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Human Error Mitigation Initiative (HEMI)

Summary Report

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Summary Report

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Abstract

Despite continuing efforts to apply existing hazard analysis methods and comply with requirements, human errors persist across the nuclear weapons complex. Due to a number of factors, current retroactive and proactive methods to understand and minimize human error are highly subjective, inconsistent in numerous dimensions, and are cumbersome to characterize as thorough. An alternative and proposed method begins with leveraging historical data to understand what the systemic issues are and where resources need to be brought to bear proactively to minimize the risk of future occurrences. An illustrative analysis was performed using existing incident databases specific to Pantex weapons operations indicating systemic issues associated with operating procedures that undergo notably less development rigor relative to other task elements such as tooling and process flow. Future recommended steps to improve the objectivity, consistency, and thoroughness of hazard analysis and mitigation were delineated.

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Introduction

While many elements of systems engineering are structured enough to measure at a high degree of fidelity and reliability, the human element introduces a distinct level of variability. Engineers often address the human element by neglecting to account for human factors entirely, making gross assumptions concerning human factors, or attempting to integrate human factors more fully, while struggling to do so in a systematic fashion.

Despite those who may underestimate the role of human factors in the nuclear weapons complex, human performance is woven and relied upon in the majority of a weapon's life cycle. Human responsibilities are significant and include: weapons design, assembly, disassembly, maintenance, and surveillance. The dependence on human performance, coupled with the potential variability introduced by humans, indicates a need to pursue means of systematic human factors analysis and design. This general need has motivated the research described in this report.

A more specific need driving this work is that despite Human Factors support to the Hazard Analysis Task Team (HATT) at Pantex, human errors continue to occur in Pantex operations (Kirby, 2003). Thus, it is clear that the current process is not sufficient to identify, analyze and mitigate all potential human factors concerns. A more complete approach would include the investigation of historical data (e.g., occurrences and incidents) to derive systemic issues that need consideration. However, this is not currently part of the current analysis process. Furthermore, human factors and hazard analysts are not equipped with supplementary tools and information to support human error analysis and mitigation.

The current research intends to develop a methodology for objective, consistent, and thorough human error analysis and mitigation. It is argued that historical records of human errors are not being used. Further, hazard analyses that address human error vary greatly across analysts and programs. Finally, the incident data examined and the hazards analyzed are not as thorough as necessary.

This report summarizes current human error analysis practices. A description of the proposed method of mitigating human error is depicted along with a review of an example implementation. In addition, opportunities for continued work in this area are described.

Current Hazard and Human Error Analyses Process

The current process of hazard and human error analysis is depicted in Figure 1, which shows that there are two distinct parts to the current analysis process. One part includes retroactive features (focusing on past events) such as the utilization of historical data. The other part includes proactive features (focusing on future events) such as the actual walkthroughs and reporting associated with the hazard analyses process.

Although a number of existing incident reporting systems exist within the DOE complex (e.g., ORPS, URs, SFIs), their use is not well defined in the current process. Thus, links to these databases in Figure 1 are represented as dashed lines. Formalized links or processes are depicted as solid lines.

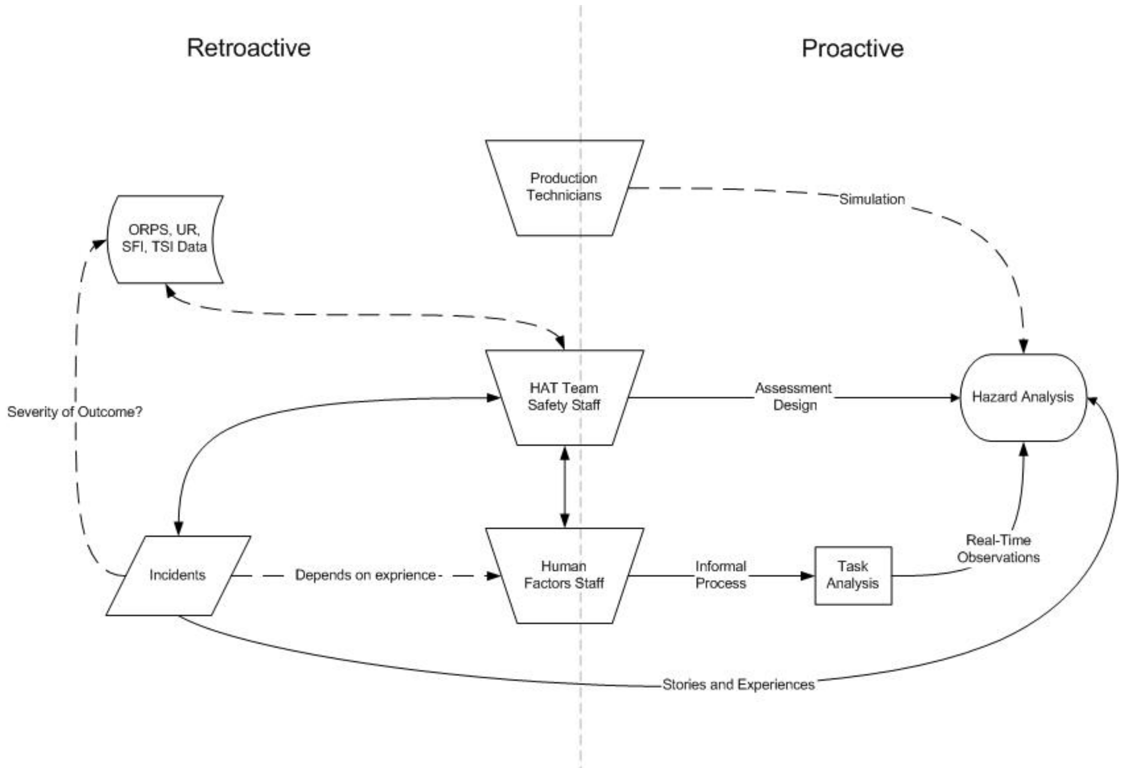

Figure 1: Current hazard analysis process. Solid lines represent formalized/established processes and dashed lines are less formal or loosely defined processes.

Retroactive Factors

Historical (or archival) data refers to existing information that has been collected by sites such as Pantex or other DOE organizations. Generally, this information has not been collected by human factors experts, nor has been designed to meet the specific needs of a human factors analysis. Nonetheless, there is often much that can be learned by reviewing this existing information. Historical data can include anything that an organization regularly collects about its operation such as: quality control data, architectural plans, design specifications and drawings, production records, personnel data records, and most critical for hazard analysis, reports from previous hazard analyses and injury and incident/accident reports. Such information can provide a deeper understanding of issues that have caused problems in the past, and can help lead the human factors expert to particular areas of concern that need consideration. However, in the current hazard analysis process, the use of historical data is incidental. Individual hazard analysis team members may rely on their memories of past experiences or well-known errors that have occurred, but there is not a systematic methodology to incorporate such data into current analyses.

The DOE Nuclear Weapons Complex has a number of historical data sources to draw from. Specific events within the complex are recorded in many different databases, depending on how and where a problem was detected. For example, databases summarizing Significant Finding Investigations (SFIs), Unsatisfactory Reports (URs), Test System Investigations (TSIs), all contain information about past interactions with various weapon systems across the DOE complex and system life cycle. Pantex itself maintains several reporting systems in which unusual events are recorded. Pantex also provides input to a DOE wide incident reporting system, the Occurrence Reporting and Processing System (ORPS). The stated goal for this system is to “provide timely notification to the DOE complex of events that could adversely affect: public or DOE worker health and safety, the environment, national security, DOE's safeguards and security interests, functioning of DOE facilities, or the Department's reputation" (ORPS website, 2003).

Incident reporting systems have become an increasingly common methodology for collecting and tracking information about undesired events. These undesired events (i.e., incidents) include both accidents (which are undesired events resulting in injury, damage or serious consequences) and near misses (which are those events or unsafe acts where the sequence of events could have caused an accident if it had not been interrupted). The advantage of including information about near-misses in an incident reporting system is that the iceberg model (first proposed by Heinrich, 1931) suggests that there is an inverse proportionality between the number of major accidents, near-misses and errors. Thus, an organization or system can have a relatively large number of errors, which lead to a fewer number of near misses, which result in even fewer accidents. Relying purely on information from accidents therefore eliminates all of the information that can be learned by studying near-misses and errors.

