Guidelines for Preventing Human Error in Process Safety

Center for Chemical Process Safety
Guidelines for Preventing Human Error in Process Safety
Publications Available from the
CENTER FOR CHEMICAL PROCESS SAFETY
of the
AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

Guidelines for Preventing Human Error in Process Safety
Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs
Guidelines for Implementing Process Safety Management Systems
Guidelines for Safe Automation of Chemical Processes
Guidelines for Engineering Design for Process Safety
Guidelines for Auditing Process Safety Management Systems
Guidelines for Investigating Chemical Process Incidents
Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples
Plant Guidelines for Technical Management of Chemical Process Safety
Guidelines for Technological Management of Chemical Process Safety
Guidelines for Chemical Process Quantitative Risk Analysis
Guidelines for Process Equipment Reliability Data, with Data Tables
Guidelines for Vapor Release Mitigation
Guidelines for Safe Storage and Handling of High Toxic Hazard Materials
Guidelines for Use of Vapor Cloud Dispersion Models
Safety, Health, and Loss Prevention in Chemical Processes: Problems for Undergraduate Engineering Curricula
Workbook of Test Cases for Vapor Cloud Source Dispersion Models
CCPS/AICHE Directory of Chemical Process Safety Services
Guidelines for Preventing Human Error in Process Safety

Center for Chemical Process Safety
To the Memory of John Embrey, 1937–1993

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New York, New York 10017

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The Center for Chemical Process Safety (CPS) was established in 1985 by the American Institute of Chemical Engineers (AIChE) for the express purpose of assisting the Chemical and Hydrocarbon Process Industries in avoiding or mitigating catastrophic chemical accidents. To achieve this goal, CCPS has focused its work on four areas:

- establishing and publishing the latest scientific and engineering guidelines (not standards) for prevention and mitigation of incidents involving toxic and/or reactive materials;
- encouraging the use of such information by dissemination through publications, seminars, symposia and continuing education programs for engineers;
- advancing the state-of-the-art in engineering practices and technical management through research in prevention and mitigation of catastrophic events; and
- developing and encouraging the use of undergraduate education curricula that will improve the safety knowledge and awareness of engineers.

It is readily acknowledged that human errors at the operational level are a primary contributor to the failure of systems. It is often not recognized, however, that these errors frequently arise from failures at the management, design, or technical expert levels of the company. This book aims to show how error at all of these levels can be minimized by the systematic application of tools, techniques and principles from the disciplines of human factors, ergonomics, and cognitive psychology. The book is the result of a project in which a group of volunteer professionals from CCPS sponsor companies prepared a project proposal and then worked with the successful contractor, Dr. David Embrey of Human Reliability Associates, to produce this book. The ensuing dialogue has resulted in a book that not only provides the underlying principles and theories of the science of human factors, but also goes on to show their application to process safety problems and to the CCPS technical management of process safety system.
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This book was written by Dr. David Embrey of Human Reliability Associates, with the assistance of the CCPS Human Reliability Subcommittee. Section 8.2, Managing Human Error by Design, which deals with the application of human factors principles in the process safety management system, was written by the Human Reliability Subcommittee.

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Glossary and Acronyms

GLOSSARY

Active Errors  An active human error is an intended or unintended action that has an immediate negative consequence for the system.

Cognitive “tunnel vision” A characteristic of human performance under stress. Information is sought that confirms the initial hypothesis about the state of the process while disregarding information that contradicts the hypothesis.

Encystment  A characteristic of human performance under stress. Encystment occurs when minor problems and details are focused on to excess while more important issues are ignored.

External Error Mode  The observable form of an error, for example, an action omitted, as distinct from the underlying process

Externals  Psychological classification of individuals who assume (when under stress), that the problem is out of their immediate control and therefore seek assistance.

Human Error Probability  The probability that an error will occur during the performance of a particular job or task within a defined time period. Alternative definition: The probability that the human operator will fail to provide the required system function within the required time.

