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Development of the NRC's Human Performance Investigation Process (HPIP)

Development Documentation

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ABSTRACT

The three volumes of this report detail a standard investigation process for use by U. S. Nuclear Regulatory Commission (NRC) personnel when investigating human performance related events at nuclear power plants. The process, called the Human Performance Investigation Process (HPIP), was developed to meet the special needs of NRC personnel, especially NRC resident and regional inspectors. HPIP is a systematic investigation process combining current procedures and field practices, expert experience, NRC human performance research, and applicable investigation techniques. The process is easy to learn and helps NRC personnel perform better field investigations of the root causes of human performance problems. The human performance data gathered through such investigations provides a better understanding of the human performance issues that cause events at nuclear power plants. Volume III is a detailed documentation of the development effort and the pilot training program.

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HUMAN PERFORMANCE INVESTIGATION PROCESS (HPIP) DEVELOPMENT DOCUMENTATION

1. WHAT IS HPIP?

The Human Performance Investigation Process (HPIP) is a state-of-the-art method for NRC investigations of events that involve human performance issues. Figure 1.1 graphically presents the combination of an investigation process with six investigation techniques. The techniques are Events and Causal Factors Charting, Barrier Analysis, SORTM, the HPIP Modules, Change Analysis, and CHAP. The process and the techniques are described in detail in Volume 1 and 2 of this NUREG/CR.

2. WHY WAS HPIP DEVELOPED?

The accident at Three Mile Island was a watershed event in the nuclear industry. Before the accident the industry was concentrating on the design, construction, and startup of new nuclear power plants. After the accident, the industry's attention turned to completing the plants already in construction, implementing the lessons learned from the accident, and improving operating and maintenance performance. As the industry matured, the focus of the industry's primary regulator, the U. S. Nuclear Regulatory Commission (NRC), changed. The NRC's focus changed from performing design reviews, licensing, and ensuring construction quality assurance to a focus on operator training, plant operations, and plant maintenance. This new focus led to increased numbers of field reviews of human performance. These reviews demonstrated a need for improved methods of analysis of human performance problems. The Human Performance Investigation Process (HPIP) was developed to meet these needs.

3. DEVELOPMENT OF HPIP

This volume documents the development of HPIP including:

- the development approach and criteria,
- a high level review of the development,
- applicable literature reviewed that identified potential tools, methods, and technical bases for HPIP (Appendix A),
- summary evaluations of the nine candidate techniques that were most applicable for adoption in HPIP (Appendix B), and
- the training strategy and learning objectives (Appendix C).

3.1 Developing HPIP

Figure 3.1 outlines the approach used to develop HPIP. The detailed steps under Task 1 and 2 are listed in Table 3.1 and described in section 3.1.1 and 3.1.2. The development started with an analysis of the user's needs and a review of available systems (Task 1). Using the information gained in these two

FIGURE 1.1: NRC Human Performance Investigation Process

FIGURE 3.1: Simplified HPIP Development Flow

steps, the development team selected existing techniques that matched the user's needs. If directly applicable techniques could not be found, existing techniques were modified or new techniques were developed. The techniques were then organized into an NRC-specific process with investigation modules. Finally, an HPIP training course was developed, and HPIP was documented in a draft NUREG/CR to complete Task 2.

TASK 1	TASK 2
1. NRC Needs Analysis	4. Develop HPIP Flow
2. Develop HPIP Criteria	5. Select Best Tools for HPIP
3. Evaluate Existing Methods	6. If Needed, Develop New Tools
	7. Develop Pilot HPIP Training Program including a Training Manual
	8. Document Development in NUREG/CR

TABLE 3.1: Steps to Develop HPIP

Task 3 was to evaluate HPIP to see if it helped investigators find the causes of human errors. The methods used to evaluate HPIP are listed in Table 3.5. They included a usability workshop at NRC Headquarters; training of Headquarters and Region I personnel and trial usage of the system by the trained personnel; an independent human factors review of the system; and a comparison of inspector reports before the implementation of HPIP to reports made after inspectors were trained in HPIP. As a result of the testing, modifications to HPIP were implemented.

Task 4 (also shown in Table 3.5) included making the recommended revisions to HPIP, teaching the revised training to personnel at NRC Headquarters and in Regions I, II, and IV, and publishing the system as a NUREG/CR.

The following sections provide a closer look at the details of the development tasks.

3.1.1 Task 1: Analysis and Evaluation

The steps in Task 1 are:

Step 1: NRC Needs Analysis. Interviewing NRC Headquarters and field personnel consumed a large portion of the development effort. One hundred and fifty-four people were involved in individual and group interviews, and five major meetings assessed the user's needs and provided user response during the development of the process. Three of the five major meetings were held at regional headquarters (Regions I, IV, and V) to provide field personnel the opportunity to shape the process. One hundred and twenty-three regional personnel, 60 of whom were senior residents or resident inspectors, participated in these sessions and provided excellent input to the development of the system criteria, the HPIP Flow, and the techniques for the system.

Group	Meeting Date	Attendees
Headquarters	March 20, 1990	Meeting: 10 NRC managers & staff personnel
Headquarters	March 20-23, 1990	Interviews: 11 NRC managers & staff personnel
Region I	April 19, 1990	Meeting: 32 resident inspectors 18 other Region I personnel
Region IV	July 10, 1990	Meeting: 18 resident inspectors 7 other Region IV personnel
Mike Jones, CP&L Manager	July 26, 1990	Phone Conversation: utility representative for root cause analysis on Plant Vogtle's IIT
Headquarters	August 2-3, 1990	Meetings: 9 NRC managers and staff personnel
Region V	August 23, 1990	Meeting: 10 resident inspectors 38 other Region V personnel

TABLE 3.2: HPIP NEEDS ANALYSIS MEETINGS

Interviews and meetings to determine the user's needs focused on the following information:

- current capabilities to assess the root causes of human performance related events,
- training and experience levels of personnel in root cause analysis techniques and human factors theory,
- responsibilities within the NRC for root cause analysis and operating experience review and organizational or regulatory constraints on the system,
- the level of detail and types of information needed to analyze plant operating experience and answer pertinent regulatory and research questions,
- the types of actions or recommendations that might be taken based on the use of HPIP,
- potential database applications and the requirements for data base access,
- the amount of time/effort currently spent on an investigation,
- the type of investigations (team or individual) performed by headquarters and regional personnel, and
- the level of utility participation in the NRC's investigations.

The results of individual interviews at NRC Headquarters were summarized in an interview database for ease of search, sort, and retrieval of information. The results of the focus group meetings at headquarters and in the regions were documented in individual trip reports. Table 3.2 summarizes the interviews and meetings held.

Table 3.3: HPIP Development Criteria & Rationale

CRITERION	RATIONALE FOR CRITERION
1. HPIP level of detail should be oriented toward identifying contributors to, and root causes of human performance difficulties that utility management can fix.	<p>A. This level of detail was seen as necessary by several NRC staff members and regional personnel.</p> <p>B. This level of detail has been found to be very useful in investigating events at utilities.</p> <p>C. Additional detail beyond this level would be difficult for the investigator to collect and may cause them to use the system less frequently because of the work it requires to collect the additional information.</p> <p>D. A level of detail that finds fixable causes would be helpful in reviewing Licensee Event Reports to see if the licensee's corrective action is applicable to the root causes identified in an NRC investigation.</p>
2. HPIP is designed to be used by NRC resident inspectors with little or no previous human factors training.	<p>A. Most resident inspectors do not have formal training in human factors and cannot be expected to in the future.</p> <p>B. Region I resident inspectors expressed a need for help in determining the causes of human performance problems.</p> <p>C. If HPIP is usable by resident inspectors, it should be usable by personnel in the regions and at headquarters - especially those with prior resident inspector experience.</p> <p>D. HPIP need not be designed exclusively for use by NRC human factors professionals because they have expert judgment, based on training and experience, to help them find human performance root causes.</p>
3. Initial HPIP training should be kept as short as possible (3 days or less) but still be sufficient to allow the identification of common human performance problems.	<p>A. Three days was the maximum time that resident inspectors thought they could afford to spend on training; headquarters personnel thought that one day may be the most that could be expected.</p> <p>B. If HPIP is kept simple, a short introductory course should provide adequate training to start performing investigations using HPIP.</p> <p>C. If a modular training approach is adopted, this could represent the initial installment of training to provide familiarization with the system and some basic human factors problems. Additional training beyond the novice user level could be provided as the investigator gains experience with the system. This should provide better overall skill development than a single dose of training over a week to two week period.</p>
4. HPIP can be broken into modules so more in-depth training on specific modules can occur in brief sessions while HPIP is in use.	<p>A. Headquarters and regional personnel expressed interest in a modular training concept.</p> <p>B. Resident inspectors don't have long periods of time to be away from their work. A modular training concept could allow more advanced training to be given each quarter as part of the resident inspector's quarterly meetings at the region.</p>

Table 3.3 HPIP Development Criteria & Rationale (Continued)

CRITERION	REASON FOR CRITERION
5. HPIP should be designed to add the minimum amount of work possible to perform an adequate investigation or review so that it does not add significantly to the work required.	<p>A. If HPIP requires significantly more work, the investigators are less likely to use it voluntarily and more likely to find reasons why it doesn't work. Also, more NRC personnel would be required to perform the same number of investigations or fewer investigations would be done - neither of which is desired.</p> <p>B. Region IV personnel stated that their biggest need was for a system that would help them do "quick & dirty" reviews of a licensee's investigation so that they could evaluate the proposed corrective actions.</p> <p>C. Once learned and practiced, formal techniques may reduce the time that an investigator spends to achieve adequate results in an investigation.</p>
6. HPIP is compatible with human factors theory.	<p>A. Adds face validity to HPIP and thereby enhances acceptance by the human factors community.</p> <p>B. To justify improvements in the design of nuclear power plant human-system interfaces, problems and their fixes should be supported by basic human factors/behavioral theory.</p>
7. HPIP separates error producing problems into non-overlapping categories.	<p>A. Simplifies analysis for cause trends and generic problems by use of a database.</p> <p>B. Simplifies use by reducing confusion that would result from an investigator choosing from multiple categories that overlapped and then having reviewers challenge the categorization by choosing different categories with about the same meaning.</p>
8. HPIP documentation is well designed (simple) so that the novice investigator can start using the system with minimal assistance.	<p>A. Although training will improve the investigator's effectiveness in using HPIP, there is a high probability that some personnel will use the system with no prior training.</p> <p>B. Simple documentation should be possible if HPIP is simple.</p>
9. HPIP should link root causes when one root cause indicates that there may be problems that should be investigated in a related root cause category.	<p>A. Experienced investigators often find patterns of problems so that finding one type of problem instinctively causes them to look for a related type of problem. If HPIP could suggest these linkages, then less experienced investigators could more quickly identify related causes.</p> <p>B. Linking causes would help investigators avoid overlooking related causes.</p>
10. HPIP ensures that investigators collect and report enough accurate information so that subsequent in-depth analysis of problems is possible.	<p>A. Past NRC event investigation experience has shown that investigation reports may lack the necessary information needed to make informed judgments about the causes of human performance problems.</p> <p>B. Post investigation peer and/or expert review of event investigations has been shown to be a valuable tool to improving event investigations and identifying additional problems not considered by the original investigator(s). Somewhat detailed, accurate information must be documented for this review to be successful.</p>

Interviewee	Purpose of Discussion	Summary of Discussion
James Danaher, National Transportation Safety Board	Discuss NTSB's investigation process	NTSB staffers guide an investigation team. They sometimes use a human performance checklist as a guide. No techniques (including Events & Causal Factors Charting) are required to be used or are used for every investigation. The NTSB relies heavily on the individual investigator's experience.
Phyllis Kayten, Federal Aviation Administration	Discuss FAA's & NTSB's investigation processes	FAA personnel may be members of an NTSB investigation and may use the same techniques used by the NTSB.
Ed Blackwood, Department of Energy	Discuss DOE's new operating experience group	New group to use performance indicators, event trending, etc. Still in organizational process and have not implemented any formal root cause analysis techniques.
Roger Stevens, Occupational Safety and Health Administration	Discuss OSHA's investigation process	OSHA does not use a formal human performance root cause analysis tool but relies on investigator's experience.
Lt. Col. Jim Christol, United States Air Force - Aviation Mishap Prevention Program (AMP)	Discuss the goals and progress of the AMP system	The Aviation Mishap Prevention system's (AMP) focus is on human performance in aircraft accidents. Workbooks, pamphlets, forms, and questionnaires have been developed to aid Air Force investigators when investigating an accident and provide a standard format for data. Major development is in progress to implement a state-of-the-art computer database to support analysis and reporting of this data. Implementation of the new database is 3-5 years away.
Jerome Lederer, Aviation / Spacecraft Safety	Discuss the variety of investigation methods and his extensive experience in aviation safety	As a pioneer in aviation/flight/spacecraft safety field, Lederer discussed his experiences in implementing improved investigations into human performance problems and a variety of methods he has seen applied or reviewed.
Rick Tarrel, Battelle, NASA - Aviation Safety Reporting System	Discuss ASRS and analysis methods	Received an overview of NASA's Aviation Safety Reporting System (ASRS) and discussed the type of data collected and its usefulness.
Peter Harle, Canadian Transportation Accident Investigation Safety Board	Discuss Canada's CTAISB's investigation methods	Harle is developing a Human Performance Division within Canadian Transportation Accident Investigation Safety Board (CTAISB) to help provide a more structured, disciplined format to investigate the human aspects of transportation accidents. A formal accident investigation protocol is in the beginning stages of development and still years away from implementation.
Ted Ferry, Accident Investigation Author	Discuss book and possible new techniques	Discussed NRC HPIP development. No new techniques were identified beyond those already included in the most recent revision of his book.

TABLE 3.4: Industry Contacts On Root Cause Analysis

Interviewee	Purpose of Discussion	Summary of Discussion
Various Individuals, 1990 American Nuclear Society Summer Meeting session on root cause analysis, Nashville, TN	Present generic method for developing root cause analysis system. Identify potential root cause analysis techniques.	Presented paper on method for developing a root cause analysis system. Attended sessions with papers on Southern California Edison's root cause system, Duke Power's root cause analysis, NRC Region V perspective on root cause analysis, and FAA perspective on issues concerning human factors and safety.
Various Individuals, Licensee Event Report / Root Cause Analysis Conference, King of Prussia	Identify any new methods used by nuclear industry for root cause analysis	No new techniques, other than those previously identified, were discovered by the development team. By discussion group comments, there is obviously no standard root cause method being applied by nuclear utilities even with INPO's emphasis on HPES. A variety of utility needs regarding investigations were discussed. Also discussed were utility impressions on the NRC's understanding of root cause analysis / evaluation and the NRC's use of LER data.
Mike Jones, Carolina Power & Light	Discuss root cause techniques used during Vogtle IIT.	Jones was the utility industry representative responsible for root cause analysis during the Vogtle Incident Investigation Team investigation of a loss of site power. Jones used a technique originally developed at Savannah River to perform the root cause analysis. Uses the same technique at CP&L to identify the root causes of plant events.
Utility Contacts, Institute of Nuclear Power Operations (INPO) - Human Performance Enhancement System (HPES)	Discuss the use of HPES at utilities and obtain latest system revisions	The Institute of Nuclear Power Operations (INPO) has developed an investigation protocol to determine the root causes of human performance problems at nuclear utilities. The Human Performance Enhancement System (HPES) includes many techniques used in other root cause analysis systems plus a proprietary causal factor worksheet. Various levels of effort are being applied to implement/use the system (with varying levels of success) at all nuclear power plants. Utilities may voluntarily report events to INPO to be included in a closely held database. INPO provides no specific information on HPES or the contents of the database to those outside its member utilities.
Utility Contacts, INPO Good Practice and Nuclear Plant Reliability Data System	Obtain copies of documents	Received INPO's <u>Root Cause Analysis Good Practice</u> (OE-907, INPO 90-004) and INPO's <u>NPRDS Failure Report Cause Categories</u> . Discussed usefulness of NPRDS cause coding.
Bob Nertney, EG&G	Obtained updated status on the MORT system	Collected most recent Management Oversight and Risk Tree (MORT) information available.
Geoff Edelman, Kepner Trego	Discuss K-T methods of root cause analysis	Collected most recent Kepner Trego (K-T) methods of problem identification and analysis.

TABLE 3.4 Industry Contacts On Root Cause Analysis (Continued)

Interviewee	Purpose of Discussion	Summary of Discussion
Renate Roske-Hofstrand, Kurt Graeber & Dave Dinges, NASA-Ames Research Center	Discuss human performance research at NASA-Ames Research Center, discuss methods of analyzing human error, attend seminar on effects of sleep deprivation/fatigue.	Discussed work to develop a human performance investigation protocol that Roske-Hofstrand performed during a summer exchange program with the NTSB. Described HPIP development. Attended a seminar by Dr. Dave Dinges describing current research on fatigue and sleep deprivation and its implications for aviation safety.
Ned Dietrich, Electric Power Research Institute (EPRI) / Nuclear Safety Analysis Center (NSAC)	Discuss EPRI / NSAC work on event investigation and root cause analysis	Described HPIP development. Discussed past EPRI/NSAC research on event investigation and root cause analysis (publication - <i>Guidelines for Analyzing and Trending Incidents in Nuclear Power Plants</i> , NSAC/119). Discussed root cause analysis reports on industry problems using techniques from NSAC/119. No new techniques discovered.
Larry Minnick, ACRS member, formerly with S. Levy, EPRI, & Yankee Atomic	Discuss event investigation & root cause analysis, techniques for trending events	Described HPIP development. Discussed past EPRI/NSAC research on event investigation and root cause analysis. Discussed current views on NRC's root cause analysis efforts. Discussed utility management roles and responsibilities.

TABLE 3.4 Industry Contacts On Root Cause Analysis (Continued)

Step 2: Develop HPIP Criteria. The HPIP development team used input from the needs analysis to create HPIP development criteria (Table 3.3). The criteria reflect the needs of NRC Senior Resident and Resident Inspectors, who are projected to be the main users of HPIP. NRC personnel reviewed drafts of the criteria and their comments helped refine the final version. The criteria were then used by the team to develop the HPIP Flow and to select HPIP's tools.

Step 3: Evaluate Existing Methods. The HPIP development team used the criteria from Step 2 and their experience with root cause systems to evaluate existing root cause and human performance analysis techniques for applicability to HPIP. These reviews included better known systems, such as Kepner-Trego, Human Performance Evaluation System (HPES), Management Oversight and Risk Tree (MORT), Change Analysis, and Events & Causal Factors Charting. The reviews also included lesser known techniques from the aerospace/defense, nuclear, and other industries. The techniques were identified from HPIP development team members' experience, by attending industry conferences on root cause analysis, by contacting industry experts (Table 3.4), and from a detailed literature search using national computerized bibliographical databases. Appendix A describes the literature search and contains abstracts from each applicable document. The techniques most applicable to HPIP are summarized in Appendix B.

3.1.2 Task 2: Develop a Draft NRC Human Performance Investigation Process (HPIP)

The steps in Task 2 are:

Step 4: Develop HPIP Flow. Using input from the early part of the needs analysis, the HPIP development team developed a generic process that an NRC resident inspector could use to investigate and report on an event. The process was turned into a flow chart and, in conjunction with Step 5, the investigation tools were added to the chart to produce the diagram in Figure 1.1. This process was discussed with personnel at NRC Headquarters and in the regions and revised. The resulting investigation model became the draft Human Performance Investigation Process. The process assumes that a resident inspector decides to perform an investigation after notification of an event (although the inspector may also decide not to investigate the event).