It is important to consider the reporting criteria for a particular database before any conclusions can be drawn from the data contained in that database. The reporting criteria correspond to the conditions under which a particular incident needs to be reported in the database. Incidents not meeting these conditions are generally not reported to the incident database, and in fact may not be recorded at all. These conditions are often outcome based, meaning they depend on the final result of an event. For example, the conditions may correspond to particular types of injuries (e.g., any time an employee must report to the medical department), costs of damage (e.g., any time more than $5000 worth of damage), significance of the event (e.g., any incident which disrupts production schedule), or any other conditions determined to be important. While basing reporting criteria on outcome alone does provide a concrete threshold to use in deciding what to report, it can also result in near-misses and errors being excluded from the database. Understanding what criteria are used is critical to understanding the data. In the case of ORPS, Pantex has developed their own site criteria, which is documented in Appendix B of the Pantex Plant Standard: Event Investigation, Critique Process and Occurrence Reporting (STD-3140; ORPS website, 1998).

Although it is clear that there is a number of existing data sources that contain information about past experiences with weapon systems, there does not seem to be a general awareness of how this information can be utilized during hazard analyses. Further, the use of this information is not formally included in the current analysis process. In the current process, a member of the hazard analysis team does not routinely access existing data sources for information, and the human factors analyst is not automatically provided access to this information.

There may be other potential sources of historical data that are currently not being utilized fully. For example, there is not currently a system in place to capture and share results or information from previous hazard analyses. Although results from hazard analyses are documented in memos, Hazard Analysis Reports, and the Weapons Response Database that may be circulated within the system team, analysts working on different systems may not be aware of issues that emerged or solutions that had been developed. Thus, different analysts or different system teams must discover for themselves issues that may have been previously identified in a previous hazard analysis using resources not necessarily staged for this purpose.

Proactive Factors

The goal of the proactive part of the hazard analysis process is to identify and predict potential problems with the proposed operations before the process is implemented in the plant. The hazard analysis consists of walkdowns of various parts of the process, with observers from different disciplines watching to try and identify any potential issues that need to be addressed. Despite first-hand experience in the day-to-day operations, production technicians have a limited role in hazard analyses. At best, one production technician will be recruited to demonstrate tasks being reviewed during process walkdowns. The technician assisting walkdowns may occasionally be prompted for their feedback. Even if the technician is prompted for feedback, there are numerous social factors that may inhibit a candid response.

Trainers, responsible for educating technicians, are more likely to be present during walkdowns. Clearly the depth of knowledge introduced by their presence and input is valuable. Nevertheless, discrepancies can exist between the trainer's view of how certain operations should be performed and the most current manner in which operations are being performed.

Human factors analysts participating in hazard evaluations can come from varied backgrounds and this can impact the range and depth of factors analyzed. For example, a human factors analyst with a focus on biomechanics[1] may attend more to factors such as the stability of loads above the technician's shoulders or anthropometric factors. A human factors expert with a background focused on training may be sensitive to the complexity of tasks where complex tasks may be more prone to confusion, skill decay, and errors. Varied backgrounds will not only influence attention to potential errors, but the form of solution offered to mitigate future errors.

Another factor that can influence the effectiveness of human factors analyses is the level of domain knowledge of the analyst. It is possible that a human factors analyst participating in a walkdown may have little experience with the particular weapon system. Consequently, the human factors analyst may have little appreciation for the significance and hazards associated with a given human error. Further, the analyst may have little experience in a domain that must prioritize nuclear explosive safety over worker safety. Again, this can be hard to appreciate for a human factor specialist with experience in areas such as industrial ergonomics, which prioritizes minimizing work-related injuries.

A closely related issue to domain knowledge is a lack of general background information going into hazard analyses. Even if the analyst has good domain knowledge, the analyst may not have an objective understanding of systemic issues in ongoing Pantex operations. The analyst may assume certain issues are significant when historically they have not been significant. Consequently the analyst risks overlooking significant issues as well as devoting time and energy to problems that are in fact insignificant. Practically speaking, the analyst's ability to identify potential errors will benefit from an objective examination of historical data.

The number of human factors staff participating in a given process walkdown varies. Some walkdowns occur with no human factors analysts present, so the analyst may only receive human factors questions (identified by staff who are not human factors experts) that arose during the walkdowns. On the other extreme, a number of human factors analysts may attend a walkdown, and may collaborate in the analysis of hazards and human error. Clearly being absent from walkdowns introduces significant risks in terms of potential errors overlooked. However, the quality of human factors assessments may not necessarily correlate with the number of staff present. Research suggests that the level of any individual's vigilance decreases as three or more collaborators are added (Kanekar, 1982 and Wiener, 1964).

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[1] The study of mechanics as it relates to the movement of living organisms.

There could be an optimum number of human factors staff to support each analysis, but there are many practical reasons why this is difficult to achieve. First, the walkdowns are typically very crowded. Staff representing a wide variety of departments currently attend each walkdown (e.g., surveillance, process engineering, tooling, authorization basis, safety, training, production technicians, Department of Energy, project management, design agency systems engineers, and several miscellaneous experts (e.g., electrostatic discharge experts, gas sampling experts, high explosive experts etc.)). Crowded walkdowns result in cumbersome reviews of processes, since just a few observers can obscure angles necessary to view a tool being demonstrated or a component being handled. Several conversations can be going while significant information, such as the description of a task, is being explained. Questions can be posed that had already been addressed because the person posing the question could not hear or see what happened or was distracted.

General Hazard Analyses

Generally, the current approach to hazard analysis has involved a group of analysts, including a human factors analyst, taking an unsystematic look at the system. Any analyst can raise a potential issue and the group then works to develop a way to address that issue. Because there is no systematic way of identifying pertinent issues, many issues are raised based on the past experiences of the particular analysts involved. This could mean that a single past experience is used to isolate causality and justify design changes, or a focus on known past problems can result in other issues being missed. Further, an analyst may not recognize an issue that has been previously identified as a concern in another analysis, which is a missed opportunity to learn from previous data.

Another concern in the current approach to hazard analysis is that the current walkdown process focuses on identifying hazards that are present if the task is performed exactly as written in the procedures. However, often the situations during the walkthroughs do not exactly mimic the situations that would be faced during actual operations. Also, there is a general assumption that the procedures are correct and unambiguous, and the technicians will be operating under ideal working conditions. There is little opportunity to focus on ways in which the actual performance of a task can vary from the way it is described in the procedures.

Proposed Method Overview

Figure 2 illustrates a proposed methodology for human factors involvement in the hazard analysis process. Elements common to Figure 2 and those shown earlier in Figure 1 for the current hazard analysis process include the retroactive and proactive division of analysis tools, methods, and resources.