Human Information-Processing  A view of the human operator as an information-processing system. Information-processing models are conventionally expressed in terms of diagrams which indicate the flow of information through stages such as perception, decision-making, and action.

Human Reliability  The probability that a job will be successfully completed within a required minimum time.

Human–Machine Interface  The boundary across which information is transmitted between the process and the worker, for example, analog displays, VDUs.
**Internal Error Mechanism**  The psychological process (e.g., strong stereotype takeover) that underlies an external error mode.

**Internal Error Mode**  The stage in the sequence of events preceding an external error mode at which the failure occurred (e.g., failed to detect the initial signal).

**Internals**  Individuals who, when under stress, are likely to seek information about a problem and attempt to control it themselves.

**Knowledge-Based Level of Control**  Information processing carried out consciously as in a unique situation or by an unskilled or occasional user

**Latent error**  An erroneous action or decision for which the consequences only become apparent after a period of time when other conditions or events combine with the original error to produce a negative consequence for the system.

**Locus of Control**  The tendency of individuals to ascribe events to external or internal causes, which affects the degree of control that they perceive they have over these events. (See also **Externals** and **Internals**.)

**Manual Variability**  An error mechanism in which an action is not performed with the required degree of precision (e.g., time, spatial accuracy, force).

**Mindset Syndrome**  A stress-related phenomenon in which information that does not support a person's understanding of a situation is ignored. (See also **Cognitive tunnel vision**.)

**Mistakes**  Errors arising from a correct intentions that lead to incorrect action sequences. Such errors may arise, for example, from lack of knowledge or inappropriate diagnosis.

**Performance-Influencing Factors**  Factors that influence the effectiveness of human performance and hence the likelihood of errors.

**Population Stereotype**  Expectations held by a particular population with regard to the expected movement of a control or instrument indicator and the results or implications of this movement

**Reactance**  Occurs when a competent worker attempts to prove that his or her way of doing things is superior in response to being reassigned to a subordinate position.

**Recovery Error**  Failure to correct a human error before its consequences occur.

**Risk Assessment**  A methodology for identifying the sources of risk in a system and for making predictions of the likelihood of systems failures.

**Risk Homeostasis**  The theory that an operator will attempt to maintain a stable perception of risk following the implementation of new technology that increases the safety of a human–machine system. The theory predicts that operators will take greater risks where more safety devices are incorporated into the system.
Role Ambiguity  Exists when an individual has inadequate information about his or her roles or duties.

Role Conflict  Exists when there is the simultaneous occurrence of two or more sets of responsibilities or roles such that compliance with one is not compatible with compliance with the other(s).

Root Causes  The combinations of conditions or factors that underlie accidents or incidents.

Rule-Based Level of Control  In the context of chemical industry tasks, the type of human information processing in which diagnoses are made and actions are formulated on the basis of rules (e.g., “if the symptoms are X then the problem is Y”).

Rule Book Culture  An organization in which management or workers believe that all safety problems can be resolved by rigid adherence to a defined set of rules.

Skill-Based Level of Control  A mode of information processing characterized by the smooth execution of highly practiced, largely physical actions requiring little conscious monitoring.

Slips  Errors in which the intention is correct but failure occurs when carrying out the activity required. Slips occur at the skill-based level of information processing.

Stereotype Fixation  Occurs when an individual misapplies rules or procedures that are usually successful.

Stereotype Takeover  Occurs when an incorrect but highly practiced action is substituted for a correct but less frequently occurring action in a similar task. Also called a strong habit intrusion.

Traditional Safety Engineering  A safety management policy that emphasizes individual responsibility for system safety and the control of error by the use of motivational campaigns and punishment.

Vagabonding  Stress-related phenomenon in which a person’s thoughts move rapidly and uncontrollably among issues, treating each superficially.

Verbal Protocol Analysis  Technique in which the person is asked to give a “self-commentary” as he or she undertakes a task.