Step 5: Select Best Tools for HPIP. Much of the remaining development effort was spent assessing and developing human performance and root cause analysis techniques to be incorporated into HPIP. This work included a computerized literature review (Appendix A), interviews with human performance and root cause analysis experts (Table 3.4), and meetings on root cause analysis (Table 3.2). Using the HPIP development team members' experience and the system development criteria, the possible candidate techniques for adoption by HPIP were reduced from those listed in the literature review to the nine that were most applicable. Appendix B contains reviews of the major systems considered for inclusion in HPIP. After additional consideration, several of these techniques were then woven into the fabric of the Human Performance Investigation Process, resulting in a tight coupling of process and techniques with each technique fitting a special need or providing information needed later in the process. The HPIP tools:

- **Barrier Analysis** (a barrier identification and analysis technique used to assess the adequacy of measures taken to prevent an event/accident - taught in MORT and HPES training),
- **Change Analysis** (a problem identification technique used to find problems caused by changes - taught in MORT and HPES training),
- **Events & Causal Factors Charting** (an event analysis technique used to develop a time line of actions leading to an event and the causal factors for each action - developed by the National Transportation Safety Board and taught in MORT and HPES training), and
- **Root Cause Tree™** (Paradies and Busch, 1990), (a root cause identification technique used at Philadelphia Electric,

Carolina Power and Light, and various other nuclear utilities - developed for the nuclear industry by System Improvements and roughly based on work originally performed by Mark Paradies and David Busch, E. I. du Pont de Nemours, at Savannah River Laboratory).

One of the techniques, the Root Cause Tree™ (Paradies and Busch, 1990), was modified by combining its categories and questions with NRC human performance research. This combination became the HPIP Modules. These modules are directly referenced from SORTM (described briefly in Step 6), thus providing an expert system that leads an investigator from general questions and human performance concerns to specific human performance root causes of the accident/incident.

Step 6: If Needed, Develop New Tools. Because the NRC had some needs that weren't satisfied by existing systems, two new tools were developed. They are:

- **SORTM (Stimulus, Operation, Response, Team performance, Management** - a simple flow chart to help an investigator decide where to concentrate her/his investigative effort without overlooking important aspects that influence human performance), and
- **CHAP (Critical Human Action Profile** - an operational / field oriented method for analyzing human actions. CHAP, roughly based on task analysis, organizes information about the critical human actions in the event and provides documentation for later in-depth analysis of the event.)

SORTM and CHAP are further described in NUREG/CR-5455, Volume 2, Appendices E and C, respectively.

Besides developing these new tools, the development team also developed an investigation procedure that documented the investigation process (shown in Figure 1.1) and the techniques. The procedure and the HPIP Modules provide the investigator with detailed guidance on how to apply the investigation techniques, what questions to ask, what information to collect during the investigation, and the references for more information on particular human performance topics.

Step 7: Develop Pilot HPIP Training Program including a Training Manual. Following the concepts of the systems approach to training, the HPIP development team developed an initial, one-day, pilot HPIP training program for NRC investigators. The purpose of the training is to provide investigators with enough familiarity with HPIP so that they feel comfortable using the techniques in the field during actual

investigations. The course strategy and learning objectives are documented in Appendix C.

A training manual, to be provided as part of the initial training, was developed by the HPIP development team to provide a reference for the system and the investigation techniques. The manual includes Volumes I and II of the NUREG/CR, copies of overheads used in the course, a detailed discussion of investigations, and a booklet for field use that consists of the procedure and modules. An investigator, without the initial HPIP training, may also use the manual to learn the system, but the development team believes that attending the initial training is a much better way to become familiar with HPIP.

Step 8: Document Development in a Draft NUREG/CR. The three volumes of the NUREG/CR represent the last step of the development of HPIP and consist of:

Volume I: A summary of the need for the human performance investigation process, the process's components, the methods used to develop the process, the methods proposed to test the process, and conclusions on the process's usefulness.

Volume II: A field manual for use by investigators when performing event investigations. Volume II includes the HPIP Procedure, the HPIP Modules, and Appendices that provide extensive documentation of each investigation technique.

Volume III: More detailed documentation of the development effort.

TASK 3	TASK 4
<ul style="list-style-type: none"> 9. Provide Oral Presentation to NRC 10. Conduct Usability Workshop at NRC Headquarters 11. Provide One-Day HPIP Training course at NRC Headquarters and at Region I 12. Collect Feedback from Inspectors that Have Used HPIP in the Field 13. Obtain an Independent Human Factors Review 14. Perform a Review of NRC Reports Before and After HPIP Training. 15. Present Project Results at 3 Meetings 16. Recommend Improvements in HPIP Based on Feedback from Steps 9 - 15 	<ul style="list-style-type: none"> 17. Revise HPIP Field Manual 18. Revise HPIP Training Program 19. Revise NUREG/CR produced in Task 2 20. Provide Revised HPIP Material to NRC 21. Provide 6 One-Day HPIP Courses for NRC Inspectors

TABLE 3.5: Steps to Improve HPIP

3.2 Improving HPIP

3.2.1 Task 3: Test / Evaluate / Refine HPIP

Step 9: Provide Oral Presentation to NRC. The HPIP development team presented HPIP to the NRC Headquarters Staff, answered questions, and received comments on HPIP improvements.

Step 10: Conduct Usability Workshop at NRC Headquarters. A workshop for NRC headquarters and regional personnel was conducted at NRC Headquarters to assess ways that HPIP could be improved. This step included the preparation for the workshop, facilitation and participation in the workshop by System Improvements and Concord Associates personnel, documentation of the results of the workshop in a report to the Project Manager, and incorporation of recommended changes in the HPIP documentation and training materials.

Step 11: Provide a One-Day HPIP Training Course at NRC Headquarters and Region I. A one-day training course was provided at NRC Headquarters for 13 NRC personnel and at Region I for 21 NRC regional investigators and resident inspectors. These investigators, inspectors, and managers represented a cross section of NRC personnel from Headquarters and Region I. Lessons learned from this training were documented in a report to the NRC project manager and incorporated into the training program.

Step 12: Collect Feedback from Inspectors that Have Used HPIP in the Field. After three to six months, an HPIP development team member called each of the people that had been trained in Step 11. The comments received showed that resident and senior resident inspectors readily accepted the system. The testing also showed that HPIP is usable in the field after only one day of training and helps investigators find root causes that otherwise would not have been identified.

Region I Resident Inspectors who had used the technique were enthusiastic and recommended that others receive training. A memo from the Director of Reactor Projects in Region I stated that, "... I believe that HPIP is a useful, effective tool that could be used by all inspectors. Using HPIP techniques yields important information with little impact on inspection time. Further, since HPIP is designed for ease of use, only one day of training was needed to provide our inspectors with the necessary knowledge to use HPIP effectively, and this short amount of time required to train inspectors is a major benefit." Also he stated that: "All the inspectors who had used HPIP provided favorable feedback. HPIP found additional root causes that were not previously identified by the inspectors or the licensee. HPIP was easy to use and was not time consuming. Those who had not used HPIP believed that the training was very good and HPIP would be useful when the occasion arose."

The comments collected from the phone conversations were summarized in a report to the project manager and considered when the system was revised.

Step 13: Obtain an Independent Human Factors Review. HPIP was reviewed by Dr. Charles Hopkins of the University of Illinois. Considering accepted human factors theory, knowledge, and practice, he evaluated the HPIP development program, the structure and content of the NUREG/CR, the training presentation, and the course materials. Dr. Hopkins documented his evaluation in a report to the HPIP development team and the NRC project manager. His recommendations for improvements were incorporated into HPIP.

Step 14: Perform a Review of NRC Reports Before and After HPIP Training. HPIP team members reviewed resident inspector reports of incidents at nuclear power plants to see what impact HPIP had on the reporting. The team reviewed three Inspection Reports and a Notice of Violation (from Oyster Creek, Salem, and Hope Creek) that were written before HPIP training was given to the Resident Inspectors. The team also reviewed three inspection reports performed after the HPIP training (from Millstone, Yankee-Rowe, and Peach Bottom). The reports chosen were from Region I (the region selected to test HPIP).

Areas of particular interest when comparing the reports were:

1. The level of root cause that was communicated. Was the cause a "root cause" (i.e., the most basic cause(s) that could reasonably be identified and that management had control to fix), or was the cause identified at some higher level (above the root cause level - such as personnel error).
2. The comparison of the root causes to the utility's corrective action plan to see if each root cause had an appropriate corrective action.
3. The thoroughness of the investigation. Were all the root causes (particularly the human performance root causes) identified?
4. The clarity of information about the event's cause(s).

The comparison was conducted by reading the reports and using HPIP to analyze the specific root causes of the reported events. The reviewer then performed a subjective evaluation of the four items listed above. The reports made after HPIP training showed that the inspectors trained in HPIP:

- Seemed to be more sensitive to the need to identify causes at a level that is correctable (root causes).
- Used more formal tools to perform their analysis (in one case they provided us with "scratch" copies of the E&CF charts that they used to establish the event's sequence).
- Tended to provide more details about the event's causes in their reports and identified more weaknesses in the utility's investigations.

These improvements tended to make their reports clearer for the report reviewer.

Step 15: Present Project Results at Meetings. A member of the HPIP project team presented the results of the HPIP development at the following meetings:

- 1991 Summer American Nuclear Society Meeting (June).
- 1991 Human Factors Society Meeting (September).
- 1991 Water Reactor Safety Meeting (October).

The talk at the American Nuclear Society Meeting received the Human Factors Division Best Paper Award. The feedback received at all the meetings was documented in the monthly reports and suggested improvements were considered for incorporation in HPIP.

Step 16: Recommend Improvements in HPIP Based on Feedback from Steps 9 - 15. The HPIP project team evaluated all the recommended improvements to HPIP resulting from steps 9 - 15 and

incorporated their recommendations for the final revision to HPIP in a report to the NRC project manager. These recommendations were reviewed and approved. They have been incorporated into Volumes I and II of this NUREG/CR.

3.2.2 Task 4: Improve HPIP and provide additional HPIP Training

Step 17: Revise HPIP Field Manual. Based on the information collected in Task 3 and the improvements approved by the NRC, the HPIP Field Manual (which consists of the HPIP Steps and the HPIP Modules from Volume II and a section of additional investigation guidance) was revised.

Step 18: Revise HPIP Training Program. Based on the information collected in Task 3 and the improvements approved by the NRC, the HPIP training program was revised. The resulting documentation, lesson plans, and overhead transparencies were provided to the NRC so that NRC personnel can teach the course through the NRC Technical Training Center or incorporate the material into the resident inspector initial training course.

Step 19: Revise NUREG/CR Produced In Task 2. Based on the information collected in Task 3 and the improvements approved by the NRC, the NUREG/CR was revised. System Improvements provided the NRC with a limited license to reproduce particular proprietary, copyrighted material that was used to develop the HPIP Modules.

Step 20: Provide Revised NUREG/CR, HPIP Field Manual, and Training Material to NRC. The revised NUREG/CR, HPIP Field Manual, and Training Materials were provided to the NRC as deliverables of this project.

Step 21: Provide Six One-Day HPIP Training Courses for NRC Inspectors. Six additional HPIP training courses were conducted for NRC Headquarters and regional personnel. Two courses were held at NRC Headquarters, two courses were held at Region I, and one course was held at each of Regions II and IV. Because of scheduling difficulties, courses were not held at Regions III and V, but personnel from those regions were invited to attend the training held at NRC Headquarters.

4. REFERENCES

1. Mark Paradies and Dave Busch, Root Cause Tree™ User's Manual, Paradies Press, Aiken, SC, 1990.

APPENDIX A

HUMAN PERFORMANCE INVESTIGATION PROCESS (HPIP)

Literature Search

February 1991

by

**System Improvements, Inc
and
Concord Associates, Inc.**

APPENDIX A

LITERATURE SEARCH

1. BACKGROUND

The objective of the bibliographic review was to search the literature to determine existing root cause analysis protocols or systems and to assemble information related to human performance in accident investigation, especially with respect to organizational/management and training issues associated with specific events or accidents.

The literature searches were targeted to cover the disciplines of human factors, engineering, psychology, general social science, aerospace, and management. These searches were conducted on databases that covered both government-sponsored and industrial research. The services of a librarian at the University of Tennessee, Knoxville (UTK) were enlisted in order to search the on-line databases of COMPENDEX, AEROSPACE, and DTIC. Other databases, PSYCINFO, ERIC, ABI-INFORM, and INFOTRAC were searched from the CD-ROM systems by project personnel. The initial search, conducted using the DTIC database, was used as a basis for keywords for subsequent searches. Based on the number and types of relevant literature retrieved, the rest of the searches were conducted with several combinations of the following descriptors: root cause, accident, analysis, accidents analysis, accident prevention, accident investigation, risk studies, risk assessment, organizational, and management. The majority of the relevant literature were collected and reviewed.

The collected literature was classified according to one of two broad categories: (1) human performance in accident investigation/root cause analysis or (2) existing protocols/systems. These were further categorized according to the name of the protocol system (or the organization if no formal name existed) or the causal area of focus. The literature was annotated with the highlights relevant to the current project. The following is a summary and integration of the review. More details are given in the annotated literature review found in section 4 0.

2. HUMAN PERFORMANCE IN ACCIDENT INVESTIGATION / ROOT CAUSE ANALYSIS

Human performance has been implicated in accidents for the following variables:

- Information Processing,
- Behavioral and Personality Characteristics,
- Small Groups, and
- Management and Organizational Factors

2.1 Information Processing

Information processing failures may be attributed to humans operating in environments that are too complex for their sensory capabilities (Key, 1986). Sensory overload might occur at the sensory or perceptual level (novel, unpredictable, or disorganized events distort human perceptions), the cognitive level (limitations in human information processing), or at the decisional level (perceptions of task difficulty is higher than reality). A classification system described by Fell (1976) elaborates on these three levels to include a fourth one of action failures (performing a physical action based on the decision reached in level three). Causal factors associated with human error can fall into one of several categories: (1) physical or physiological failures (heart attacks, falling asleep), (2) impaired physical or mental states (due to drugs, alcohol, fatigue, pressure), (3) experience or exposure (novel situations, training), (4) conflicting behaviors or preoccupation (talking, ignoring important stimuli), and (5) risk-taking behavior (violating procedures, improper actions). Related to risk-taking behaviors, Evans (1985) pointed out that, especially for self-paced tasks, engineering changes to various components of the system will affect users differently depending on their perception of risk. He uses the example of large cars. These cars are perceived to be safer to drive than small cars, but in reality drivers of large cars are involved in more crashes than the drivers of smaller, "higher-risk" cars.

Information overload was discussed as a root cause factor in the Three Mile Island (TMI) accident (Burns, 1985). When interpretation, processing, and application of information is overloaded, an individual will resort to his own preconceived notions in order to understand a situation. Cognitive dissonance allows humans to ignore, refute, or forget warnings or data indicative of trouble. In the Chernobyl accident, cognitive difficulties of humans and complex systems were implicated (Reason, 1987). This is evident in the way people deal with complex systems. They are aware of the main effects of their actions on the main goal, but not of their side-effects on the remainder of the system.

2.2 Behavioral and Personality Characteristics

Personality and behavioral characteristics of the human operator have been identified as major root causes of helicopter accidents (Adams, 1987). These factors include over-confidence, complacency, inadequate planning, and poor situational awareness. Pressures from economic, marital, or interpersonal relationship problems with peers or superiors (Alkov, Borowsky, & Gaynor, 1982), and life events such as a recent engagement to be married, or other major decisions regarding the future were found to be related to operator errors in accidents. Life changes and problems were viewed as symptoms of stress rather than stressors themselves, and accidents as a symptom of inadequate stress-coping strategies. Parker (1979) recommended that Holmes and Rahe's (1967) Schedule of Recent Experiences be used to determine which social stresses might likely be a factor in accidents. Other stressors that should be recognized as important factors in accident causation include environmental, emotional, and physiological stresses.

2.3 Small Groups

Along with individual information processing, small group factors have been found to be causal in events. For air traffic control operations, (an example of a system that is shifting to high levels of automation) more than 90% of events leading up to system errors were attributed to failures in attention, judgement, and communication (Danaher, 1980). Problems in communication are complicated in systems requiring the coordination of more than one operator (Davies, McCann, & Margerison, 1986). The highest amount of errors in performance of cockpit crew teams were related to management skills, followed by communication, planning, decision-making, and problem-solving. Problems of "groupthink" are also possible when there is more than one operator (Reason, 1987). These problems were evident in misconceptions of invulnerability, rationalizations of hazard warnings, self-righteous beliefs, poor estimation of the system's limitations, and self-censoring of individual's doubts.

2.4 Organizational and Management Factors

Organizational and management factors have been implicated as causal in accidents and events in several categories. Besides communication at the small group level, communication at the organizational level is essential to safety. Organizational communication is important in the following areas: understandable writing, participative communication, and bottom-up information flow (Lederer, 1985). Bailey and Peterson (1989) claim that organizational ignorance of psychological and sociological research concerning human behavior and motivation is partially responsible for many employee injuries. Adams (1985) presented the point that accidents in the workplace have their root cause in the management structure. This includes the objectives of the organization, the organization of management's work, and the planning and implementation of operations. In Minkes' (1988) description of the Presidential Commission on the Space Shuttle Challenger accident, he identified a number of management features responsible for the fateful decision to launch under inadequate safety states. These included: the cultural climate of NASA, the information and communication problems, changing criteria, and organizational structure. Lotts (1989) traced deficiencies at the High Flux Isotope Reactor at the Oak Ridge National Laboratory to the root causes of insufficiencies in funding, staffing, and training discipline. NRC's TMI-Action Plan points out the necessity of upgrades in staff size, education and experience of staff members, plant operating and emergency procedures, management awareness of and attention to safety matters, and numbers and types of personnel available to respond to accidents (cited in Sommers, 1983). Lenz and Lyles (1986) claimed that every human problem is due to three possible causes: (1) the disruption of social and political structures in the organization, (2) failure to match individuals' aptitudes with assigned planning tasks, or (3) inadequate support for strategic planning. These causes may become evident by such effects as resistance to change, avoidance behavior, or cognitive strain.

Sommers (1983) compiled major organizational and management issues identified in the government literature on nuclear power plant safety. They are

categorized according to the organization of work, policies and procedures, staffing, and external relationships. Factors related to safety in the organization of work include:

- top management errors and deficiencies,
- redundant structures and a separate organizational strategy
- single high-level person to coordinate safety policy and regular training,
- management commitment through positive action,
- separate safety review functions distinct from quality assurance,
- formal safety review committees, and
- support system of scientists and engineers.

Procedures must be adequate (with improvement in the areas of staffing responsibilities, information flow and directives, budgets and accountability, safety goals and criteria, and incident reports and corrective action), should pay attention to work situation and capacity of workers, should be understandable, should plan for bi-annual review, and should incorporate human factors requirements in areas such as accident prevention, safety engineering, and operational safety. The operators and those who initiate and review LERS require proper and adequate selection, training, and certification. Utility presence and involvement should exist in the selection, training, and qualifications of those personnel. Safety management training in corrective action should be provided to scientists, engineers, and skilled craftsmen. Key management should have experience in operations. External relations are important both for the feedback and assimilation of lessons learned from others' operating experiences, judgments, findings, and technology to prevent recurrence of an event.

3. EXISTING PROTOCOLS/SYSTEMS

3.1 Aviation-Related Systems

A brief summary of the literature on protocol systems follows. The literature search for existing protocols turned up several aviation-related systems:

- Buys (1988) discussed the use of the Post-Accident Events Analysis (PAE) used in the identification and evaluation of various types of post-accident interventions. The PAE is an adaptation of the Time Loss Analysis developed by the National Transportation Safety Board (NTSB). PAE can feed into and supplement SAF-T-TREE Analysis and Hazard Barrier Analysis.
- Cooper (1982) discussed the FAA-NASA Aviation Safety Reporting System (ASRS) with a summary of the way it functions.
- Clauzel and Stone (1982) discussed a proposal by Douglas Aircraft Company to improve the ability to use the NTSB records, the FAA Service Difficulty Reports (SDR), the World Aviation Accident Summaries (WAAS), and the Operational Incidents Reports (OIR). This effort would provide the ability to search these databases through one program, process customer requests for historical accidents and incidents data, and provide consulting services in interpreting these data.

