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Development of a Methodology for Conducting an Integrated HRA/PRA - Task 1
An Assessment of Human Reliability Influences During LP&S Conditions in PWRs*

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ABSTRACT

During Low Power and Shutdown (LP&S) conditions in a nuclear power plant (i.e., when the reactor is subcritical or at less than 10-15% power), human interactions with the plant's systems will be more frequent and more direct. Control is typically not mediated by automation, and there are fewer protective systems available. Therefore, an assessment of LP&S related risk should include a greater emphasis on human reliability than such an assessment made for power operation conditions. In order to properly account for the increase in human interaction and thus be able to perform a probabilistic risk assessment (PRA) applicable to operations during LP&S, it is important that a comprehensive human reliability assessment (HRA) methodology be developed and integrated into the LP&S PRA. The tasks comprising the comprehensive HRA methodology development are as follows: (1) identification of the human reliability related influences and associated human actions during LP&S, (2) identification of potentially important LP&S related human actions and appropriate HRA framework and quantification methods, and (3) incorporation and coordination of methodology development with other integrated PRA/HRA efforts. This paper describes the first task, i.e., the assessment of human reliability influences and any associated human actions during LP&S conditions for a pressurized water reactor (PWR).

1.0 INTRODUCTION

In support of the U.S. Nuclear Regulatory Commission (NRC) effort to appropriately address the need for the development of a methodology for conducting an integrated PRA/HRA, Brookhaven National Laboratory (BNL) is providing an assessment of the HRA needs.

The objectives of this paper are as follows: (1) to identify classes of human actions (errors and recoveries) during LP&S conditions, (2) to identify LP&S related human reliability influences (also referred to as human performance shaping factors) and assess their relative contribution to human error, (3) to assess the differences between human reliability influences and any associated human actions during LP&S conditions and those modeled in full-power PRAs and (4) to propose human reliability influences to be incorporated into the integrated PRA/HRA detailed quantification for LP&S conditions.

The assessment of human reliability influences and associated human actions during LP&S conditions consisted of two essentially sequential phases. First, a review of appropriate reports and reported events was conducted and a classification of selected human actions was developed; second, based on the review results and previous experience, an interview protocol was developed and interviews were conducted with knowledgeable personnel from NRC, industry, and a NPP.

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2.0 REVIEW OF REPORTED EVENTS AND ASSOCIATED STUDIES AND CLASSIFICATION OF EVENT-SPECIFIC DATA

The major effort in identifying and classifying human actions and influences impacting human performance during LP&S conditions consisted of gathering and evaluating appropriate sources of data. The data collected for this investigation consisted of both event-based and non-event-based data. A classification scheme was developed and applied to the evaluation of event-based data. These evaluations yielded various insights with respect to the occurrence of human errors and recovery actions and their associated influences during LP&S.

The Human Action Classification Scheme (HACS) was developed in order to organize information important to human performance from event data for LP&S conditions. The development of this classification scheme was influenced by the important issues identified in reports related to LP&S conditions, experience in evaluating event data for human performance issues, the intention to store the collected information in a computer database, and the process of applying the scheme to the specific event data evaluated for this project. A brief explanation of each of the HACS database fields is included in Attachment 1.

The sources of data available to identify human actions and influences impacting human performance are divided into two groups; those that provide direct, actual event-related human action data, and those that also provide human reliability information, but not from a specific event. The data source documents are identified in Section 5.0, References.

The actual event-related human action data are derived primarily from documents providing the most level of detail about the particular event with a minimum of previous analysis. Three principal sources of data were used. These were (1) NRC Augmented Inspection Team (AIT) reports, describing significant LP&S events, (2) NRC AEOD reports describing significant human factors LP&S events, and (3) full-text LP&S Licensee Event Reports (LERs). The human action data derived from AIT and LER sources are categorized in accordance with HACS, and along with the AEOD source, includes only plant-specific events. The preferred data source was the AIT reports because of their detailed and independent evaluations of the circumstances of these significant events. Due to the small number of such evaluations, selected full-text LERs were also reviewed. Table 1 shows the data sources for event-based data which formed the major portion of the evaluations.

Since there are literally thousands of LP&S-related LERs for PWRs mentioning human performance issues, the strategy used to-date for LER sampling has been to concentrate on events referenced in draft NUREG-1449. In particular, those PWR LP&S events which have been included in the evaluation were those used as part of the NRC AEOD Special Evaluation Report on shutdown and refueling and the NRC Accident Sequence Precursor methods, as noted in draft NUREG-1449.

Using the March 1990 Vogtle Unit 1 event as an example, Table 2 illustrates the typical amount of information detail found in summary LERs, full-text LERs, and event-based reports. In general, the most important information to the objectives of this endeavor consist of pre-existing plant conditions; the number, type, and other characteristics of human errors (and actions); and influences on human errors (and actions). Table 2 shows that event-based NRC reports contain the most information with respect to all of these information categories and summary LERs the least. This finding influenced the data evaluation strategy of this effort to emphasize the evaluation of full-text LERs and event-based reports.

Table 1. Sources of Event-Based LP&S Data

Plant	Data Sources	
	LERs[1]	NRC Reports
ANO-1	10/26/88 12/19/88 12/05/89	
A[illegible]	05/04/88	
Braidwood 1	12/01/89	12/01/89 - AIT Report. 10/04/90 - AEOD Human Factors Study Report.
Braidwood 2	02/23/89	
Byron 1	09/19/88	
Catawba 1	04/28/85 04/22/85	03/20/90 - AEOD Human Factors Team Report.
Crystal River 3	02/02/86 10/16/87	12/08/91 - AEOD Human Performance Study Report.
Diablo Canyon 1		03/07/91 - AIT Report.
Diablo Canyon 2	04/10/87	04/10/87 - NUREG-1269.
Farley 2	11/27/87	
Fort Calhoun	03/21/87 02/26/90	
Haddam Neck	08/21/84	
Harris 1	10/11/87	
Indian Point 2	11/05/87	
McGuire 1	09/16/87 11/23/88	
Millstone 2	12/09/81 02/04/88	
Oconee 3	09/11/88	03/08/91 - AIT and AEOD Human Factors Study Reports.
Palisades	11/21/89	
Prairie Island 2		02/20/92 - AIT and AEOD Human Performance Study Reports.
Salem 1	03/16/82 05/20/89	
Sequoyah 1	05/23/88	
Turkey Point 3	05/28/87	
Vogtle 1	03/20/90	03/20/90 - NUREG-1410, IIT Report.
Waterford 3	07/14/86	
Yankee Rowe	11/16/88	
Zion 2	12/14/85	

[1] Both full-text and summary reports; full-text reports used for HACS evaluation.

Table 2
Typical Amount of Detail from Various Sources Using Vogtle "Loss of Offsite Power" Event (3/20/90) as an Example

Data Available	DATA SOURCE		
	Summary LER	Full-Text LER	NUREG-1410 - IIT
Type and number of human errors and recovery actions	Initiator: 1	Initiator: 1 Latent: 1 Recovery: 1	Initiator: 1 Latent: 3 Recovery: 2
Type and number of human reliability influences	Organizational Factors: 1	Organizational Factors: 1 Procedures: 1 Training: 1	Organizational Factors: 1 Procedures: 4 Training: 3 Communications: 1 Human Engineering: 2 Design: 1
Plant configuration information	• Refueling • Train B RAT & DG out of service (OOS) for maintenance	• After Refueling • Train B RAT & DG OOS for maintenance	• After Refueling • Train B RAT & DG OOS for maintenance • 9 "above" actual Midloop • Charging pump B OOS for valve maintenance • All SG nozzle dams removed, but only SG #1 and 4 primary manways replaced • Pressurizer manway removed • Containment equipment hatch removed

RAT = Reserve Auxiliary Transformer.
DG = Diesel Generator.
OOS = Out of Service.