Violation  An error that occurs when an action is taken that contravenes known operational rules, restrictions, and/or procedures. The definition of violations excludes actions taken to intentionally harm the system (i.e., sabotage).

ACRONYMS

AT  Area Technician

CADET  Critical Action and Decision Evaluation Technique
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<tr>
<td>CADs</td>
<td>Critical Actions or Decisions</td>
</tr>
<tr>
<td>CCPS</td>
<td>Center for Chemical Process Safety</td>
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<tr>
<td>CCR</td>
<td>Central Control Room</td>
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<td>CCTV</td>
<td>Closed-Circuit Television</td>
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<td>CHAP</td>
<td>Critical Human Action Profile</td>
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<td>CPI</td>
<td>Chemical Process Industry</td>
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<td>CPQRA</td>
<td>Chemical Process Quantitative Risk Assessment</td>
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<td>CR</td>
<td>Control Room</td>
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<td>CRT</td>
<td>Cathode Ray Tube</td>
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<td>Generic Error Modeling System</td>
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<td>Human Error Analysis</td>
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<td>Human Factors Assessment Methodology</td>
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<td>Human Factors Engineering and Ergonomics Approach</td>
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<td>Human–Machine Interface</td>
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<td>Human Performance Evaluation System</td>
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<td>Human Performance Investigation Process</td>
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<td>Human Reliability Analysis</td>
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<td>Human Reliability Assessment Method</td>
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<td>HRP</td>
<td>Hazard Release Potential</td>
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<td>Hazard Severity Potential</td>
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<td>Influence Modeling and Assessment System</td>
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<td>IRS</td>
<td>Incident Reporting Systems</td>
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<td>ISRS</td>
<td>International Safety Rating Systems</td>
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<tr>
<td>LTA</td>
<td>Less Than Adequate</td>
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<td>MAST</td>
<td>Memory and Search Test</td>
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<tr>
<td>MORT</td>
<td>Management Oversight and Risk Tree</td>
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<td>MSM</td>
<td>Molecular Sieve Module</td>
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<td>NRC</td>
<td>US Nuclear Regulatory Commission</td>
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<tr>
<td>OAET</td>
<td>Operator Action Event Tree</td>
</tr>
<tr>
<td>OSD</td>
<td>Operational Sequence Diagram</td>
</tr>
<tr>
<td>P&amp;ID</td>
<td>Piping and Instrumentation Diagram</td>
</tr>
<tr>
<td>PA</td>
<td>Public Address</td>
</tr>
<tr>
<td>PCS</td>
<td>Process Control System</td>
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<tr>
<td>PDCC</td>
<td>Program Development and Coordination Committee</td>
</tr>
<tr>
<td>PHEA</td>
<td>Predictive Human Error Analysis</td>
</tr>
<tr>
<td>PIF</td>
<td>Performance Influencing Factors</td>
</tr>
<tr>
<td>PORV</td>
<td>Pilot-Operated Relief Valve</td>
</tr>
<tr>
<td>PPE</td>
<td>Personal Protective Equipment</td>
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<tr>
<td>PRV</td>
<td>Pressure Relief Valve</td>
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<td>PSA</td>
<td>Probabilistic Safety Analysis</td>
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<td>PSF</td>
<td>Performance Shaping Factors</td>
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<td>QRA</td>
<td>Quantitative Risk Assessment</td>
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<td>RCAS</td>
<td>Root Cause Analysis System</td>
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<td>Risk Homeostasis Theory</td>
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<td>SFG</td>
<td>Signal Flow Graphs</td>
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<td>SLI</td>
<td>Success Likelihood Index</td>
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<td>SLIM</td>
<td>Success Likelihood Index Method</td>
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<td>SM</td>
<td>Separator Module</td>
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<tr>
<td>SOP</td>
<td>Standard Operating Procedure</td>
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<tr>
<td>SORTM</td>
<td>Stimulus Operation Response Team Performance</td>
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<tr>
<td>SP</td>
<td>Set Points</td>
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<td>SPEAR</td>
<td>System for Predictive Error Analysis and Reduction</td>
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<td>SRK</td>
<td>Skill–Rule–Knowledge-Based Model</td>
</tr>
<tr>
<td>STAHR</td>
<td>Sociotechnical Approach to Human Reliability</td>
</tr>
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<td>STEP</td>
<td>Sequentially Timed Events Plotting Procedure</td>
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<tr>
<td>TA</td>
<td>Task Analysis</td>
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<td>THERP</td>
<td>Technique for Human Error Rate Prediction</td>
</tr>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
</tr>
<tr>
<td>TSE</td>
<td>Traditional Safety Engineering</td>
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<td>VDU</td>
<td>Visual Display Unit</td>
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Guidelines for Preventing Human Error in Process Safety
1