- The United Kingdom Defence Flight Safety Authority has developed a procedure to incorporate the human factors specialist as a member of a multidisciplinary accident investigation team (Feggetter, 1982). Subjective information is gathered through a checklist interview with pilots, crew members, and Air Traffic Control concerning the perception and feelings about a particular event. The checklist and its techniques for using it are presented.

3.2 Army/Air Force-Related Systems

Army and Air Force sponsored work related to root cause systems was also found as follows:

- The Army's Centralized Accident Investigation (CAI) is used to investigate on-duty, fatal, nonprivately owned vehicle accidents (Graham, 1985; McGehee, Armstrong, & Hicks, 1987).
- Magistro and Panger (1980) have developed a workshop known as the Failure Analysis Seminar Techniques and Teams (FASTT) for functional engineers and mid-level engineering personnel.
- An Army program for the M1A1 Main Battle Tank fires assembles an interdisciplinary team that works together as a group to analyze root causes of tank incidents.
- Santilli (1980) looked at Air Force aircraft Class A accidents where damage exceeded \$200,000, a fatality occurred, or an aircraft was destroyed and the cause was attributed to the operator. Thirty-four variables, involving either environmental or operator, were defined.

3.3 Nuclear-Related Systems

The nuclear industry has contributed to root cause analysis activities. Several existing protocols were found for nuclear-related systems:

- The Boiling Water Reactor Owner's Group chartered its Scram Frequency Reduction program to reduce the frequency of reactor scrams to 3 per year (Kluch, 1988). The report discusses the use of Kepner Tregoe for root cause analysis.
- NRC's Office for Analysis and Evaluation of Operational Data (AEOD) is tasked to collect, screen, analyze, and feed back operating experience to appropriate NRC offices, the nuclear community, and the public (Lam, 1990).
- AEOD has developed and implemented a procedure to apply probabilistic risk perspectives to the assessment of operating events.
- NRC's Risk Methods Integration and Evaluation program (RMIEP) is another initiative addressing root cause analyses.
- EPRI's Common Causes Research Program (Mueller & Bezella, 1985), addressing the common cause failures, was performed at Sandia National Laboratory and was reviewed by Parry, Mitchell, Whitehead, Paula, and Rasmusson (1989).
- EPRI also funded research for the CYGNA Energy Services to identify generic problems, causes, and solutions related to modification activities at nuclear power plants (Moran & Shulman, 1988).

- The Human Error Classification (HEC) was used to look at root causes for maintenance errors in nuclear power plants in Taiwan (Wu & Hwang, 1989). Four major categories of error causes were identified: (1) human ability limitations, (2) design deficiencies, (3) disturbances of the external environment, and (4) induced circumstances.

3.4 Process-Related Systems

Other research was supported by the Insurance Technical Bureau and International Oil Insurers to develop a model to facilitate understanding, analysis, and predication of the influence of individual and organizational factors in process safety (Powell & Canter, 1985). A tool is described for the evaluation of the contribution of human and social factors to losses arising through fires and explosions in the chemical and petrochemical industry. The tool is based on the notion of the Instantaneous Fractional Annual Loss (IFAL) algorithm, a method for assessing expected average annual financial losses arising through fires and explosions expressed as a fraction of the total process.

4. **ANNOTATED LITERATURE REVIEW**

4.1 Background

The literature that follows was classified according to the two broad categories of (1) existing protocols/systems or (2) human performance in accident investigation/root cause. They were further categorized according to the name of the protocol system (or the organization if no formal name exists) or the causal area of focus. The following is not intended to be a summary of the literature, merely a summary of the information relevant to the current project.

4.2 Literature

E. E. Adams, "Accident investigation procedure: Some Guidelines for Classification," Professional Safety 30, 30-33 (1985). Available in public technical libraries.

Category: Human Performance in Accident Investigation/Root Cause Organization & Management

A system is described that is based on the philosophy that accidents in the workplace have their root cause in the management structure. This includes the objectives of the organization, the organization of management work, and the planning and implementation of operations. As middle and lower management respond to this structure, strategic operational errors and administrative mistakes occur, that result in tactical accident-causing errors in workplace conditions and behavior. The descriptive parameters of a useful safety program include: voluntary, never-ending-continuous, unemotional, educational, forward looking, integrated, implemented at the local level, designed to involve everyone, designed to define "no injury" as the goal, productive of measurable and visible results, and cost-effective. The safety management system described includes four stages: awareness, definition, review, implementation.

The awareness stage includes the stages of management commitment, coordination, and audit. During the definition stage the following occurs: expertise development, monitor, problem definition, and plan development. Implementation involves education, control, and Think No Injuries. Review includes the iterative process of re-cycle.

E. E. Adams, "Accident Prevention as a Safety Management System," Professional Safety 22, 28-31 (1977). Available in public technical libraries.

Category: Human Performance in Accident Investigation/Root Cause - General

This article focuses on the ability of a safety professional to recognize accidents that indicate significant problems. A rating guide was developed to create a safety management tool to quickly identify those accident/injury incidents that are of significant consequence. A guide is given to rate the specific factors concerning accidents/injuries that are most influential in this recognition. These factors are: The severity of the injury, the key personnel injured, the energy level involved, the equipment type, and the material type. Each of these factors is given an accident/injury rating from critical to non-critical. The tool is designed to classify an accident by points so that the investigative procedure can be adjusted to fit the significance of the incident. For accidents rated at 50 points, a classification of "catastrophe" is given, and investigation by upper management team is recommended. The purpose of the investigation should be for basic cause determination, the identification of operational errors or oversights, and recommendations on management procedures and practices. The MORT format is recommended to guide the analysis. For accidents rated between 40-49 points, a "critical" classification is given with the same recommendations as the "catastrophe" category. "Severe" accidents (between 26-39 points) are given the same recommendations except that the investigation should be given by a plant management team. Investigations of accidents between 26-39 points, "Serious" accidents, should be performed by the supervisor, with the identification and correction of the immediate causes. In the lowest category, "Non-critical," a record of the incident or complaint by the employee is sufficient.

R. J. Adams, "Root Causes of Helicopter Pilot Error Accidents," Proceedings of the International Symposium on Aviation Psychology, 761-767, April 27-30, 1987.

Category: Human Performance in Accident Investigation/Root Cause: General Factors

Underlying root causes of helicopter accidents was performed by interviewing helicopter pilots regarding their perception of the hazards associated with their operations. The statistical information they looked at indicated bad decisions, over-confidence, complacency, inadequate planning, poor situational awareness, fatigue, and economic pressures as the key pilot error accident root causes.

R. A. Alkov, M. S. Borowsky, and J. A. Gaynor, "Stress Coping and the US Navy Aircrew Factor Mishap," Aviation, Space, and Environmental Medicine 53, 1112-1115, (1982). Available for public technical libraries.

Category: Human Performance in Accident Investigation/Root Cause - Personality

This research was conducted by the Naval Safety Center, Naval Air Station, Norfolk, Virginia. The objective was to study the relationship of stress to accidents. They were taking the position that many of the factors that are considered life changes (such as divorce, being fired, problems at work) may more likely be considered symptoms of stress rather than stressors. So it follows from this position that mishaps may also be a symptom of inadequate stress-coping strategies. A person (aviator in this case) with inadequate coping skills for stress would "act out" with interpersonal problems, disciplinary problems. Accidents are viewed as another symptom of the failed stress coping mechanisms. The authors developed a 22-item questionnaire and sent it to the flight surgeon member of aircraft mishaps boards. The questionnaire focused on all aircrew members (pilots, copilots, student pilots, and naval flight officers) who might have influenced the outcome of the flight. The flight surgeon obtained information through interviews with superiors, peers, and family members. These aircrew members were divided into two groups: those with an aircrew causal or contributory factors (n = 248) and those with no aircrew error assigned (n = 230). The at-fault group were more likely to have marital problems, difficulty with interpersonal relationships, trouble with superiors, and trouble with peers or others. Two life events, recently becoming engaged to be married and recently making a major decision regarding the future, were related to the at-fault group. Phrases such as maturity, professionalism, and the ability to handle potentially troublesome situation were also related.

M. E. Armstrong, "Human Factors in Incident Investigation," Proceedings of the 33rd Annual Meeting of the Human Factors Society, Santa Monica: Human Factors Society 1989

Category: Existing Protocols/Systems: Root Cause Tree

Discussion of the root cause analysis for Savannah River Site (SRS). This analysis consists of two parts: the Events and Causal Factor (C&CF) Charting and Root Cause Coding using a Root Cause Tree. The objectives of the analysis were to provide a systematic method for identifying the root causes of a given incident in order to make detailed recommendations for preventing its recurrence, and to provide a database of incident root causes for identifying problem areas across incidents. (See Paradies and Busch, (1988) for more detail.)

T. J. Armstrong, R. G. Radwin, D. J. Hansen, and K. W. Kennedy, "Repetitive Trauma Disorders: Job Evaluation and Design," Human Factors 2, 325-336 (1986). Available in public technical libraries.

Task analytic procedures were given for analysis, identification of recognized risk factors, and engineering control of occupational repetitive trauma disorders.

P. Babson, "Stop Repeat Failures of Turbine Blades," Electrical World 203, 44-46 (1989).

Category: Human Performance In Accident Investigation/Root Cause - General

Used investigative procedures, testing methods, and analytical tools to determine the cause of turbine blade failures for large steam turbines.

C. W. Bailey, and D. Peterson, "Using Perception Surveys to Assess Safety System Effectiveness," Professional Safety 34, 22-26.(1989).

Category: Human Performance In Accident Investigation/Root Cause - Organization & Management

This article describes a study conducted by a committee appointed by the Safety Section Steering Committee of the Association of American Railroads. It was partially funded through two contracts with the Federal Railroad Administration. The study was conducted under a contract with the Office of Rails Safety Research with help and support from safety experts at the Ballistic Research Laboratory at Aberdeen Proving Grounds and the National Space Technology Laboratory, including statisticians from Computer Sciences Corporation. The Masters of Industrial Safety Program faculty at the University of Minnesota, provided assistance with survey data collection and evaluation and development of a training seminar to familiarize safety officers with results of the study. The objective was to determine methods of improving safety program effectiveness in the railroad industry. There was concern for increasing employee injuries with little or no reduction through government and industry efforts to comply with OSHA standards. The authors take the stand that organizational ignorance of psychological and sociological research concerning human behavior and motivation were in part responsible. The study examined both a systems approach to management of safety activities (what they call procedural- engineered factors) and a behavioral-based approach to safety. Two railroads, one with the best safety performance and the other with a poor performance record, were surveyed. Questionnaires were given to five levels of the organization, with common questions and questions specific to that management level. Common questions were used to determine where gaps in communications might be affecting safety performance. Safety officers on the two study railroads received training in administering the survey and answering questions. Analysis of the data led to the development of an 18 category profile for each railroad's safety efforts.

G. Basso, W. Fusari, G. Zanussi, M. Nobile, S. M. Fiori, and G. Morandi, "Trend Analysis of Scrams at Caorso NPP," Symposium on Reducing Reactor Scram Frequency, Tokyo, April 14-18.1986.

Category: Human Performance In Accident Investigation/Root Cause - General

Looked at 93 scrams during 1983 at the Caorso NPP. An analysis based on the scram initiating signals and root causes is performed. The three main root cause categories are: procedure deficiency, human error, and component failure. No detail or additional information is given as to how these root causes are determined.

J. Beeler, "Shell Sleuths Solve Error Mystery, Save Millions," Computerworld 21, 89-94.(1987).

Category: Existing Protocols/Systems: Shell Oil Company

Case Study-Shell Oil Company's in-house computing group has launched a formal program to boost the quality of its services. They claim to have chopped the error rate for one of its crucial systems by a factor of three. Through root-cause analysis, Shell tracked the problem to a flawed production process at one of the vendors that supplies chips to the system's manufacturer. No information or detail was given concerning the techniques of the root cause analysis.

G. J. Beels, "Look Beyond the Bottom Line," Quality 24, 50-54 (1985).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This is an interview with RADM Frank Collins, Jr., vice president for Avco Corporation, retired from a position as executive director of quality assurance in the Defense Logistics Agency. He describes steps he is taking to solve Avco's quality problems. These include an adaptation of the Demming wheel for the following steps: investigate to identify and quantify, evaluate to determine the root cause, premeditate or make a plan to correct the root cause, integrate or implement the plan, participate (management involvement), motivate people of the importance and priority of the task, interrogate after the plan is working, eradicate if the corrective action isn't accomplishing the goal.

B. J. Bell, "Evaluating the Contribution of Human Errors to Accidents," Professional Safety 33, 27-32 (1988).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This is a description of task analytic processes used to evaluate the contribution of human error to accidents.

D. L. Bever, Safety: A Personal Focus, pp. 30-35, Times Mirror/Mosby College Publishing: St. Louis, 1984.

Category: Existing Protocols/Systems

Summarizes the following approaches to accident investigation: failure mode and effect, fault tree analysis, cost benefit analysis, hazard analysis, and computer profiles.

C. Burns, "Three Mile Island: The Information Meltdown," Information Management Review 1, 19-25 (1985).

Category: Existing Protocols/Systems

The sequence of events leading up to and following the Three Mile Island (TMI) accident were reviewed. The author's position is that the confusion surrounding these events could have been avoided if the planning of TMI had considered how people interpret, process, and apply information. Burns discusses how the conditions of information overload in the control room contributed to the accident. Under conditions of information overload, one's ability to reach the right decision is lost in a "circus" of coping mechanisms that ultimately resolve themselves in a reinforcement of preconceived notions. The design of the

control room could have presented key data on a few hundred sophisticated gauges that did not require the operator to integrate thousands of small details before understanding the situation. Burns also describes cognitive dissonance and how it contributed to people ignoring, refuting, or forgetting warnings, data, and indications of trouble at TMI. Better information management could have averted many and contributed to a speedier and more rational solution of problems.

J. R. Buys, "No Reruns," Safety & Health 137, 32-35 (1988).

Category: Protocols/Systems for Accident Investigation/Root Cause

This article discussed the use of Post-Accident Events Analysis (PAE) in the identification and evaluation of various types of post-accident interventions. The PAE is an adaptation of the Time-Loss Analysis developed by the National Transportation Safety Board. The analysis begins with the mishap's occurrence at time (t₀) and continues to the determination of final loss. All interveners (either people or things) are identified and evaluated. Loss events and interventions are described by brief statements (i.e., safety department arrived). It should be specified as to whether the intervention made things better, worse, or had no effect. The interventions and loss events should be evaluated as to the significance of the event and its impact on both the natural loss pattern and the final outcome. This is depicted in a Post-Accident Events table and graphically on a time-loss diagram. PAE can feed into and supplement SAF-T-TREE Analysis and Hazard Barrier Analysis and represents an amplification of the accident response phase of causal factor and loss factor determinations.

J. S. and G. Stone, "Communicating Safety Information Through an Integrated Aircraft Accident, Incident and Maintenance Data System," 164-183 (1982).

Category: Existing Protocols/Systems

Looked at historical aircraft accident and incident data from such sources as National Transportation Safety Board records (NTSB), FAA Service Difficulty Reports (SDR), World Aviation Accident Summaries (WAAS), and operational incident reports (OIR). Douglas Aircraft Company is proposing a cooperative effort with customer airlines and other interested organizations. An initial step to improving these data systems is to provide for the ability to search through one program. They plan to process customer requests for historical accidents and incident data from its files and provide consulting services in interpreting these data.

W. E. Collins, A. R. Mastrullo, W. R. Kirkham, D. K. Taylor and P. M. Grape, "An Analysis of Civil Aviation Propeller-to-Person Accidents: 1965-1979, Technical Report No. FAA-AM-81-15: FAA Office of Aviation Medicine Reports.(1981).

Category: Existing Protocols/Systems: Analysis of reports from NTSB

This is a report of an examination of all propeller-to-person accidents from 1965 through 1979. These reports contain information concerning time of day, statement of cause, nature of injuries, etc.

G. E. Cooper, "Observations of the Accomplishments and Benefits from the Aviation Safety Reporting System," International Air Safety Seminar Proceedings 35th Publication by Flight Safety Foundation, Inc., 142-150.

Category: Existing Protocols/Systems: ASRS

Discusses the FAA-NASA Aviation Safety Reporting System (ASRS), with summary of the way it functions and the results and benefits obtained from the first seven years of operation.

J. W. Danaher, "Human Error in ATC System Operation," Human Factors 22, 535-545.(1980).

Category: Human Performance in Accident Investigation/Root Cause - Attention, Judgement, and Communication

Discusses the changes in the role of Air Traffic Control (ATC) operators with the increase in automation, most specifically the shift to human as a monitor of equipment. The FAA System Effectiveness Information System (SEIS) data bases (1974) contain information of nearly all ATC system errors reported. This information is taken from the System Error Review Board Reports prepared by facility personnel in accordance with FAA Order 8020.3A. This order requires that specific data on the personnel involved and on details of the events leading up to a system error be recorded, locally reviewed, and forwarded to FAA headquarters. Each system error is assigned one direct cause and a number of contributing factors. Categories of causes are: attention, judgment, communications, stress, equipments, operations, management, environment, procedures, and external factors. Each category is further divided into subcategories. In a study of these data, more than 90% were attributed to failures in attention, judgment, and communications.

R. Davies, D. J. McCann and C. J. Margerison, "Team Management on the Flight Deck of Commercial Jet Aircraft," Journal of Managerial Psychology 1, 12-18 (1986).

Category: Human Performance in Accident Investigation/Root Cause

Focus of the article is on the cockpit crew teams and the extent to which crew members can manage their information and resources. Another study was referred to in which data was acquired from the Aviation Safety Reporting System (ASRS). Errors related to management skills were the highest, followed by communication, planning, decision-making, and problem-solving. The authors of this study designed a workshop to examine how crew teamwork in the cockpit can be enhanced. This workshop was called Aircrew Team Management Programme (ATM) and was sponsored by Trans Australia Airlines (TAA). The authors (from the Management Education Research Unit at the University of Queensland) worked together with TAA management and union representatives to develop a participative workshop for pilots and flight engineers in order to develop the skill of teamwork. This is done through knowledge of oneself and self development, improving communication skills, understanding group processes involved in making decisions, and learning how to deal with other crew members. It was implemented in November of 1985.

D. M. DeJoy, "A Behavioral-Diagnostic Model for Self-Protective Behavior in the Workplace," Professional Safety 31, 26-30 (1986).

Category: Existing Protocols/Systems: Behavioral Focus

This article focuses on the behavioral factors in accident causation, specifically the failure of individuals to engage in self-protective behaviors. A behavioral-diagnostic model of workplace self-protective behavior is presented, that is based on the PRECEDE framework. The model begins with an identification of the proximate causes (behavioral or non-behavioral) of the accident any actual or potential injury, health, or property loss outcome). The behavioral causes are examined according to the following: (1) develop an inventory of behaviors, (2) rate the behaviors in terms of importance (3) rate the behavioral in terms of changeability, (4) choose the behavioral targets (behaviors that, if modified would contribute most to improving the identified safety problems, behaviors that are important to the outcome and that can be readily altered) and (5) state strategies to change these behavioral targets in terms of behavioral objectives. The behavioral causes (any behavior thought to be related to the problem in question) are then grouped according to their determinants: predisposing factors (individual characteristics such as beliefs, attitudes, values, and perceptions that facilitate or hinder self protective behavior), enabling factors (environment or system characteristics that promote or block safe behavior, such as the availability and accessibility of resources, i.e., training, work aids, pace of work), or reinforcing factors (rewards or punishments that follow as a consequence of the behavior such as feedback from supervisors or co-workers). Finally, accident prevention strategies (directive - focus on eliciting, shaping, and maintaining specific target behaviors, i.e. training, positive reinforcers, organizational change, i.e., inclusion of safety performance as an evaluation criterion in the performance appraisal process, having safety director report directory to top management, or non-directive - general attitudinal or dispositional tendencies, i.e., management style, communication patterns, safety consciousness) are selected in order to modify these factors.