Besides using AIT reports, AEOD reports, and LERs to provide event-specific human actions and influences impacting human performance, there are other sources of information to determine non-event specific data associated with the LP&S influences on human reliability. Draft NUREG-1449 (and its supporting details) provided most of the non-event-based information used in the process of characterizing and identifying human actions, errors, and influences. Also, useful non-event-specific information was obtained from NUMARC 91-06 guidelines.

The evaluation of event data (i.e., LERs, AIT reports) with HACS involved six different phases:

- initial review of LERs and AITs during HACS development
- talk-through of HACS application to the review of sample LERs and AIT reports
- in-depth evaluation of LERs and AIT reports with HACS
- group discussion regarding the HACS evaluations of 4 AIT reports
- comparison of all HACS evaluations (i.e., LERs and AIT reports) for common characteristics, general observations, etc.
- independent review of HACS database for consistency and completeness

The HACS framework was found practical in the evaluation of all events, though the level of detail and the completeness of the analysis varied because the content of the reports vary. Certain full-text LERs and more recent reports did provide enough detail to address most of the HACS fields. While AIT reports contained the most complete event information, the greatest amount of insight was obtained from a combination of an AIT report and a full-text LER for the same event.

The disciplines of human reliability analysis and human factors engineering were important in the identification of human actions and influences impacting human performance. Human actions pertinent to each event could include human errors which initiated events, latent human errors which affected the response to the event, and recovery actions for mitigating the event. In most cases, more than one human action was identified for each event. Similarly, influences specific to each of the identified human actions were identified from the event data. Additional notes and observations which are not accommodated by HACS but are pertinent to potential influences on human performance (e.g., root causes such as management or planning) were stored as comment fields in the HACS database. A tally of all influences identified as impacting human performance, both positively and negatively, was also taken for selected events.

The following sections present the results of the review of information sources. For each of the sources, there are discussions of the kinds of events, actions, and errors, and of the patterns of influences found to be significant. Table 3 presents a summary of the significant influences.

Due to differences with respect to their context and format, the discussions of the various information sources vary. For example, for two sources (the LERs and the NSAC report), the analysis uses statistics such as event counts. This usage of statistics is due to the fact that LERs and the like can provide large quantities of data but at a relatively superficial level. In contrast, the AIT and AEOD Human Factors reports are far fewer but provide a greater richness of information. Therefore, the discussion of these events focuses more on the details of the errors and the circumstances surrounding them. Summary event descriptions are provided for each of these events in the form of tables. Finally, for the non-event data, a summary of the NRC and NUMARC findings is presented.

Table 3. Summary of Human Reliability Influences

Influence	Non-event-based Results		Event Analyses			
	NRC[1]	NUMARC[2]	NSAC[3]	AIT[4]	AEOD[5]	LERs[6]
Procedures	(6.6.1.1)	3.3, 3.4	11/47	-4, +3	-10, +3	25/39
Human Engnrg.	(6.6.1.1)		13/47	-6, +2	-6, +2	18/39
Training	6.4	3.5	2/47	-5, +3	-3, +1	11/39
Communications			2/47	-5, +1	-6, +1	5/39
Org. Factors	6.2	3.1, 3.3	2/47	-5, +0	-7, +0	2/39
Supervision		3.6	1/47	-1, +0	-2, +1	2/39
Stress	6.3	3.2		-0, +0	-3, +0	0/39
Other[7]	---	---	16/47	-0, +4	-0, +3	0/39

Notes:

1 Section number in draft NUREG-1449 that describes staff's findings related to this influence (parentheses indicate indirect findings).

2 Section number in NUMARC 91-06 providing guidance on this influence.

3 Fraction of loss-of-RHR events discussed in NSAC-156, Appendix A, for which this influence was identified.

4 Number of times in four Augmented Inspection Team (AIT) reports where this influence was identified by BNL team as significant ("-" had a negative influence, "+" had a positive influence).

5 Number of times in five AEOD human factors reports where this influence was identified by BNL team as significant ("-" had a negative influence, "+" had a positive influence).

6 Relative fraction of human actions reviewed in this study where this influence was found to be significant.

7 Includes design issues, mechanical failures, and the effect of extensive technical knowledge.

2.1 Licensee Event Reports (LERs) Review Results

Section 2.1 of draft NUREG-1449 identifies 42 events associated with PWRs that were reviewed by AEOD as being representative of LP&S problems. The dates of these events range from 1981 to 1990, with the majority being in the range 1987 to 1989.

The full text version of these event reports were requested from the NRC Public Document Room; reports for four events were not found. Reports for the remaining 38 events were obtained, reviewed, analyzed, and summarized in the HACS database. Of the 38 reports reviewed, 32 were identified as potentially important to LP&S safety and relevant to the purposes of this study; the six events not reviewed in depth included deficiencies in power operations safety analyses and an inadvertent reactor protection control rod trip signal during testing while shutdown.

As part of the evaluation of the LERs, a grading of major, minor, or detectable was assigned to each LER as an indication of relative event level of significance. This evaluation was based on the subjective judgement of a person with licensed plant operations and HRA experience. Of the 32 events reviewed, 13 were classified as major, 15 as minor, and four as detectable. Table 4 provides summary information from selected full-text LER findings.

Table 4. Summary Information from 32 Selected Full-Text LER Findings

Event Description Summary		
13	Loss of Shutdown Cooling	
7	Loss of Electrical Power	
2	Loss of Electrical Power and Loss of Shutdown Cooling	
2	Loss of Reactor Coolant Inventory and Loss of Shutdown Cooling	
3	Loss of Reactor Coolant Inventory	
2	Engineering Safety Features Actuation	
1	Emergency Diesel Generator Inadvertent Start	
1	Loss of Charging Pump	
1	Boron Dilution of Reactor Coolant	
Event Initiator Summary		
20	**Human Error**	
12	**Not Human Initiated**	
Error Effect Summary		
21	**Active**	
	(7 for Major Level of Significance Events)	
18	**Latent**	
	(10 from Major Level of Significance Events)	
	15	Latent, Discovered Prior to Startup
	3	Latent, Discovered During/After Startup
Personnel-Involved Summary		
39	**Selected Errors**	
	15	Vendor/Contractor
	11	Maintenance/Instrumentation Technician
	9	Licensed (Control Room) Operator
	4	Non-Licensed (Equipment) Operator
	1	Senior Licensed Operator
27	**Recovery Actions**	
	26	Licensed (Control Room) Operator
	18	Non-Licensed (Equipment) Operator
	4	Maintenance Technician
	1	Senior Licensed Operator