Introduction: The Role of Human Error in Chemical Process Safety

1.1. INTRODUCTION

1.1.1. Objective

This book has been written to show how the science of human factors can be applied at the plant level to significantly improve human performance and reduce human error, thus improving process safety.

1.1.2. Scope and Organization

The application of the science of human factors to eliminating error in all aspects of process design, management, operation, and maintenance is the focus of this work. Human error has been a major cause of almost all of the catastrophic accidents that have occurred in the chemical process industries (CPI). If one adopts the broad view of human error as being the result of a mismatch between human capabilities and process demands, then clearly management’s role is critical in the following areas:

- Defining the process
- Providing the resources to manage, operate, and maintain the process
- Setting up the feedback systems to monitor the processes which are critical to ensuring safe operation

The book begins with a discussion of the theories of error causation and then goes on to describe the various ways in which data can be collected, analyzed, and used to reduce the potential for error. Case studies are used to teach the methodology of error reduction in specific industry operations. Finally, the book concludes with a plan for a plant error reduction program and a discussion of how human factors principles impact on the process safety management system.
The book is organized as follows:

**Chapter 1, The Role of Human Error in Chemical Process Safety**, discusses the importance of reducing human error to an effective process safety effort at the plant. The engineers, managers, and process plant personnel in the CPI need to replace a perspective that has a blame and punishment view of error with a systems viewpoint that sees error as a mismatch between human capabilities and demands.

**Chapter 2, Understanding Human Performance and Error**, provides a comprehensive overview of the main approaches that have been applied to analyze, predict, and reduce human error. This chapter provides the reader with the underlying theories of human error that are needed to understand and apply a systems approach to its reduction.

**Chapter 3, Factors Affecting Human Performance in the Chemical Industry**, describes how a knowledge of "performance-influencing factors" (PIFs), can be used to identify and then eliminate error-causing conditions at the plant.

**Chapter 4, Analytical Methods for Predicting and Reducing Human Error**, contains a discussion and critique of the various methods that are available for analyzing a process for its potential for human error.

**Chapter 5, Quantitative and Qualitative Prediction of Human Error in Safety Assessments**, describes a systematic process for identifying and assessing the risks from human error, together with techniques for quantifying human error probabilities.

**Chapter 6, Data Collection and Incident Analysis Methods**, examines the pitfalls involved in collecting data on human error and suggests possible approaches to improving the quality of the data.

**Chapter 7, Case Studies**, uses examples that illustrate the application of the various error analysis and reduction techniques to real world process industry cases.

**Chapter 8, A Systematic Approach to the Management of Human Error**, explains how the manager and safety professional can use human factors principles in the management of process safety. This chapter also provides a practical plan for a plant human error reduction program that will improve productivity and quality as well.