J. Dowalgo, "Root Cause Analysis, Tank Fire Problem, M1A1 Main Battle Tank," U.S.Army Armament Research Development and Engineering Center (1989).

Category: Existing Protocols/Systems

Describes a failure investigation strategy for root cause analysis (RCA) of tank fire problems. The report is a case study of the major activities performed by the Root Cause Analysis Team that was assembled to review the M1A1 tank fires. The work was funded by the Army Armament Research Development and Engineering Center. The RCA team consisted of ten members with interdisciplinary skills; work commenced on 27 September 1988 and ended on 28 October 1988. The team was briefed and guided by Augustine Magistro on root cause methodology. Magistro authored two reports (given in the references on RCA) that were seminars for the Army on RCA (see Magistro's summary in this bibliography). The team examined first proceeded with a failure analysis. They listed all the possible failure modes of the M865 round, including its effect on related systems to establish a list of candidate root causes. They listed every conceivable area that could cause a tank ammunition fire. Discussions and ideas freely evolved and were recorded without evaluation. This produced 33 failure modes, events, or conditions that could

have contributed to the tank ammunition fire problem. Then the team constructed a chart listing these candidates categorized into one of four major problem areas: crew, ammunition, gun, and turret. Next the team postulated failure sequences (who, what, when, where, why, and how) for each of the candidates and recorded them in columns in a chart. They listed supporting and refuting data. Then they ranked (by voting) each candidate for each incident.

L. England, "The Role of Accidents Investigation in Road Safety," Ergonomics 24, 409-422 (1981).

Category: Human Performance in Accident Investigation/Root Cause - Human Perception

With an estimate of human error as a contributory factor in 95% of road accidents, some influencing factors are described. These are the limitations of the human perceptual system during high speed driving and discrepancies between perceived and actual risk levels. The accident investigation method used by the Accident Investigation Unit of Nottinghamshire County Council is described.

Ecosystems International, Inc., "Railroad Safety Program," Technical Report No. NASA- CA-173598 (1983).

Category: Existing Protocols/Systems

This report is a summary of the National Inspection Plan (NIP) developed by the Federal Railroad Administration (FRA) in 1981. This report was prepared for NASA Headquarters (CODE LGT-1), Washington, D.C.

L. Evans, "Factors Controlling Traffic Crashes," Journal of Applied Behavioral Science 23, 201-218 (1987).

Category: Human Performance in Accident Investigation/Root Cause - Risk Perception, Social Norms, and Legislature

Statistics for fatalities for rural sections of US interstate highway system during 1966-1983 were considered. Factors influential to these accidents were categorized according to human infrastructure (individual human behavior, legislature interventions) or engineering infrastructure (roadways, traffic control systems, vehicles). The human infrastructure is considered to have greater influence than the engineering. Individual human behavior consists of closed loop compensatory feedback (a driver's perception of immediate adverse consequences influences behavior) and social norms (social norms evolve in response to the more widespread use of vehicles).

L. Evans, "Human Behavior Feedback and Traffic Safety," Human Factors 27, 555-576 (1985).

Category: Human Performance in Accident Investigation/Root Cause - Risk Perception

Presents the point that for tasks that are self-paced (such as driving a car), engineering changes to various components of the system will affect users differently depending on their perception of risk involved. For example, drivers of larger cars (more likely to be safer) are involved in more crashes than drivers of smaller cars (less likely to be safer). What is stressed is that every estimate of

future effectiveness of a safety change must contain some assumption of the interaction effects with human behavior.

J. C. Fell, "A Motor Vehicle Accident Causal System: The Human Element," Human Factors 18, 85-94 (1976).

Category: Human Performance In Accident Investigation/Root Cause: Information Processing Error

Category: Existing Protocols/Systems National Highway Traffic Safety Administration

Described a classification system based upon cause and effect relationships (motor vehicle accidents). The effect is the primary behavior that led directly to the accident; the cause is the reason behind the behavior. Effects are categorized as four types of information-processing failures: (1) perception (sensing and detecting the environment), (2) comprehension (understanding or recognizing the information), (3) decision (making a decision based upon the information), and (4) action failures (performing some physical action based upon the decision). The reasons for these failures are varied; some are due to the system or the environment in which the operator functions. This article deals with those causal factors that are due to the human operator. These are (1) physical or physiological failures (such as heart attacks, falling asleep, situations that take the operator out of the system); (2) conditions or states (such as drugs, alcohol, mental pressure, fatigue - these are physical or mental states that affect the operator's processing behavior, they may affect the attitude, reaction and decision time, rationality, ability to discriminate and comprehend); (3) experience or exposure (such as an inexperienced operator, novel situations - these are situations in which the operator's past experience or exposure to similar situations affects the way information is processed); (4) conflicting behaviors or preoccupation (such as talking, mentally processing other stimuli and losing the important one - behaviors that interfere with the perception or comprehension of the stimuli); and (5) risk-taking behaviors (violating procedures, making improper actions, intentional risk-taking actions that affect the ability to process and compensate for danger signals). Degrees of assurance can be applied to each cause and effect relationship, these are (1) accident causation (primary or principal cause), (2) severity increasing factor, or (3) relevant conditions. Examples of the utilization of this model are given.

A. J. Feggetter, "A Method for Investigating Human Factor Aspects of Aircraft Accidents and Incidents," Ergonomics 25, 1065-1075 (1982).

Category: Existing Protocols/Systems: United Kingdom Defence Flight Safety

The United Kingdom Defence Flight Safety Authority have developed a procedure to incorporate the human factors specialist as a member of a multidisciplinary accident investigation team at an early stage of investigation. Subjective information is gathered through a checklist interview with pilots, crew members, and ATC concerning the perception and feelings about a particular event. The checklist is described. It takes into account cognitive (acquisition, storage, manipulation, and use of information), social (role perception, role conflicts, and pressures from the crew, ground crew, senior officers, passengers, or company), and situational factors (physical and environmental

stresses). The checklist is presented in the paper along with techniques for using it. It is designed to be used by a trained human factors specialist.

K. Fitzgerald, K., "Nuclear Weapons Reactors: Too Hot to Handle?" IEEE Spectrum 26, 37-41 (1989).

Historical and general information concerning safety at the Savannah River reactors site.

D. L. Gano, "Root Cause and How to Find It," In the Proceedings of the ANS Topical Meeting, American Nuclear Society: La Grange Park, Illinois (1987).

Existing Systems: Boiling Water Reactor Owners' Group Scram Frequency Reduction Committee (BWROG SFRC)

The purpose of this paper is to document what has been learned through participation in the Boiling Water Reactor Owners' Group Scram Frequency Reduction Committee (BWROG SFRC). Gano defines root cause as "the most basic reason(s) for an effect, which if corrected will prevent recurrence." The following criteria must be met in order to be effective at implementing the principles of root cause: a solution that prevents recurrence, a solution that is within our control, and a solution that allows us to meet our other objectives. The process used consisted of the following: (1) use an expert team, (2) start with the primary effect, (2) use the cause-and-effect process in conjunction with the three root cause criteria above, (3) apply the root cause definition to the root cause in order to verify it. Root causes are categorized according to either personnel errors, procedural failures, or equipment failures. These categorizations are then broken down into subcategories, and then root causes.

R. E. Graham, "Centralized Accident Investigation Program," Professional Safety 30, 38- 40 (1985).

Category: Existing Protocols/Systems: ARMY's CAI System

Brief description of the US Army's program to investigate catastrophic accidents. The program, known as Centralized Accident Investigation (CAI), was initiated October 1, 1983, to investigate on-duty, fatal, nonprivately-owned vehicle accidents, or accidents that results in more than \$500,000 property damage. The following briefly summarizes the CAI process. When an accident meeting the CAI criteria occurs, the US Army Safety Center is notified by telephone. Within two hours, the center sends a team consisting of a field grade officer, another military investigator, and a civilian investigator. Technical expertise is obtained from members of the installation (but not the unit) where the accident occurred. Local commanders secure the accident site, identify witnesses, gather records of equipment involved, and secure the medical, training, and personnel records of all Army personnel involved. The local safety manager coordinates interactions between the Safety Center team and the unit involved. An on-site investigation is completed that may consist of pictures, diagrams, briefing by the on-site people, inspection of the vehicle, and interviews with surviving accident victims. Each day the board begins by summarizing the previous day's findings and planning for the day's work. Upper management, although not directly involved in the accident is interviewed for information about standing procedures, training, and policy. Then the board reviews the evidence and develops tentative findings and

recommendations and offers suggestions for remedies. The report is finalized and briefed to the Safety Center Commander after a quality review by technical advisors and human factors analysts.

J. A. Griver, "Applied Problem Analysis Plus," Compsych Systems, Inc. Marina del Rey, California (1988). Griver, J.A. (1988).

Category: Existing Protocols/Systems

Provides a process to analyze and solve problems. It is an easy to read and follow book tailored for management and administrative support.

S. B. Haber, "Influence of Organizational Factors on Performance Reliability, Volume I: Overview and Detailed Methodological Development, "NUREG/CR-5538 (in press).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This report discusses an organizational structural concept of nuclear power plants called Nuclear Organization and Management Analysis (NOMAC). NOMAC is based on a generalized model of organizational structures of Mintzberg. It has five groups of organizational units with coordination among them. NOMAC is used to facilitate the identification of the organization's structural and key managers and supervisors. The goal is to identify and describe direct and indirect impacts on safety and the personnel responsible for these influences. After documenting this model, the paper identifies methods to assess organizational factors that affect nuclear power plant safety performance. The three data collection methods that were proposed were: (1) functional analysis of the organizational work flow, (2) assessment of the organizational culture/environment, and (3) observation of managers and supervisors. The NOMAC methodology was pilot tested at the Pittsburg Power Plant in Pittsburg, California, and at the Diablo Canyon Power Plant in San Luis Obispo, California. The methodology was shown to be practical, acceptable, and useful. These initial demonstrations identified the organizational factors. These factors include: communication, organizational culture, decision-making, standardization of work processes, and management attention and oversight. Communication was determined to be critical for effective operation. Communication included intra-organizational (vertical and horizontal) and inter-organizational (the organization and its constituents). The modes of communication include face-to-face, written, electronic, and telephone. It can either be formal, such as scheduled meetings, or informal, such as spontaneous discussions. Organizational culture includes the beliefs, perceptions, and expectations that individuals have about the organization. It is a very important variable behind performance. Decision-making reflects the organization's nature and culture and the ability of management to choose among competing alternatives. It includes problem-solving behaviors (identification and reporting of problems, analysis of root cause, selection and implementation of corrective actions, and learning from experience). Standardization of work processes are the ways that the nuclear power plants coordinate work. This includes personnel role definitions, procedures, policies, programs, and training. Management attention, involvement, and oversight of work flow enhances organizational awareness.

D. M. Haynes, "Applications of System Safety at Ontario Hydro," Professional Safety 32, 39-43 (1987).

Category: Human Performance in Accident Investigation/Root Cause

Detailed studies of Ontario Hydro's historical safety performance were conducted. They identified the occupational fatalities over 20 years (1962-1982), and related them to their generic causes (falls, transportation, electricity, and falling objects), then conducted various statistical relationships. No further breakdown is given as to root causes.

H. C. Jacobs, J. T. Nieburg, "Accident Investigations," Supervisory Management, 34, 13-16 (1989).

Category: Existing Protocols/Systems: DuPont Safety Services

Describes the incident investigation method used by DuPont Safety Services, used for the investigation of serious incidents (lost workday). General description, no details.

H. E. Johns, "The Work Environment: OSHA's Impact on Human Resources Management," Personnel Journal 67, 102-104 (1988).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Looked at the impact of the OSHA (1971) law on Tennessee manufacturing firms with 100 or more employees. The frequencies and percentages of different conditions of safety and health policies (management strategy, employee selection and training, union-management relations, accountability for safety and health, and health and medical programs) were documented. They were listed according to those that were formulated before OSHA, changed after OSHA, and brought about after OSHA.

W. G. Johnson, "MORT: The Management Oversight and Risk Tree," Journal of Safety Research 27, 4-15 (1975).

Category: Existing Protocols/Systems: MORT

Description of MORT

E. L. Jordan, C. E. Rossi, R. N. Singh, and J. G. Partlow, "Use of Operating Reactor Events Data to Assess Plant Safety Performance," Proceedings of an NEA Symposium on Reducing the Frequency of Nuclear Reactor Scrams, 157-173 (1987).

Category: Human Performance in Accident Investigation/Root Cause - Perception of Risk

This article describes the NRC's Office of Inspection and Enforcement. That program responds to plant emergencies, screens and evaluates reactor events to identify generic problems, assesses trends in plant safety performance, and identifies problem plants and areas requiring improvements within the plant. An example is given from an operator reactor event at the Davis-Besse nuclear power station.

N. Key, "Action to Prevent Traffic Violence," Professional Safety 31, 22-25 (1986).

Category: Human Performance in Accident Investigation/Root Cause - Perception of Risk

Takes the position that individuals may be operating in environments with environmental and interacting elements that are too complex for their own sensory capabilities. Sensory overload can occur on at least three levels: (1) sensory or perceptual (novel, unpredictable, or disorganized events distort human perceptions), (2) cognitive or thought (limitations in processing of information), (3) decisional or judgmental (perception of task difficulty is higher than reality).

J. G. Kluch, "Root Cause Analysis: Methods and Mindsets," Paper presented at the Annual Nuclear Instructors' Workshop of the Midwest Nuclear Training Association, 3rd, Columbus, Ohio, September 22, 1988.

Category: Existing Protocols/Systems

The Boiling Water Reactor Owner's Group (BWROG) chartered its Scram Frequency Reduction program to conduct Operations Activity programs such as information exchange meetings, engineering design studies for plant modification, and plant maintenance practices to reduce the frequency of reactor scrams to 3 scrams per year. The Operations Activity programs commissioned this introductory training program in Root Cause Analysis. The root cause analysis method as performed by Electricite de France is described. Other information that is important is a description of the Kepner Tregoe (KT) method as a tool for root cause analysis.

P. Lam, "Application of Risk Perspectives in the Analysis and Evaluation of Operation Data," Reliability Engineering and System Safety 27, 5-21 (1990).

Category: Existing Protocols/Systems: Office for Analysis and Evaluation of Operational Data (AEOD)

The NRC's Office for Analysis and Evaluation of Operational Data (AEOD) is tasked to collect, screen, analyze, and feed back operating experience to appropriate NRC offices, the nuclear community, and the public. AEOD has developed and implemented a procedure to apply probabilistic risk perspectives to the assessment of operating events.

J. Lederer, "Human Factors in Operational Communications," Professional Safety 30, 15-18 (1985).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Communication focuses on the importance of communication in safety. The importance of attending to different types of communication in an organization is stressed for the following: understandable writing (writing for the user, not for the designer of the equipment), participative communication (consultation with individuals to ensure compliance with instructions), communication from the bottom up (promotes morale and loyalty), and punishment (form of communication).

R. T. Lenz and M. A. Lyles, "Managing Human Problems in Strategic Planning Systems," Journal of Business Strategy 6, 57-66 (1986).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Traced every human problem to one of three causes: (1) the disruption of social and political structures in the organization, (2) failure to match individuals' aptitudes with assigned planning tasks, or (3) inadequate executive support for strategic planning. The effects and symptoms of each of these were discussed. For disruption of social and political structures in the organization, the effects were resistance to change (individual resists changes in the status quo) and avoidance behavior (avoidance of new or different tasks). The effect of failure to match individuals' aptitudes with planning tasks is cognitive strain (condition in which an individual cannot adequately perform assigned planning tasks). The cause of inadequate executive support for strategic planning has the effect of role stress (when formal statements about the significance of planning are inconsistent with the actual support and rewards given for strategic planning). Symptoms of these effects are discussed.

A. L. Lotts, "The HFIR: Lessons Learned," Oak Ridge National Laboratory Review, 14-23 (1989).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Describes the history of the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory, its shut down on November 14, 1986, and the analyses that followed. Twenty teams and committees reviewed the HFIR and its operating organizations. The relevant part of this review to our project is the investigation of the adequacy of the organizational and management functions, including quality assurance, oversight of the reactor programs by DOE and Energy Systems, operations and maintenance practices, design practices, training efforts, and safety and health practices. In the original assessments, the reviewers found many areas of management and operations lacking. The deficiencies were traced to three root causes: lack of sufficient staff, lack of sufficient funds, and lack of discipline in training, operations, maintenance, and management. Corrections were listed as the following: completely revamp the systems for training, operations, maintenance management, and quality assurance; staff the program adequately; fund the program adequately; and prove capability of safe reactor operations. No details of the exact nature of the root cause analysis are given.

A. Magistro and M. H. Panger, "Failure Analysis Seminar: Techniques and Teams," Seminar Notes for U.S. Army Armament Research and Development Command, Volume 1 (1980).

Category: Existing Protocols/Systems

This report describes the Failure Analysis Seminar Techniques and Teams (FASTT), a workshop designed for functional engineers and mid-level engineering management personnel. Root cause analysis is used in this course for confronting technical and managerial problems. It is a manager and team development course that is based on a technical report entitled "Root Cause Analysis - A Diagnostic Failure Analysis Techniques for Managers" by

Augustine Magistro, Picatinny Arsenal and Lawrence R. Seggel, US Army Missile Command.

R. M. McDonald, "Organizational Context and the Use of Accident Investigation Training," Journal of Safety Research 20, 55-60 (1989).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This article presents a discussion of the organizational variables that have an effect on accident investigation training. Its purpose was to identify those problems and conditions in the organizational environment that commonly block or impede the application of accident investigation training. 391 law enforcement trainees who had successfully completed a 2-week accident investigation course completed questionnaires that asked them to rate 29 problems/conditions in organizations. This offers information to the implementation of an accident investigation methodology.

M. B. McGehee, R. N. Armstrong and J. E. Hicks, "U.S. Army Human Error Related Data Bases," Human Error Avoidance Techniques Conference, 17-22 (1987).

Category: Existing Protocols/Systems: US Army Aircraft Investigation - CAI

The accident investigation plan used by the Army is organized in a four-phase process. Phase 1, Organization and Preliminary Examination, allows the investigation team to formulate a collective mental picture of the crash site and accident scenario. Phase 2, Data Collection, includes accumulation of all personnel, material, and records data pertinent to the accident. Phase 3, Data Analysis, determines why the accident occurred. Phase 4, Completing the Technical Report, gives findings and recommendations for accident prevention. Description of the CAI process (see Graham) is included. This process involves investigation by boards formed from three person teams from the US Army Safety Center (USASC), in Fort Rucker, Alabama, supplemented with technical personnel from the field and elsewhere (instructor pilots, flight surgeons, maintenance personnel, engineers). Prior to this article (1987) USASC maintained five aviation and two ground teams to investigate a total of sixty to seventy accidents annually. The US Army Safety Management Information System plays an important role in obtaining data during accident investigation. This article also describes the Army Safety Management Information System (ASMIS), a computerized network located at USASC.

A. L. Minkes, "The Presidential Commission on the Space Shuttle Challenger Accident: A Management Perspective," International Journal of Technology Management 3, 579-586 (1988).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management (Decision-Making Process)

The commission, set up by President Reagan, was tasked to "establish the probable cause or causes of the accident and to make recommendations for corrective or other action." This article is based on Volume 1 of the report and only focuses on some of the managerial aspects of the accident. The proximate cause of the disaster was a technical defect, but the questions to which the

Commission addressed itself were why the launch took place and what would be done to ensure that such a disaster would never be repeated. Since the launch (or any other course of action is the outcome of a decision process), a number of management features were identified: the cultural climate of NASA (a legendary can-do attitude), the problem of information and communication (quantity of information available, noise and ambiguity, information flow), effects of changing criteria (the clarification and communication of these criteria), and organizational structure (decision-making structure, communication of decisions, rules and practices).