Error Type Summary		
26	**Mistakes**	
	(11 from Major Level of Significance Events)	
	14	Mistake, Inadequate Procedure
	8	Mistake, Faulty Diagnosis
	2	Mistake, Inadequate Planning
	2	Mistake, Miscommunication
13	**Slips**	
	(6 from Major Level of Significance Events)	
	10	Slip, Inadvertent Actuation
	2	Slip, Incorrect Execution Mistake
	1	Slip, Selection of Wrong Item

Human Reliability Influences Summary	
25	**Procedures** (including 14 procedure wrong or incomplete/situation not covered; 6 procedure followed incorrectly/details less than adequate)
18	**Human Engineering** (including 7 human-system interface instrument displays less than adequate)
11	**Training** (including 7 training/understanding less than adequate)
6	Engineering Design
5	Communications
2	Organizational Factors
2	Supervision
0	Stress

Error Mode Summary		
30	**Error of Commission**	
	(13 from Major Level of Significance Events)	
	17	Commission of Undesired Task, Analysis, or Step
	11	Commission (Other Human Factors)
	2	Commission of Undesired Adjustment or Calibration
	0	Commission of Undesired Alarm Response
9	**Error of Omission**	
	(4 for Major Level of Significance Events)	
	5	Omission of Task, Analysis, or Step
	4	Omission (Other Human Factors)
	0	Omission of Alarm Response
	0	Omission Within Allotted Time
	0	Omission of Adjustment or Calibration

There is an apparent difference in the nature of the events classed as major compared with the events overall. The prototypical overall event is associated with errors by technicians (plant staff or contractors) working outside the control room performing tests. While performing this work, the technician makes an error of commission, which is a result of a procedural inadequacy (often, the procedure does not cover some particular step or contingency occurring in the test) and inadequate training. The deficiency in the procedure is often revealed when a situation is encountered (e.g., other equipment failure or human error, or an operation taking place in some other part of the plant) that was not in the expectation of the procedure developer. These errors of commission result in an immediate consequence, such as a loss of electric power that results in loss of shutdown cooling. The event is recovered by actions inside the control room, with some actions taken outside the control room (e.g., rack in breakers or open valves manually) to recover equipment taken out of service for maintenance or due to an earlier latent error.

For the events considered major, the prototypical event is different. It is much more likely that the errors are committed by the control room operators while performing some task associated with RCS level and inventory control. This error is as likely a slip (i.e., a human error where what is performed was not intended) or a mistake (i.e., a human error where the intention was erroneous, but is purposefully executed), with temporary level instrumentation often playing a key role. The effect of the error is to lead to loss of shutdown cooling, sometimes in association with inadvertent loss of RCS inventory through multiple RCS drain paths. In the case of the major events, typically several human reliability influences are involved. These could include inadequate instrumentation (e.g., level indication), inadequate procedures (e.g., no planning for failures or requiring complex calculations), inadequate training, and (sometimes) miscommunications between plant personnel as to the plant status. In many cases, recovery requires prolonged actions outside the control room to restore mechanical equipment, such as venting RHR pumps following air-binding.

2.2 NSAC-156, Residual Heat Removal Experience Review and Safety Analysis Review Results

The NSAC-156 report summarizes the experience of loss of RHR events during LP&S operations at U.S. PWR plants between 1982 and 1989. This report represents an update of an earlier report, NSAC-52, which provided a similar evaluation for loss of RHR events up to 1981. The primary data source for the NSAC evaluation was LERs, supplemented by INPO and AEOD reports, though the events listed do not identify the subject plant. The greatest level of detail for the events described in this report corresponds approximately to that of summary LERs; in many cases, it was not possible to identify fully the information required for the HACS database.

Appendix A of the NSAC-156 report identified 49 events involving loss of RHR capability (partial and complete) in the period 1985 to 1989. This time window is the period during which LER reporting requirements have remained relatively constant. Of the 49 events, two were the result of design deficiencies and were not considered further. The summary descriptions provided in NSAC-156 of the remaining 47 events were studied for the activities, errors and contributions of the human reliability influences. Because of the lack of detail, only about 22 contained sufficient information about the specific errors, activities, and recovery data for evaluation. However, information concerning the human reliability influences was obtainable from all 47.

The largest contribution to the 47 loss of RHR events was from human engineering, with the greatest fraction of those events involving inadequacies in the man-machine interface, and the balance from the work environment. The most common man-machine interface problems were inadequate temporary level instrumentation and difficulties in observing annunciator indications during the outage condition. Problems in the work environment were principally reflected in inadvertent contact with relays or control equipment while performing Instrumentation and Control (I&C) or electrical maintenance or testing. The next largest overall contribution to the 47 loss of RHR events was from procedures, with the largest fraction being attributable to an incomplete procedure or the wrong procedure for the application. In most cases, it seemed that conditions were encountered that were not anticipated in the procedures, such as equipment not being found "as expected" or plant configurations existing that, when the procedure was implemented, led to loss of RHR (e.g., electrical interconnections).

In conclusion, because of the incomplete information presented in the event summaries in NSAC-156, it is difficult to draw clear conclusions about the patterns of errors and actions from their review. However, most errors were errors of commission, resulting from mistakes induced by inadequate man-machine interface, poor procedures or inadequate instrumentation.

2.3 Augmented Inspection Team (AIT) Evaluation Review Results

As shown in the comparison given in Table 2 of the information contained in an LER to that in an event-based report, the four AIT reports which were evaluated (see Table 1) contained more information and detail than that contained in the full-text LERs reviewed. Consequently, while each of the AIT reports was coded into HACS, the important information contained in the AIT reports were details on plant conditions and defenses, human actions and errors, and influences and not the statistics on types of events and human errors, error modes, error types, error locations, etc. To the extent possible, details judged to be important to human reliability and performance have been extracted from the AIT reports. Table 5 provides the details of the Prairie Island Unit 2, February 1992, event analysis.

The evaluation of events discussed in the AIT reports include three loss of RHR events and one loss of essential electric supplies. All four AIT events were initiated by human errors. The loss of electric power event (Diablo Canyon Unit 1, 03/07/91) and two of the loss of shutdown cooling events (Oconee Unit 3, 03/08/91 and Braidwood Unit 1, 12/01/89) were initiated outside the control room (two active and one latent error, respectively). The third loss of shutdown cooling (Prairie Island Unit 2, 02/20/92) was initiated in the control room (active error). In each case, there were multiple errors made. Commonly, latent failures existed such that, when some final error occurred, the incident resulted. For the three events involving loss of RHR, two involved significant mistakes associated with negative influences: poor labeling and procedures. In addition, in each of the four events, training played a contributing role. In most cases, the licensee had not provided training for the activities being performed, as in the case of the calculations of RCS level at Prairie Island Unit 2. Also, communications and organizational factors were also issues in three of the four events. Human engineering was the most frequent contributor to human performance in the four AIT reports reviewed. While all the events exhibited the effects of multiple influences, ranging from five (Braidwood Unit 1) to eight concurrent influences (Oconee Unit 3). There was no consistent pattern of combination of influences.

Evaluations of the AIT reports are consistent with the full-text LER evaluations in that all types of human errors and actions were included in both. As shown in Table 3, the identification of procedures, training, communications, organizational factors, and human engineering as important contributors to events in AIT reports is also consistent with the findings of the LER evaluation. In addition, multiple influences were identified in both LERs and the AIT reports. However, the information available in the AIT reports also allowed the identification of influences which contributed positively to events, i.e., correct procedures or good communication contributed to the mitigation or early detection of an event. The AIT reports contained more detailed information on both positive and negative impacts of human actions.

