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IN-PLANT RELIABILITY DATA BASE FOR NUCLEAR PLANT COMPONENTS: A FEASIBILITY STUDY ON HUMAN ERROR INFORMATION

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FOREWORD

Initial efforts in the late 1950's to investigate the influences of the human in performance of tasks quickly uncovered the fact that there was little human factors data available. AIR Data Store[1] was one of the earliest sources of human error rates but it, and many of the sources which followed it, contained error estimates involving considerable expert judgment due to the lack of new data. As human reliability studies progressed, this lack was increasingly apparent. One data base, developed by Sandia National Laboratories in the late 1960's, was created with the intent of receiving raw data input on an "as available" basis.[2]

Although the military sector and aerospace industry were the initial motivators in human error research, the mid-1970's saw the application of human reliability analysis techniques to nuclear plant scenarios. Specifically, this was shown in WASH-1400[3] by the use of A. D. Swain's THERP model. Despite the availability of some actual data from military situations, judgment still played a considerable role at this time in the development of human error rates. With the occurrence of the Three Mile Island incident, public interest spurred on desire of the industry for greater accuracy in error quantification; especially those which were human-related. Probabilistic risk assessment became recognized as a potentially effective tool for identifying non-human risk sensitive areas, but the human had to be figured into the system as well: so the data need grew yet larger as the demand for input to human reliability analysis (HRA) increased.

The U.S. Nuclear Regulatory Commission, recognizing that actual human error data were necessary, funded Brookhaven National Laboratory in 1980 to review the Licensee Event Report (LER) data summaries for all U.S. nuclear plants.[4] Data on safety-related pumps and valves for a two to three year period from 1975 to 1978 were collected, reviewed, and utilized to calculate human error rates (HERs) based on the ratio of actual human errors (HEs) to the number of opportunities for HE (separated into categories). Although this provided a useful alternate method of HE calculation using data from actual plants, it was recognized that the LERs addressed only significant failures of reportable components, and for this reason LER data have been known to be both incomplete and inconsistent.

The on-going In-Plant Reliability Data (IPRD) Program[5,6,7] was established in 1977 to gather maintenance and failure data directly from nuclear plant records for constructing a hardware component reliability data base. By 1982, records from four nuclear power stations had already been collected and were readily available. In the summer of 1982, the NRC decided to investigate the potential for extracting human error information from these records. This report describes the pilot study conducted to determine whether and what information on human error could be gathered by reviewing all the maintenance and repair records from the one plant record set (out of four) chosen to be most suitable for an in-depth human error search.

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EXECUTIVE SUMMARY

This report documents the procedure and final results of a feasibility study which examined the usefulness of nuclear plant maintenance work requests in the IPRDS as tools for understanding human error and its influence on component failure and repair. Developed in this study were (1) a set of criteria for judging the quality of a plant maintenance record set for studying human error; (2) a scheme for identifying human errors in the maintenance records; and (3) two taxonomies (engineering-based and psychology-based) for categorizing and coding human error-related events.

The set of criteria was applied to maintenance record sets from four plants in the IPRDS. The chosen plant record set was then searched to identify the human error-related records and these records were classified according to the two taxonomies. The two criteria judged to be most important for documenting human error in maintenance records were a) the records must contain sufficient detail to understand the problem, and b) the records must clearly separate the problem from the corrective action. After applying the criteria to the four plant record sets and selecting one plant record set, over 5800 maintenance records from the one plant were reviewed. Over 450 records or 7.9% were classified as definitely documenting human error-related events. The most prevalent human error in the maintenance records was in attaching components which account for approximately 50% of the human errors according to the engineering-based taxonomic coding. Errors of commission represented 73% of all human errors as determined using the psychology-based taxonomy.

Two conclusions were apparent from this feasibility study: the technical approach was demonstrated to be practical for identifying human errors in the maintenance records and the taxonomies were appropriate for categorization of the identified human errors. To further develop this method of using maintenance records to understand human error, it is recommended that:

(1) the two maintenance task error taxonomies be refined and integrated;
(2) the resultant error taxonomy be applied to maintenance records of additional plants; and
(3) a study be made of the potential use of standardized maintenance syntax for recording all maintenance actions in nuclear plants.

1. INTRODUCTION

The In-Plant Reliability Data System (IPRDS) is being developed to provide failure rates and repair times for use in reliability and risk analysis. The development of such a data base has required the extraction and encoding of maintenance work records on pumps and valves, their drivers, diesel generators, batteries, chargers and inverters to enable analyses of the type, severity, and frequency of their failures. In the course of these analyses, a number of failure/repair occurrences were identified which appeared clearly caused by human error. The percentage of such failures appeared to be in the order of 5 to 10%. This indicated the potential for identifying substantial numbers of human errors as a result of a systematic search for such errors. Therefore, it was proposed that a review of the records of a single plant be undertaken with an eye toward identifying human-related errors. Maintenance errors which occurred during the performance of a maintenance action and led to an equipment malfunction were of primary interest.

The objective of this pilot study was to determine whether human error frequencies could be obtained from inspection of the maintenance and repair records of a nuclear power plant (NPP), and, if so, to what degree. The first step in the technical approach used the selection of an optimum plant record set from the four available in the IPRDS. This selection was made by applying prioritized criteria consensually developed by a human factors specialist and a systems analyst. The record set chosen was considered the one most likely to contain human error information. The 5800 records from the selected set were physically maintained, sorted, and accounted for in an index card file. Previously encoded pump and valve repair information was also included by placing each repair action from computer printouts into the data base on a separate card. Each index card was coded, sorted, and labeled according to the date the request for work was filed. Science Applications, Inc. (SAI) staff reviewed each card as the Applied Science Associates, Inc. (ASA) staff performed a simultaneous independent review of the pump and valve maintenance action printouts. Based upon the criteria of: (1) repetitive failure of the same part, (2) stated or implied indication of human error, and (3) significant delay between failure and repair dates, decisions were made to extract and color code selected cards as being human error (HE) related.

Through a study performed for Sandia National Laboratories, (unpublished) a maintenance task syntax was developed to systematically and uniquely identify tasks using specific verb and noun identifiers. Adaptations of this syntax were developed for the current study to create separate HE taxonomies (engineering and psychology-based taxonomies respectively) for use in encoding the maintenance records. The hierarchical structure of the taxonomies enabled the labeling of each step in the breakdown of the task description with an alphanumeric code. Each HE card was then reviewed to determine the information to be inserted into the code system. The code categories provided space for (1) the assignment of a code from each of the two taxonomies, (2) the notation as to whether the action did, or did not, involve a potential HE, and (3) the inclusion of component-identifying information. The number of HEs identified for each step in each taxonomy was then tabulated and recorded.

2. PURPOSE AND OBJECTIVES

The purpose of this pilot study was to examine the practicality of extracting human error information from IPRDS records. The objectives of this study were to develop methodology for assessing human errors in maintenance records and to use this methodology on records from one nuclear power plant in the IPRDS.

3. SCOPE

The report describes the process of extracting records with human error-related maintenance actions from one IPRDS plant maintenance record set and the categorization of human errors based upon a predeveloped task syntax. Insights into the findings, limitations of the study, and recommendations for future applications are documented in this report on the feasibility study.

4. EXTRACTION OF RECORDS WITH HUMAN ERROR-RELATED MAINTENANCE ACTIONS

A flow diagram depicting the extraction of human error-related maintenance records is shown in Fig. 4.1. The following sections describe the criteria for, and the process of, extraction of records with suspected and potential human error-related maintenance actions.

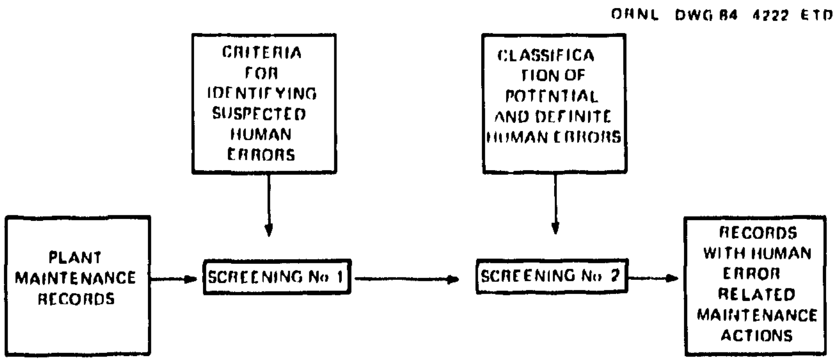

Fig. 4.1. Extraction of human error-related maintenance records.