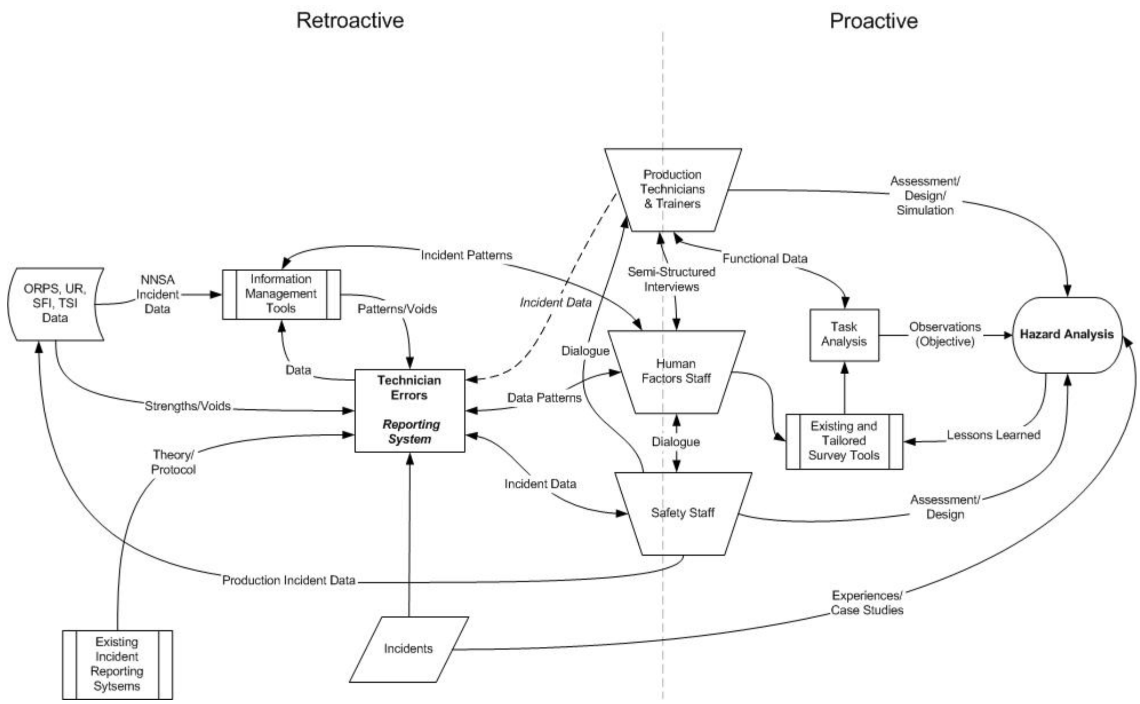

Figure 2: Proposed Hazard Analysis Process.

An important addition to the retroactive side is the use of information management tools. A feature common to most incident reporting databases is a significant amount of text-based information. Current methods of reviewing such databases are limited to manually reading through a large amount of text to extract information and knowledge. Increasingly, information technology tools have been developed to automate this process. As a result, the current research sought to explore the utility of such technology.

Another feature to contrast between the current process (Figure 1) and the proposed process (Figure 2) is the increased amount of information flowing to the proactive half of the hazard analysis process. This is primarily motivated by the observation that hazard analysis staff are provided little to no supplementary information prior to the analysis of nuclear weapons processes and tasks resulting in more subjective, inconsistent, and incomplete analyses. Therefore, it was of interest to enhance the effectiveness of resources provided to hazard analysis staff.

The proactive side of Figure 2 includes the role of survey or work assessment tools. Work assessment tools include questionnaires and other established methodologies to be used by human factors staff to thoroughly, consistently, and objectively review hazards. Many opportunities exist to leverage lessons learned from other industries (e.g., aircraft maintenance) to significantly improve the review of weapons processes and tasks.

Task analysis methods have been added that improve the delineation of contextual factors that could affect the probability of human error. Significant research associated with fields known as cognitive work analysis (Vicente, 1999), operator function modeling (Mitchell, 1987), and cognitive systems engineering (Flach, 1998) have yielded techniques that should be investigated for integration with current hazard analysis processes.

Another motivation reflected in Figure 2 involves feedback from proactive analyses to retroactive components. Findings from proactive elements can refine the information collected in retroactive resources.

Phase I – Example Application and Lessons Learned

The first phase of this research allowed for the exploration of how some of the proposed methodological improvements to the process (as shown in Figure 2) could be applied. The following sections summarize the approach, findings and lessons learned for these methodologies.

Approach

Retroactive Data Analysis: Identification of Systemic Issues

In order to compile information pertaining to human related incidents, several existing databases were explored to search for possible error patterns. The first step was identifying any incident resources and databases available throughout DOE that would contain a readily accessible compilation of occurrences and reports that would help identify failure patterns within the system. A number of subject matter experts throughout the laboratories – which included hazards analysts, safety specialists and surveillance and reliability experts – were consulted to help identify the needed resources. It was interesting to note that although a series of resource databases exist throughout the DOE Complex; many employees are unaware that such resources exist. After researching the existing resources, the data sources that appeared to provide the most potential for finding useful information on incidents relating to human error were Occurrence Reporting and Processing System (ORPS), Significant Findings Investigation (SFI) reports, Test System Investigation (TSI) reports, and Unsatisfactory Reports (UR).

The ORPS database contains information about occurrences related to DOE owned and leased facilities, the causes of those occurrences, and suggested corrective actions. However, while this database contains a large number of reports, the search interface is difficult to use, which makes relevant information cumbersome to find. A major concern for ORPS, and for many other databases, is that human factors analysts cannot rely solely on the categorization of incidents used in the database. Because different people with different areas of expertise are responsible for entering incident reports into the database, there is no assurance that all similar incidents will be categorized in the same manner. The categories chosen to code incident causes and contributing factors may be colored by the investigators' own expertise. For example, what may seem like a human related error to one person may seem like a procedure based error to another. Further, since many of the investigators are not familiar with human factors, there may be a tendency for errors to be considered solely human errors instead of fully considering the other factors that may have contributed to the incident.

Since the existing categorization system could not reliably be used to run searches through the ORPS database, the search for possible error patterns required the manual reading of each incident. To help limit the number of incidents to be reviewed, the scope of the incidents searched was narrowed, with a focus on Pantex reports from the most recent years. The focus on Pantex restricted the incidents to weapon assembly and disassembly tasks; while the focus on recent years ensured that any error patterns that were detected were not based on causes and problems that were no longer relevant. After narrowing the scope, reports were searched using different keywords and several identification categories included in the ORPS database. While reading through the incidents it became apparent that while there was a large array of incident causes listed on the reports, most errors were in some way related to the procedures that are used. When this pattern of errors related to procedures and/or policies in relation to nuclear weapons operations was identified, the search was broadened to include Pantex reports beginning in 1991.

The Significant Findings Investigation (SFI) reports are typically based on investigations set forth by electrical or mechanical problems that are found in a weapon system. The SFIs were accessed through Web FileShare on Sandia's classified network. The search was conducted for SFI monthly reports but summaries were only available starting in October 2002 (all previous documents were not posted). These summaries stated what SFIs were opened and closed each month. In addition, short summaries were given for each weapon incident that included the fields: Brief Description, Potential Indicators, and Recent Actions/Status. However, if there was any human attributed error, there was no way of knowing from the summaries. Full reports were available in paper form. However, there were no references to the human component of the system in the reports. All SFIs referred to mechanical and electrical problems inherent to the system.

Test System Investigation (TSI) reports are follow-ups on SFIs that were blamed on the tester and encompass other outside factors. These reports are generally stored in paper folders and are somewhat arranged by date and by weapon, consequently, there is no known means to search for specific information besides simply reading through all the reports. The descriptions given are sometimes detailed and other times not and the organizational system of all the reports is poor. In order to find any underlying human error component, much interpretation of the reports is needed.

Unsatisfactory reports (UR) are submitted to the military liaisons at the Laboratories by the military for further investigation. If necessary, these reports will become SFIs. The URs were accessed through the Military Liaison link contained in the workbox on the SRN. The Advance Search option contained several search fields, but the only one that appeared to contain human error data was the "Maintenance/Handling" choice under the "Probable Cause" field. The search produced more than 300 reports. However, the reports did not have descriptive titles - only report numbers - therefore, all the reports had to be read before any determination on underlying causes could be made. Descriptions were detailed in some reports and scarce or blank in others. It seems that all human error was stored under the heading of maintenance/handling and there appeared to be no way to search a whole array of documents using a key word.

Information Technology to Assist in Retroactive Analysis

An information technology tool of particular interest was Knowledgist™ (http://www.invention-machine.com/prodserv/knowledgist.cfm). The general capability provided by Knowledgist™ is semantic indexing of text-based documents. The developers of the software describe Knowledgist™ as a "knowledge-mining" solution. Various patterns of subject-action-object combinations can be derived from the database linked with Knowledgist™. The tool includes linguistic mechanisms to provide summaries of documents. Summary detail is at the user's discretion and can vary from one sentence to several pages. Knowledgist™ was viewed as a promising tool to point towards large incident databases such as ORPS.

Review of Proactive Methodologies

Although several of the researchers supporting the current research were already familiar with some task analysis methods, an additional review of such methods was conducted. The review utilized literature databases, internet and intranet resources, and fellow human factors research contacts outside of Sandia National Laboratories.