2.4 AEOD Human Factors Evaluation Review Results

Like the AIT reports, the primary usefulness of the AEOD reports to this project stems from the depth of detail provided about human actions and errors and their associated influences. Similarly, the details judged to be important to human reliability and performance have been extracted from the AEOD reports. These reports provide the results on-site evaluations of the roles human-factors issues played in a series of events at nuclear power plants from 1990 to 1992. Included in these were five events that occurred at PWRs during low power and shutdown operations. These events were at: Catawba Unit 1 (3/20/90), Braidwood Unit 1 (10/8/90), Oconee Unit 3 (3/8/91), Crystal River Unit 3 (12/8/91), and Prairie

Table 5

Plant: Prairie Island Unit 2 | **Event: Loss of RHR for 21 minutes** | **Event Date: 02/20/92**

Situation	Acts	Defenses	Conditions	Influences
1. Day 2 of outage; decay heat is high (approximately 6 MW). In-vessel boiling occurred. 2. Installed permanent level instrumentation not compatible with planned evolution (N_2 gas overpressure). 3. Temporary level instrumentation required accurate manual calculations. 4. Both permanent and temporary redundant instrumentation relied on single common pressure measurement sensor. 5. Small errors in estimated timescale for drain to midloop led to unacceptable plant conditions (airbinding of cooling pumps).	1. Two rounding errors made by operators in calculating RCS level. 2. Operators over-reduce RCS level, which causes vortez (this is based on Shift Manager's faulty calculation of drain-down time). RHR pump fails due to airbinding. 3. Little discussion with shift operations management about problems during event.	1. Multiple RCS refill routes available. *+Design* 2. Operators trip RHR pump on early evidence of airbinding. *+Training* 3. Once RHR pump was tripped, AOP, and EOP led operators to successful recovery. *+Procedures* 4. Containment evacuated according to procedure. *+Procedures*	1. Two related procedures (RCS level and draindown time) required extensive and detailed calculations with no aids provided. *-Human Engineering* 2. Temporary RCS level instrumentation very difficult to read in poor environment. *-Human Engineering* 3. Operating personnel had limited or no training in draindown tasks. Experienced personnel allocated to other parallel tasks. *-Training, Supervision* 4. Draindown procedure not clear on prerequisites for instrumentation availability. *-Procedures* No communication with shift operations management led to lost opportunities to correct errors in level control. *-Communications* 5. No communications from plant personnel, who heard pump "burping;" delay in identifying impending airbinding. *-Communications*	Procedures: -1; +2 Training: -1; +1? Communications: -2 Organizational Factors: Human Engineering: -2 Supervision: -1 Stress: Design: +1

Source: AIT Report 50-306/92-005.

Island Unit 2 (2/20/92). Two of these events, Prairie Island and Oconee, are the same as those reviewed in the AIT reports. A summary of the Prairie Island event, including the actions, errors, and influences is presented in Table 6.

These five events include two losses of shutdown cooling, two losses of RCS pressure control (one over pressure and one underpressure), and one RCS LOCA. All were initiated by human errors, with two events having pre-existing latent failures caused by human errors. In each case human actions taken in the control room recovered the plant. Of the seven errors total (identified in the five events), four were errors of omission and three were errors of commission; of the errors of omission, most were performed by maintenance technicians. Control room personnel were principally involved with the errors of commission. Most of the errors were of the mistakes category involving actions in response to inadequately planned procedures or inadequate instrumentation.

A comparison of Table 5 and 6 shows that the human influence contributions identified in the AEOD reports for the Prairie Island Unit 2 event were similar but not identical to those found in the parallel AIT reports.

These differences may be attributable to the differences of focus for the two on-site investigations; i.e., human performance issues only for the AEOD reports and more general issues for the AIT reports. Like the AIT reports, the AEOD reports contained information indicating the existence of both negative and positive influences on human performance.

2.5 NUMARC 91-06, Guidelines for Industry Actions to Assess Shutdown Management Review

This industry document provides guidance to utilities in how to prepare for specific hazard states in planning for and controlling an outage. Specific hazard states addressed include loss of shutdown cooling, loss of inventory, loss of electrical supplies, and inadvertent reactivity addition. For example, the document discusses the key safety functions and alternative means of restoring them. The planning and control section, Section 3, discusses human factors issues, planning, and so on.

As Table 3 shows, NUMARC provides guidance in several areas of interest to this project. Procedures are discussed in Section 3.3 - Providing Defense in Depth, and Section 3.4 - Contingency Planning. NUMARC recommends that "Procedures should be developed that are designed to mitigate the loss of KEY SAFETY FUNCTIONS." As part of contingency planning, procedures are one means of re-establishing the planned defense in depth as equipment failures and human errors erode the defenses.

Training is identified specifically as a separate topic in Section 3.5 - Training. The NUMARC guidelines state that operator training should provide: (1) knowledge (through simulator training if practicable) of applicable safety issues associated with the expected outage, and (2) training for other plant personnel (including contractors and other temporary workers) for their assigned roles in outage activities that contribute to safety.

Organizational factors are discussed in Section 3.1, Integrated Management, and Section 3.3, Providing Defense in Depth. Section 3.1 indicates that senior management should issue a policy defining the nuclear safety philosophy for the outage, that schedules should be developed to ensure adequate defense in depth and that changes in schedule should be reviewed for adequate safety coverage, that availability of key safety equipment and the performance of "higher risk evolutions" should be communicated frequently to personnel, and that post-outage critiques should be conducted to improve future

Table 6

Plant: Prairie Island Unit 2 | **Event: Loss of RHR** | **Event Date: 02/20/92**

Situation	Acts	Defenses	Conditions	Influences
1. Two days into refueling outage. 2. RV draining to mid-loop started. 3. Operators performing draindown were extra personnel from another shift. 4. Newly installed electronic level instrumentation considered operable but reading off-scale. 5. Tygon tube only instrument providing usable level information during draindown. 6. Manual calculations required correction for nitrogen pressure effects. 7. Evening shift - 11:10 pm at time of RHR loss. 8. Plant behavior with respect to the "burping" action of the S/G tubes was different compared to previous draindowns. Past experience of one RO was that draining was almost done when burping stopped; could not tell when burping stopped during this draindown.	1. Problems calculating RV level and inaccuracies introduced by rounding off. 2. Operators over-reduce RCS level, causing RHR pump vortexing. (Caused in part by the Shift Manager's faulty calculation of the draindown time.) 3. RV level restored using charging pumps and SDC re-established.	1. Alarms for RHR low suction pressure, low motor-amp, etc. lead to pump trip. *+Human Engineering* 2. AOP and EOP lead to recovery. *+Procedures* 3. Command and coordination of the operating crew during recovery from the event was a positive factor in the crew's response - shift supervisor in direct command of the procedures. *+Supervision*	1. Operators not trained on using draindown procedure (mid-loop training not available on simulator) and performing the conversion calculations in situations of high nitrogen pressure. *-Training* 2. Draindown procedure contained sparse information on nitrogen pressure control, did not include a conversion factor for calculating the draindown time, and did not require logging of the actual water level (to provide trending information). *-Procedures* 3. The draindown crew was inexperienced, not sure who was in charge, and received infrequent supervision by the Shift Manager and Shift Supervisor because they were assumed to be experienced enough to proceed with the procedure. *-Supervision* 4. Operators did not communicate their concerns to the supervisors. *-Communications* 5. Guidance in draindown procedure did not compensate for inexperience of System Engineer assisting in the draindown. *-Human Engineering* 6. Difficulty in local reading of tygon tube - poor lighting, etc. *-Human Engineering* 7. Entry into EOP delayed due to ambiguity in the entry conditions. *-Procedures*	Procedures: -2; +1 Training: -1 Communications: -1 Organizational Factors: Human Engineering: -2; +1 Supervision: -1; +1 Stress: Design:

