonstration will be used to assess the usefulness and understandability of the guidelines including, their ease of implementation and consistency with expectations and other PRA/HRA results.

Some potential applications also being considered for the refined HRA framework and event analysis approach/results include:

- General improvements in the understanding of human contributions to safety (ultimately addressing both PWRs and BWRs, for both LP&S and at-power operations);
- Identification and analysis of trends of events with respect to human performance and its contribution to risk;
- Identification of potential improvements that can be made in outage planning and management;

- Identification of potential human reliability improvements that can be made through changes to for instance, procedures, training, human engineering, and organizational processes;

- Increased understanding of influences on human performance outside the control room which may be applicable to maintenance activities for both LP&S and at-power conditions.

In addition, since the data analyses of "real" events performed for this project have identified gaps between current PRA methods and the "real world," the development of analytical methods to fill these gaps may be critical to the transition to regulation on the basis of operating experience, i.e., performance-based regulation.

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