As in the case of task analyses, the research team had some knowledge of work assessment tools. Nevertheless, an additional review of work assessment tools was conducted as a part of the current research. Further, a review of the literature concerning the use of formalized procedures was conducted to better understand the results from the retroactive analysis.

Findings

Retroactive Data Analysis

Unexpectedly, one of the hurdles that had to be overcome in an attempt to locate and gain access to the desired data sources was the organization and logistics of the approval process for each data source. Once the pools of data that could be used had been identified, additional detailed information and proper access had to be acquired in order to locate and review the reports. This proved to be a difficult task, as there appears to be islands of data sources that are not readily available, effectively connected or even properly advertised. Finding the proper contact person for a specific data source was time consuming and sometimes ineffective if a person chose to ignore the requests. In addition, many individuals were unaware that these data and databases existed, in part because these resources are not being effectively used to provide reliable data on incidents trends and the reports are seemingly just being blindly filed away. Some of the data sources may very well contain the same type of information or even the same reported incident, however, they are being compiled in different places, when it would perhaps be best to collect them all in an all-inclusive database that can be easily searched and reviewed for proper trend analysis.

Most of the search effort was focused on the ORPS database, as it appeared to contain the most comprehensive array of reports. After reading through many reports, it was decided that the pattern of errors for the majority of the reports had their root in procedure based issues. As such, all reports were screened for any incidents that included any procedural difficulties or problems that contributed to the final incident. The reports were restricted by date, from 1991-2003 and by facility to BWXT Pantex. After reading through more than a hundred reports, different trends within the procedure related problems began to emerge. From the available data, it was decided that the procedure based incidents could be divided into six different categories: lack of procedure or policy, non-defined or easily misinterpreted procedures, lack of sufficient training, inadequate administrative controls/different procedures specific to area or weapon, conflicting procedures, and procedures not enforced. These categories, however, are not entirely distinctive, as many incidents include several breakdowns within the procedure system. In addition, due to the nature of the descriptions, the different authors' perspective and the tendency to place blame on something or someone leaves the causes and drives of the incidents open for several interpretations of the true underlying causes. The six categories are defined as follows:

Lack of procedure or policy: This category refers to instances when an action may have been taken inappropriately due to the lack of readily available procedures.

Non-defined or easily misinterpreted procedures: This refers to instances where workers may have thought they were following procedures correctly, but in fact did not due the interpretable wording of the procedure. It also refers to instances where a procedure was not clearly defined, or where parts of the procedures were not included.

Lack of sufficient training: This refers to any incidents that occurred due to insufficient worker training, improper training or insufficient refresher training.

Inadequate administrative controls/ procedures too specific to area or weapon: Incidents under this category occurred due to insufficient administrative controls and included oversights such as failure to provide appropriate procedures and safety regulations in all areas, failure to update procedures in all locations after standards are changed, and failure to provide generalized specifications that apply to all necessary facilities. It also includes incidents where procedures given for a specific area or weapon were in contradiction to similar procedures for other areas or weapons.

Conflicting procedures: This category includes incidents where workers were expected to refer to other documents for essential information within procedures containing reference to incorrect documents or where procedures had reference to several other different or conflicting procedures.

Procedures not enforced: This category refers to procedures that are not properly enforced through other physical controls and/or formal administrative aids (such as not providing facility log entry documenting turnover of the facility in an area where it is required) and includes failures to coordinate procedures that apply to the same situation but are written and applied by personnel with different responsibilities (e.g., maintenance and the contractor).

More specific results from ORPS are summarized in Figure 3. It is evident that procedures not defined or easily interpreted are the most common type of incident surrounding confusion or difficulty associated with procedures.

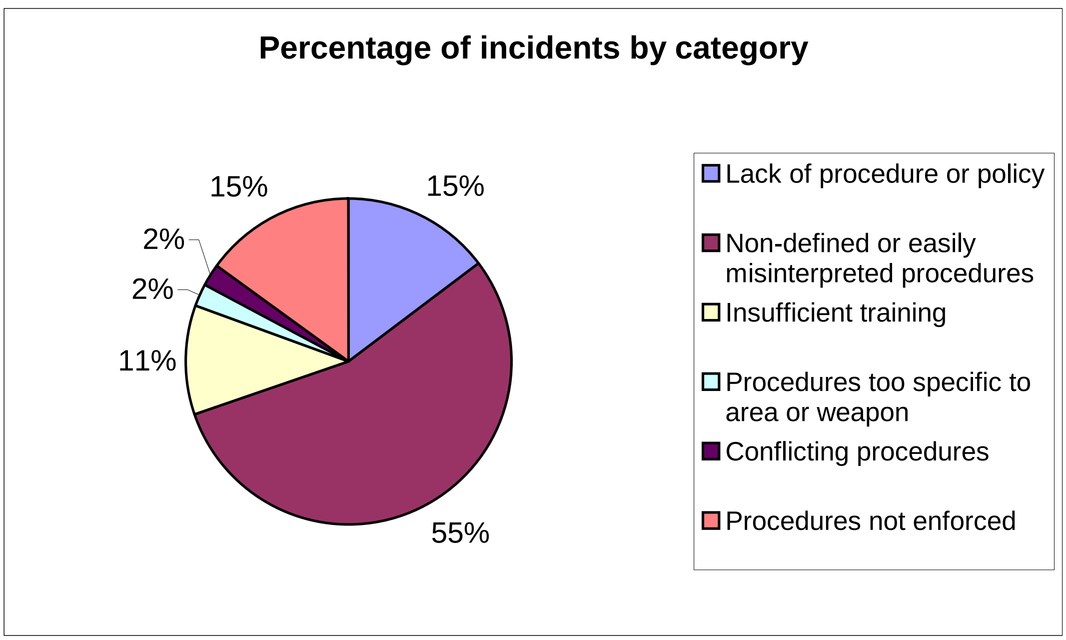

Figure 3: Delineation of incidents surrounding confusion or difficulty associated with procedures.

The other data sources that were reviewed for incident trends were not as thorough concerning the human component of the incident. As stated previously, the SFI reports did not contain information on any type of human interaction with the system. The TSI reports did include some information on the human component, but the reports were not detailed enough to allow for any patterns to emerge. However, after reading through several reports, some procedural issues were evident. Some human error issues found were: Lack of written processing specifications, poor quality inspection, and improperly written procedures, thereby supporting the patterns found in the ORPS database.

The Unsatisfactory Reports (URs) did provide some more information on human factors issues, including violations of cautions in procedures, improper training, incorrect or interpretable procedures, improper installation or assembly, and damage caused by dropped components. The reports in this database centered more on damage to specific parts. In most cases, the human component of the system was not thoroughly investigated; therefore, the underlying trends of human related issues could not be determined. However, the results of the report review did concur with the findings from the ORPS database as about 60% of the incidents reviewed in the database that related to human or maintenance handling issues (i.e., those reports found under the "Maintenance/Handling" choice under the "Probable Cause" field) were related to procedure problems. Nevertheless, the search for reports listing human related incidents would have been more complete if key word searches had been possible. A more detailed search of the available reports in this database would probably provide further results.

Information Technology

While offering promising features, the utility of Knowledgist™ was low for this application. ORPS has a web search interface which gathers information from the ORPS database itself. Knowledgist™ needs to have access to the database directly and consequently Knowledgist™ could initially only provide reports for the web content. The administrators of ORPS could not provide direct access to the ORPS database in time for this first project year. However, a less automated and temporary solution was to use the ORPS user interface to manually download ORPS search results and compile a local (i.e., on a Sandia machine) database. As a result, the compiled and local database was accessible to Knowledgist™. Even so, however, the results obtained through Knowledgist™ were found to be less effective than manually reading the reports.

Task Analysis Methods

Kirwan and Ainsworth (1992) define task analysis as, "the study of what an operator (or team of operators) is required to do, in terms of actions and/or cognitive processes, to achieve a system goal." Traditional task analysis methods have been described as normative (Vicente, 1999), and use clear constraints (e.g., tools available, system design features) to describe how the tasks should be performed. While this is an inherent part of developing and analyzing processes, it is void of many variables that could significantly impact human performance. In addition, normative approaches often consist of erroneous assumptions (e.g., "it works for me, so it will work for everyone else").