Source: AEOD Human Performance Study Report, April 1992.

performance. Section 3.3 of NUMARC 91-06 provides guidelines for ensuring adequate depth of defenses. These include: using the outage schedule to establish which systems, structures and components provide safety function back-ups; optimizing the availability of safety systems; assuring the functionality of safety systems by means of testing and administrative controls; and developing appropriate procedures for mitigation of safety system losses.

Supervision is discussed in Section 3.6, Outage Safety Review. Guidelines in this area suggest: that the outage schedule should be reviewed by personnel not involved in its development to ensure that the management philosophy on outage safety has been implemented; that higher risk evolutions should be clearly identified with contingency plans identified; and that changes to the plan be reviewed by appropriate levels of authority.

Finally, in Section 3.2, Level of Activities, the NUMARC guidelines recommend that an outage overtime policy should be established which requires prior approval by appropriate levels of management for overtime hours for outage personnel.

2.6 Conclusions Based on Data Analysis Review

First of all, the event analyses of the six data sources addressed during this study (i.e., NRC's draft NUREG-1449, NUMARC 91-06, NSAC-156, the four NRC AIT reports, the five NRC/AEOD human factors reports, and LERs) yield consistent results. The analyses based on the LERs (both in the present review and that of NSAC) provided an extensive survey of the types of actions involved during LP&S, the context in which actions and errors occur, and the "primary" influences affecting the personnel. In this sense, "primary" influences are the immediate and direct influences that shaped the behaviors at the time the errors occurred. Particularly, there is a consistent pattern of procedures providing inadequate guidance or not covering actual situations, and inadequate human engineering such as poor instrumentation or inadequate labeling. As summarized in Table 3, these two influences predominate in the evaluations based on LERs. In many cases, these human reliability influences resulted from temporary procedures, temporary or newly changed level instruments, and labels associated with equipment only operated or accessed during outages.

However, a more complex picture emerges from the review of the more detailed event analyses provided by the AIT reports and the human-factors reviews for AEOD. In these studies, the same "influences" are still important but additional influences emerge to make the events more complex. In particular, training, communications, and organizational factors become apparent. What these "secondary influences" appear to indicate is that those plants that do not prepare comprehensively for LP&S operations may face unanticipated situations, for which no contingency plans exist, which are outside the envelope of the instrumentation, and for which no channels of communication are prepared. These identified multiple influences revealed as a result of detailed event analysis (for example, see Table 2), usually act in a synergistic manner, thereby achieving an effect of which each individual contributing influence is incapable. In many cases, these multiple influences are the result of some common organizational deficiency such as inadequate identification of safety-critical plant evolutions.

In terms of the kinds of errors, the inevitable consequence of combinations of influences, such as those identified in the AIT and AEOD reports, is that mistakes will be induced by the lack of adequate procedures and instrumentation. These mistakes will be principally rule-based (use of inadequately planned procedures and inadequate knowledge of the plant state). Because so many tasks involve direct manual interactions, the result is often errors of commission--namely, operators take the wrong actions or take an action at the wrong time. This result is in contrast to full-power operations where operators are more frequently performing a supervisory function of monitoring automatic equipment.

The LER-based data provided little information on the recovery of events (other than the timescales) for human and hardware responses; whereas the more detailed analyses indicate that, in most cases, procedures and training were effective in ensuring an adequate recovery. In fact, the apparent paradox of the same influences scoring both positive and negative in Table 3 is because the "temporary" procedures or training were a significant causal factor in creating the event, but the "permanent" procedures and training resulted in recovery of the event. Only those events involving mechanical damage and short timescales for core heatup were problematic.

3.0 INTERVIEWS WITH KNOWLEDGEABLE INDIVIDUALS

To complement the classification of data extracted from LP&S reported events and associated studies, interviews were held with knowledgeable NRC, Industry (EPRI and NUMARC) and utility personnel. A standard interview protocol consisting of questions pertaining to LP&S issues was developed for this purpose.

The interview protocol provided the interviewers with a standardized means for obtaining interviewee responses on LP&S issues including: important lessons to be learned from reviews of LP&S activities; important characteristics of LP&S operations that influence safety; important LP&S human reliability influences; differences in human influences between LP&S and full power operations; and important observable factors that distinguish a good outage from a poor outage. Additional questions solicited insights an interviewee might have gained through exposure to LP&S incidents with significant human performance implications. To accommodate differences in operational information, a slightly revised protocol was utilized for interviews with utility personnel.

Interviewees were selected to provide a diversified representation of knowledgeable individuals in the areas of human performance and LP&S operation. This sample included NRC, EPRI, NUMARC, and utility personnel. Interviewees were involved with LP&S-related reports and guidelines, data source development, plant visits (i.e., AITs, IITs, and EOP inspections), the accident sequence precursor program (analysis of LP&S events), and LP&S plant operation, including maintenance, training, and planning.

3.1 Information Obtained from Interviews with NRC and Industry Representatives

Plant configuration when an event occurs was reported to have a significant impact on event severity and mitigation. Movement of radioactive fuel was reported to impact safety. Other plant configuration characteristics reported to impact safety included the ability to close containment, reduced RCS inventory control, decay heat removal, and less than adequate control over switchyard activities. It was reported that during shutdown plant configurations are changing continuously and human-system interactions are much more frequent. There are major configuration changes, more people, and an increase in diverse activities making control and communication a more demanding task. The overall consensus was that LP&S was a more complicated and dynamic condition requiring a different approach than that of normal operation, with a much greater emphasis on the importance of communication, organizational factors, supervision, and stress.

Procedures and training were rated high in importance. A synergistic relationship was reported to exist between procedures and training such that if both were "bad," the operators could really get into trouble. However, good training could compensate for poor procedures.

Stress, communication, human engineering, supervision, and organizational factors were reported to be situation-specific with respect to their importance as potential contributors to human performance during LP&S. Stress due to fatigue was reported to be more important as an influence for plant staff than for contractor staff and was considered an important influence to both event initiation and recovery.

especially when coming out of an outage. Communication was discovered to be an important influence for both event initiation and recovery, especially during equipment configuration changes. Human engineering and supervision were rated low in importance as recovery influences but high as influences to event initiation. In general, supervision and organizational factors were rated lower in importance while during full power than at LP&S.

Training was reported to be of significant importance for maintaining plant safety during LP&S. It was stressed that with adequate training operators would not be surprised, or ill prepared, when unexpected or unanalyzed phenomena occur. It was further stressed that communication played a significant role, especially with respect to communicating experience from past events and PRA findings to improve the knowledge base of working level personnel. The importance of having systems beyond instrumentation (e.g., outage control centers to communicate timely and reliable indications of plant status and configuration to plant personnel) was cited.