4.1 Criteria for Extraction of Records with Suspected Human Error-Related Maintenance Actions

During initial screening, maintenance actions were suspected of being human error-related when the records met any one of the following criteria:

1. Direct o· indirect implication of human error in the maintenance record.
2. Repeated failure of a part. If a part was reported to have failed within a year of a previous maintenance action on the part, the maintenance actions were selected for further investigation. Repeated failures could potentially indicate mismaintenance.
3. A long delay (several months) between the initial incident and the repair action, or the issuing of several reports before the repair action. This may have implications in determining unavailability of components due to human error in handling maintenance action documentation.

Those records that met any of the above criteria were extracted from the card file for a second, closer review to determine whether the maintenance actions were indeed human error-related.

4.2 Identification and Classification of Human Error-Related Maintenance Actions

A rubber stamp was used to identify those records extracted from the card file for suspected human error-related maintenance actions. This stamp provided convenient documentation and traceability of the human error-related records selected and classified. The stamp provided the following item identifiers:

1. The system and component type codes were based on the generic systems list and component types list of the In-Plant Reliability Data System (IPRDS).[5,6,7] For example, the control rod drive system was coded as N02 and the control rod drive mechanism was coded as CRDRVE.

2. The component identification (ID) no. was the code used by the utility to identify the component on the maintenance record or other documents.

3. The human error and potential human error code identified suspected and potential human error-related maintenance actions after screening the records as shown in Fig. 4.1. A Yes (Y) or No (N) code was used.

4. The HE cause code was for coding the potential human errors according to the error taxonomy coding schemes.

5. The severity code was a single-character code intended to denote the extent to which the component was unable to perform its function due to human error. The three levels of severity were catastrophic (C), degraded (D), and incipient (I).

In screening the records with suspected human error-related maintenance actions, the specific causes of equipment malfunctions and failures that led to maintenance actions were reviewed. Those malfunctions or failures classified as definitely human error-related were clearly documented in the records and could be categorized in one of four general classes. The definition of each class and an example of how each class might be represented in actual maintenance records is given below.

1. Personnel error — Record clearly identified an individual as the source or cause of the event, such as electrician inadvertently removed mechanical linkage on valve operator, or operator ran jib crane boom into relay panel.

2. Procedural discrepancy — Record clearly indicated that following the recommended procedure was the source or cause of the event, such as pump start procedure requires valve alignment, pump cannot start with this alignment.

3. Design error — Record clearly indicated that wrong equipment was specified and/or installed or wrong limits were specified, such as a motor with incorrect speed was specified and installed.

4. Fabrication error — Record clearly indicated that mistakes were made in the manufacturing or construction of the equipment or parts, such as cracked valve casing due to poor casting, or faulty wiring by manufacturer.

Other failure or repair descriptions that would indicate or imply human error-related maintenance actions included:

1. Operational errors such as parts knocked off, elements burned up, water line frozen, or devices inadvertently turned off.

2. Maintenance errors such as overtightening, misalignment, or improper adjustment.

3. Parts missing, lack of lubrication or cleaning.

4. Wrong parts or equipment used in repair, incorrect wiring or improper clearance.

5. CATEGORIZATION OF HUMAN ERRORS IN MAINTENANCE ACTIONS

The preliminary human error taxonomies in this study were developed to be compatible with a devised maintenance task syntax. Descriptions of preliminary applications of these initial taxonomies to the categorization of human error in plant maintenance records are presented in this section.

5.1 Maintenance Task Syntax

The approach used in the development of a taxonomy was based on a previously developed, unpublished task syntax. The maintenance task syntax was developed by using a matrix consisting of rows of behavioral coordinates and columns of situational coordinates as illustrated in Fig. 5.1 for nuclear power plant (NPP) maintenance tasks. The rows (behavioral coordinates) consist of verbs such as read, interpret, etc., and the columns (situational coordinates) consist of nouns such as meter, switch, etc. A combination of verbs and nouns is the intersection of row and column. For example, "read-meter" indicates a task involving human-equipment interaction. However, not all the possible combinations are allowed. Only those combinations that are semantically valid and applicable to NPP maintenance tasks were retained. The surviving combinations were indicated by a dot placed in the matrix, as shown in Fig. 5.1. These syntactical combinations were used to create a maintenance task syntax. The complete maintenance task syntax is included in Appendix C.

5.2 Development of Human Error Taxonomy

As mentioned previously, separate human error taxonomies were developed from the task syntax. These taxonomies are intended, ultimately, to be combined into one comprehensive taxonomy. The following sections describe the preliminary development of these human error taxonomies.

5.2.1 Psychology-based human error taxonomy

This taxonomy was based on a human error taxonomy for maintenance actions previously developed for the U.S. Army Research Institute. The Army taxonomy was adapted to be compatible with the conceptualization of behavior categories developed by J. Rasmussen.[8] The taxonomy was further adapted and expanded to be compatible with the task syntax system in this report.

The psychology-based error taxonomy is a hierarchical structure, and is conceptually similar to those used for biological classifications (i.e., genus-species type). As shown in Table 5.1, at the top of the structure is the distinction of error type (commission versus omission). A commission error is performing a covert, or overt, action(s)

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1.0 Nominal Operations

1.2 Maintenance Tasks

Behavioral Coordinates 1.2.1 \ Situational Coordinates 1.2.2		Plant Equipment 1.2.2.1: Display 1.2.2.1.1						Control 1.2.2.1.2					Tools 1.2.2.1.3	Components 1.2.2.1.4	Communications Media 1.2.2.2: Written 1.2.2.2.1		Non written 1.2.2.2.2	
		Meter 122111	Digital 122112	Chart 122113	CRT 122114	Indicator 122115	Annunciator 122116	Switch 122121	Valve 122122	Keyboard 122123	Pushbutton 122124	Connector 122125	12213	12214	Procedure 122211	Policy 122212	Skill 122221	Oral 122222
Calibration, Measurement and Test 1.2.1.1	Read 1.2.1.1.1	●	●	●	●	●	●								●	●		
	Interpret 1.2.1.1.2	●	●	●	●	●	●								●	●		
	Confirm 1.2.1.1.3													●	●		●	●
	Locate 1.2.1.1.4	●	●	●	●	●	●	●	●	●	●	●		●				
	Manipulate 1.2.1.1.5							●	●	●								
	Set 1.2.1.1.6							●		●	●							
	Attach 1.2.1.1.7											●						
	Remove 1.2.1.1.8	●	●	●	●	●	●	●	●	●	●	●		●				
	Record 1.2.1.1.9	●	●	●	●												●	●
Scheduled Maintenance 1.2.1.2	Read 1.2.1.2.1														●	●		
	Interpret 1.2.1.2.2														●	●		
	Confirm 1.2.1.2.3													●	●		●	●
	Locate 1.2.1.2.4							●	●	●	●	●	●	●				
	Manipulate 1.2.1.2.5							●	●	●			●	●				
	Set 1.2.1.2.6							●		●	●			●				
	Attach 1.2.1.2.7											●		●				
	Remove 1.2.1.2.8	●	●	●	●	●	●	●	●	●	●	●		●				
Corrective Maintenance 1.2.1.3	Read 1.2.1.3.1														●	●		
	Interpret 1.2.1.3.2														●	●		
	Confirm 1.2.1.3.3													●	●		●	●
	Locate 1.2.1.3.4							●	●	●	●	●	●	●				
	Manipulate 1.2.1.3.5							●	●	●			●	●				
	Set 1.2.1.3.6							●		●	●			●				
	Attach 1.2.1.3.7											●		●				
	Remove 1.2.1.3.8	●	●	●	●	●	●	●	●	●	●	●		●				
Inspection 1.2.1.4	Read 1.2.1.4.1	●	●	●	●	●	●								●	●		
	Interpret 1.2.1.4.2	●	●	●	●	●	●								●	●		
	Confirm 1.2.1.4.3													●	●		●	●
	Locate 1.2.1.4.4	●	●	●	●	●	●	●	●					●				
	Record 1.2.1.4.5	●	●	●	●												●	●

Fig. 5.1. Maintenance tasks syntax matrix.