Alternatives to normative approaches have emerged due to a gradual transition to a greater reliance on automation, where it is not always possible to observe everything that an operator must perform. Although many tasks in the weapons domain are observable (e.g., removing bolts, connecting wires), many less observable tasks exist and are increasing, as in the use of Interactive Electronic Procedures. As a result, task analyses are less straightforward and consist of more subtleties that have prompted human factors engineers to pursue alternatives to normative task analysis.

A consequence of a strong reliance on normative approaches is the fragile means of responding to human error. If an error occurs, where a human performs the task different from the way it "should" have been performed, a common conclusion is that the human was negligent and they need refresher training. However, training is not a reliable predictor of human performance (Bailey, 1989). While training is necessary and valuable, it should not be a dominant means of mitigating human error.

An alternative to training is to assess the context and environmental factors associated with a task. Simon (1981) uses the analogy of an ant walking across sand to illustrate this notion. Like an ant, a human can be viewed behaviorally as a simple system. Over time, however, the complexity of the human's behavior is consistent with the complexity of the environment. An ant may not walk in a straight line across sand due to the contours or other factors in the sand (see Figure 4). Accounting for these "contours" with respect to human performance is a central objective common to many of the more recent advances in task analyses.

Figure 4: Simon's (1981) analogy of an ant's path influenced by its environment.

Methodologically, a common feature of modern task analyses is the use of field studies. Field studies involve the observation and interaction with subject matter experts (SMEs) in their natural environment. In order the extract the subtleties of complex task domains the traditional method of observing performance remains but is augmented by a greater emphasis on interacting with the SMEs. Such interaction typically includes semi-structured interviews or dialogue between the analyst and the SMEs. Analysts may be prepared with general issues to discuss, but the specific flow of the discussion can follow topics or concepts as they arise.

One descriptive task analysis technique is Operator Function Modeling (Mitchell, 1987; Brannon & Narayanan, 1997). The product of this technique is a descriptive representation of activities. The activities may be multiple and concurrent, and perhaps performed by more than one person. The representation is typically a network diagram of hierarchic and heterarchic activities. An example is shown in Figures 5 and 6 for a wastewater supervisory control task. Hierarchically, the highest level is typically the goals or task objectives. The model delineates the more specific activities that support that goal working down to more specific tasks such as using controls or reading displays. The heterarchic feature of the model accommodates the description of concurrent activities.

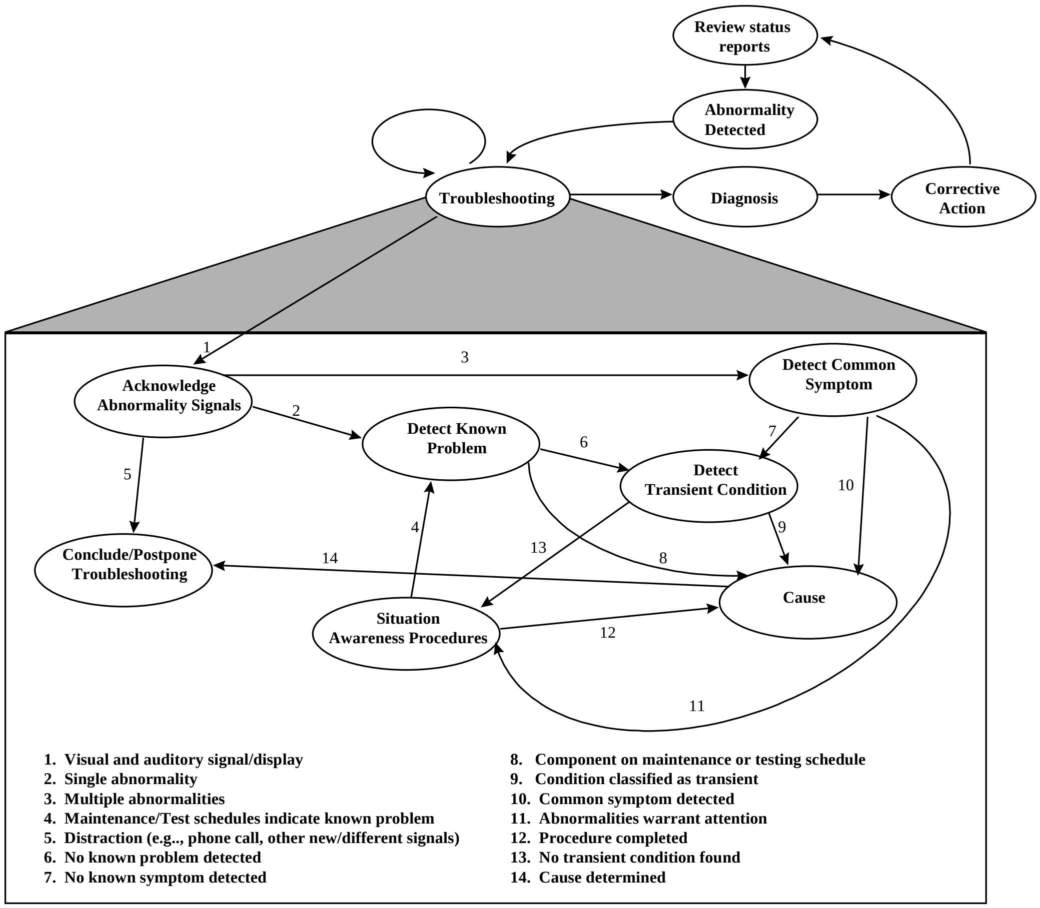

Figure 5: Higher level of OFM of wastewater supervisory control operations (Brannon & Narayanan, 1997).