I. I. Mitroff, T. Pauchant, M. Finney, and C. Pearson, "Do (Some) Organizations Create Their Own Crisis? The Cultural Profiles of Crisis-Prone vs. Crisis-Prepared Organizations," Industrial Crisis Quarterly 3, 269-283 (1989).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This article discussed how unconscious, unobservable factors exert a strong effect on the behavior of organizations. These factors, known as the organizational culture, are defined as "the set of rarely articulated, largely unconscious beliefs, values, norms, and fundamental assumptions that the organization makes about itself, the nature of people in general, and its environment." These unwritten rules give guidance as to what is considered acceptable. This article describes interviews with executives for the purpose of exploring the effects of corporate culture on crisis management. A model is developed of crisis prone and crisis adverse organizations. There are aspects of the organization that are easy to observe (the formal actions and policies of the organization and the organizational structure) and those that are hard to observe directly (organizational assumptions/beliefs and the core organization identity).

J. C. Montgomery, C. D. Gaddy, J. L. Toquam, C. W. Holmes, D. A. Seaver, J. T. Hauth, A. J. Scurgin and A. N. Beare, "Team Interaction Skills Evaluation Criteria for Nuclear Power Plant Control Room Crews," Technical Report Number PNL-7250-UC-500, Prepared for Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission by Pacific Northwest Laboratory (1990).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management (Team Interaction)

This research addressed the measurement of team interaction skills. Rating scales were developing using the following seven dimensions: (1) two-way communication of objectives/plant status, (2) inquiry, (3) advocacy, (4) conflict resolution and decision-making, (5) resource management, (6) stress management, and (7) team spirit. The scales will be undergoing additional work before they can be used as a tool in the field.

J. V. Moran, and M. N. Shulman, "Nuclear Plant Modification and Design Control: Guidelines for Generic Problem Prevention," Technical Report No. NP-5640 (1988).

Category: Existing Protocols/Systems: MDC - NRC and EPRI

This work was prepared by CYGNA ENERGY SERVICES in Walnut Creek, California, and funded by the Nuclear Construction Issues Group at EPRI (W.J. Bilanin - Project Manager). The purpose was to identify generic problems, causes, and solutions related to modification activities at nuclear power plants. Volume 1 summarizes and describes each element of the modification and design control (MDC) task, the generic problems, root causes, and guidelines, while volume 2 provides details of the analysis. The MDC task goal is to provide information regarding these generic problems and their causes in a form that is immediately useful in reducing them. MDC problems were identified from questionnaires completed by several utilities, discussions with utility people involved with modification activities, and violations from five years of NRC inspection reports. From these sources generic aspects of problems, their root causes, and their occurrences in the MDC process have been determined. Determination of the root causes included contacting utility sources for information as well as analyzing the problems. Analysis of 66 example problems yielded 160 specific causes; further analysis and reduction, resulted in the identification of these seven root causes: (1) inadequate procedures, (2) insufficient training activities, (3) inadequate reviews, (4) inadequate interface, (5) insufficient personnel awareness, (6) lack of clear accountability, and (7) inadequate personnel qualifications. For each root cause, guidelines were developed to address the problem. Example is given.

C. J. Mueller, and W. A. Bezella, "The Development of a Reliability program Approach to Assuring Operational Nuclear Safety," International ANS/ENS (1985)

Category: Existing Systems: RMIEP and Common Cause

Topical Meeting on Probabilistic Safety Methods and Applications.

Work performed by Argonne National Laboratory for NRC that sought to develop and demonstrate a recommended set of reliability engineering and management techniques. Briefly mentioned two initiatives addressing root cause analysis: NRC's Risk Methods Integration and Evaluation Program (RMIEP) and EPRI's common cause research program

M. W. Paradies, and D. Busch, "Root Cause Analysis at Savannah River Plant," In the Proceedings of the IEEE Fourth Conference on Human Factors and Power Plants, New York, Institute for Electrical and Electronic Engineers (1988).

Category: Existing Protocols/Systems: Root Cause Tree

In 1985 the Reactor Safety Evaluation Division (RSED) at the Savannah River Plant (SRP) began to study methods to determine and analyze the root causes of events. They created a system for analysis that incorporated the best features of several of these systems. They defined "root cause" as "the most **basic** cause that can **reasonably** be identified and that management has control to **fix**." The system begins with Events and Causal Factors (E&CF) Charting and includes a Root Cause Tree. The E&CF Charting was developed by the National Transportation Safety Board to investigate the sequence of events leading to transportation accidents. It displays a time line of the event and the immediate reasons why the event occurred (the causal factors). The investigator determines which causal factor, if removed, would have prevented the event from occurring. Each of these factors is analyzed further using the

Root Cause Analysis Tree. The tree format enables the investigator to categorize each event or causal factor in detail to its root causes (or as close as possible). There are six major levels that code the causal factor from a general cause to detailed information about the root causes.

M. W. Paradies and D. Busch, "Update: root Cause Analysis," In the Fourth Annual, NSAC/ORSERG Workshop (1987).

Category: Existing Protocols/Systems: Root Cause Tree

(See Paradies and Busch , 1988.)

M. W. Paradies and D. A. Busch, "Using a Cause Coding Tree to Identify Event Root Causes," In the Proceedings of the American Nuclear Society Annual Meeting, Dallas, Texas, June 7-11, 1987.

Category: Existing Protocols/Systems: Root Cause Tree

Describes the Cause Coding Tree. See Paradies and Busch (1988)

M. W. Paradies and D. A. Busch, "Savannah River Experience Using a Cause Coding Tree to Identify the Root Cause of an Incident," In the Proceedings of the EPRI/NSAC Annual Independent Safety Analysis Group Conference 1986.

Category: Existing Protocols/Systems: Root Cause Tree

Describes the Savannah River Plant (SRP) Cause Coding Tree. See Paradies and Busch (1988). The tree format begins with coding of an event or causal factors and proceeds down the tree as far as possible to the root causes.

M. W. Paradies, M. and D. A. Busch, "Using Operating Experience and a Cause Coding Tree to Identify Improvements for Nuclear Process Control," Presented at the Fourth Mid-Central Ergonomics/Human Factors Conference 1987.

Category: Existing Protocols/Systems: Root Cause Tree

(See Paradies and Busch, 1988.)

G. B. Parker, "Why Doesn't Aircraft Accident Investigation Prevent Accidents?" SAFE Journal 9, 5-9 (1979).

Category: Human Performance in Accident Investigation/Root Cause - Stresses

Gives justification for finding the root causes of accidents rather than the symptomatic causes. Argues that the effects of stress are not being recognized as important factors in accident causation. The four basic categories of stresses are (1) social stresses, (2) environmental stresses, (3) emotional stresses, and (4) physiological stresses. Holmes and Rahe's (1967) Schedule of Recent Experience lists forty-two social stresses, many of these are likely to be factors in accidents.

G. W. Parry, D. B. Mitchell, D. W. Whitehead, H. M. Paula and D. M. Rassmusson, "A Cause-Coupling Defense Approach to Common Cause Failures," International Topical Meeting on Probability, Reliability, and Safety Assessment.

Category: Existing Systems: Common Cause Failures

Article reviews the status and history of common cause failures (CCF); it was performed at Sandia National Laboratory and supported by NRC. Mention is

made of a report sponsored by EPRI and NRC (Procedures for Treating Common Cause Failures in Safety and Reliability Studies - NUREG/CR-4780) that describes a procedural framework for common cause failure analysis. A theme in NUREG/CR-4780 is that CCF result from some root cause of failure, a coupling mechanism or agent that results in more than one component failing, and inadequacies in administration or physical defenses against the root cause or the coupling.

N. F. Pidgeon, "Risk Assessment and Accident Analysis," Acta Psychologica 68, 355-368 (1988).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

The view taken here is that the analysis of accidents in technological systems suggests that accidents are the result of complex and systemic, human and organizational factors. These factors may not be able to be specified as an exhaustive set of failure scenarios. Three types of strategies are discussed that are useful for addressing this incompleteness in risk assessment: (1) problem structuring - in order to generate richer sets of failure scenarios, (2) incompleteness evaluation - the effort to evaluate potential incompleteness, and (3) decision for control - insurance against error by placing value on the controllability and flexibility of choice alternatives.

J. K. Plastiras, "The Application of Fault Tree Analysis to Accident Investigation," Conference on Reliability - Key to Industrial Success, 135-141.

Category: Existing Protocols/Systems: Fault Tree Analysis

Used fault tree analysis in order to quantify hardware and human factors in accidents.

J. Powell and D. Canter, "Quantifying the Human Contribution to Losses in the Chemical Industry," Journal of Environmental Psychology 5, 37-53 (1985).

Category: Existing Protocols/Systems: The Management Factor

The research was supported by the Insurance Technical Bureau and the International Oil Insurers. This paper discusses an attempt to develop a model to facilitate understanding, analysis, and prediction of the influence of individual and organizational factors on process safety. It identifies the problems with using engineering type of approaches to identify and incorporate all of the salient human factors. A tool is described for the evaluation of the contribution of human and social factors to losses arising through fires and explosions in the chemical and petrochemical industry (the Management Factor). The tool is based on the notion of the Instantaneous Fractional Annual Loss (IFAL) algorithm. IFAL is a way of assessing expected average annual financial losses arising through fires and explosions in chemical and petrochemical process expressed as a fraction of the total at risk. The authors produced a list of 50 human and social factors that may influence the occurrence of fires and explosions and their associated consequences. These were referred to as the Management Factor Items and were classified under the following general headings (1) organizational structure (e.g., identifiability of roles), (2) risk management (e.g., communication of risk to personnel), (3) manning (e.g., aspects of training, selection, satisfaction with the physical and social

environment, (4) emergency measures (e.g., emergency training), and (5) general management (e.g., working procedures). 11 different plants were visited and these ideas were discussed with individuals with experience in plant operation, safety management, or loss control. The list was revised to 46 Management Factors Items (listed in the article). Then loss control components (from the IFAL method) are introduced. These are four stages that describe loss through fires and explosions in chemical plants (such as Stage 2: The escaped substance may find a source of ignition). The control of these stages are broken down into 11 detailed physical and engineering objectives [i.e., to control ignition the two objectives are (1) control of background ignition source and (2) control of naked flame sources]. Now 6 experts are asked to rate, on a scale from 1 to 9, the relative contribution made by each of the 46 Management Factor Items to each of the 11 Loss Prevention Objectives. A multidimensional scaling technique (Smallest Space Analysis - SSA) is then applied to the expert weightings in order to obtain a geometric representation of the different variables as points in a Euclidean space. The distance between pairs of points in the space correspond to the correlations of the variables. This output enables the user to determine the relationship between the Management Factor Items.

R. B. Rayman, "Negative Transfer: A Threat to Flying Safety," Aviation, Space and Environmental Medicine 53, 1224-1226 (1982).

Category: Human Performance In Accident Investigation/Root Cause - Organization & Management

Discusses the problems involved with switching from similar systems with different designs or configurations. Minimization of this threat is possible in two ways: standardization of the environments in which operators will be required to be transferred between, and analysis of the different environments and operational requirements to ascertain differences that could cause operator error due to negative transfer.

J. Rasmussen, "Approaches to the Control of the Effects of Human Error on Chemical Plant Safety," Professional Safety 33, 23-29 (1988).

Category: Human Performance In Accident Investigation/Root Cause - Organization & Management: Cognitive Information Processing

Discusses the point that analysis of human errors must be performed in terms of cognitive information processing capabilities and limitations related to diagnosis, goal evaluation, setting priority, and planning. These mental functions are not so much influenced by external task conditions as they are influenced by individual choices. Rasmussen also makes the point that task performance should not be thought of at a stable level of training, rather that learning and adaptation during performance will be significant features of many situations. Rasmussen discusses the idea of approaching errors as occasions of human-task mismatches, rather than causes of accidents. It follows then that the task of system designers is to make error-tolerant systems, where errors are observable and can be reversed before unacceptable consequences. Rasmussen offers a taxonomy for classifying human errors (from his error reports from nuclear power plants), based on his conception of three levels of

control of human activities. At the level of skilled-based performance (automated, sensori-motor schemata) errors occur related to improper precision due to lack of one or more of the following: spatial or temporal precision, topographic coordination, or precision in using physical force. Other errors are related to systematic interference between the schema needed for the intended action and other, typically highly trained, schemata that take over control and lead to capture errors. Rule-based performance (know-how, rules-of-thumb) involves errors related to memory characteristics and mistaken alternatives. The final category (knowledge-based) is different because it goes beyond the inherent human variability to inadequate human ability to follow the variability of the system, such as during a plant disturbance. It represents the failure of an operator to switch to the rational analysis based on knowledge about the functioning of the plant that is need to perform a proper diagnosis.

J. Reason, "Managing the Mangement Risk: New Approaches to Organizational Safety," Draft paper for Workshop on Managing New Technologies
Reason, J. (1990). Managing the management risk: New approaches to organisational safety. Draft paper for Workshop on Managing, New Technologies, Bad Homburg, 3-5 May 1990.

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Reason explains his position that failures in complex systems are analogous to resident pathogens in the human body that combine with local triggering factors to overcome the immune system and produce disease. Accidents causation is viewed in the following light:

- the likelihood of an accident is a function of the number of pathogens within the system;
- the more complex and opaque the system, the more pathogens it will contain;
- simpler, less, well-defended systems need fewer pathogens to bring about an accident;
- the higher a person's position in the decision-making structure of the organization, the greater that person's potential for producing pathogens,
- local accident triggering factors are hard to anticipate;
- resident triggering factors can be identified ahead of time;
- identifying and neutralizing pathogens is likely to have a greater payoff than minimizing active failures;
- researchers are directed to establish organizational signs that indicate the safety status of a technical system.

S. R. Santilli, "Critical Interfaces Between Environment and Organism in Class A Mishaps: A Retrospective Analysis," Technical Report No: SAM-TR-80-3: U.S. Army Aeromedical Laboratory (1980).

Category: Existing Protocols/Systems: USAF

Study looked at USAF aircraft Class A (where damage cost exceeds \$200,000, a fatality occurs, or an aircraft is destroyed) where the cause has been attributed to the operator. The methodology used built on a prior methodology that had been used in a study by Roger Crewse of the AF Inspection and Safety Center,

Reports and Analysis Division (unpublished study). This study was funded by the USAF School of Aerospace Medicine (VDB) at Brooks Air Force Base in Texas. The mishaps were divided into two major categories (1) collision with ground/water/other aircraft and (2) loss of control. The categories were further divided by aircraft type. Then these categories were listed horizontally on a matrix with 34 major variables describing contributing factors on the vertical axis/ These 34 variables were derived from four sources (1) a study conducted by the US Army Agency for Aviation Safety (USAAVS) in 1973, (2) the AF form 711gA, a standard form used by the flight surgeon member of Safety Investigation Boards to identify psychophysiological and environmental causal factors of mishaps, (3) 17 second-level causes identified in the study by Crewse, and (4) the author's observation during 11 years of operational experience. The 34 variables are divided into either environment or operator. The environmental variables are further broken down into physical factors (variables that address climatology and physical limitations imposed by equipment), system factors (variables that address the degree to which the operator was prepared by the system to perform the mishap task, and task descriptive factors (variables that specify the activity engaged in at the time of the mishap). The operator variables were broken down into physical/physiological/pathological states, skill level of the operator, and psychological/psychosocial factors (variables that address limiting perceptual sets, habit patterns, or attitudes of the operator). Each of the 34 variables is defined.

P. Sommers, "A Guide to Literature Relevant to the Organization and Administration of Nuclear Power Plants," Battelle Human Affairs Research Center: Pacific Northwest Laboratory (1983).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

This report includes a review of organizational and administrative issues relevant to NPPs. and safety.

E. Stark, "Wildblue Blunders," Psychology Today 22, 30-32 (1988).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management: (Communication)

Briefly mentions the importance of better communication and teamwork for safe performance among cockpit crews. Problems such as a subordinate being hesitant to forcefully contradict a superior and crews not begin given enough time to get acquainted are described.

W. F. Stock, "Human Factors of Safety Management," Occupational Hazards 48, 57-60 (1963).

Category: Human Performance in Accident Investigation/Root Cause - Organization & Management

Looked at the four basic principles that successful organizations practice and follow. These are the principles of (1) participation (motivation increases as people are given the opportunity to participate), (2) communication (motivation increases as people are informed about matters affecting their goals), (3) reciprocated interest (people tend to be motivated to accomplish the results you want, to the extent you show interest in the results they want), and (4)

recognition (motivation increases as people are given recognition for their contributions). Other factors that were examined are reinforcing safe behavior; giving people the capacity to grow, achieve, and utilize their abilities; and getting a psychological profile of people to understand their unique ways of dealing with each other.

R. Tarbell, "Gaining Safety Success," Professional Safety 31, 18-21.

Category: Human Performance In Accident Investigation/Root Cause - Organization & Management: Common Goals

One way to reduce accidents is to ensure that people are motivated to control accidents. The means to this end is to ensure that management and workers share the same goal.

C. I. Thompson, "Investigating the Carless Act," Professional Safety 34, 39-41 (1989).

Category: Human Performance In Accident Investigation/Root Cause - Physical and Mental Incompatibilities

Discusses the concept that people commit careless acts due to becoming "out of sync with" their immediate task as a result of physical and mental limitations or a combination called chemical impairment. The causes of Physical Incompatibilities are congenital defects, prior injury or illness, mechanical strength, anatomical dimensions, manual dexterity, environmental extremes, and personal habits. Mental Incompatibilities causes are ignorance, retention, attention span, aptitude, stress, awareness, and attitude. Various controls are given for the causes.

W. A. Wagenaar, J. Groeneweg, "Accidents at Sea: Multiple Causes and Impossible Consequences," International Journal of Man-Machine Studies 27, 587-598 (1987).

Category: Existing Protocols/Systems

This study analyzed 199 accidents at sea and classified human errors according to a categorization proposed by Feggetter (see Feggetter, 1982). The authors present a description of the construction of causal networks used for the schematization of scenarios leading to accidents. Events are connected by logical AND-gates and OR-gates leading from the root causes of the accident to the event. Next the human errors are classified according to the categorization proposed by Feggetter.

T. M. Wu and S. L. Hwang, "Maintenance Error Reduction Strategies in Nuclear Power Plants, Using Root Cause Analysis," Applied Ergonomics 20.2, 115-121 (1989).

Category: Existing Protocols/Systems

Used the Human Error Classification (HEC) approach to look at root causes for maintenance errors in NPPs in Taiwan. A conceptual model of maintenance tasks was used to describe the overall operational process of maintenance tasks. Four major categories of error causes were identified (1) human ability limitations (e.g., perceptual limitations), (2) design deficiencies in hardware and software (e.g., insufficient communication equipment), (3) disturbances of the external environment (e.g., temperature, illumination), and (4) induced

circumstances (e.g., momentary distractions, emergency situations). A classification scheme consisting of one external classification level and one internal classification level was developed. Under each extrinsic error cause, it is assumed that a set of causes on the internal level may induce human error. Extrinsic error causes are characterized into six categories, according to historical event types (see article for categories), and five categories of internal classification for error contributions, based on the previous four error causes. Internal and external factors are presented in a matrix and frequencies are accumulated.

APPENDIX B

**HUMAN PERFORMANCE
INVESTIGATION PROCESS
(HPIP)**

**Evaluation of Major
Root Cause and
Human Performance
Evaluation Systems**

March 1991

by

**System Improvements, Inc
and
Concord Associates, Inc.**

APPENDIX B

EVALUATION OF MAJOR ROOT CAUSE AND HUMAN PERFORMANCE ANALYSIS SYSTEMS

1. INTRODUCTION

Collecting, assessing, and developing human performance and root cause analysis techniques was a major part of the development of HPIP. This work included a computerized literature review (see Appendix A), interviews with human performance and root cause analysis experts (see Table 13.4), and attending meetings on root cause analysis (see Table 13.4).