Table 5.1. Psychology-based human error taxonomy

Error type	Error base	Behavioral coordinate	Situational coordinate
Commission	Knowledge	Misreads	Meters Dials Instructions Charts
		Misunderstands	Verbal Written Instructions Reports Orders
		Misjudges	System state Actions Force Time Level
		Misuses	Instructions Tools Measuring instruments
		Incorrect memory	Meters Dials Instrument ratings System states Chart lines Procedures Techniques
	Rule	Incorrect procedure	Written Learned Verbal
		Incorrect order	Task steps
		Incorrect comparison	Meters/dials to specs Meters/dials in memory
		Incorrect specification	Adjustments Force Alignment Lubrication
	Skill	Misuse tool	Repair instrument Adjustment instrument
		Force	Bolts Nuts Screws Switches Lamps

Table 5.1 (continued)

Error type	Error base	Behavioral coordinate	Situational coordinate
		Timing	Sequence of movements Task actions
		Sequences	Series of movements Task actions
		Inappropriate technique	Task actions Lubrication Installation Alignment Etc.
		Incorrect orientation	Parts
	Slips —	Mismatch between intent and action	
Omission	Knowledge	Failure to remember	Instructions Motors/dials System knowledge
		Failure to gather information	Motors Dials Instruments and charts
		Failure to use information	Motors Dials Instruments Charts Instructions
		Failure to decide	Procedure System State
	Rule	Failure to follow procedure	Calibration Alignment Replacement Lubrication Assembly Disassembly
		Omit step in procedures	Calibration Alignment Replacement Lubrication Assembly Disassembly

Table 5.1 (continued)

Error type	Error base	Behavioral coordinate	Situational coordinate
		Omit check-out	Task steps Final operation availability
	Skill	Failure to use technique	Task actions Lubrication Installation Alignment Etc.
		Failure to use good mechanical practices	Task actions Lubrication Installation Alignment Etc.
		Not use appropriate tool	Test equipment Wrench Special tools

incorrectly, including errors of sequence. An error of omission is the failure to perform a required covert, or overt, action(s).

The next level specifies the error base. These categories (skill-based, rule-based, and knowledge-based) are borrowed from Rasmussen's categories of control room behavior. For maintenance behavior, these categories of behavior and corresponding errors are defined as:

1. Skill-based. Skill-based behavior is behavior that occurs automatically and without constant "cognitive monitoring." A skill-based error is an error that occurs during the execution of skill-based behavior.

2. Rule-based. Rule-based behavior is behavior that is guided by specifically stated, inflexible procedures and training. A rule-based error, therefore, is related to the misuse of such guidelines.

3. Knowledge-based. Knowledge-based behavior is behavior that depends on the performer's knowledge of the operating system. A knowledge-based error is an error that occurs when the performer has insufficient knowledge, or an insufficient understanding, of the system.

4. Slips. For commission errors, the additional categories of slips[4] is included. A slip is an error that occurs when a maintenance person performs an action that is not intended. An action "slip" error defies classification as skill-, rule-, or knowledge-based and, hence, is included as a separate case.

The last two levels in the structure are more detailed specifications of errors. The third level (behavioral coordinate) is basically a listing of possible covert and overt error processes. The fourth level (situational coordinate) contains objects or modifiers of the error (e.g., misreads dial, incorrect specification for alignment, fails to remember instructions). This four-level error taxonomy provides a framework for classifying maintenance errors.

By examining the third and fourth levels, errors can be placed in the taxonomy. Reference to the first and second levels allows classification of error type and error base. For example, in the psychology-based coding scheme, the coding for commission type, knowledge-based error "Misreads Meters" consist of:

Error of commission	A
Knowledge-based behavior	1
Misreads	a
Meters	1

The complete coding for this error classification is "Ala1," as illustrated in the list included as Appendix D. These latter classifications are useful for suggesting remedial measures.

5.2.2 Engineering-based human error taxonomy

The task syntax (App. C) is utilized in a hierarchical classification structure for human error-related maintenance actions. The classifications consist of plant state, task type, task behavioral coordinates, and task situational coordinates (Fig. 5.1). Such an engineering-based human error taxonomy is listed in Table 5.2.

Once the error taxonomy was established, the next step was to develop a coding scheme for numerically representing the various human errors identified from maintenance records. The coding for the engineering-based taxonomy was develop similarly to that of the psychology-based coding scheme and documented in Appendix E.

Table 5.2. Engineering-based human error taxonomy

Behavioral coordinates		Situational coordinates	
A. Calibration, Measurement, and Test	1. Read	Display	Meter Digital Chart CRT Indicator Annunciator
		Written Material	Procedure Policy
	2. Interpret	Display	Meter Digital Chart CRT Indicator Annunciator
		Written Material	Procedure Policy
	3. Confirm	Component State	
		Non-written Material	Skill Oral
	4. Locate	Display	Meter Digital Chart CRT Indicator Annunciator
		Control	Switch Valve Keyboard Pushbutton Connector
	5. Manipulate	Control	Switch Valve Keyboard
	6. Set	Control	Switch Keyboard Pushbutton
	7. Attach	Control	Connector
	8. Remove	Display	Switch Digital Chart CRT Indicator Annunciator

Table 5.2 (continued)

Behavioral coordinates				Situational coordinates	
				Control	Switch Valve Keyboard Pushbutton Connector
		9.	Record	Display	Meter Digital Chart CRT
B.	Corrective Maintenance	1.	Read	Written Material	Procedure Policy
		2.	Interpret	Written Material	Procedure Policy
		3.	Confirm	Component State	
				Written Material	Procedure
				Non-written Material	Skill Oral
		4.	Locate	Control	Switch Valve Keyboard Pushbutton Connector
				Tools	
				Components	
		5.	Manipulate	Control	Switch Keyboard
				Tools	
				Components	
		6.	Set	Control	Switch Keyboard Pushbutton
				Components	
		7.	Attach	Control Components	Connector
		8.	Remove	Display	Meter Digital Chart CRT Indicator Annunciator

Table 5.2 (continued)

Behavioral coordinates	Situational coordinates	
	Control	Switch Valve Keyboard Pushbutton Connector
	Components	

6. RESULTS

Upon initial inspection of the over 5800 maintenance records from the selected IPRDS plant, approximately 1000 records were separated as suspected human error-related. After further extensive review, 457 were judged to be definitely human error-related based upon the criteria explained in section 4.2.

A tally of the human error-related maintenance records has shown the distribution of records by year to be:

1975 — 16
1976 — 15
1977 — 102
1978 — 102
1979 — 87
1980 — 97
1981 — 38

A more detailed distribution of the records by month is given in Table 6.1 for 1977-1980. The percentage of records per month are shown as well as monthly and yearly totals and percentages. The percentages are calculated as HE records in the time period divided by total number of records in the same period.

Each of the 457 HE records were classified using the two developed taxonomies. Tables 6.2 and 6.3 present the results of this classification for the engineering and psychology-based taxonomies, respectively. Given in these tables are the number and percentage of the HE records associated with each taxonomic category.

Within the engineering-based taxonomy, the number of human errors in calibration, test, and measurement tasks versus that in corrective maintenance tasks was 28 vs. 429, or ~6% vs 94%. The majority of human errors in calibration, test, and measurement tasks, 15 of 28, were classified as "Error in Confirming Component State." The most common human error in corrective maintenance tasks was "Error in Attaching Components" — 230, followed by "Error in Setting Components" — 72, and "Error in Confirming Component State" — 37.

In the psychology-based taxonomy, commission type human errors outnumbered omission type human errors by 332 to 125, or ~73 to 27%. The most frequent commission type error was "Misapplies Technique-Others" — 144, followed by "Misjudges System State" — 57, and "Misapplies Technique Installation" — 55. The majority of omission type errors, 86 of 125, appeared under "Failure to Use Good Mechanical Practices-Others."