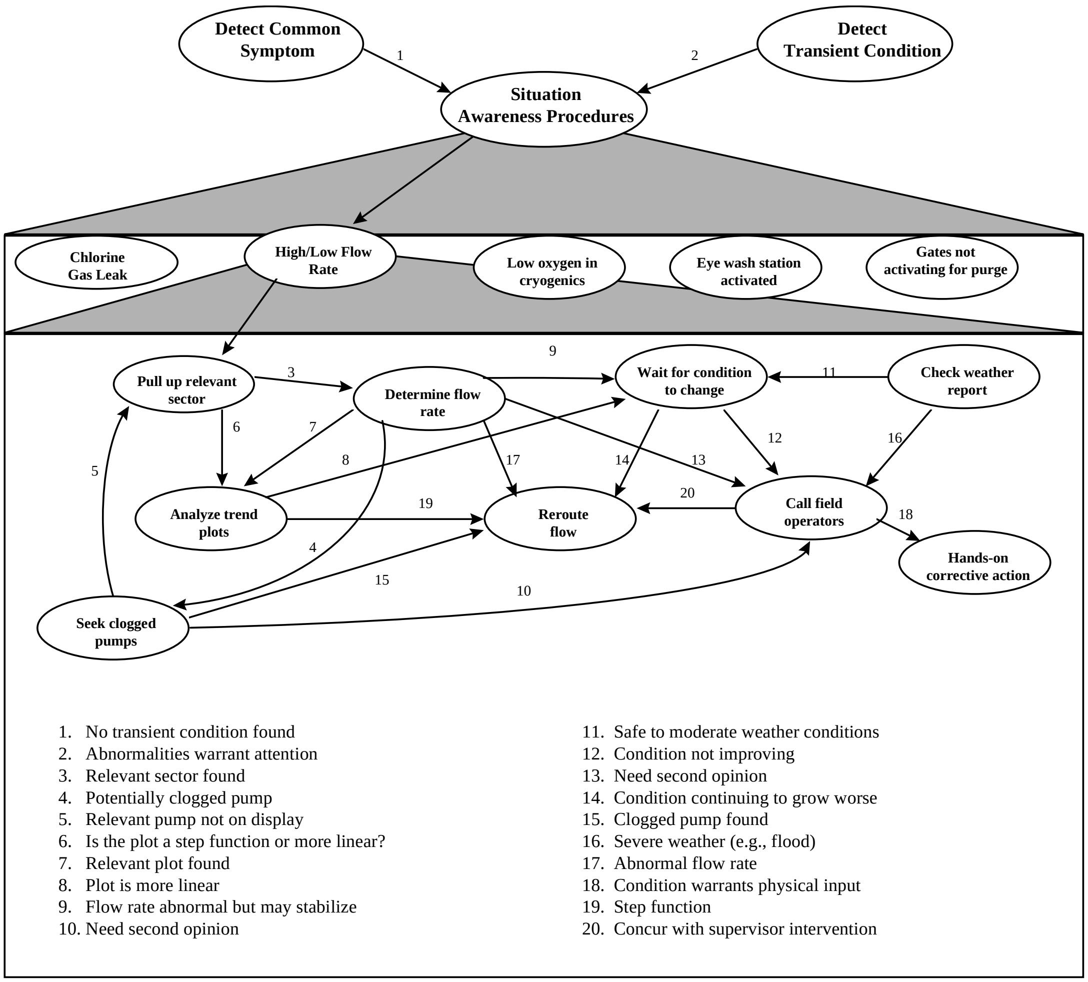

Figure 6: OFM decomposition of situation awareness procedures (Brannon & Narayanan, 1997).

Review of Work Assessment Tools

There are a significant number of tools that have been developed to help perform human factors and hazard assessments. These tools range from generic checklists that can be used to identify potential hazards in a generic work environment to tools that have been specifically designed for use in a specific industry. For example, Hammer (1989) provides generic checklists that can be used to help assess common industrial and occupational hazards, and Chervak and Drury (1995) developed an ergonomic audit program specifically designed to assess the hazards involved in aviation maintenance and inspection tasks. The goal of all of these tools is to provide analysts with a consistent, objective and thorough means of looking at a system and identifying potential problems.

Developing a set of tools for use in hazard walkthroughs will require more investigation into how existing tools can be adapted for use in the specific Pantex environment. This adaptation will draw from existing work assessment tools, including a tool developed by Human Factors staff at Los Alamos National Laboratories which includes an annotated list of relevant Issues and Considerations that may impact human performance along with a checklist to be used during walkthroughs (Pond, Gilmore and Houghton, 2003). Further, information gleaned from retroactive analyses can be used to further tailor these tools towards specific hazards.

Literature Review of Human Performance Involving Formalized Procedures

Marcus, Cooper and Sweller (1996) define understanding of instructions as the ability to follow instructions successfully and readily. They suggest that understanding instructions is influenced by two factors which interact with each other and with relevant characteristics of the human information processing system: the intrinsic complexity of the information, and the manner in which the information is presented. Specifically, information that is too complex or that is presented in a confusing manner may overload the working memory of the person using the instructions. Thus, working memory capacity may be the limiting factor in understanding instructions and solving problems (Sweller, 1994). Understanding is promoted by ensuring that the information does not contain multiple elements that must be considered simultaneously, and by presenting the information in a manner that does not impose a heavy cognitive load (Marcus, Cooper and Sweller, 1996).

There is a considerable body of research into the design and use of instructions in work domains. The design of instructions is similar to the design of any product. Thus, guidelines for good software and product design are all applicable when designing instructions or procedures. Information pertaining to the design of good technical documents is also relevant and should be incorporated when writing instructions. There are many references that summarize good technical writing principles (e.g., Haydon, 1995; Hartley, 1994; Schoff and Robinson, 1984; Wright, 1977) that can be applied when writing work instructions.

Airline maintenance is similar to the work being done at Pantex in that both involve highly proceduralized tasks for high consequence systems. While an error at Pantex may result in a nuclear weapons accident, an error in the airline maintenance environment may result in the loss of a commercial jet. There has been research addressing the design of good airline maintenance workcards (Drury and Sarac, 1997; Patel, Drury and Lofgren, 1994). In addition, previous research has indicated that improving the format and/or layout of airline workcards results in improved comprehension of the instructions (Drury, Sarac and Kritkausky, 1998).

Patel, Prabhu and Drury (1993) developed a taxonomy describing the important issues in documentation design for work instructions. The four basic categories in this taxonomy are: information readability, information content, information organization and physical handling and environmental factors. Information readability refers to typographic layout of the documentation, as well as conventions concerning sentences, words and letters. Information content is concerned with what information to give, how to give it, and in what order so that the documentation is appropriate, accurate, complete and easily comprehensible to the users. Information organization refers to how the information is categorized (e.g., categories of different types of information are clear and distinct) within the document. Physical handling and environmental factors refers to ensuring that the form in which the instructions are presented is compatible with the working environment. It is important to remember that these issues apply to all documentation, whether presented on paper or on computer-based systems. Patel, et al. (1995) compared an original paper based workcard system to an improved paper-based system and to a computer-based system. They found that the computer-based system was easier to understand, made it easier to find information, increased organization and consistency of information and increased overall workcard usability. However, these same improvements were also found in the improved paper-based system, suggesting that it is the improvements in readability, content and organization that improve performance rather than the medium in which it is presented.

Ramos and Gilmore (2003) performed a usability evaluation of the Interactive Electronic Procedures (IEP) system that is being introduced at Pantex. The IEP system consists of hardware and software that will provide all work instructions to the Pantex technicians electronically. The electronic presentation will help ensure that information readability and information organization are consistent across procedures. The IEP may also support improved information content by ensuring that additional support information is readily accessible to the technicians who need this information. However, since there has not been a concerted effort to rewrite the procedures before they are entered into IEP, there remains a concern that any problems (e.g., confusing descriptions, references to other documents, missing or incomplete instructions) that exist in the current paper version of the procedures will simply be carried over into the electronic version.

Lessons Learned

Retroactive Data Analysis

As was previously stated, the data sources were not easily retrieved due to the logistics of finding and gaining access to the desired information in all the separate and scattered sources of data. In addition, the software interface for the ORPS database was excessively cumbersome and complicated. Much time was spent trying to manipulate and become familiar with the database interface in order to retrieve the necessary reports. Also, downloading the reports proved to be a burdensome task, as in some cases the search results were so large that the downloading time was incredibly lengthy. The interface of the database needs much improvement in order to be able to provide a more user-friendly interface that allows for less cumbersome searching.

In addition, compiling a list of all the available data sources, with a categorization or explanation of each one's data collection purpose, would facilitate trend analysis across the complex. As it is right now, it is not very clear what the overall purpose of all the data sources are and how they differ from one another or even what purpose they serve in trend analysis, if any. In fact, it seems that some reports, such as TSIs, are just being stored away and are in no way being compiled for future analysis.

The content of the reports was also limited in its utility with respect to human error analysis. The categorization varied significantly between data sources and within the data sources themselves. For example, there were no definite descriptive categories within the ORPS database and what someone may have considered to be an administrative control error another individual may have considered a technician error. As such, it was difficult to look for trends based on the direct cause categorization without reading through a whole report.

Reports need to be structured in a manner that facilitates trend analysis. Currently, the reports do not generate enough depth to analyze the incident and provide corrective actions beyond training and reprimands. Often, latent causes are present throughout incidents that are not directly identifiable and a thorough analysis of events that occurred prior to an incident may help bring out hazards that can be controlled to avoid similar future incidents. Simply providing training or blaming an individual does not address the larger systemic issues that may be present. Therefore, the right questions need to be asked during an incident reporting investigation, in addition to providing distinct categories with appropriate descriptions and more detailed analysis of the probable causes. This is where a well-structured data collection device can assure that the appropriate information is collected, which will allow the analysis of incidents and a proactive approach to accident prevention.

As previously mentioned, a problem with the reports available from the data sources, particularly those from the ORPS database, was that they are written with a bias toward attributing blame. This not only becomes an issue during the investigative part of the incident, but it also affects the workers' motivation to report an incident. Most individuals are not going to report an incident in a corporate culture where blame will most likely be attributed to themselves or fellow workers or when they will be punished for making the report. The purpose of the reports should not be to "point the finger" at someone in order to protect the overall process, but rather to compile incidents in order to find problems - overt as well as latent - within the overall system. Another issue is that most reports are written by a third party, who has interpreted the explanations of the people involved in the incident in order to complete the investigation. It would be advantageous to provide a section in the report where the individuals involved are allowed to report their own version of what occurred.