The original method envisioned for evaluating the techniques and selecting the final candidates for inclusion in HPIP was to develop a numerical rating system based on the system development criteria. However, after beginning development of the HPIP, it became obvious that the techniques and the process were so tightly coupled that one technique couldn't be rated without consideration of how it fit with the other techniques and the process in general. Therefore, a more qualitative review was performed (summarized here) that considered the particular technique and how the technique supported the HPIP process and other potential techniques in the process, as well as how well the technique individually met the system development criteria.

Therefore, by quickly reviewing the many techniques and using the system development criteria and the team members' experience, the many possible candidate techniques were reduced to nine that were the most applicable for adoption in HPIP. These nine techniques were then more closely examined and evaluated. Summaries of the reviews of the nine techniques are contained in this Appendix. The nine techniques are:

- ☐ Barrier Analysis
- ☐ Change Analysis
- ☐ Events and Causal Factors Charting
- ☐ HSYS
- ☐ INPO Root Cause Analysis Methodology
- ☐ Kepner Tregoe
- ☐ MORT
- ☐ Root Cause Tree™
- ☐ Technic of Operations Review (TOR)

The following nine summaries include:

- ☐ brief description of each technique,
- ☐ comments on the use and acceptance of the technique, and
- ☐ the advantages and disadvantages for incorporation of the technique into HPIP.

After completing these reviews, the following techniques were selected for use in HPIP:

- Barrier Analysis
- Change Analysis
- Events and Causal Factors Charting
- Root Cause Tree™

The HPIP Centerfold demonstrates the way in which these techniques are woven into the fabric of HPIP.

2. BARRIER ANALYSIS

2.1 Background

Barrier analysis (Reference 1) embodies the basic concepts of MORT and supports the overall MORT assessment. In MORT, an incident is an event for which a barrier to an unwanted energy flow is inadequate or fails without loss or consequence, and an accident is an unwanted flow of energy or exposure to an environmental condition that results in adverse consequences. Thus the analysis of actual and potential barriers is an inherent part of the MORT process of event/accident investigation. Barrier analysis provides systematic guidance for the analyst to examine the basic ingredients of an accident, which in the MORT philosophy are:

- The energy flow or environmental condition that does the harm;
- The vulnerable people or objects that can be hurt by that energy flow or environmental condition;
- The failure or lack of barriers and controls that are designed to keep them apart;
- The events and energy flows that lead into the final accident phase.

2.2 Approach

Barrier analysis begins with an identification and assessment of the potentially harmful energy flow or environmental condition that resulted in or was associated with the accident. The analyst is guided by a series of questions through a flow chart (see Figure B.1), which helps structure her assessment of both "functional" (related to the process) or "nonfunctional" (external to the process) energy sources or environmental conditions and determine whether controls or diversion were adequate or practical.

Barriers to wanted and unwanted energy flows are then identified and analyzed for adequacy using questions and the flow chart in Figure B.2. Generally, barriers to wanted flows are controls - approved work methods, training, basic design features, etc. Barriers to unwanted flows are safety devices or measures such as protective equipment, safety training, or emergency planning. Barrier characteristics of importance are the following:

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Figure B.1 Harmful Energy Flow or Environmental Condition

INEL 3 1308

Figure B.2 Barriers and Control

○ Function

- Prevention
- Control
- Minimization

○ Location

- Between source and worker
- On worker
- Separation through time and space

○ Type

- Physical barriers
- Equipment design
- Warning devices
- Procedures/work processes
- Knowledge and skill
- Supervision

Possible problems or limitations of barriers that are examined to identify causal factors generally are one of three types: barriers being non-existent because they are impractical, barriers failing, or barriers practical but not provided or not used.

Given the characterization of the energy flow or environmental condition and of the actual or potential barriers, the analyst is then guided through an assessment of vulnerability. The flow chart shown in Figure B.3 is used to determine the vulnerable targets of the energy flow or environmental hazard. These targets, like the energy flow or environmental condition, may be functional (related to the process/system) or nonfunctional (external to the process/system, such as the general public). The purpose of the assessment is to identify the specific targets and how they might have been protected, i.e., how impact may have been avoided or controlled.

The final step in the barrier analysis is to identify and examine the precursors to the energy flow or environmental condition specifically associated with the accident or incident. What events, energy flows, and barrier failures preceded the specific ones under assessment, which were necessary for the accident/incident to occur?

2.3 Summary Evaluation

Barrier analysis has its basis in human factors concepts associated primarily with personnel or industrial safety, and application in that context is more readily visualized than in process safety. However, the basic concepts are clearly valid for both, and the thought processes involved are very useful for assessment of reactor events using HPIP. These basic concepts have

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Figure B.3 Vulnerable People or Objects

been adopted, though the specific guidance in the form of questions and MORT flow charts has not.

2.4 Primary Reference(s)

1. W. A. Trost and R. J. Nertney, MORT document "Barrier Analysis", DOE 76-45/29, System Safety Development Center, EG&G Idaho, Inc., July, 1985.

3. CHANGE ANALYSIS

3.1 Background

Change Control and Analysis (Reference 1) is a part of the MORT program and family of tools for safety program assessment and accident investigation. It is based on the simple, essentially intuitive, concept that in order for a safety problem to exist or accident to occur some change to the normal functioning of the system must have occurred, and that therefore investigation of any change that has taken place can be fruitful for determination of causes of problems and identification of remedies. Change control is carried out by monitoring the system for changes and assuring that potential safety impacts of changes have been identified and appropriately assessed. Change analysis for accident investigation requires comparison of an accident-free reference base to the accident situation and systematically searching out and assessing changes pertinent to the accident.

3.2 Approach

There is not a rigid structure or detailed prescriptive process for change analysis. In Reference 1, MORT provides a suggested format for a "Change-Based Accident Analysis Worksheet". (See Figure B.4). The worksheet lists 25 factors associated with the system hardware, procedures, personnel, work situation, etc. that should be examined for changes with potential significance to the accident. However, MORT guidance to the analyst is to consider the form flexible and to add to it or adapt it as appropriate. Conceptually, the process is to simply consider each factor as it is in the present (post-accident) situation, compare it to the situation prior to the accident, identify differences, and then assess those differences to determine whether a causal mechanism is suggested or a safety problem identified. The MORT authors stress the importance of first listing all of the changes, without evaluating their importance, and then analyzing the differences both independently and collectively. This is because combinations of seemingly insignificant changes can produce a significant effect. Change analysis is complementary to and supports an overall process such as the MORT tree or Root Cause Tree™. For example, Figure B.5 illustrates incorporation of the results of change analysis into a sequence diagram of an accident.

Change-Based Accident Analysis Worksheet

Subject _____

Factors	Present Situation?	Prior, Comparable?	Differences?	Allective Changes?
What Object(s) Energy Defects Protective Devices				
Where On the Object In the Process Place				
When In Time In the Process				
Who Operator Fellow Worker Supervisor Others				
Task Goal Procedure Quality				
Working Conditions Environmental Overtime Schedule Delays				
Trigger Event				
Managerial Controls Control Chain Hazard Analysis Monitoring Risk Review				

Figure B.4 Change-Based Accident Analysis Worksheet

SEQUENCE DIAGRAM

WBL-5-10 308

Figure B.5 Sequence Diagram with Change Analysis Incorporated

3.3 Summary Evaluation

Change analysis is a very useful and effective technique to be included in the set of tools for accident investigation. It helps to focus collection of data during the early stages of the investigation and helps identify potential causes for further investigation. The concepts and application are extremely simple and do not require extensive training. And the format is flexible and readily adapted to the individual circumstances of the event and experience of the investigator. Finally, the documentation can be used directly in the final report and is readily understandable by managers or reviewers not trained in root cause analysis. Change analysis has been included in the recommended techniques for HPIP, though it is not considered a "requirement" for every investigation.

3.4 Primary Reference(s)

1. M. G. Bullock, "Change Control and Analysis," DOE 76-45/21, SSDC-21, EG&G Idaho, Inc., March, 1981.

4. EVENTS AND CAUSAL FACTORS CHARTING

4.1 Background

Events and Causal Factors Charting was originally developed as an accident investigation tool by the National Transportation Safety Board (NTSB), based on concepts originated by Benner (Reference 1). It is designed to aid identification of the important events in an accident sequence and the factors causing those events, and to depict the sequence, events, and causal factors in a simple diagrammatic form. While the technique may be used by itself to identify root causes, it more commonly has been incorporated as one of a set of tools or techniques in a broader scoped accident investigation approach. Both MORT and INPO's HPES, for example, incorporate Events and Causal Factors Charting and provide training on the technique.

4.2 Approach

There are two basic principles identified by Benner that underlie Events and Causal Factors Charting:

- 1) Accidents are the results of a set of successive events that produce unintentional harm (i.e., personal injury or property damage).
- 2) The accident sequence occurs during the conduct of some work activity.

The essence of Events and Causal Factors Charting, then, is simply to identify and document the sequence of events that was occurring in the work activity from the beginning to the end of the accident, and to identify the factors - conditions, failed barriers, energy flows, etc. - that contributed to the unintentional harm.

Events and Causal Factors Charting should begin very early in the event investigation, as soon as factual information is received. Indeed, it will help organize the information that is received and guide the investigation in a logical systematic manner. It is complemented by and interactive with change analysis and barrier analysis, and supports a causal analysis using a tree structure such as MORT or the Root Cause Tree™.

There have been various forms of events and causal factors diagrams. While the particular choice of construction rules or symbol convention is not important, it is important to have them. The rules and convention need to be simple, clearly documented, and readily understood by analysts, users of the investigation report, and those involved in the accident who may be interviewed. They should be viewed as guidelines and not be overly prescriptive. The diagram is an aid to communication and is itself a useful form of presentation of findings in the final report. An example of an events and causal factors chart reproduced from Reference 2 is shown in Figure B.6. The MORT convention for symbols is as follows:

- Events are enclosed in rectangles; conditions in ovals.
- Events are connected by solid arrows.
- Conditions are connected to each other and to events by dashed arrows.
- Events and conditions that are not based on valid factual evidence are indicated as presumptive by using dashed lines, rectangles, or ovals.
- The primary sequence of events is depicted in a straight horizontal line with events joined by bold printed connecting arrows.
- Secondary sequences, contributing factors, and systematic factors are depicted on horizontal lines at different levels above or below the primary sequence.
- Events are arranged chronologically from left to right.
- Events are tracked in a logical progression from the accident initiation to preaccident, to accident, to amelioration, and include all pertinent occurrences. This implies that a clear beginning and end of the sequence be defined by the analyst.

Guidance on the use of Events and Causal Factors Charting from the MORT program includes the following:

- Each event should describe an occurrence or happening and not a condition, state, circumstance, issue, conclusion, or result.
- Each event should be described by a short sentence with one subject and one active verb.

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Figure B.6 Events and Causal Factors Chart Example

- Each event should be precisely described.
- Each event should describe a single, discrete occurrence.
- Each event should be quantified when possible.
- Each event should be derived directly from the event and conditions preceding it.

4.3 Summary Evaluation

Events and Causal Factors Charting is a versatile and extremely useful tool for accident investigation. It provides a systematic process for an analyst to collect data, order information logically and chronologically, and identify all of the factors that need to be investigated. It helps identify multiple causes, which is important since most significant accidents are the result of multiple problems or failures, not single causes. With little training, the diagram can be used as a basic tool for communication about the accident sequence, events and causal factors. And the diagram can be a very effective part of the documentation and reporting on the accident and the investigation process. The technique is more effective when used in conjunction with one of the more detailed logical trees, because the trees give more specific guidance for digging deeper into the causal factors and determining the one or few root causes.

4.4 Primary Reference(s)

1. Ludwig Benner, Jr., "Accident Investigations: Multilinear Events Sequencing Methods," Journal of Safety Research 7, 2, 1975. (Cited in Reference 2 below)
2. J. R. Buys and J. L. Clark, "Events and Causal Factors Charting," DOE 76-45/14, (SSDC-14) Rev. 1, EG&G Idaho, Inc., August, 1978.

5. **HSYS**

5.1 BACKGROUND

HSYS (Reference 1) was developed at Idaho National Engineering Laboratory (INEL) for the NRC as a methodology for analyzing human performance in technologically complex, operational settings. It was originally developed to investigate incidents and accidents involving human performance deficiencies, but its developers indicate it is also suited for operational and design assessments not related to a specific event. It is a fairly extensive diagrammatic tool (approximately 45 pages of flow chart or "tree") plus associated guidance (approximately 72 pages of questions and 9 pages of definition of terms) to aid the analyst in tracing through the tree. During validation efforts, it was recognized that a more abbreviated form would be easier to use for specific event investigation. An abbreviated form was developed, which is intended to lead the investigator to identify items requiring more detailed investigation.

HSYS is relatively new and has not yet received significant use in actual practice.

5.2 Approach

The HSYS concepts and tools are all built around a simple model of human performance that treats all human performance as consisting of five sequential components:

- Input Decision
- Understanding of Input Meaning
- Action Selection
- Action Planning
- Action Execution

The model asserts that all five components of human performance are required, to varying degrees, are involved in any specific human performance, and must be successful if the human performance is to be successful. Thus, successful human performance can be represented by an **AND** gate for all five components, or conversely, inadequate human performance can be represented by an **OR** gate for failure of any one of these five components. This model, then, is extended throughout and undergirds the diagrammatic analysis tools. Each element of the model is expanded to subcomponents that are also necessary and sufficient elements of successful human performance.

For example, "Input Detection" consists of "Attention", "Input Recognition", and "Input Discrimination". This is represented with Input Detection at the top of an **AND** gate associated with the three subelements. Similarly, "Understanding of Meaning" consists of "Generation of Explanations", "Evaluation of Explanations", and "Selection of Explanations". The HSYS tree is constructed by breaking down these five categories hierarchically to lower levels using **OR** gates and asking questions to determine if any of the subelements is less than adequate (LTA). There may be multiple levels in the hierarchy (typically 3-6 levels), and each box under each level has a question associated with it for the analyst. Frequently, the lower levels can be expanded by use of "modules" that are common to many subelements. These are some 20 of these modules that can be used repetitively. Figure B.7 illustrates the hierarchical structure of the HSYS for the path: Human Performance Less Than Adequate (LTA); Performance of Action LTA; Action Control LTA; etc.

5.3 Summary Evaluation

HSYS appears to be a fairly comprehensive structure for guiding a human factors analyst systematically through an "interactive" assessment of actual or potential human performance problems. It is based on a straightforward and logical model of human performance that provides a reasonable theoretical

Figure B.7 HSYS Hierarchical Structure Example

structure. While we have not tried to exercise the model in the field, we have tried to informally talk-through a "hypothetical" analysis with experienced event investigators. The diagrammatic tools appear to be rather cumbersome to use.

Also, while the "theoretical" basis in the simple five-element model is attractive, the investigative questions in practice sometimes appear to be focused too much toward a theoretical description of human performance rather than an operational view. Thus, the analysis will likely require considerable experience in human factors and practice. The extensive breadth and depth of the trees are desirable for a more theoretical understanding of the human performance involved; however, they lead to a system that appears to be difficult to use in a field environment. And it does not appear that the rather strict constraints on training time identified in the needs analysis could be met. The general concept of the five-element human performance model (which, in fact, is essentially a representation of the well-established Stimulus, Organism, Response paradigm) does provide a reasonably practical theoretical base for the tools. It was one of the stimuli for development of the SORTM screening tool for HPIP.

5.4 Primary Reference(s)

1. J. L. Harbour and S. G. Hill, "HSYS A Methodology For Analyzing Human Performance in Operational Settings," EGG-HFRU-8806, INEL, 1990.

6. INPO ROOT CAUSE ANALYSIS METHODOLOGY (HPES)

6.1 Background

In response to the industry's need for a systematic process to investigate human performance problems in nuclear plant operation, the Institute of Nuclear Power Operations (INPO) developed the Human Performance Evaluation System (HPES)(Réference 1). It is a non-punitive, self-reporting system that attempts to identify underlying causes of actual or potential human performance errors or problems and means for improving safety and effectiveness of operations by eliminating those underlying causes. Over the past several years a considerable number of utility personnel have been trained in the HPES approach and techniques, and the system has gained fairly wide acceptance at utilities.

HPES is the central element of INPO's recommended practice in root cause analysis, though INPO's guidance (Reference 2) recognizes a number of techniques and does not necessarily prescribe use of HPES. Other techniques included are Events and Causal Factors Charting, Fault Tree Analysis, Change Analysis, and Barrier Analysis. However, these techniques are discussed individually elsewhere in this report except in the case of Fault Tree Analysis which is a generic technique not peculiar to root cause analysis, therefore, they are not discussed further below.

A general overview of the INPO recommended good practice for root cause analysis is provided below, but the discussion focuses on HPES. INPO provides support for individual utilities who wish to use HPES, but does not

make HPES or data/information from the system available to other parties, including the NRC. Information summarized below is based on INPO descriptive documents obtained through various informal industry sources and has not been reviewed or verified by direct communication with INPO or participating utilities.

6.2 Approach

The intent of the INPO root cause analysis methodology is both to identify specific root causes of performance problems and to develop corrective actions that will prevent recurrence of the problems. As noted above, the methodology employs various techniques that have been used by others in root cause analysis, but is centered around use of HPES, certainly for human performance problems. There are seventeen general causal factors identified in HPES, twelve of them related to human performance:

☐ Verbal Communication	☐ Written Procedure and Documents
☐ Man-machine Interface	☐ Environmental Conditions
☐ Work Schedule	☐ Work Practice
☐ Work Organization/Planning	☐ Supervisory Method
☐ Training/Qualifications	☐ Change Management
☐ Resource Management	☐ Managerial Method

Part of the guidance provided to utilities is how to determine when to perform a root cause analysis. Since there are many events that can occur during the routine operation of a complex facility such as a nuclear power plant, and root cause analysis can require significant resources, this guidance for a "threshold" for event investigation is useful for utilities. The analysis process has five basic steps or phases:

- (1) Collect Data
 - Data Collection
 - Data Review
- (2) Assess
 - Event analysis
 - Root cause determination
 - Validation of root cause
- (3) Correct
 - Identification, review, and implementation of corrective action

- (4) Inform
 - Internal communication
 - External notification (if required or of value to industry)
- (5) Follow-up
 - Effectiveness review to ensure problem is fixed and is not recurring.

Reference 2 provides general guidance, recommended techniques, and some additional references (primarily HPES documentation) for accomplishing each of these phases. The major portion of methodology description is the five techniques recommended for event analysis: event and causal factors charting, fault tree analysis, change analysis, barrier analysis, and HPES. By far, the bulk of this guidance is that on HPES. There are seventeen causal factor worksheets, one for each major causal factor identified for human and equipment performance problems. An example of a causal factor worksheet, for Verbal Communication, is provided in Figure B.8. Each sheet can address up to four performance problems associated with the event and requires/aids the investigator(s) to:

CAUSAL FACTOR WORKSHEET

A. Verbal Communication - The spoken presentation or exchange of information.

☐ Applicable ☐ Not Applicable

1. Communication Type	I	II	III	IV
a Face-to-face				
b Telephone				
c Intercom or page				
d Hand signal				
e Radio/headset				
f Other (specify)				

2. Intended Function	I	II	III	IV
g Shift/job turnover				
h Pre-job briefing				
i Job performance				
j Post-job follow-up				
k Other (specify)				

Why was communication a cause?