Table 6.1 Total human errors identified

Month	1977		1978		1979		1980		1977-1980	
	A	B	A	B	A	B	A	B	A	B
1	1	4%	13	10%	24	13%	10	10%	48	16%
2	0	0%	4	7%	6	6%	5	7%	15	6%
3	2	9%	7	8%	2	2%	14	17%	25	8%
4	2	4%	8	10%	5	10%	16	19%	31	10%
5	2	20%	3	3%	10	10%	9	9%	24	8%
6	19	19%	8	8%	4	4%	10	10%	41	10%
7	2	10%	6	9%	6	8%	6	8%	20	8%
8	3	12%	1	1%	3	4%	4	8%	11	5%
9	21	17%	12	12%	8	10%	3	4%	44	11%
10	23	14%	8	8%	7	8%	6	7%	44	14%
11	14	10%	16	13%	6	7%	9	10%	45	10%
12	13	13%	16	11%	6	10%	5	7%	40	11%
TOTAL	102	13%	102	8.5%	87	4.4%	97	9.7%	388[a]	7.9%

A = Total HE found in the maintenance records for the time period.

B = Percentage of maintenance actions identified as HE within the time period.

[a]Total does not include results from incomplete years of data, i.e. 1976 and 1981.

Table 6.2. Distribution of human errors according to psychology-based taxonomy

			No. of errors		Percent
A.	**Error of Commission**				
	A1a	Misreads	6		1.5
	A1a1	Misreads Meters		5	
	A1a3	Misreads Instructions/Procedures		1	
	A1c	Misjudges	58		12.5
	A1c1	Misjudges System State		57	
	A1c5	Misjudges Level		1	
	A1d	Misuses	1		<1.0
	A1d1	Misuses Instructions		1	
	A2b	Misapplies	4		1.0
	A2b1	Misapplies Task Steps		1	
	A2b3	Misapplies Specification		3	
	A3b	Misuses Force	4		1.0
	A3b1	Misuses Force - Bolts		1	
	A3b3	Misuses Force - Screws		2	
	A3b4	Misuses Force - Switches		1	
	A3e	Misapplies Technique	259		54.5
	A3e1	Misapplies Technique - Task Actions		20	
	A3e3	Misapplies Technique - Installation		55	
	A3e4	Misapplies Technique - Alignment		40	
	A3e5	Misapplies Technique - Others		144	
	Subtotal			332	73.0
B.	**Error of Omission**		No. of errors		
	B1d	Failure to Decide	1		<1.0
	B1d3	Failure to Decide - Procedure		1	
	B2a	Failure to Follow Procedure	10		2.0
	B2a1	Failure to Follow Procedure - Calibration		1	
	B2a3	Failure to Follow Procedure - Replacement		3	
	B2a4	Failure to Follow Procedure - Lubrication		6	
	B2b	Omit Steps in Procedure	2		<1.0
	B2b1	Omit Steps in Procedures - Calibration		1	
	B2b5	Omit Steps in Procedures - Assembly		1	
	B3a	Failure to Use Technique	4		1.0
	B3a1	Failure to Use Technique - Task Actions		3	
	B3a5	Failure to Use Technique - Others		1	
	B3b	Failure to Use Good Mech. Practices	108		23.5
	B3b1	Failure to Use Good Mech. Practices - Task Action		4	
	B3b2	Failure to Use Good Mech. Practices - Lubrication		1	
	B3b3	Failure to Use Good Mech. Practices - Installation		9	
	B3b4	Failure to Use Good Mech. Practices - Alignment		8	
	B3b5	Failure to Use Good Mech. Practices - Others		86	
		Subtotal		125	27.0
		Total		457	100.0

Table 6.3. Distribution of human errors according to engineering-based taxonomy

Taxonomy Coding		No. of errors		Percent
A. Calibration, Measurement and Test Tasks		No. of errors		Percent
A1a	Error in reading a Meter	4		1.0
A1a1	Error in Reading a Meter		2	
A1a4	Error in Reading a CRT Display		1	
A1a5	Error in Reading an Indicator		1	
A2a	Error in Interpreting	4		1.0
A2a1	Error in Interpreting a Meter Reading		3	
A2a5	Error in Interpreting an Indicator		1	
A3d	Error in Confirming	19		4.0
A3d1	Error in Confirming Component State		15	
A3e1	Error in Confirming a Procedure		4	
A7b	Error in Attaching	1		<1.0
A7b5	Error in Attaching a Connector		1	
	Subtotal		28	6.0
B. Corrective Maintenance Tasks		No. of errors		
B3d	Error in Confirming	43		9.5
B3d1	Error in Confirming Component State		37	
B3e1	Error in Confirming a Procedure		6	
B5b	Error in Manipulating	4C		8.5
B5b2	Error in Manipulating a Valve		3	
B5c1	Error in Manipulating Tools		5	
B5d1	Error in Manipulating Components		32	
B6b	Error in Setting	97		21.0
B6b1	Error in Setting a Switch		25	
B6d1	Error in Setting Components		72	
B7b	Error in Attaching	246		54.0
B7b5	Error in Attaching a Connector		16	
B7d1	Error in Attaching Components		230	
B8a	Error in Removing	3		<1.0
B8a1	Error in Removing a Meter		1	
B8d1	Error in Removing Components		2	
	Subtotal		429	94.0
	Total		457	100.0

7. OBSERVATIONS

The technical approach and results described in the study represent the first attempt at extracting human error information directly from plant maintenance records. The following summarizes the insights gained into the capability and limitations of this technical approach.

7.1 Organization of Plant Maintenance Records

The organization of plant maintenance records into one card file involved time-consuming manual handling. It would be desirable to encode human error information and enter the coded information from maintenance records into the existing IPRDS computer data base. This would facilitate the sorting and correlation of human error information from the maintenance records.

7.2 Identification and Categorization of Human Errors from Maintenance Records

Two interesting highlights can be gleaned from examination of the application of psychology-based taxonomy to these maintenance data. The first is that almost three-quarters of the human errors are Errors of Commission. The second highlight to be noted is that three-quarters of Errors of Commission are skill-related errors, and that almost 90% of the Errors of Omission are skill-related. In fact, over 82% of all errors found in these data are skilled-related errors. These findings may imply that these maintenance personnel are adequately trained in plant-specific procedures and components; but inadequately trained in terms of basic tool-use and job skills. This information should be of importance to persons responsible for personnel training, selection, and qualification.

8. CONCLUSIONS

The following conclusions may be made regarding the effectiveness and significance of this feasibility study.

8.1 Human Errors Covered by Maintenance Records

The technical approach used in this study was demonstrated to be practical in extracting information from maintenance records for many categories of human errors. However, classes of human errors, including functional failures that did not result in maintenance requests, were not reflected in the maintenance records. For example, personnel beginning a shift might find incorrect valve alignment and make the necessary correction. In this case, a human error has been committed, but no maintenance action would be recorded. The human error events associated with contractor personnel also would not be included in this particular set of plant maintenance records unless they resulted in an event which required the generation of a subsequent maintenance record.

We can confidently say that there were at least 457 human maintenance errors committed for 5803 recorded corrective maintenance actions. Each recorded maintenance action is the opportunity for an error, and thus provides the denominator for error rate estimates. The number of human error-related maintenance actions divided by the total number of maintenance records for all components was 457/5803 or 7.9%. By comparison, the number of pump and valve events due to human errors, extracted from pump- and valve-related Licensee Event Reports (LERs) was 384/3054 or 12.6%, according to a Brookhaven National Laboratory study.[9]

8.2 Usefulness of Taxonomies

Both taxonomies are clearly in preliminary form, as evidenced by the large number of undifferentiated errors in the "Components" category in engineering-based taxonomy and the "General" category in psychology-based taxonomy. Resource limitations in this study precluded the subsequent steps of tailoring the taxonomies to the requirements of these data. These subsequent steps are necessary, however. A basic principle of data base management is that maximum usability for data base taxonomies is gained when the taxonomies completely specify each element of the data domain. When this is true, users can combine categories as needed. On the contrary, when large numbers of data elements are "pregrouped," the potential user has less flexibility in sorting and recombining categories to suit his needs. The taxonomies are complementary, not competitive, and although they provide alternate data structures for different potential user groups, we believe that the two are wholly compatible and should be combined.