Information Technology

With regard to information technology tools and specifically lessons learned with Knowledgist™, it is believed that more useful software will soon become available. Areas of automated linguistics and natural language processing are being researched more heavily and it is likely therefore that this work will yield more enabling tools. Nevertheless, this is not to say that Knowledgist™ has been dismissed as useless. More time is needed to explore the utility of the results produced by Knowledgist™.

Task Analysis Methods

A review of various task analysis methodologies in the literature reveals several common elements. First, an emphasis is placed on performing field studies in the expert's natural environment. Second, the analyst must interact with the subject matter expert to some capacity in order to elicit their unique knowledge. Finally, the product results in a descriptive representation of the experts' activities.

To some degree the review of nuclear weapons operations is consistent with the literature's descriptions associated with "field studies." Experts participate and high fidelity trainers are used along with the same tools used to perform maintenance tasks. In the interest of easing some of the administrative burdens associated with security, walkthroughs are typically conducted outside of the most secure areas in what are referred to as "training bays." It would be ideal with respect to fidelity to conduct reviews of operations in the actual bays and cells. This is not to say that observing actual operations is not possible. If specific issues of higher priority are of interest with a greater need to evaluate what is being done "on the line," then arrangements can be made to observe actual nuclear weapons operations to resolve such issues. Nevertheless, given the administrative requirements associated with such a visit, this is understandably burdensome.

Path Forward

Phase II

With advances in automated processing of text databases, the goal to reduce manual reading of large and complex databases will likely be fulfilled in the near term. Software that automatically scans and structures large and complex text databases continues to be developed. Continued investigation into information technology software is warranted. As noted earlier, tools like Knowledgist™ need more time and research to determine their utility. One hurdle that must be addressed is the connection between tools such as Knowledgist™ and web-based databases such as ORPS. Phase II will include efforts to close this gap and facilitate open and more comprehensive searches. Such effort will include work with database administrators to establish secure network connections between machines loaded with information technology tools and incident database servers.

Phase II will also include the development of a prototype tool for use in proactive analyses. This tool will merge the methodologies associated with modern task analysis and the work assessment tools discussed earlier. The outcome would be a tool designed for human factors analysts supporting hazard analysis task teams (HATT) evaluating weapons operations at Pantex.

The information recorded in databases including ORPS is cumbersome to review for the purpose of deriving systemic issues. The content recorded in the incident reports is influenced significantly by the forms and tools reporters are required to use. As a result, Phase II will include the development of prototype incident reporting forms. The forms will be designed to place a minimal time and labor burden on those reporting incident details, while at the same time facilitate the recording of incident data that is well staged for subsequent analyses.

Phase III

A central objective in Phase III will be to progress toward a more centralized retroactive database for human factors and hazard analysts. Currently there are many separate resources of information that could provide insight as to the variables contributing to incidents of human error. Such "islands of information" are not designed for use by human factors analysts, and the lack of integration further inhibits the utility of the resources. The conceptual idea for a more usable and integrated resource is known as the Technician Error Reporting System (TERS). The goal of such a system would be to record information about near-misses and errors, in addition to reporting incidents that have occurred.

Users and contributors to TERS would include: human factors engineers, hazard analysts, safety engineers, production technicians, and production technician trainers. Input from production technicians is well understood to be a sensitive concept. Still, this should not inhibit progress toward a reporting system that maintains anonymity, blocks repercussions, and most importantly publishes critical contextual factors surrounding errors or near misses. If such a system can be instituted in the aircraft maintenance community (Aviation Safety Recording System, NASA), it may be possible to institute such a system in the nuclear weapons community as well.

Human factors engineers can utilize a system like TERS to reflect findings from proactive analyses. Through the interaction with technicians, trainers and other general staff during processes like process walkdowns, many insights can be gained that help shape the context and environmental constraints associated with nuclear weapons work. Such insights can be captured in TERS for use in the future for development of subsequent versions of task analysis tools and methods.

There are many insights to be derived from other domains such as aircraft maintenance in terms of the design of a reporting system. Critical features such as the form of questions to prompt those entering information need to be delineated in Phase III.

Although a proposed new database would be developed, the other, existing databases (e.g., ORPS) would remain useful. An objective then would be to bring structure to the use of data from other sources and formalize the means of networking such data with TERS.

Conclusion

The reliance on human effectiveness is a significant component in the domain of nuclear weapons maintenance. The human represents the most significant source of variability as illustrated by a steady stream of incidents related to human error reported across the nuclear weapons complex. The current hazard analysis process and efforts to control human error lack consistency, thoroughness, and objectivity.

Considerable opportunities exist to leverage historical data and objective analysis tools to facilitate more targeted and thorough analyses of human error. Human factors and hazard analysts can be equipped with rich background information and effective tools that can help them to assess and control human error. The current report offers short, near, and long-term solutions that could enhance the current means of hazard analysis and human error mitigation.

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APPENDIX A: List of ORPS Reports by Category

List of ORPS Reports by Category

A	C	D	E	F	G
Lack of procedure/ Policy	Not Specific or Defined - Easily Misinterpreted	Not Known by Worker (no training)	Specific to Buildings, Weapons, etc.	Involve Numerous Documents or Refer to Numerous Documents	Not Enforced
Total: 77	Total: 289	Total: 58	Total: 11	Total: 12	Total: 79
Percent: 15%	Percent: 55%	Percent: 11%	Percent: 2%	Percent: 2%	Percent: 15%
1991-0012	1991-0039	1991-1024	1991-0032	1993-0020	1991-1032
1991-0020	1991-1004	1992-0023	1992-0067	1994-0028	1992-0075
1991-0022	1991-1011	1992-0058	1992-0074	1995-0032#	1993-0013
1991-0028	1991-1041	1992-0078	1993-0022	1996-0129	1993-0031
1991-0034	1991-1043	1993-0035	1994-0019	1996-0187%	1993-0036*
1991-0035	1992-0003	1993-0042	1995-0006	1997-0037	1993-0060
1991-0036	1992-0007	1993-0044	1995-0010	1998-0006%	1994-0016
1991-0038	1992-0019	1994-0009	1996-0011	1998-0008*	1994-0069*
1991-0040	1992-0023	1994-0076	1997-0064	1998-0060*	1994-0124*
1991-0041	1992-0028	1994-0090	2001-0002	1999-0021%	1994-0163*
1991-0041	1992-0033	1994-0112	2001-0098	1999-0051*	1994-0167*
1991-1033	1992-0036	1994-0127		1999-0077	1994-0168*
1992-0020	1992-0039	1994-0151			1995-0039
1992-0023	1992-0050	1995-0209			1995-0051*
1992-0030	1992-0052	1995-0210			1995-0060*
1992-0035	1992-0055	1996-0068			1995-0103*
1992-0053	1992-0058	1996-0069			1995-0120*
1992-0063	1992-0059	1996-0072			1995-0122*
1993-0029	1992-0064	1996-0107			1995-0124*
1993-0048	1992-0077	1996-0108			1995-0132
1993-0048	1992-0080	1996-0115			1995-0137*
1994-0004	1992-0081	1996-0122			1995-0153*
1994-0038	1992-0083	1996-0129			1995-0159*
1994-0108	1993-0008	1996-0153			1995-0176*
1994-0118	1993-0011	1996-0206			1995-0195*
1994-0129	1993-0012	1996-0236			1995-0197*
1994-0145	1993-0028	1997-0073			1995-0202*
1994-0152	1993-0041	1997-0077			1995-0205*
1994-0170	1993-0045	1998-0018			1995-0211
1994-0172	1993-0051	1998-0048			1995-0227*
1995-0011	1993-0057	1998-0087			1995-0228*
1995-0079	1993-0063	1998-0091			1995-0229*
1995-0083	1993-0064	1999-0008			1996-0001*
1995-0090	1994-0007	1999-0020			1996-0008
1995-0108	1994-0014*	1999-0026			1996-0016*
1995-0110	1994-0022	1999-0049			1996-0017*
1995-0144	1994-0026	2000-0027			1996-0018*
1995-0215	1994-0027	2000-0032			1996-0020*
1995-0226	1994-0028	2000-0033			1996-0022*
1996-0045	1994-0043	2000-0078			1996-0023*
1996-0084	1994-0054	2000-0081			1996-0024*
1996-0183	1994-0056	2000-0087			1996-0044
1996-0184	1994-0059	2000-0093			1996-0056*
1996-0206	1994-0068	2001-0037			1996-0061*
1996-0225	1994-0074	2001-0047			1996-0066*
1996-0231	1994-0076	2001-0058			1996-0083*
1997-0019	1994-0090	2001-0078			1996-0096
1997-0054	1994-0095	2001-0088			1996-0098*
1997-0068	1994-0096	2001-0097			1996-0124*