### 1.1.3. Purpose of This Book

The objectives of this book are ambitious. It is intended to provide a comprehensive source of knowledge and practical advice that can be used to substantially reduce human error in the CPI. The following sections describe how this is achieved.
1.1.3.1. **Consciousness Raising**

A major objective is to provide engineers, managers, and process plant personnel in the CPI with an entirely new perspective on human error. In particular, the intention is to change the attitudes of the industry such that human error is removed from the emotional domain of blame and punishment. Instead, a systems perspective is taken, which views error as a natural consequence of a mismatch between human capabilities and demands, and an inappropriate organizational culture. From this perspective, the factors that directly influence error are ultimately controllable by management. This book is intended to provide tools, techniques, and knowledge that can be applied at all levels of the organization, to optimize human performance and minimize error. One of the major messages of this book, with regard to implementing the ideas that it contains, is that methods and techniques will only be effective in the long term if they are supported by the active participation of the entire workforce. To this extent, the consciousness raising process has to be supported by training. The primary focus for raising the awareness of approaches to human error and its control is in Chapters 2 and 7.

1.1.3.2 **Provision of Tools and Techniques**

This book brings together a wide range of tools and techniques used by human factors and human reliability specialists, which have proved to be useful in the context of human performance problems in the CPI. Although many human factors practitioners will be familiar with these methods, this book is intended to provide ready access to both simple and advanced techniques in a single source. Where possible, uses of the techniques in a CPI context are illustrated by means of case studies.

Chapter 4 focuses on techniques which are applied to a new or existing system to optimize human performance or qualitatively predict errors. Chapter 5 shows how these techniques are applied to risk assessment, and also describes other techniques for the quantification of human error probabilities. Chapters 6 and 7 provide an overview of techniques for analyzing the underlying causes of incidents and accidents that have already occurred.

1.1.3.3 **Provision of Solutions to Specific Problems**

In addition to raising consciousness and acquainting the reader with a selection of tools for error reduction, this book is also intended to provide assistance in solving specific human error problems that the reader may be experiencing at the plant level. It should be emphasized that no textbook can substitute for appropriate training in human factors techniques or for the advice of human factors specialists. Readers requiring advice should contact professional bodies such as the Human Factors and Ergonomics Society (USA) or the Ergonomics Society (England) who have lists of qualified consultants.
However, given appropriate training, it is quite feasible for personnel such as engineers and process workers to apply techniques such as task analysis (Chapter 4) and audit methods (Chapter 3) to reducing error potential in the workplace.

1.1.3.4. Provision of a Database of Case Studies
The book provides a comprehensive set of examples and case studies that cover a wide variety of process plant situations. Some of these are intended to illustrate the range of situations where human error has occurred in the CPI (see Appendix 1). Other examples illustrate specific techniques (for example, Chapter 4 and Chapter 5). Chapter 7 contains a number of extended case studies intended to illustrate techniques in detail and to show how a range of different techniques may be brought to bear on a specific problem.

1.1.3.5 Cross-Disciplinary Studies
Although this book is primarily written for chemical process industry readers, it also provides a sufficiently wide coverage of methods, case studies and theory to be of interest to behavioral scientists wishing to specialize in process industry applications. Similarly, it is hoped that the a comprehensive description of current theory and practice in this area will stimulate interest in the engineering community and encourage engineers to gain a more in-depth knowledge of the topic. Overall, the intention is to promote the cross-disciplinary perspective that is necessary for effective problem solving in the real world environment.

1.1.3.6. A Complement to Other CCPS Publications
A final objective of this book is to complement other books in this series such as Guidelines for Chemical Process Quantitative Risk Assessment (CCPS, 1989b), Guidelines for Investigating Chemical Process Incidents (CCPS, 1992d), and Plant Guidelines for the Technical Management of Chemical Process Safety (CCPS, 1992a). In the latter volume, human factors was identified as one of twelve essential elements of process safety management. The application to this area of the concepts described in this book is addressed in Chapter 8.

1.2. THE ROLE OF HUMAN ERROR IN SYSTEM ACCIDENTS
After many years of improvements in technical safety methods and process design, many organizations have found that accident rates, process plant losses and profitability have reached a plateau beyond which further improvements seem impossible to achieve. Another finding is that even in organizations with good general safety records, occasional large scale disasters occur which shake public confidence in the chemical process industry. The common