The error taxonomies developed were useful in discriminating the number and types of human errors and may represent a valuable tool in estimating the rate of their occurrence. The estimated rate would be the number of a specific type of human errors identified divided by the number of opportunities for such errors to be determined from other sources of information. However, the scope of the study did not allow for a useful estimation of human error probabilities (HEPs) or human error rates (HERs) so that only a first order, general estimation of overall HERs was obtained. An alternate approach for obtaining the denominator (i.e., number of opportunities for errors) would be to use the estimating technique developed by Brookhaven National Laboratory.[10] Application of the Brookhaven approach should allow the estimation of HERs from the frequency distribution of human errors and the number of opportunities for such human errors associated with the operation and testing of nuclear power plants.

9. RECOMMENDATIONS FOR FUTURE WORK

Based upon the findings of this pilot study, it is recommended that the following future work be pursued.

1. The two maintenance task error taxonomies should be revised and combined. This should commence after a thorough review of the work descriptions used in actual maintenance records and the relevant results from a task analysis project conducted by the Institute for Nuclear Power Operations (INPO).[11] It is expected that additional action verbs in engineering-based taxonomy are needed to cover every step or element of most, if not all, maintenance tasks.

A well defined error taxonomy would provide a systematic categorization of human errors in nuclear power plant (NPP) maintenance tasks and allow for the unambiguous assignment of nominal HEPs or HERs to specific task errors. The taxonomy may be utilized to develop a data base structure for correlation with the maintenance task human error data from Chap. 20 of NUREG/CR-1278.[12] This development should improve the search for specific maintenance task HEP data contained in Chap. 20, and the identification of those maintenance tasks for which HEP data have yet to be developed.

The error taxonomy would also be useful to the performance of job analyses and task analyses, and the evaluation of knowledge-skill-ability (KSA) requirements for training of maintenance personnel.

2. The revised error taxonomy should be applied to the maintenance records of additional plants for extraction and classification of human error information from these records. The combined study results from additional plants could provide credible, useful data on human errors reflected in the maintenance records of nuclear power plants.

3. A study should be made on the potential use of standard maintenance task syntax for recording all maintenance actions in nuclear plants. The development and adoption of a task syntax standard would enhance implemention of a comprehensive and realistic human error data base.[13] A possible effort would be the initiation of a joint pilot program with an operating nuclear facility to introduce the syntax to plant maintenance personnel and to test its reception by them. The program should be implemented over a period of 1 to 1-1/2 years in order to assess the effectiveness of such a syntax standard.

Appendix A

SELECTION OF A PLANT RECORD SET

The following sections describe the analysis of the IPRDS plant maintenance record sets, application of criteria to these sets, and the numerical ranking of each set. Interim steps are documented for traceability of the prioritization process and selection of one IPRDS plant record set for further study. A diagram of the overall technical approach is provided in Fig. A.1.

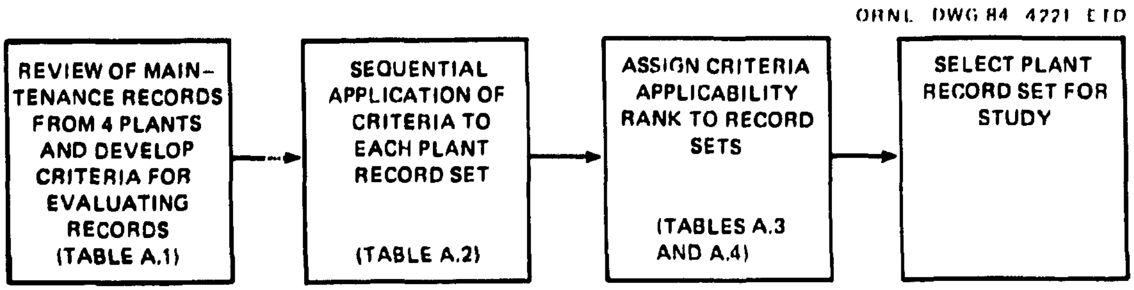

Fig. A.1. Overall technical approach for selection of plant record set.

Sequential Review of Plant Records

In order to apply a prioritized list of criteria, it was necessary first to review the plant record sets and become familiar with the different formats used in each plant to record data. The review procedure involved the investigation of the collected records to determine which of the material was relevant to this study. Maintenance and repair history records were of primary importance. Each plant maintenance record set was analyzed to determine the method of data presentation used, and which of the data categories of each plant recording format applied to the information requested in the selection criteria. For example, each data set may have utilized different terminology to express a similar concept, such as "Failure Description" and "Nature of Maintenance." Also, some plants have developed particular abbreviations for terminology or numerical system and equipment codes for their own use which needed clarification prior to analysis. Further investigation of information from the collected record sets yielded definitions for these specific terms and keys to the numerical codes. Plant equipment was often identified by specific component numbers, the equipment identification (I.D.). These I.D. lists were of value in their ability to link components to systems and clarify the internal structure of interrelationships within the plant. A sequential review was performed, beginning with Plant No. 1 and ending with Plant No. 4, and notes and sketches were made of the format details of each plant record set. This assisted in the analysis stage by preventing repeated investigation of the meaning of plant-specific terms.

Once the familiarization process was completed for each plant record set, the criteria application process was begun.

Sequential Application of Criteria to Records

The criteria developed by a systems analyst and a human factors specialist were synthesized to develop one criteria set to be applied to select the plant record set most likely to contain evidence of human error. This criteria list (provided as Table A.1) was applied to the four plant record sets available in IPRDS.

Table A.1. Final prioritized criteria

1. Individual record data in sufficient detail to understand the problem
2. Individual record data in sufficient detail to separate the problem from the corrective action
3. Availability of personnel for interview
4. Individual record data in sufficient detail to separate the source of the problem from the cause of the problem
5. Quantity of repair actions
6. Individual record data demonstrating verification of the repair/corrective action
7. Systematic coding of records (accessibility)
8. Systematic index of records (cross-tab ability)
   a. Date and time problem was discovered
   b. Date and time corrective action was made
   c. Equipment identification data
9. Identification (by step or phase) of operational and/or maintenance procedure during which the problem was discovered
10. Consistency of reporting for a complete set of records

Starting with Plant No. 1, the analyst reviewed notes taken on the format and read through the record set, applying each criterion from 1 to 10. The following general rules were used for each criterion to determine the degree of applicability:

<u>Criterion No. 1</u>: Descriptions of the problem encountered had to be specific, but lengthy detail was not required since the criterion used the

term "sufficient detail." Vague accounts, such as "bad valve" were not considered sufficient.

Criterion No. 2: Again, a specific description of both problems and corrective action was needed. Statements such as "Replace Valve X" for problem and "Valve X Replaced" for corrective action were not considered sufficient.

Criterion No. 3: The analyst determined that personnel would be available for interview if contact had been maintained between plant personnel and the principal investigator since the last plant visit.

Criterion No. 4: The requirements for criteria Nos. 1 and 2 were applied here as well, with the additional use of the definitions of "source" and "cause":

Source: The piece of hardware whose failure is perceived by some warning device.
Cause: The actual malfunction that caused the piece of hardware to fail (i.e. a subcomponent, another component, human error).

Criterion No. 5: The method for tabulation of repair action was dependent upon the method of presentation. For those plants which recorded repair on a system basis, four or five systems were reviewed to determine the average number of repairs per system. For those which recorded actions on an individual repair basis, one quarter of the pages in each folder of recorded material were reviewed and the resulting number was multiplied by 4 to determine the amount per folder. Totals were derived by adding up all the numbers for all folders of records. The plants which accounted for repairs on a monthly basis required the review of two representative months per year then the multiplication by six to determine a yearly amount. The amounts per year were added to derive a total. Approximately 150 records were actually reviewed from each plant record set.

Criterion No. 6: Verification was considered to be the name or signature of a plant employee.

Criterion No. 7: For this criterion, the factor by which records were combined was examined; for example, by system, by year, by document number. The analyst then made a judgment as to the potential for difficulty involved in extracting a single repair action on a specific component to determine accessibility.