Rate (1, 2, 3) each contributing factor:

- 1 = Primary
- 2 = Secondary
- 3 = Possible

3.		I	II	III	IV
a	Pre-job briefing not performed/completed				
b	Consequences of potential error not discussed before starting work				
c	Notification not made/required when job began, was interrupted, or was completed				
d	Shift turnover not performed/completed				
e	Supervisor not notified of suspected problem				
f	Pertinent information not transmitted				
g	Information sent but not understood				
h	Inaccurate message transmitted				
i	Too much unfamiliar information presented at once				
j	Information communicated too late				
k	No means of communication available				
l	Inadequate/malfunctioning communication equipment				
m	Improper use of communication equipment				
n	Not properly coordinated with change implementation				
o	Interpretable/non-standard language used				
p	Receiver not listening to sender				
q	Much of the information provided exceeded receiver's needs				
r	Priorities of assigned tasks not discussed				
s	Other (specify)				

Recommended Corrective Actions:

Figure B.8 HPES Causal Factor Worksheet Sample

- indicate whether that factor is applicable or not applicable;
- identify and document some basic information about the nature of the problem, design features, conditions, etc. involved in the event;
- indicate whether each of a number of sub-factors was a primary, secondary, or possible contributing factor; and
- document recommended corrective actions.

Several sheets are provided to document an executive summary of the analysis including event identification information, a brief narrative event description, identification of human and/or equipment performance problems, a longer chronological description of the event sequence, a summary of key factors influencing the human/equipment performance, a summary of causes, proposed corrective actions, and any additional comments by the evaluator. This executive summary, plus the causal factors worksheets, provide fairly thorough summary documentation of the HPES analysis for informing and notifying others of the event or problem.

6.3 Summary Evaluation

The INPO root cause analysis methodology, especially with the inclusion of the four techniques in addition to HPES, is certainly one of the most comprehensive systems available. It is heavily supported (for participating utilities) with training, guidance, and advisory services from INPO. The causal analysis worksheets are relatively easy to follow and provide guidance for a reasonably detailed assessment and identification of causal factors. The other elements of the system, such as general guidance for assessing effectiveness of recommended corrective actions are not sophisticated, but could be of some use to NRC investigators. The guidance for identifying a threshold of when a root cause analysis should be done may be of particular interest for NRC to develop comparable guidance for its own purposes. That would involve a number of organizations within NRC with different needs for information from root cause analysis, as well as inspectors. It has not yet been included as part of this effort.

Technically, the primary drawbacks to HPES from the point of view of NRC's needs are: (1) the amount of material required to be handled to complete the causal factor analysis, which makes it somewhat awkward for field use, and (2) the fairly extensive training required for evaluators, which would not be possible for NRC inspectors. It should be noted that we do not necessarily consider the latter point a criticism of the INPO method for its users and intended purposes. Ideally, NRC inspectors will also have more in-depth training, and the approach being taken is to develop modular training that can be provided over an extended period of time. The point is that the constraints on HPIP identified in the needs assessment regarding minimal training are very real ones that needed to be addressed in the design of HPIP.

Regardless of technical adequacy or problems, adoption of the HPES system by NRC, e.g., training of NRC inspectors and direct use of INPO documentation is not possible because of restrictions placed by INPO on use only by utilities.

6.4 Primary Reference(s)

1. "Human Performance Evaluation System Coordinator Manual," INPO 86-016, Institute of Nuclear Power Operations, Atlanta, GA, 1986.
2. "Root Cause Analysis," Good Practice OE-907, INPO 90-004, Institute of Nuclear Power Operations, Atlanta, GA, January, 1990.

7. **KEPNER TREGOE**

7.1 Background

Kepner Tregoe is an overall approach to problem solving and part of a broader philosophy of "rational" management that addresses much broader issues than root cause analysis. Developed by Charles H. Kepner and Benjamin B. Tregoe from their research work in the late 1950s and early 1960s, the concept of "the rational manager" was described in Kepner and Tregoe's 1965 book by the same name. Thousands of people have since received Kepner Tregoe training, and the techniques, presumably, are in widespread use. In their more recent book, *The New Rational Manager* (Reference 1), Kepner and Tregoe updated their work based on feedback from many organizations that have used their concepts and techniques, and they emphasize application on an organization-wide basis rather than for individual managers alone.

7.2 Approach

The essence of rational management is "making full use of the thinking ability of the people in an organization". Consistent with this overall philosophy, the Kepner Tregoe techniques deal with basic patterns of thinking and provide guidance to aid systematic thinking. These patterns of thinking are reflected in basic kinds of questions asked by managers:

- **What's going on?** (Clarification)
- **Why did this happen?** (Cause-and-effect)
- **Which course of action should we take?** (Choice among alternatives)
- **What lies ahead?** (Assessment of what might happen)

The Kepner Tregoe approach includes four basic processes:

- (1) **Problem Analysis.** Problem analysis aids in the explanation of "any situation in which the expected level of performance is not being achieved and in which the cause of the unacceptable performance is

unknown." The basic pattern of thinking is "cause and effect" - a problem is a visible effect of some cause(s) that reside in the past. Problem analysis is the Kepner Tregoe process most directly aligned with root cause analysis in HPIP, and is discussed further below.

- (2) **Decision Analysis.** Decision analysis provides systematic guidance through the process of making choices. It consists of four elements: (1) Decision Statement - recognizing that a decision must be made and clearly identifying what the decision is; (2) Statement of Objectives - criteria for what the decision is to accomplish, "musts" and "wants"; (3) Identification of Alternatives, and (4) Assessment of Consequences - identifying potential adverse consequences and addressing them before a final decision is made.
- (3) **Potential Problem Analysis.** Potential problem analysis involves identification and evaluation of problems that may occur in the future and identification of actions in the present that will avoid problems. With regard to HPIP, it can be especially useful in the evaluation of utility corrective actions to help structure thinking about problems that may be introduced if a proposed remedy is implemented. Potential problem analysis involves four basic activities: (1) identification of vulnerable areas of plant operation, systems, procedures, etc. that are associated with the proposed action; (2) identification of specific potential problems within those vulnerable areas that merit action now; (3) identification of likely causes of potential problems and of actions to prevent them from occurring; (4) identification of contingency actions if preventive actions are infeasible or ineffective.
- (4) **Situation Appraisal.** Situation appraisal is an evaluative technique that helps to assess a problem or complex situation and to select and structure the use of the three analytical techniques above. It provides a systematic way of recognizing concerns, separating concerns into manageable components, setting priorities, and planning resolution of concerns. Generally, situation appraisal corresponds more to thought processes of NRC diagnostic type investigations rather than event investigations.

As indicated above, problem analysis is the Kepner Tregoe process most directly related to root cause analysis. It includes five basic types of techniques, or process steps:

- (1) **Definition of the problem, or statement of the deviation.** The problem must be clearly defined and precisely stated before it can be solved. In root cause analysis thorough identification of event conditions must be obtained from interviews and event reports in order to identify specific human/equipment performance problems.
- (2) **Description of the problem.** The problem definition is expanded with specific information that will begin to lead to identification of

possible causes. Kepner Tregoe emphasizes the four dimensions of description:

- **Identity** - exactly what is the deviation that requires explanation
- **Location** - where was it observed
- **Timing** - when did it occur
- **Magnitude** - how serious, how extensive is it

To crystallize the problem description and aid analysis, the description is further broken into statements of what it **IS**, what it **COULD BE**, and what it **IS NOT** in terms of the four dimensions above. This systematic process of defining and describing the problem, explicit consideration of what related problems there could be, and what clearly is not the problem aids in rigorous problem assessment and often leads directly to identification of potential causes.

- (3) **Extraction of key information to generate possible causes.** The purpose of the above problem description approach is to aid thought processes that will identify possible causes for the deviation. In general, this requires some way of noting something different between what is and what is suppose to be - some distinction or discrimination. What is different about the particular equipment or human performance, this time, in this location, in degree of deviation - that could have caused the problem to occur or become evident in this case when it hasn't before. The **IS/COULD BE/IS NOT** comparison is intended to help draw these distinctions. Another approach is to focus on **changes**. What has changed in the system that is relevant to this deviation? Change analysis, which is commonly used in root cause analysis systems is discussed in Section 3.2.2 of this report.
- (4) **Testing for most probable cause.** In the generation of possible causes, it is important to be inclusive, important not to eliminate a possible cause prematurely. In this stage, possible causes are systematically excluded by a simple "If/Then" questioning. "If this is the true cause of the problem, **then** how does it explain each dimension in the specification?" The "true cause" must explain each and every aspect of the deviation, since it was the cause of the exact effect observed.
- (5) **Verification of the true cause.** Verification involves testing, physically if possible but at least analytically, to verify the cause and effect relationship of the cause identified and the effect observed.

7.3 Summary Evaluation

Kepner Tregoe approaches are logical, basic approaches to problem solving that have stood the test of time and are widely recognized and accepted. There is some direct relevance to the NRC root cause analysis needs, particularly in the problem analysis technique. The presumed strength of Kepner Tregoe is that it addresses analysis and resolution of problems in a "rational" way that are believed to be consistent with the way that managers "naturally" think about problems. Whether or not this is true, i.e., that this is the way that managers solve real problems, is, we believe, an open issue for cognitive science research. Kepner and Tregoe cite considerable experiential evidence that their approach and techniques have been used effectively by many different organizations, and this certainly appears to be the case.

The problem in adaptation of Kepner Tregoe to the specific needs of NRC is directly related to its strengths. Because it is dealing with basic thinking processes rather than prescriptive guidance, it is presented at a very general level. Concepts are simple and have strong intuitive appeal. But effective application requires considerable experience, often by trial and error. This is true in general of root cause analysis and has been addressed in different ways in different systems. Clearly a tradeoff exists. If the process of analysis, which can involve complex analytical thought and which is strongly dependent on the specifics of the situation, is formalized and documented to be comprehensive, the tools and techniques can become unmanageable and will not be used. If the guidance is too general or high level, it will be used (and probably is inherently used) by experienced investigators but will not be adequate to assist the investigator who is not already an expert. Our assessment is that HPIP can (and has) benefited from application of the concepts of Kepner Tregoe, but that more specific guidance and analysis aids are required.

7.4 Primary Reference(s)

1. Charles H. Kepner and Benjamin B. Tregoe, The New Rational Manager, Kepner-Tregoe, Inc., Princeton, NJ, 1981.

8. **MORT**

8.1 Background

The Management Oversight and Risk Tree (MORT) (Reference 1) was developed by Idaho National Engineering Laboratory (INEL) in the early 1970s for the Department of Energy (DOE). It was patterned after and intended to capture and adapt the essential concepts of system safety pioneered by National Aviation Safety Association (NASA) and the the Department of Defense (DOD). While the heart of MORT is the analytical "logic tree" designed to guide an analyst through a systematic assessment of an event or problem, it is broader in scope and includes:

- A schematic representation of a dynamic "idealized" safety system model by using Fault Tree Analysis methodology and symbols.
- A methodology for analyzing an existing safety program by evaluating the adequacy of implementation of the individual system safety elements in comparison to the "idealized" model.
- A philosophy and general guidance for broad application of MORT system safety concepts and criteria for assessment of effectiveness of their implementation.

An integral part of the DOE program with MORT is presentation of seminars (five-day for the full course on the tree), and many seminars have been conducted throughout the DOE system and elsewhere since the inception of MORT. Therefore, there is fairly widespread familiarity with the concepts and tools of MORT in the community of potential users. The extent of actual usage of MORT for root cause analysis in the nuclear industry is not known (at least to the authors of this report).

The MORT tree itself is broader in scope than root cause analysis, but since it is the part of MORT most pertinent to the objectives and scope of NRC's needs, it is summarized in a little more detail below.

8.2 Approach

The MORT tree is a logic diagram that embodies the concepts and philosophy of MORT and can be used as a "master work sheet" to analyze either a specific event or an existing safety program. The tree encompasses 1500 "basic events", and nearly 100 different "generic problems" in broader areas of management and accident prevention. Central concepts to MORT are "barriers" and "change analysis."

8.2.1 Basic Concept

In MORT, an incident is defined as a Barrier-Control inadequate or failure without consequence. An accident is defined as unwanted flow of energy or environmental condition that results in adverse consequences.

It is central to MORT's philosophy that an accident occurs because of lack of adequate *barriers* and/or *controls* upon the unwanted energy transfer associated with the incident. There are usually multiple factors involved, but an accident is usually preceded by initiating sequences of planning errors and operational errors that produce failures to adjust to *changes* in human factors or environmental factors. The failure to adjust satisfactorily leads directly to unsafe conditions and unsafe acts that arise out of the risk associated with that activity. The unsafe conditions and unsafe acts, in turn, provoke the flow of unwanted energy. Thus "barrier analysis" and "change analysis" are critical techniques to implementation of the MORT tree. These two techniques have been summarized previously.

The MORT tree is intended to guide the analyst through a very detailed trace of the unwanted energy sources, along with consideration of the adequacy of the barriers provided. Particular attention is focused on any system changes, both planned and unplanned. Whenever a change is detected, more in-depth change analysis is suggested. Change analysis is intended to assist the analyst in determining whether changes are needed in a stable operational system, or whether changing the operational system requires safety-related counter-changes. For investigation of specific accident events change analysis can provide strong indication of a potential causal factor.

Another basic concept of MORT is that of defined risk acceptance at the appropriate level of management, as opposed to the undefined risk due to oversights and omissions. MORT recognizes that there is inherent risk in any endeavor, and that a critical part of good management is deciding which risks or what level of risk to accept. Thus not every identified change-related risk requires a safety-related change in the system.

8.2.2 Construction of the MORT Tree

Figure B.9, reproduced from the MORT User's Manual (Reference 1), summarizes the highest level, or TREE TOP of the MORT diagram. There are three main branches - Specific and Management (S/M), Oversight and Omissions, and Assumed Risks (R).

R factors can be listed only if they have been analyzed and accepted by the proper level of management. Unanalyzed or unknown risks are not considered Assumed Risks.

M factors are shown separate from the analysis of the process system and the specific event. Examination of general features of the management system may suggest particular aspects of the specific event that may need to be examined more closely. And, conversely, examination of the particular event may suggest more general problems with the management system.

Development of the S branch is keyed to the specific system/process and the specific event, but also to the time sequence of events. Left to right is earlier to later in the sequence, and bottom to top of the tree shows causal sequence from the basic detailed causes to generic causes.

The analyst develops the tree by answering specific questions based on information available from documentation and interviews about the event or about the safety program. Starting at the top of the diagram with the actual loss resulting from an accident (or potential loss for a programmatic evaluation), the analyst considers each branch in turn. Detailed consideration of the S branch is accomplished by reasoning backward in time through several sequences of contributing factors. Analysis of each question continues until a clear "yes" or "no" is obtained.

Figure B.9 MORT TOP Events

There is a structured set of rules and symbols for constructing the trees. The MORT User's Manual has a seven-page appendix explaining construction of the trees and the logic symbols used. Figures B.10 and B.11 are the logic symbols reproduced from that appendix. The User's Manual also has approximately 38 pages of questions for the analyst to proceed through the tree. And, the MORT system permits and encourages input of new insights from the individual analyst.

8.3 Summary Evaluation

MORT is a comprehensive tool for safety management assessment that has been fairly widely distributed and well supported by DOE with training and other support services. It embodies important fundamental concepts of system safety and provides thorough overall structure for programmatic assessment of safety and for event investigation. The major strength is its comprehensiveness and, secondly, its rigorous structure to force systematic assessment of problems. Techniques embodied in MORT, in particular barrier analysis, change analysis, and even the concept of a tree logic, are highly useful and effective concepts to be captured by the NRC-HPIP.

The major strength of MORT - comprehensiveness - may also be its weakest point with regard to the NRC-HPIP needs. The MORT tree requires fairly extensive training and experience to use effectively. The MORT User's Manual notes that, "Repeated practice and experience with the MORT diagram are necessary before good dexterity and skill in its application are acquired." Furthermore, the extensiveness of the tree and the associated guidance make application in a field environment, e.g., by NRC Resident Inspectors at a plant site, cumbersome. Interviews and informal comments from potential users during the needs analysis conducted for the HPIP effort frequently indicated that many of the people who were "MORT trained" recognize the potential value of MORT and application of the MORT concepts; and while they feel they do use the concepts, they do not use the diagram and full process because of actual or perceived complexity and difficulty of use.

8.4 Primary Reference(s)

1. N. W. Knox and E. W. Eicher, "MORT User's Manual, For Use with the Management Oversight and Risk Tree Analytical Logic Diagram," DOE-76/45-4, SSDC-4 (Rev.2), EG&G, Idaho, Inc., May, 1983.

AND-Gate Symbol

Coexistence of all inputs required to produce output.

OR-Gate Symbol (Nonexclusive)

Output will exist if at least one input is present.

CONDITIONAL AND-Gate Symbol (Can also be OR)

Input produces output provided conditional input is satisfied. Description of condition is written in the oval.

(Sometimes called a CONSTRAINED-Gate or an INHIBIT-Gate.)

CONSTRAINT Symbol

Applies conditions or constraints to basic logic gate or output event. When applied to basic AND-gate or OR-gate, creates special conditional gate such as Inhibit, Priority And, Exclusive Or, etc.

RISK Symbol

Indicates transfer to "Assumed Risk" branch of tree. Used for problems with no known or practical countermeasure.

Figure B.10 MORT Logic Symbols

RECTANGLE

An event resulting from the combination of more basic events acting through logic gates.

CIRCLE

An event described by a basic component or part failure. The event is independent of other events.

DIAMOND

An event not developed to its cause. Sequence is terminated for lack of information or lack of consequences.

TRIANGLE

A connecting or transfer symbol. All tree construction below the "out" triangle is transferred in at "in" triangle location(s).

SCROLL

An event that is normally expected to occur.

STRETCHED CIRCLE

An event that is satisfactory. Used to show completion of logical analysis.

Figure B.11 MORT Event Symbols

9. ROOT CAUSE TREE™

9.1 Background

The Root Cause Tree™ (Reference 1) is a root cause analysis tool developed by System Improvements, Inc. based on work by Paradies and Busch (References 2 and 3) at DOE's Savannah River Plant. It was designed to allow identification of root causes of events and develop the information for a data base for trending of root cause information over a plant's history. It is developed in a simple hierarchical tree structure that addresses both equipment and human performance problems. The technique is intended to be used in conjunction with Events and Causal Factors Charting. The method has been applied at commercial nuclear utilities and is fairly widely referenced as one of the major root cause analysis techniques available commercially and currently used in the nuclear industry.

9.2 Approach

As indicated above, the methodology is centered around a hierarchical tree that guides the analyst from the most general information about an event, e.g., did it involve an operations problem vs. an equipment problem, to a detailed level with specific root causes. The tree is intended to be used to investigate causal factors that have first been identified by using Events and Causal Factors Charting. The Root Cause Tree™ User's Manual (Paradies and Busch, 1990) provides an introductory description of the use of Events and Causal Factors Charting and detailed explanation of each entry in the tree to guide the investigator through construction and use of the tree from the top level down to the root cause level. Notable features of the tree are its simplicity and compactness.

A basic "philosophical" viewpoint regarding the level of detail appropriate to pursue is represented by the definition of a root cause as, "The most basic cause(s) that can be reasonably identified *and that management has the control to fix*" (Paradies and Busch, 1990). How deep to dig in the search for a root cause is determined by the practical tradeoff between "cost" of the search and identifying the "ultimate" fix to end all future problems of this type. This basic definition of a root cause recognizes this tradeoff and suggests that management makes the decision as to how much investigation is enough. Further, it suggests that a satisfactory root cause must be something that can be addressed by management; it does little good to identify an underlying cause that is impossible for management to control.

Human performance causal factors are examined under seven categories:

- Procedures
- Training
- Quality Control
- Communications

- Management System
- Human Factors
- Immediate Supervision

Each of the seven categories has from two to four subcategories, and each subcategory has several potential root causes associated with it. Questions leading to and associated with each individual root cause are provided in the Root Cause Tree™ User's Manual (Paardies and Busch, 1990). The intent is to find distinct, non-overlapping root causes for each significant event. A unique coding corresponding to the six levels of the tree is assigned to each root cause. However, experience has shown that on some occasions root causes or higher level factors are inherently interrelated, and that it is fruitful for an investigator to pursue other factors on a different branch concurrently with continuing down through a specific branch to the lowest level. The Root Cause Tree™ User's Manual recognizes this and permits dual coding, giving specific guidance as to which causes may typically be related. There is no guidance on the tree itself, however, to relate causes for dual coding.