Additional reported issues included the importance of addressing changes in work assignments (roles and responsibilities) and the need to control and coordinate group activities. An example provided made reference to the very different role the control room crew has during LP&S and the influence these role changes have on performance. In addition, the vast increase in work activities being performed on multiple components makes control and coordination of LP&S activities a critical concern.

The process of entering or exiting an outage was reported to create an environment conducive to errors. Keeping communication lines open during such major transitions (which could be prolonged over several shifts) and minimizing time lag of information dissemination were reported to be of paramount importance. Another recommendation provided was to use the same people each outage to make use of accumulated experience.

Poor outage planning was cited as being a significant contributor to many LP&S events. It was recommended that outage planning should focus on safety functions and not solely on desired equipment maintenance. It was further recommended that the licensee's outage plan be clearly understood. Planning procedures should be available and utilized. The plan should make schedule sense (i.e., is equipment available when needed the most) and address safety reviews, ways to prevent failures, feedback mechanisms as well as allocation and control of resources. It should contain an identification of the vulnerabilities (i.e., the critical functions that must be maintained) and specifications for contingency plans. The plan should also include a reasonable assessment of resources in terms of people and hours per task, and a clear program to ensure coordination and communication between all groups (e.g., end of shift meetings). The plan should not contain any unfamiliar task or configuration requirements.

Other important factors identified as being important for maintaining plant safety during LP&S include provisions for defense in depth, adequate training, a safety attitude (culture), sufficient levels of supervision, and barriers and notices protecting critical equipment.

Several interviewees commented on the need for additional requirements (e.g., technical specifications) to control shutdown conditions. European plants were cited as taking a much more cautious view of plant risk during LP&S and having more stringent technical specifications covering LP&S plant configurations.

3.2 Information Obtained from Interviews with Utility Personnel

The greatest challenge to critical safety functions comes from the possibility of simultaneous unavailability of equipment causing the loss of a given function. There was general agreement that operating with reduced RCS inventory under circumstances in which the RHR function might be compromised represented a serious challenge to the safety of the unit.

During an outage, the role of the operations staff changes considerably as compared with full power operation. Full power operations were characterized as more relaxed, consisting of such activities as surveillance testing, review of procedures and training. The operator responsible for the "up" unit of a two-unit plant during an outage has the added task of closely monitoring activities in the "down" unit, since there may be common equipment or cross-tie capability. The operating circumstances during an outage are more demanding, the work more intensive, and shift turnovers more difficult. Reduced inventory operations were identified as presenting the greatest challenge to the operator. Also noted as difficult were maintaining awareness of plant status, keeping track of unavailable equipment, and avoiding loss of information during shift turnovers.

From the operators' perspective, the level of concentration required of the operators is the primary difference between at-power and LP&S operations. There are more people working in the control room and an increased number of manual interventions and manipulations needed in LP&S. The number and complexity of the maintenance activities performed during LP&S operations is greatly increased. The tasks are also typically longer in duration than during full-power operations, so that communication during shift turnovers becomes an important factor.

Utility personnel reported that critical safety functions are protected by proposed outage activities being subject to multiple reviews. The operations manager and operations coordinator review plant technical specifications, outage activities and "windows" (i.e., periods of time during which activities may occur). Proposed outage activities are also reviewed by the shift supervisor. The SRO in the control room is ultimately responsible for any activity performed on his shift, although ROs will also be familiar with technical specifications and other requirements.

As noted above, reduced inventory operations (i.e., midloop) were judged to be the most challenging conditions. In addition to the above reviews, safety is maintained during reduced inventory operations by the presence of two independent RCS level indications in the control room (in addition to local sight glass indication used during draindown). Procedures call for results of mass balance calculations to be constantly compared to level indications.

Operators are periodically trained in RHR operation; such training is scheduled as close to the start of an outage as possible. Specific pre-outage training and operational checks are designed to avoid entering adverse configurations. Training is provided on the RHR system, draindown and midloop. Loss of RHR accidents and mitigation are simulated. These topics are refreshed in requalification training. An attempt is made to present such simulations just prior to an outage if possible. In the opinion of some interviewees, RCS draindown is not particularly troublesome at present since procedures and training have been optimized based on industry experience with LP&S.

Staffing changes reflect changes in the difficulty of the operator's role such that additional RO and SRO personnel are assigned to the "down" unit during an outage. As many as 5 SROs may be on a shift during an outage. In addition, paperwork related to work orders, tagouts, etc. is handled outside the control room during an outage in order to reduce the load on control room operators.

Interviewees were in agreement that outage planning was important to the success of the outage. Maintenance personnel judged the availability of manpower and replacement parts to be critical to safe and timely completion of outage maintenance. Coordination and communication with operations personnel were also seen as important. Outage planning personnel emphasized that the success of an outage depends on close, continuing coordination with operations personnel and meticulous management of the plan as it evolves through multiple revisions. Outage planners further remarked that they made a concerted effort to involve personnel from all functional groups (operations, maintenance, engineering, management) in the development of the outage plan. It had been their experience that participation leads to commitment and a willingness to take responsibility, while lack of involvement leads to resistance and fault-finding.

3.3 Conclusions Based on Interviews

Utility personnel provided the insight that operating with reduced inventory under circumstances in which the RHR function might be compromised posed a very real concern about plant safety. NRC and industry personnel echoed these concerns and specified fuel movement, containment closure, and switchyard control as additional challenges to plant safety during LP&S operation.

Similar insights were reported on the differences between LP&S and full power human reliability influences. Both groups cited changing roles for plant personnel, increased work activities, and the critical importance of communicating plant status as significant human reliability influences unique to LP&S. Utility personnel elaborated on these differences emphasizing shift turnover and the increased number of manual (human) interventions and manipulations required during LP&S, while NRC and industry personnel emphasized the increased importance of training and procedures.

Utility personnel insights on maintaining plant safety during LP&S had an expected plant operations emphasis (i.e., specific examples of necessary instrumentation and RCS drain down training were provided). Utility planners highlighted the importance of involving personnel from all functional groups in the development of the outage plan. Both groups similarly reported on the critical role a well developed outage plan, coupled with adequate training, procedures and staffing, plays in maintaining plant safety. NRC and industry personnel provided insights on the particular problems represented by transitions such as entering and exiting an outage. The need for additional technical specifications to control LP&S activities was expressed by NRC personnel.

4.0 RESULTS AND CONCLUSIONS

This section presents the results of the evaluation of event and non-event data and the interviews with knowledgeable personnel. Section 4.1 summarizes the results in terms of the kinds of errors and actions, the influences that bear upon these errors and actions, and how these may differ from full power operations. Section 4.2 discusses these results in terms of their implications for the selection of frameworks and development of methods for detailed human reliability analyses of LP&S operations.

4.1 Results

The results of this work are: (1) a characterization of the human actions and errors that could have a significant impact on safety during LP&S operations; (2) an evaluation of primary influences on human performance during LP&S operations; and (3) a review of how these actions, errors, and influences differ from those human actions, errors, and influences important to safety during full-power operations.