A	C	D	E	F	G
Lack of procedure/ Policy	Not Specific or Defined - Easily Misinterpreted	Not Known by Worker (no training)	Specific to Buildings, Weapons, etc.	Involve Numerous Documents or Refer to Numerous Documents	Not Enforced
1997-0104	1994-0104^	2002-0005			1996-0131
1998-0007	1994-0105	2002-0013			1996-0178*
1998-0061	1994-0112	2002-0033			1996-0216*
1998-0063	1994-0125	2002-0044			1996-0239
1998-0070	1994-0126	2002-0046			1997-0004*
1999-0001	1994-0127	2002-0062			1997-0007*
1999-0009	1994-0132	2002-0063			1997-0016*
1999-0038	1994-0133	2003-0007			1997-0033*
1999-0052	1994-0137&	2003-0023			1997-0048
1999-0071	1994-0139				1997-0060*
1999-0082	1994-0140				1997-0070
2000-0003	1994-0150				1997-0077
2000-0024	1994-0155				1997-0086*
2000-0041	1994-0156				1997-0094
2000-0056	1994-0171				1998-0009
2000-0067	1994-0175				1998-0034
2000-0098	1994-0195				1998-0039@
2001-0034	1994-0196				1998-0058*
2001-0085	1994-0197				1998-0075
2001-0092	1995-0010				1998-0076*
2002-0003	1995-0014^				1998-0079
2002-0033	1995-0020^				1998-0090
2002-0037	1995-0034				1999-0023
2002-0056	1995-0036				1999-0032@
2002-0059	1995-0043				1999-0033
2003-0019	1995-0056				1999-0041*
2003-0021	1995-0057				2000-0025
2003-0027	1995-0063				2000-0064
	1995-0071				2001-0064*
	1995-0094				2002-0064
	1995-0113				
	1995-0114				
	1995-0121				
	1995-0126				
	1995-0128				
	1995-0130				
	1995-0132				
	1995-0135				
	1995-0143				
	1995-0150				
	1995-0152				
	1995-0160				
	1995-0170				
	1995-0174				
	1995-0177				
	1995-0181				
	1995-0184				
	1995-0194				
	1995-0203				
	1995-0206				
	1995-0207				
	1995-0210				
	1995-0217				
	1995-0223				
	1995-0225				
	1996-0029				
	1996-0037				
	1996-0039				
	1996-0040				
	1996-0054				

A	C	D	E	F	G
Lack of procedure/ Policy	Not Specific or Defined - Easily Misinterpreted	Not Known by Worker (no training)	Specific to Buildings, Weapons, etc.	Involve Numerous Documents or Refer to Numerous Documents	Not Enforced
	1996-0059				
	1996-0065				
	1996-0067				
	1996-0085				
	1996-0102				
	1996-0104				
	1996-0109				
	1996-0112				
	1996-0126				
	1996-0130				
	1996-0134				
	1996-0147				
	1996-0162				
	1996-0166				
	1996-0171				
	1996-0172				
	1996-0173				
	1996-0186				
	1996-0189				
	1996-0205				
	1996-0209				
	1996-0224				
	1996-0228				
	1996-0237				
	1997-0010				
	1997-0011				
	1997-0028				
	1997-0029				
	1997-0031				
	1997-0045				
	1997-0046				
	1997-0065				
	1997-0072				
	1997-0073				
	1997-0082				
	1997-0085				
	1997-0088				
	1997-0092				
	1997-0098				
	1997-0099				
	1997-0100				
	1997-0101				
	1997-0103				
	1998-0011				
	1998-0012*				
	1998-0016				
	1998-0019				
	1998-0020				
	1998-0021				
	1998-0032				
	1998-0033				
	1998-0035				
	1998-0040				
	1998-0047				
	1998-0055				
	1998-0056				
	1998-0057				
	1998-0059				
	1998-0062				
	1998-0064				

A	C	D	E	F	G
Lack of procedure/ Policy	Not Specific or Defined - Easily Misinterpreted	Not Known by Worker (no training)	Specific to Buildings, Weapons, etc.	Involve Numerous Documents or Refer to Numerous Documents	Not Enforced
	1998-0066				
	1998-0069				
	1998-0071				
	1998-0073				
	1998-0074				
	1998-0079				
	1998-0081				
	1998-0083				
	1998-0084				
	1999-0002				
	1999-0005				
	1999-0011				
	1999-0015				
	1999-0016				
	1999-0020				
	1999-0025				
	1999-0029				
	1999-0030				
	1999-0035				
	1999-0042				
	1999-0044				
	1999-0050				
	1999-0060				
	1999-0066				
	1999-0067				
	1999-0069				
	1999-0073				
	1999-0078				
	1999-0081				
	1999-0086				
	1999-0087				
	1999-0088				
	1999-0089				
	2000-0002				
	2000-0005				
	2000-0010				
	2000-0011				
	2000-0014				
	2000-0016				
	2000-0017				
	2000-0020				
	2000-0023				
	2000-0025				
	2000-0027				
	2000-0028				
	2000-0031				
	2000-0032				
	2000-0045				
	2000-0047%				
	2000-0057				
	2000-0058				
	2000-0063				
	2000-0065				
	2000-0073				
	2000-0079				
	2000-0080				
	2000-0082				
	2000-0096				
	2000-0097				
	2001-0003(MHC)				

A	C	D	E	F	G
Lack of procedure/ Policy	Not Specific or Defined - Easily Misinterpreted	Not Known by Worker (no training)	Specific to Buildings, Weapons, etc.	Involve Numerous Documents or Refer to Numerous Documents	Not Enforced
	2001-0004				
	2001-0005				
	2001-0005(MHC)				
	2001-0006				
	2001-0008				
	2001-0010				
	2001-0012				
	2001-0013				
	2001-0022				
	2001-0029				
	2001-0045				
	2001-0051				
	2001-0055				
	2001-0057				
	2001-0058				
	2001-0059				
	2001-0062%				
	2001-0069				
	2001-0071				
	2001-0076				
	2001-0079				
	2001-0090				
	2001-0091				
	2001-0095				
	2001-0097				
	2001-0101				
	2001-0105				
	2001-0106				
	2001-0108				
	2001-0111				
	2001-0113				
	2001-0115				
	2002-0002				
	2002-0004				
	2002-0007				
	2002-0008				
	2002-0009				
	2002-0010				
	2002-0013				
	2002-0018				
	2002-0021				
	2002-0025				
	2002-0026				
	2002-0027				
	2002-0031				
	2002-0034				
	2002-0040				
	2002-0043				
	2002-0049				
	2002-0063				
	2003-0002				
	2003-0006				
	2003-0007				
	2003-0015				
	2003-0016				
	2003-0018				
	2003-0026				
	2003-0028				
	2003-0029				
	2003-0034				

Distribution:

1	MS0313	Paul Yourick	06340
1	MS0405	Susan Camp	12346
1	MS0405	Celestino Casaus	12346
1	MS0405	Martha Charles-Vickers	12346
1	MS0405	Alton Donnell	12346
1	MS0405	Todd R. Jones	12346
1	MS0405	Teresa Sype	12346
1	MS0428	David Carlson	12300
1	MS0428	Victor Johnson	12340
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