Criterion No. 8: For (a) and (b), degree of applicability was based upon the specification of dates and time on the records or the recording of the number of hours needed to complete the corrective action. Part (c) was evaluated on the completeness of equipment I.D. records and the degree of traceability of part or system numbers to the I.D. numbers used on the repair records.

Criterion No. 9: The determination of discovery of the problem was dependent upon the detail of the problem or corrective action description. This information was often unavailable.

Criterion No. 10: Consistency of reporting was judged by the evidence of yearly sequences from dates recorded and by plant specific repair recording requirements.

Through the use of the preceding guidelines, the plant records were reviewed and beginning with Plant No. 1, the criteria were applied from 1 to 10 for each plant record set. A short paragraph was written describing the degree of applicability of each record set to each criterion. These verbal descriptions are recorded in Table A.2. The next part of the study required the determination of a numerical rank based upon applicability of each record set to each criterion.

Assignment of Criteria Applicability Rating to Records

Originally, a scale of one to ten was to be used to reflect low to high applicability to each criterion. This scale provided a wide range of numbers between highest and lowest degree of applicability. The judgment process to discern between a level of 5 and 6 would therefore have been less traceable and the ranking less distinct. For these reasons, the scale was narrowed to the use of one for low applicability up to five for high applicability.

On the basis of the one to five scale, the analyst reviewed the narrative summaries from each plant for criterion No. 1 and determined the relative level of applicability for Plants 1 through 4. This emphasized that the ranking of pertinence to each criterion was not based upon an abstract concept of potential applicability of plants outside the study, but was limited to the comparison between the four record sets at hand. For each criterion in sequence, the relevance of the record set was compared and a number assigned. The numbers were then inserted into Table A.3.

Another modification of the matrix in Table A.3 was the recognition that the prioritized criteria needed to be weighted. This produced the need for a mechanism to weight the criteria differently according to their determined importance to the study. In establishing the weighting factors, the numerical ranks placed in each box of Table A.3 were multiplied by a specific number for each criterion. Because a higher number was intended to imply greater applicability, the Criterion No. 1 numerical ranks were multiplied by ten; Criterion No. 2 numbers were multiplied by nine; and so on, with the lowest priority Criterion No. 10 rating numbers remaining the same as they were multiplied by one. These weighted numerical applicability ratings were placed into a separate matrix which is included as Table A.4.

Selection of Candidate Plant

The selection of one candidate plant record set for further study was carried out by tabulating the numbers for each plant for all criteria using Tables A.3 and A.4. The total applicability ratings for each plant record set are given in Table A.3 for unweighted values and in Table A.4 for values weighted by criterion priority. In both tables, plant No. 4 was determined to be the most applicable since it received the highest total rating.

Table A.2. Criteria application matrix

Criterion No.	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
1	Individual maintenance accounts appear to be in clear, concise form; problem is understandable	Descriptions of failures and tasks are very brief; just adequate to describe the task, yet problems and actions taken are clear	Very brief descriptions of maintenance actions; no detail	Form provides space for problem description — valuable because description is in plant employee's own words; degree of detail depends upon the individual form
2	Divisions of records format provide for separation between problem and work performed; however, format given is not always used	Format of records provides clear distinction between failure description and corrective action	Inconsistent reporting of problem and corrective action; difference is seldom clear: frequent use of ambiguous terms like "bad" to describe problems	Problem and corrective action are often well defined (70% of the records) but sometimes the problem is a description of the corrective action needed
3	Contacts with plant personnel fairly well maintained	Contacts with plant personnel well maintained	Contact with plant personnel not certain	Contacts with plant personnel maintained
4	"Source" and "cause" of problem not generally distinguishable; repair descriptions appear to be based upon assumed knowledge or discovery of actual problem	Format of records provides clear distinction between "source" and "cause" of problem	Format of records provides for some distinction between "source" and "cause" based upon assumption that component involved is actual source	If description of trouble was written describing the problem, the corrective action often indicated discovery of the actual cause of the problem by the maintenance personnel. If the description of trouble was written directing the corrective action to be taken, the cause of the problem was either unclear, predefined or contained with the description statement
5	Approx. in total 6000	Average of 30 per system; approx. 2200 total	Approx. 1000 total	Approx. 6800 in total
6	No visible verification of corrective actions	No visible verification of corrective actions	No visible verification of corrective actions	Verification available for each repair and maintenance action; signed by various work supervisors
7	Coded by System identification (ID) number and Component ID number; maintenance history recorded on sequential pages under these ID numbers	Coded by system; each system is given an ID number and verbal description title	Records organized by year and month with all system and component maintenance history combined; separation between electrical, instrument and mechanical maintenance work	Records organized by Job Order number from form or by date

Table A.2 (continued)

Criterion No.	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
8	a and b. No specific day date; only month and year is logged; number of hours job required is recorded c. List available with equipment sorted by instrument identification (ID) number with component description, location and system ID number included	a. Discovery date of problem can be calculated by taking date and time of repair and substracting number of hours needed to complete job b. Complete date and exact time of repair completion available c. Excellent ID list; computer printout master equipment list for each component by system, mark number, NPRD component type code	a and b. Dates mostly available, but not times; unsure whether dates are for discovery or corrective action completion c. Lists by component ID numbers with component name; lists of components per reactor building	a. Date and time of discovery logged for each job b. Date of corrective action is logged, but seldom is time recorded c. Plant description manuals available with diagrams and lists of components (with Component ID numbers) for each plant system
9	No evidence of ability to determine problem discovery phase	No evidence of ability to determine problem discovery phase	No evidence of ability to determine problem discovery phase	Engineer describes problem; under the "Work Performed" section of the form the actual problem is often described as having been discovered
10	Consistency very good especially for systems; most records date from 1975 to 1981	Reporting complete from 1976 to 6/30/78	Consistent in that monthly reports were logged 1/75—4/79; maintenance either increased in frequency or reporting in 1979	Consistency of reporting ensured by requirement that form be filled out for each job; records run from 1977—1981

Table A.3. Plant records review and evaluation matrix[a]

Criteria	UNWEIGHTED Applicability rating 1-5 (low to high)			
	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
1	4	2	1	5
2	4	5	1	3
3	5	5	1	4
4	1	5	2	3
5	4	3	1	5
6	1	1	1	5
7	4	5	1	2
8	3	5	1	4
9	1	1	1	5
10	4	3	1	5
Total	31	35	11	41

[a]*Total possible points for each plant = 50.*

Table A.4. Plant records review and evaluation matrix[a]

Criteria	UNWEIGHTED Applicability rating 1-5 (low to high)			
	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
1	40	20	10	50
2	36	45	9	27
3	40	40	8	32
4	7	35	14	21
5	24	18	6	30
6	5	5	5	25
7	16	20	4	8
8	9	15	3	12
9	2	2	2	10
10	4	3		5
Total	183	203		220

[a]Total possible points for each plant = 275.