There is a consistency in results between the evaluation of data described in Section 2 and the opinions of knowledgeable individuals summarized in Section 3. Lowering RCS water level, maintaining decay heat removal, and maintaining electrical supplies were identified as important to safety in both the event analyses and the interviews. During these operations, configurations can be encountered that make the plant more vulnerable to errors by personnel or failures of equipment. Because human-system interactions during LP&S operations are more direct, with operators more frequently manually operating equipment and changing plant configurations, there is a greater opportunity for these interventions to "go astray," resulting in mistakes leading to errors of commission. Both latent and active errors appear to play a significant role. In most of the detailed event descriptions (i.e., AIT and AEOD report analyses), both latent and active failures were present to cause the situation; this was less clear in the

LER-based information, however. In all three event-based data sources, active human error most likely initiated the event.

As with the kinds of errors and actions, there seems to be a convergence in the findings of important human reliability influences from the evaluation of events and from the interviews. Through all the sources of information, the most frequently identified influence is procedures. The event data indicate that procedures are frequently deficient, either in providing inadequate guidance or in omitting instructions for unexpected contingencies while performing evolutions. The interviews indicate procedures are rated highly as a human reliability influence, particularly in certain plant configurations when other influences come into play. These other situation-specific influences include human engineering, communications, organizational factors, and stress. This combination is again reflected in the interviews and the event data, especially the more detailed analyses of the AIT and AEOD reports. The combination of influences (as many as three or four) is seen as an important finding in this study.

Recovery actions were frequently aided by use of abnormal or other contingency procedures once an event had been initiated and (often) a safety function was lost. In addition, the detailed event analyses and the interviews indicated that training and the detailed technical knowledge of plant operators can be important in assisting in the recovery of lost safety functions and stabilization of the plant.

In summary, the principal findings in terms of influences on human performance are that:

- most events of any significance to safety involve multiple influences;
- the most frequently cited human reliability influences are procedures and human engineering;
- the more detailed descriptions of events indicate that these deficiencies are symptomatic of poor planning and preparation, as indicated by frequently concurrent deficiencies in training, communications, and organizational factors;
- the combinations of influences giving rise to performance problems appear to be very sensitive to the context of the plant conditions; and
- recovery is frequently aided by situation appropriate procedures, specific training, and/or the technical knowledge of the operations personnel.

Through the data evaluations discussed in Section 2 and the opinions of knowledgeable individuals given in Section 3, a number of significant differences between the human actions, errors, and influences important to LP&S operations and that of full-power operations have been identified. Aspects of the following identified features are unique and important to LP&S operations: the kinds of human interactions and events; the classes, modes, and types of human errors (and actions); influences on human performance; and plant conditions and configurations.

Unlike full-power operations, LP&S operations are performed under continuously changing plant conditions and configurations. Frequent changes in the plant situation result in changes in the potential consequences of events and the availability of redundant (and, in some cases, front-line) equipment in event responses. In addition, the changing plant environment during LP&S increases the importance of communications in order to safely perform outage activities and to appropriately respond to LP&S events. Also, as mentioned previously, equipment is more frequently manually operated during LP&S operations, and responses to LP&S events are also typically achieved through manual human actions rather than automatic equipment response.

For LP&S events, human-induced initiators, both inside and outside the control room, comprise a significant portion of observed errors. In full-power PRAs, however, it is typically assumed that human-initiated events at full power are relatively uncommon and can be captured in data collected at the component, system, or plant level. The data evaluations given in Section 2 indicated that mistakes (vs. slips) and errors of commission (vs. omission) predominate the types and modes of human errors which occur during LP&S. In addition, mistakes and errors of commission occur both inside and outside the control room during LP&S. In contrast, the human errors modeled in full-power PRAs are typically errors of omission or mistakes are occurring inside the control room.

Procedures, human engineering, training, organizational factors, and communications were identified as significant influences on human performance during LP&S. Procedures are typically important in modeling human errors in full-power PRAs. However, human engineering (especially in the control room), organizational factors, and communications, as well as the less important influences identified in Table 4, are not typically identified as important influences on human performance at full power. In addition, the event-based data evaluations strongly indicated that contributions from multiple influences are common for human actions and errors during LP&S. Also, the available time for event response, frequently an important factor in human performance at full power, does not appear to be a concern in LP&S (except in the case of events initiated shortly after shutdown when decay heat is high).

Based on the evaluation of primary human reliability influences and the discussion of the differences between full-power and LP&S operations previously, the following influences are proposed for consideration during LP&S detailed HRA quantification, namely: procedures, training, communication, organizational factors, human engineering, and supervision. Note that depending on the particular LP&S human action, two or more of the above influences may have to be used in various combinations.

4.2 Conclusions

The conclusions of this work are that human actions and errors are important contributors to risk during PWR LP&S operations. The principal important errors under such conditions are associated with manual control actions (e.g., reducing level) and control of equipment configuration for maintenance and test that lead to loss of defense-in-depth. The quality of procedures and information systems (e.g., temporary instrumentation, number of alarms indicating, etc.), and control and coordination of plant status (e.g., inadvertently working on two trains) influence human performance and play an important role in the frequencies of errors in LP&S operations. Recovery actions seem to be available for most kinds of problems, though failures during the early stages of an outage when decay heat levels are still significant present greater challenges because of reduced timescales to core uncovery. These kinds of problems are different from those during full-power operations in that a much greater emphasis is placed on manual control actions. Also, personnel not normally at the plant (e.g., headquarters engineering and contractors) and not intimately familiar with the day-to-day work practices and normal operating procedures may be performing tasks important to safety. In addition, real or perceived problems can exist in terms of the operators' ability to observe the state of the plant and the configuration of its equipment. These differences from full-power operations help create a situation where errors are more likely and their consequences less observable. A significant mitigating factor is that, after the first few days of an outage, the time required for fuel uncovery to occur following loss of cooling, for example, is sufficiently extended such that delays in recovering from errors can be tolerated with less impact on risk.

It should be recognized that the methods used by plants to plan for, and control, outages have changed and will continue to change. For example, plants are now completing their responses to NRC's generic letter issued in 1988 following the Diablo Canyon event. In addition, the NUMARC guidelines, issued in 1991, are intended to improve the planning and management of outages, particularly in preparing defenses for inadvertent accidents. Therefore, it is recognized that some of the issues described in this report may become less significant. However, as the Prairie Island event in 1992 shows, plants continue to demonstrate vulnerabilities in LP&S operations.

These conclusions set the stage for the development of human reliability methods in the next phase of the project. The following are considered the most important factors that will determine the selection of a framework and development of a method for quantifying human reliability parameters:

- errors important to safety, particularly those that initiate events, are very context-specific and therefore the framework will need to account for the context in which actions are taken - this context may require more information about dynamic plant conditions than a typical PRA cutset scenario provides;

- the kinds of errors, particularly mistake-driven acts of commission, that have been found to be very important in LP&S events are not considered in any of the commonly used human reliability methods - those methods evaluating acts of commission (e.g., THERP) do so only for slip-driven acts, not for mistake-driven ones;

- the synergistic effects of multiple influences, e.g., procedures, training, human engineering, etc., are not practically considered in any commonly used human reliability methods, nor are the implications of inadequate planning and control of an outage;

- the presence of a much larger and less experienced body of staff at the plant, as well as the influence of extended work periods, can play significant roles in increasing the workload of operators. These sources of stress are not considered in any commonly used human reliability methods; and

- commonly used techniques used to model recovery actions do not take into account the possible complexities of restoring mechanically failed or disassembled equipment.