9.3 Summary Evaluation

The Root Cause Tree™ is a comprehensive and well structured tool for investigation of root causes. It is best used in conjunction with other techniques, in particular Events and Causal Factors Charting, Barrier Analysis and Change Analysis to provide a complete accident investigation methodology. The categorization of human performance causal factors is reasonably comprehensive. It has similarities and differences from MORT and other root cause tools, but no particular strengths or weaknesses associated with those differences. A particularly positive characteristic of the tree is that it is very much oriented toward practical application by non-experts in human factors, and uses common, non-specialized language. Further, as noted above, it is very efficiently constructed and compactly laid out so that it is easy to use in the field and not intimidating to the investigator. There is no special symbolic language that must be memorized, and essentially no guidance is needed to understand the mechanics of using the tree. The explanations and questions provided in the User's Manual also are simple and straightforward and should be readily interpretable by operations personnel. The Root Cause Tree™ User's Manual (Paardies and Busch, 1990) is well-designed and easy to follow.

The primary problem with the tree is shared by virtually all techniques examined. That is, that effective use of the tree requires considerable knowledge and some experience on the part of the investigator. While the tree provides systematic guidance to a trained investigator to assure comprehensive and rigorous examination of all or most of the potential causal factors, it does not provide guidance on how to make the judgements and evaluations as to adequacy of the various factors. Training, experience, and additional documentation are required to support use of the tree or any of the techniques available. Additional documentation, of course, tends to make the tool more difficult to use, and training time is limited for investigators. The Root Cause Tree™ does appear to be simpler and more nearly self-explanatory than some

of the other comprehensive approaches, and therefore should require less training to be used at least in a minimally effective manner by novice users.

The tree does not claim to be 100% comprehensive in identification of specific causes. It is highly experience based and addresses most of the practical causes that are likely to be identified. Individual investigators in specific events will inevitably find some factors or conditions that are not addressed in the tree. The judgement of the developers was that the additional coding and documentation necessary to broaden the listing of causes would be counter-productive. In the end, the level of specificity and breadth of the listing is a judgement call for the developers of each technique. Our opinion is that the Root Cause Tree™ has made an effective categorization that strikes a proper balance between comprehensiveness, level of detail, and practicality for use in real operational environments.

9.4 Primary Reference(s)

1. Mark Paradies and Dave Busch, Root Cause Tree™ User's Manual, Revision 1, Paradies Press, Aiken, SC, 1990.
2. M. W. Paradies and D. A. Busch, "Savannah River Experience Using a Cause Coding Tree to Identify the Root Cause of an Incident," In the Workshop Notebook: Third Annual NSAC/ORSERG Workshop, Palo Alto, CA, Electric Power Research Institute, 1986.
3. M. W. Paradies and D. A. Busch, "Root Cause Analysis at Savannah River Plant," Proceedings of the IEEE Fourth Conference on Human Factors and Power Plants, 479-483, New York, NY, Institute of Electrical and Electronic Engineers, 1988.

10. TECHNIC OF OPERATIONS REVIEW (TOR)

10.1 Background

The Technic of Operation Review (TOR) was developed by Weaver (Reference 1) as a diagnostic training and accident prevention tool but has potential application as an accident investigation process. It is highly focused toward detection of management oversights and omissions rather than operator or hardware factors. TOR has been used, apparently successfully, by Employers Insurance of Wausau and its client organization for a number of years. The primary source of information for this review is Chapter 13 of Ferry (Reference 2).

10.2 Approach

The TOR analysis centers around the TOR Analysis Sheet, reproduced as Figure B.13. It lists potential causes and contributing factors in eight categories, each category with six to eight sub-factors. Each sub-factor is numbered

1 COACHING

- 10 Unusual situation, failure to coach (new man, tool, equipment, process, material, etc.) 44, 24, 62
- 11 No instruction. No instruction available for particular situation 44, 22, 24, 80
- 12 Training not formulated or need not foreseen 24, 34, 86
- 13 Correction. Failure to correct or failure to see need to correct 42, 20, 30
- 14 Instruction inadequate. Instruction was attempted but result shows it didn't take 15, 16, 42
- 15 Supervisor failed to tell why 44, 24, 83
- 16 Supervisor failed to listen 11, 81
- 17
- 18
- 19

3 AUTHORITY (Power to decide)

- 30 Bypassing, conflicting orders, too many bosses 44, 13
- 31 Decision too far above the problem 36, 83, 85
- 32 Authority inadequate to cope with the situation 81, 83
- 33 Decision exceeded authority 20, 26, 14
- 34 Decision evaded, problem dumped on the boss 36, 14, 85
- 35 Orders failed to produce desired result. Not clear, not understood, or not followed 40, 46, 13, 15
- 36 Subordinates fail to exercise their power to decide 26, 12, 83, 85
- 37
- 38
- 39

2 RESPONSIBILITY

- 20 Duties and tasks not clear 44, 34, 14, 53
- 21 Conflicting goals 80, 33
- 22 Responsibility, not clear or failure to accept 26, 14, 54, 82
- 23 Dual responsibility 47, 34, 13
- 24 Pressure of immediate tasks obscures full scope of responsibilities 36, 12, 51
- 25 Buck passing, responsibility not tied down 44, 26, 55, 60
- 26 Job descriptions inadequate 80, 86
- 27
- 28
- 29

4 SUPERVISION

- 40 Morale. Tension, insecurity, lack of faith in the supervisor and the future of the job 15, 56, 64, 80
- 41 Conduct. Supervisor sets poor example 13, 84
- 42 Unsafe Acts. Failure to observe and correct 24, 11, 52
- 43 Rules. Failure to make necessary rules, or to publicize them. Inadequate follow-up and enforcement. Unfair enforcement or weak discipline 25, 36, 12, 52
- 44 Initiative. Failure to see problems and exert an influence on them 22, 34, 30
- 45 Honest error. Failure to act, or action turned out to be wrong 10, 12, 15, 81
- 46 Team spirit. Men are not pulling with the supervisor 40, 21, 56
- 47 Co-operation. Poor co-operation. Failure to plan for co-ordination 23, 25, 15, 66
- 48
- 49

Figure B.13 TO:

sis Sheet

5 DISORDER

- 51 Work Flow. Inefficient or hazardous layout, scheduling, arrangement, stacking, piling, routing, storing, etc. 41, 24, 31, 80
- 52 Conditions. Inefficient or unsafe due to faulty inspection, supervisory action, or maintenance 21, 32, 14, 86
- 53 Property loss. Accidental breakage or damage due to faulty procedure, inspection, supervision, or maintenance 43, 20, 80
- 54 Clutter. Anything unnecessary in the work area. (Excess materials, defective tools and equipment, excess due to faulty work flow, etc.) 44, 36, 80
- 55 Lack. Absence of anything needed. (Proper tools, protective equipment, guards, fire equipment, bins, scrap barrels, janitorial service, etc.) 44, 36, 80
- 56 Voluntary compliance. Work group sees no advantage to themselves 40, 15, 41
- 57
- 58
- 59

7 PERSONAL TRAITS (When accident occurs)

- 70 Physical condition — strength, agility, poor reaction, clumsy, etc. 44, 26, 65
- 71 Health — sick, tired, taking medicine 44, 24, 65
- 72 Impairment — amputee, vision, hearing, heart, diabetic, epileptic, hernia, etc. 44, 24, 65
- 73 Alcohol — (If definite facts are known) 80
- 74 Personality — excitable, lazy, goof-off, unhappy, easily distracted, impulsive, anxious, irritable, complacent, etc. .. 44, 13
- 75 Adjustment — aggressive, show off, stubborn, insolent, scorns advice and instruction, defies authority, antisocial, argues, timid, etc. 44, 13
- 76 Work habits — sloppy. Confusion and disorder in work area. Careless of tools, equipment and procedure 44, 13
- 77 Work assignment — unsuited for this particular individual 42, 65
- 78
- 79

6 OPERATIONAL

- 60 Job procedure. Awkward, unsafe, inefficient, poorly planned 44, 32
- 61 Work load. Pace too fast, too slow, or erratic 44, 51, 63
- 62 New procedure. New or unusual tasks or hazards not yet understood 43, 44
- 63 Short handed. High turnover or absenteeism 80, 40, 61
- 64 Unattractive jobs. Job conditions or rewards are not competitive 81, 46
- 65 Job placement. Hasty or improper job selection and placement 80, 86
- 66 Co-ordination. Departments inadvertently create problems for each other (production, maintenance, purchasing, personnel, sales, etc.) 45, 35, 13
- 67
- 68
- 69

8 MANAGEMENT

- 80 Policy. Failure to assert a management will prior to the situation at hand 24, 81, 83
- 81 Goals. Not clear, or not projected as an "action image" .. 83, 86
- 82 Accountability. Failure to measure or appraise results ... 36
- 83 Span of attention. Too many irons in the fire. Inadequate delegation. Inadequate development of subordinates 12, 86
- 84 Performance appraisals. Inadequate or dwell excessively on short range performance 20, 65
- 85 Mistakes. Failure to support and encourage subordinates to exercise their power to decide 36, 33
- 86 Staffing. Assign full or part-time responsibility for related functions 66
- 87
- 88
- 89

consecutively with blank spaces for the analysts to add sub-factors. Each sub-factor also references the analyst to other sub-factors that are related. While the analysis can be carried out by an individual, the guidance strongly recommends it be conducted by a group because of the multiple viewpoints and expertise, the synergism of small-group interaction, and the benefits of mutual support in presentation of conclusions and recommendations to management. A group of middle managers is recommended, and it is suggested that the group appoint its own leader. The analysis is conducted in four basic steps:

- (1) **State.** The group interviews people involved with or knowledgeable of the accident, reads accident reports, findings, and other available information, and arrives at a consensus description of exactly what happened.
- (2) **Trace.** The TOR analysis sheet is used to trace through the various factors suggested by the information available as potential causes or contributing factors. The group determines what it believes to be the most likely or primary cause of the accident, one of the eight major blocks of the analysis sheet, to begin the tracing. Ferry indicates that, "Experience has shown ...that if damage or injury is involved, Block 7, 'Personal traits,' should be considered first for a starting place."

Regardless of the starting point selected, the group progresses through a brief discussion and listing of the factors that are considered potential causes or contributing factors, following the connections to other factors indicated by the numbers to the right of each factor. At this point there is not an in-depth analysis conducted, simply a brief review of each factor by the group and a listing of those that are to be considered further. The listing continues until all factors considered important have been identified (until there are no new numbers indicated by the tracing). This suggests that the choice of starting place can have a fairly significant impact on the analysis conducted.

Typically, the group is left with six to twelve factors to consider in more depth. While the analysis during the trace is limited, the group should have reviewed in some breadth, albeit limited depth, its own organization and the organization's role in the accident.

- (3) **Eliminate.** The remaining factors are now examined in more detail to identify those that were truly causes, and eliminate those that, although they may have been present and may be examined separately for improvement of overall system operation, were not true causes or direct contributions to this accident.
- (4) **Seek.** The final step in the process is to identify solutions for the problems identified. The TOR Analysis Sheet does not provide guidance for this step and technically it is not part of the TOR analysis.

10.3 Summary Evaluation

TOR appears to have been developed largely from the perspective of industrial or personnel safety rather than process safety. We think the statement by Ferry noted above regarding "Personal Traits" being the primary cause for accidents reflects this derivation. That statement also suggests a viewpoint and/or experience that leads to emotional condition, personality, etc. - as primary causal factors in accidents. This is consistent with results of our interviews with NTSB which suggest that NTSB places a great deal of emphasis and energy on the investigation of such individual behavioral factors of the crew involved in airline accidents.

We note this primarily because this has not been the practice in nuclear plant accident investigations, where most of the focus has been on system (hardware) problems and, more recently, human engineering, procedures and training problems. Speculation as to the reasons for this apparent difference in viewpoint/experience includes the historic emphasis by the nuclear safety community on process vs. industrial safety, basic differences in the degree of direct operator involvement in the control loop in aircraft vs. nuclear plant operations, and the fact that the nuclear industry is dominated by an "engineering culture" and only relatively recently is incorporating viewpoints from behavioral and social science. Whatever the reasons, the emphasis placed on these factors by other accident investigative agencies and processes suggests that further examination by the nuclear industry may be warranted.

With regard to the needs of HPIP, it appears that there are a number of factors listed in the TOR analysis sheet that should be included under management, supervision, procedures or other categories; and many of them are. On the other hand, we find a number of them interesting descriptions of behavior but not very useful, e.g., "work habits sloppy" or "honest error". These and a number of the categories do not seem to identify true root causes for which solutions are apparent. Further, despite the asserted intention of identifying management or operations problems rather than placing blame, we find the implications of a number of the categories being simply identifying "bad people" rather than badly designed systems.

We find the linkage of causes an interesting and potentially useful facet, which is indeed covered in MORT and the Root Cause Tree™, though it is not as tightly structured in those systems. Certainly, guidance to root cause analysis using HPIP should clearly indicate the interrelationship of many factors and the possibilities for multiple root causes.

We do not find any particular advantage in the formatting or structuring of the analysis sheet. It is simply a list of potential causes or contributing factors, with no particularly strong or obvious rationale for the categorization scheme chosen. While it has some similarities to and some differences from other schemes, there is no particular strong points or especially weak points to its chosen organization.

10.4 Primary Reference(s)

1. D. A. Weaver, "TOR Analysis: A Diagnostic Training Tool," p. 24-29, ASSE Journal, ASSE, Park Ridge, IL, June, 1973. (Cited in Ferry, Referenced below.)
2. Ted S. Ferry, Modern Accident Investigation and Analysis, Chapter 13, p. 173-179, John Wiley & Sons, New York, NY, 1981.

APPENDIX C

**HUMAN PERFORMANCE
INVESTIGATION PROCESS
(HPIP)**

**Training Strategy,
and
Learning Objectives**

August 1992

by

**System Improvements, Inc
and
Concord Associates, Inc.**

APPENDIX C

HPIP TRAINING STRATEGY AND LEARNING OBJECTIVES

1. PURPOSE

To ensure that NRC personnel performing investigations of events are familiar with and can apply basic root cause analysis tools/modules and can use the tools and modules to identify common human error producing situations.

2. STRATEGY

About 20 NRC Headquarters personnel and 120 Regional personnel (60 of which are currently NRC Senior Residents or Resident Inspectors) were interviewed or participated in focus group meetings to determine the user's needs for a Human Performance Investigation Process (HPIP). These interviews and meetings provided the information necessary to develop the HPIP Flow Chart, Figure C.1, which displays the generalized process for the NRC's investigation of an event, the purpose of each step, and the tools that are needed for each step. These tools are the focus for the HPIP training program.

During the needs analysis several criteria/constraints for HPIP were identified. One criterion identified in the user needs analysis was that the HPIP training be kept as short as possible while still allowing the identification of common human performance problems. This criteria was developed because HPIP needs to be implemented on a broad basis with existing personnel (mainly NRC Senior Resident and Resident Inspectors) who are extremely busy and can afford no more than one day of initial training. However, keeping the training short is complicated by the fact that most of the potential users have had no training in human factors and some may have little experience using any formal root cause analysis techniques. The residents do have the opportunity for additional training (in two- to eight-hour increments) at their quarterly regional resident inspector meetings if the regions requested the training. Therefore, the SI/CA Team decided to implement a modular training program that keeps the initial training to a minimum but allows additional training at a later date. The initial training would be limited to one day and would include the minimum amount of information necessary to allow a user to understand and apply HPIP. The training would be supported by reference material that could be used to review the techniques or learn more advanced techniques when the need arose. Additional training modules (from two to eight hours each quarter) could be presented on a continuing basis to provide additional human factors knowledge and root cause system expertise.

Analysis of the essential functions necessary to understand and apply HPIP showed that the residents must recognize the need for the system, understand the HPIP Flow Chart, be able to use Events and Causal Factors Charting, SORTM, and the HPIP investigation modules to analyze a utility's event or review their report and proposed corrective actions. The need to understand these tools was further highlighted in the pilot training courses and in the trial implementation of HPIP. Therefore, this basic knowledge and these skills are the basis for the initial training terminal and enabling learning objectives.

FIGURE C.1: NRC Human Performance Investigation Process

2 of 2

3. LEARNING OBJECTIVES

As discussed in the Strategy section, the initial HPIP training is limited to that information necessary to allow an NRC resident inspector to understand and use HPIP. The following learning objectives are based on the SI/CA Team's evaluation of the training that will be required to reach that goal.

Terminal Learning Objective 1: Describe the importance of root cause analysis, how it is used, and the flow of the Human Performance Investigation Process (HPIP).

Enabling Learning Objective 1.1: Define a root cause.

Enabling Learning Objective 1.2: Given a list of different types of causes of events, use the definition of a root cause to identify those causes that are root causes.

Enabling Learning Objective 1.3: Describe the general process used in root cause analysis.

Enabling Learning Objective 1.4: Discuss how root cause analysis can be used to identify and correct operating and safety problems.

Enabling Learning Objective 1.5: Given an HPIP Flow Chart, identify the purpose of each activity and the tools that are required.

Terminal Learning Objective 2: Demonstrate the ability to appropriately apply Events and Causal Factors Charting and SORTM.

Enabling Learning Objective 2.1: State the purpose of Events and Causal Factors Charting and describe why and when it can be useful.

Enabling Learning Objective 2.2: Describe when, in the HPIP Flow, Events and Causal Factors Charting should be applied.

Enabling Learning Objective 2.3: Given an event description, identify events and causal factors, describe the difference between them, and draw the appropriate symbols for each.

Enabling Learning Objective 2.4: Given an event description, draw an Events and Causal Factors Chart.

Enabling Learning Objective 2.5: Describe how to identify the causal factors that should be analyzed using SORTM.

Enabling Learning Objective 2.6: Describe how barrier analysis can be used to evaluate the effectiveness of proposed corrective actions.

Enabling Learning Objective 2.7: State the purpose of SORTM and describe why and when it can be useful.

Enabling Learning Objective 2.8: Describe when, in the HPIP Flow, SORTM should be used.

Enabling Learning Objective 2.9: Demonstrate a practical understanding of SORTM by applying it in an in-class exercise.

Terminal Learning Objective 3: Demonstrate knowledge of the HPIP Modules.

Enabling Learning Objective 3.1: Discuss the purpose of the Root Cause Tree™ and how it is incorporated into the HPIP Modules.

Enabling Learning Objective 3.2: Identify the Basic Cause Category, Near Root Cause, and Root Cause levels in the Root Cause Tree™ and the HPIP Modules.

Enabling Learning Objective 3.3: Describe the format of a typical module and how to apply the modules when investigating an event.

Enabling Learning Objective 3.4: Discuss the types of problems that each module can be used to identify.

Enabling Learning Objective 3.5: Given an example investigation report, use SORTM and an HPIP investigation module to identify the example's root causes.

Terminal Learning Objective 4: Demonstrate knowledge of additional HPIP tools and resources.

Enabling Learning Objective 4.1: Discuss why and when Change Analysis may be used when applying HPIP.

Enabling Learning Objective 4.2: Discuss why and when Critical Human Action Profile (CHAP) may be used when applying HPIP.

Terminal Learning Objective 5: Discuss the modified use of HPIP to review a utility's event investigation.

Enabling Learning Objective 5.1: Discuss how Events and Causal Factors Charting, SORTM, Barrier Analysis, and the HPIP Modules can be used to review a utility's event investigation report.

Enabling Learning Objective 5.2: Given an example investigation preliminary report and information sheets from interviews, use the HPIP tools and modules to identify the root causes of the event.

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