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Appendix C

MAINTENANCE TASK SYNTAX

1.2 Maintenance Tasks

1.2.1 Behavioral Coordinates

1.2.1.1 Calibration, Measurement and Test

1.2.1.2.1 Read

```
[Read/Display          /Meter       ]
[Read/Display          /Digital     ]
[Read/Display          /Chart       ]
[Read/Display          /CRT         ]
[Read/Display          /Indicator   ]
[Read/Display          /Annunciator]
[Read/Written Material/Procedure   ]
[Read/Written Material/Policy      ]
```

1.2.1.1.2 Interpret

```
[Interpret/Display          /Meter       ]
[Interpret/Display          /Digital     ]
[Interpret/Display          /Chart       ]
[Interpret/Display          /CRT         ]
[Interpret/Display          /Indicator   ]
[Interpret/Display          /Annunciator]
[Interpret/Written Material/Procedure   ]
[Interpret/Written Material/Policy      ]
```

1.2.1.1.3 Confirm

```
[Confirm/Component           /State                ]
[Confirm/Written Material    /Procedure            ]
[Confirm/Non-written Material/Skill                ]
[Confirm/Non-written Material/Oral Communication]
```

1.2.1.1.4 Locate

```
[Locate/Display/Meter       ]
[Locate/Display/Digital     ]
[Locate/Display/Chart       ]
[Locate/Display/CRT         ]
[Locate/Display/Indicator   ]
[Locate/Display/Annunciator]
[Locate/Control/Switch      ]
[Locate/Control/Valve       ]
```

1.2.1.1.5 Manipulate

```
[Manipulate/Control/Switch   ]
[Manipulate/Control/Valve    ]
[Manipulate/Control/Keyboard]
```

1.2.1.1.6 Set

```
[Set/Control/Switch     ]
[Set/Control/Keyboard   ]
[Set/Control/Pushbotton].
```

1.2.1.1.7 Attach

[Attach/Control/Connector]

1.2.1.1.8 Remove

[Remove/Display/Meter]
[Remove/Display/Digital]
[Remove/Display/Chart]
[Remove/Display/Indicator]
[Remove/Display/Annunciator]
[Remove/Control/Switch]
[Remove/Control/Valve]
[Remove/Control/Keyboard]
[Remove/Control/Pushbutton]
[Remove/Control/Connector]
[Remove/Component]

1.2.1.1.9 Record

[Record/Display /Meter]
[Record/Display /Digital]
[Record/Display /Chart]
[Record/Display /CRT]
[Record/Non-written Material/Skill]
[Record/Non-written Material/Oral Communication]

1.2 Maintenance Tasks

1.2.1 Behavioral Coordinates

1.2.1.2 Scheduled Maintenance

1.2.1.2.1 Read

[Read/Written Material/Procedure]
[Read/Written Material/Policy]

1.2.1.2.2 Interpret

[Interpret/Written Material/Procedure]
[Interpret/Written Material/Policy]

1.2.1.2.3 Confirm

[Confirm/Component /State]
[Confirm/Written Material /Procedure]
[Confirm/Non-written Material/Skill]
[Confirm/Non-written Material/Oral Communication]

1.2.1.2.4 Locate

[Locate/Display/Meter]
[Locate/Display/Digital]
[Locate/Display/Chart]
[Locate/Display/CRT]
[Locate/Display/Indication]
[Locate/Display/Annunciator]
[Locate/Control/Switch]
[Locate/Control/Valve]
[Locate/Tool]
[Locate/Component]

1.2.1.2.5 Manipulate

[Manipulate/Control/Switch]
[Manipulate/Control/Valve]
[Manipulate/Control/Keyboard]
[Manipulate/Tool]
[Manipulate/Component]

1.2.1.2.6 Set

[Set/Control Switch]
[Set/Control/Keyboard]
[Set/Control/Pushbutton]
[Set/Component]

1.2.1.2.7 Attach

[Attach/Control/Connector]
[Attach/Component]

1.2.1.2.8 Remove

[Remove/Display/Meter]
[Remove/Display/Digital]
[Remove/Display/Chart]
[Remove/Display/CRT]
[Remove/Display/Indicator]
[Remove/Display/Annunciator]
[Remove/Control/Switch]
[Remove/Control/Valve]
[Remove/Control/Keyboard]
[Remove/Control/Pushbutton]
[Remove/Control/Connector]
[Remove/Component]

1.2 Maintenance Tasks

1.2.1 Behavioral Coordinates

1.2.1.3 Corrective Maintenance

1.2.1.3.1 Read

[Read/Written Material/Procedure]
[Read/Written Material/Policy]

1.2.1.3.2 Interpret

[Interpret/Written Material/Procedure]
[Interpret/Written Material/Policy]

1.2.1.3.3 Confirm

[Confirm/Component /State]
[Confirm/Written Material /Procedure]
[Confirm/Non-written Material/Skill]
[Confirm/Non-written Material/Oral Communication]

1.2.1.3.4 Locate

[Locate/Display/Meter]
[Locate/Display/Digital]
[Locate/Display/Chart]
[Locate/Display/CRT]
[Locate/Display/Indication]
[Locate/Display/Annunciator]
[Locate/Control/Switch]
[Locate/Control/Valve]
[Locate/Tool]
[Locate/Component]

1.2.1.3.5 Manipulate

[Manipulate/Control/Switch]
[Manipulate/Control/Valve]
[Manipulate/Control/Keyboard]
[Manipulate/Tool]
[Manipulate/Component]

1.2.1.3.6 Set

[Set/Control Switch]
[Set/Control/Keyboard]
[Set/Control/Pushbutton]
[Set/Component]

1.2.1.3.7 Attach

[Attach/Control/Connector]
[Attach/Component]

1.2.1.3.8 Remove

[Remove/Display/Meter]
[Remove/Display/Digital]
[Remove/Display/Chart]
[Remove/Display/CRT]
[Remove/Display/Indicator]
[Remove/Display/Annunciator]
[Remove/Control/Switch]
[Remove/Control/Valve]
[Remove/Control/Keyboard]
[Remove/Control/Pushbutton]
[Remove/Control/Connector]
[Remove/Component]

1.2 Maintenance Tasks

1.2.1 Behavioral Coordinates

1.2.1.4 Inspection

Appendix B

MAINTENANCE RECORD CARD FILES

The plant maintenance records were originally grouped by disciplines [i.e., instruments (I), electrical (E), mechanical (M), and some that were not classified]. Those records involving pumps and valves including their drivers and controls, had been previously processed and computer printouts of these records were used. These printouts were converted into pump and valve maintenance record index card files. The remaining miscellaneous maintenance records (not pump or valve) by discipline group were identified by date and serial number, and then converted into card files.

1.2.1.4.1 Read

[Read/Display /Meter]
[Read/Display /Digital]
[Read/Display /Chart]
[Read/Display /CRT]
[Read/Display /Indicator]
[Read/Display /Annunciator]
[Read/Written Material/Procedure]
[Read/Written Material/Policy]

1.2.1.4.2 Interpret

[Interpret/Display /Meter]
[Interpret/Display /Digital]
[Interpret/Display /Chart]
[Interpret/Display /CRT]
[Interpret/Display /Indicator]
[Interpret/Display /Annunciator]
[Interpret/Written Material/Procedure]
[Interpret/Written Material/Policy]

1.2.1.4.3 Confirm

[Confirm/Component /State]
[Confirm/Written Material /Procedure]
[Confirm/Non-written Material/Skill]
[Confirm/Non-written Material/Oral Communication]

1.2.1.4.4 Locate

[Locate/Display/Meter]
[Locate/Display/Digital]
[Locate/Display/Chart]
[Locate/Display/CRT]
[Locate/Display/Indicator]
[Locate/Display/Annunciator]
[Locate/Control/Switch]
[Locate/Control/Valve]
[Locate/Component]

1.2.1.4.5 Record

[Record/Display /Meter]
[Record/Display /Digital]
[Record/Display /CRT]
[Record/Display /Indicator]
[Record/Display /Annunciator]
[Record/Non-written Material/Skill]
[Record/Non-written Material/Oral Communication]

Appendix D

PSYCHOLOGY-BASED CODING SCHEME

A - Errors of Commission

1 - Knowledge-Based Behavior

A1a1 Misreads - Meters
A1a2 Misreads - Dials
A1a3 Misreads - Instructions/Procedures
A1a4 Misreads - Charts

A1b1 Misunderstands Verbal Instructions
A1b2 Misunderstands Written Instructions

A1c1 Misjudges - System State
A1c2 Misjudges - Task Actions
A1c3 Misjudges - Force
A1c4 Misjudges - Time
A1c5 Misjudges - Level

A1d1 Misuses - Instructions
A1d2 Misuses - Tools
A1d3 Misuses - Measuring Instruments

A1e1 Misrecalls - Meters
A1e2 Misrecalls - Dials
A1e3 Misrecalls - Instrument Ratings
A1e4 Misrecalls - System States
A1e5 Misrecalls - Chart Lines
A1e6 Misrecalls - Procedures
A1e7 Misrecalls - Techniques

2 - Rule-Based Behavior

A2a1 Misapplies - Task Steps
A2b2 Misapplies - Comparison
A2b3 Misapplies - Specification

3 - Skill-Based Behavior

A3a1 Misuse Tool - Repair Instrument
A3a2 Misuse Tool - Adjustment Instrument

A3b1 Misuses Force - Bolts
A3b2 Misuses Force - Nuts
A3b3 Misuses Force - Screws
A3b4 Misuses Force - Switches
A3b5 Misuses Force - Lamps

A3c1 Mistimes Sequence of Movements
A3c2 Mistimes Task Actions

A3d1 Mistakes Sequences - Series of Movements
A3d2 Mistakes Sequences - Task Actions

A3e1 Misapplies Technique - Task Actions
A3e2 Misapplies Technique - Lubrication
A3e3 Misapplies Technique - Installation
A3e4 Misapplies Technique - Alignment
A3e5 Misapplies Technique - Etc.