5.0 REFERENCES

AEOD Human Factors Team Report - Catawba, Unit 1 - March 20, 1990, "On-Site Analysis of the Human Factors of an Event," U.S. Nuclear Regulatory Commission, May 1990.

AEOD Human Factors Team Report - Braidwood, Unit 1 - October 4, 1990, "On-Site Investigation and Analysis of the Human Factors of an Event," U.S. Nuclear Regulatory Commission, October 1990.

AEOD Human Performance Study Report - Oconee, Unit 3 - March 8, 1991, "On-Site Analysis of the Human Factors of an Event (Loss of Shutdown Cooling)," U.S. Nuclear Regulatory Commission, May 1991.

AEOD Human Performance Study Report - Crystal River, Unit 3 - December 8, 1991 "On-Site Analysis of the Human Factors of an Event (Pressurizer Spray Valve Failure)," U.S. Nuclear Regulatory Commission, January 1992.

AEOD Human Performance Study Report - Prairie Island, Unit 2 - February 20, 1992, "On-Site Analysis of the Human Factors of an Event (Loss of Shutdown Cooling)," U.S. Nuclear Regulatory Commission, March 1992.

AEOD Special Evaluation Report, "Review of Operating Events Occurring During Hot and Cold Shutdown and Refueling," U.S. Nuclear Regulatory Commission, December 4, 1990.

Generic Letter No. 88-17, "Loss of Decay Heat Removal," U.S. Nuclear Regulatory Commission, October 1988.

Generic Letter No. 88-20, "Individual Plant Examination," U.S. Nuclear Regulatory Commission, November 1988.

Inspection Report No. 50-306/92-005, Prairie Island, Unit 2, "Loss of RHR (February 20, 1992)," Augmented Inspection Team Report, U.S. Nuclear Regulatory Commission, March 17, 1992.

Inspection Report No. 50-275/91-009, Diablo Canyon, Unit 1, "Loss of Off-Site Power (March 7, 1991)," Augmented Inspection Team Report, U.S. Nuclear Regulatory Commission, April 17, 1991.

Inspection Report No. 50-287/91-008, "Oconee Unit 3, Loss of RHR (March 9, 1991)," Augmented Inspection Team Report, U.S. Nuclear Regulatory Commission, April 10, 1991.

Inspection Report No. 50-456/89-006, Braidwood, Unit 1, "Loss of RCS Inventory via RHR Relief Valve (December 1, 1989)," Augmented Inspection Team Report, U.S. Nuclear Regulatory Commission, December 29, 1989.

NSAC-52, "Residual Heat Removal Experience and Safety Analysis, PWRs," Electric Power Research Institute, January 1983.

NSAC-84, "Zion Nuclear Power Plant Residual Heat Removal PRA," Electric Power Research Institute, January 1985.

NSAC-156, "Residual Heat Removal Experience Review and Safety Analysis, PWRs, 1982-1989," Electric Power Research Institute, August 1991.

NUMARC 91-06, "Guidelines for Industry Actions to Assess Shutdown Management," NUMARC, December 1991.

NUREG-1269, "Loss of Residual Heat Removal System," (Diablo Canyon, Unit 2, April 10, 1987), U.S. Nuclear Regulatory Commission, June 1987.

NUREG-1410, "Loss of Vital AC Power and the Residual Heat Removal System During Midloop Operation at Vogtle Unit 1 on March 20, 1990," U.S. Nuclear Regulatory Commission, June 1990.

NUREG-1449, "Shutdown and Low-Power Operation at Commercial Nuclear Power Plants in the United States," Draft Report for Comment, U.S. Nuclear Regulatory Commission, February 1992.

NUREG/CR-3905, "Sequence Coding and Search System for Licensee Event Reports," U.S. Nuclear Regulatory Commission, April 1985.

NUREG/CR-4639, "Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR), User's Guide Volume 4," U.S. Nuclear Regulatory Commission, October 1990.

NUREG/CR-5655, "Human Performance Investigation Process (HPIP)," to be published.

Reason, James, Human Error, Cambridge University Press, 1990.

Senders, John W., and Moray, Neville P., Human Error: Case, Prediction, and Reduction, Lawrence Erlbaum Associates, 1991.

ATTACHMENT 1
Human Action Classification Scheme (HACS) Database Fields for PWR Low Power and Shutdown Plant Operational States

Field 1 - Event or Document Identification
e.g., LER-dkt/yr-nnn, AIT-dkt/yr-nnn, NUREG-nnnn, or other as appropriate

Field 2 - Event Description Summary
high level description of event; adapted from classes of events identified in NUREG-1449, categories used in SCSS

Field 3 - Event Date
mm/dd/yy

Field 3a - Event Time
time of action in 24-hour format (hhmm)

Field 4 - Plant Type/Vendor
xWR/vendor

Field 5 - Unit Status
based on BWR or PWR Plant Operational States (POSs) with additional more general categories

Field 6 - Noteworthy Plant Conditions
text description with emphasis on unusual equipment and/or plant configurations (not human actions)

Field 7 - Other Unit(s) Status
status of other unit(s) at same site, or "N/A" to represent "no other unit"

Field 8 - Human Action Number & Description
1,2,3... for events with multiple human actions with brief (3-5 word) description of action

Field 9 - Responsible Personnel Type
based on personnel types used in NUCLARR Level 1 and 2 with additional types appropriate to low-power/shutdown operation

Field 10 - Event Activity (Ongoing)
coded as in SCSS "Personnel System Codes" with additional types appropriate to low-power/shutdown operation

Field 11 - Human Action Location
control room or outside control room

Field 12 - System Identification
based on IEEE Std 805 - 1984, Recommended Practice for System Identification in Nuclear Power Plants and Related Facilities, Table 1 (used also in "full text" LERs)

Field 13 - Component Identification
based on NUCLARR Level 2 (NUREG/CR-4639, v.4, pp. A61-A68); see Coding Conventions

Field 14 - Displays/Instruments/Controls Identification
based on NUCLARR Level 3 (NUREG/CR-4639, v.4, pp. A69-A75); see Coding Conventions

Field 15 - Human Action Descriptor (Ongoing)
based on NUCLARR Level 1,2,3 (NUREG/CR-4639, v.4, pp. A77-79)

Field 16 - Error Mode
omission or commission as coded in SCSS

Field 17 - Error Type
slip, mistake, or circumvention (as conventionally defined)

Field 18 - Active/Latent Effect
active, latent (prior/after startup)

Field 19 - Error Influences
coded according to the HPIP classification with additions

Field 20 - Recovery Time
time from failure to recovery in minutes

Field 21 - Recovery Locus
control room or outside control room

Field 22 - Recovery Origin
basis for decision/action: skill, rule, knowledge

Field 23 - Related Automatic Equipment Response
text description

Field 24 - Fission Products Barrier Breached/Threatened
fuel clad, RCS pressure boundary, containment, effluent treatment

Field 25 - Other Effects
text description

Field 26 - Level of Significance
major, minor, detectable, questionable

Field 27 - Unique to Low Power or Shutdown
Yes/No, per subject matter expert judgement

Field 28 - Corrective Action Taken
long term remedy