A3f1 Misorients Parts

B - Errors of Omission

1 - Knowledge-Based Behavior

B1a1 Forgets Instructions
B1a2 Forgets - Meters/Dials
B1a3 Forgets - System Knowledge

B1b1 Failure to Gather Information - Meters

B1b2 Failure to Gather Information - Dials

B1b3 Failure to Gather Information - Instruments and Charts

B1c1 Failure to Use Information - Meters
B1c2 Failure to Use Information - Dials
B1c3 Failure to Use Information - Instruments
B1c4 Failure to Use Information - Charts
B1c5 Failure to Use Information - Instructions

B1d1 Failure to Decide - Procedure
B1d2 Failure to Decide - System State

2 - Rule-Based Behavior

B2a1 Failure to Follow Procedure - Calibration
B2a2 Failure to Follow Procedure - Alignment
B2a3 Failure to Follow Procedure - Replacement
B2a4 Failure to Follow Procedure - Lubrication
B2a5 Failure to Follow Procedure - Assembly
B2a6 Failure to Follow Procedure - Disassembly

B2b1 Omit Step in Procedures - Calibration
B2b2 Omit Step in Procedures - Alignment
B2b3 Omit Step in Procedures - Replacement
B2b4 Omit Step in Procedures - Lubrication
B2b5 Omit Step in Procedures - Assembly
B2b6 Omit Step in Procedures - Disassembly

B2c1 Omit Checkout - Task Steps
B2c2 Omit Checkout - Final Operation Availability

3 - Skill-Based Behavior

B3a1 Failure to Use Technique - Task Actions
B3a2 Failure to Use Technique - Lubrication
B3a3 Failure to Use Technique - Installation
B3a4 Failure to Use Technique - Alignment
B3a5 Failure to Use Technique - Etc.

B3b1 Failure to Use Good Mechanical Practices - Task Actions
B3b2 Failure to Use Good Mechanical Practices - Lubrication
B3b3 Failure to Use Good Mechanical Practices - Installation
B3b4 Failure to Use Good Mechanical Practices - Alignment
B3b5 Failure to Use Good Mechanical Practices - Etc.

B3c1 Not Use Appropriate Tool - Test Equipment
B3c2 Not Use Appropriate Tool - Wrench
B3c3 Not Use Appropriate Tool - Special Tools

Appendix E

ENGINEERING-BASED CODING SCHEME

A-	**Calibration, Measurement and Test Tasks**
A1	**Read in a C, M, T Task**
A1a1	Error in Reading a Meter
A1a2	Error in Reading a Digital Display
A1a3	Error in Reading a Chart
A1a4	Error in Reading a CRT Display
A1a5	Error in Reading an Indicator
A1a6	Error in Reading an Annunciator
A1e1	Error in Reading a Procedure
A1e2	Error in Reading a Policy
A2	**Interpret in a C, M, T Task**
A2a1	Error in Interpreting a Meter Reading
A2a2	Error in Interpreting a Digital Readout
A2a3	Error in Interpreting Chart Information
A2a4	Error in Interpreting a CRT Display
A2a5	Error in Interpreting an Indicator
A2a6	Error in Interpreting an Annunciator
A2e1	Error in Interpreting a Procedure
A2e2	Error in Interpreting a Policy
A3	**Confirm in a C, M, T Task**
A3d1	Error in Confirming Component State
A3e1	Error in Confirming a Procedure
A3f1	Error in Confirming a Skill-related Communication
A3f2	Error in Confirming an Oral Communication
A4	**Locate in a C, M, T Task**
A4a1	Error in Locating a Meter
A4a2	Error in Locating a Digital Display
A4a3	Error in Locating a Chart
A4a4	Error in Locating a CRT Display
A4a5	Error in Locating an Indicator
A4a6	Error in Locating an Annunciator
A4b1	Error in Locating a Control Switch
A4b2	Error in Locating a Valve
A4b3	Error in Locating a Keyboard Control
A4b4	Error in Locating a Pushbutton
A4b5	Error in Locating a Connector
A4d1	Error in Locating a Component
A5	**Manipulate in a C, M, T Task**
A5b1	Error in Manipulating a Control Switch
A5b2	Error in Manipulating a Valve
A5b3	Error in Manipulating a Keyboard Control

A6	Set in a C, M, T Task
A6b1	Error in Setting a Control Switch
A6b3	Error in Setting a Keyboard Control
A6b4	Error in Setting a Pushbutton
A7	Attach in a C, M, T Task
A7b5	Error in Attaching a Connector
A8	Remove in a C, M, T Task
A8a1	Error in Removing a Meter
A8a2	Error in Removing a Digital Display
A8a3	Error in Removing a Chart
A8a4	Error in Removing a CRT Display
A8a5	Error in Removing an Indicator
A8a6	Error in Removing an Annunciator
A8b1	Error in Removing a Control Switch
A8b2	Error in Removing a Valve
A8b3	Error in Removing a Keyboard Control
A8b4	Error in Removing a Pushbutton
A8a5	Error in Removing a Connector
A8d1	Error in Removing Component
A9	Record in a C, M, T Task
A9a1	Error in Recording a Meter Reading
A9a2	Error in Recording a Digital Readout
A9a3	Error in Recording Chart Information
A9a4	Error in Recording a CRT Display
A9f1	Error in Recording a Skilled-related Communication
A9f2	Error in Recording an Oral Communication
B-	Corrective Maintenance Tasks
B1	Read in a Corrective Maintenance Task
B1e1	Error in Reading a Procedure
B1e2	Error in Reading a Policy
B2	Interpret in a Corrective Maintenance Task
B2e1	Error in Interpreting a Procedure
B2e2	Error in Interpreting a Policy
B3	Confirm in a Corrective Maintenance Task
B3d1	Error in Confirming Component State
B3e1	Error in Confirming a Procedure
B3f1	Error in Confirming a Skill-related Communication
B3f2	Error in Confirming an Oral Communication

B4	**Locate in a Corrective Maintenance Task**
B4b1	Error in Locating a Control Switch
B4b2	Error in Locating a Valve
B4b3	Error in Locating a Keyboard Control
B4b4	Error in Locating a Pushbutton
B4b5	Error in Locating a Connector
B4c1	Error in Locating Tools
B4d1	Error in Locating Component
B5	**Manipulate in a Corrective Maintenance Task**
B5b1	Error in Manipulating a Control Switch
B5b2	Error in Manipulating a Valve
B5b3	Error in Manipulating a Keyboard Control
B5c1	Error in Manipulating Tools
B5d1	Error in Manipulating Components
B6	**Set in a Corrective Maintenance Task**
B6b1	Error in Setting a Control Switch
B6b3	Error in Setting a Keyboard Control
B6b4	Error in Setting a Pushbutton
B6d1	Error in Setting Components
B7	**Attach in a Corrective Maintenance Task**
B7b5	Error in Attaching a Connector (Wire)
B7d1	Error in Attaching Component
B8	**Remove in a Corrective Maintenance Task**
B8a1	Error in Removing a Meter
B8a2	Error in Removing a Digital Display
B8a3	Error in Removing a Chart
B8a4	Error in Removing a CRT Display
B8a5	Error in Removing an Indicator
B8a6	Error in Removing an Annunciator
B8b1	Error in Removing a Control Switch
B8b2	Error in Removing a Valve
B8b3	Error in Removing a Keyboard Control
B8b4	Error in Removing a Pushbutton
B8b5	Error in Removing a Connector
B8d1	Error in Removing Component

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