GUIDELINES FOR
Investigating
Chemical
Process
Incidents
Second Edition
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Chemical
Process
Incidents

Second Edition
This book is one of a series of titles published by the Center for Chemical Process Safety of the American Institute of Chemical Engineers. A complete list of available titles appears at the end of this book.
GUIDELINES FOR
Investigating Chemical Process Incidents
Second Edition

Center for Chemical Process Safety
of the
American Institute of Chemical Engineers
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Preface

The American Institute of Chemical Engineers (AIChE) has helped chemical plants, petrochemical plants, and refineries address the issues of process safety and loss control for over 30 years. Through its ties with process designers, plant constructors, facility operators, safety professionals, and academia, the AIChE has enhanced communication and fostered improvement in the high safety standards of the industry. AIChE's publications and symposia have become an information resource for the chemical engineering profession on the causes of incidents and the means of prevention.

The Center for Chemical Process Safety (CCPS), a directorate of AIChE, was established in 1985 to develop and disseminate technical information for use in the prevention of major chemical accidents. CCPS is supported by a diverse group of industrial sponsors in the chemical process industry and related industries who provide the necessary funding and professional guidance for its projects. The CCPS Technical Steering Committee and the technical subcommittees oversee individual projects selected by the CCPS. Professional representatives from sponsoring companies staff the subcommittees and a member of the CCPS staff coordinates their activities.

Since its founding, CCPS has published many volumes in its "Guidelines" series and in smaller "Concept" texts. Although most CCPS books are written for engineers in plant design and operations and address scientific techniques and engineering practices, several guidelines cover subjects related to chemical process safety management. A successful process safety program relies upon committed managers at all levels of a company who view process safety as an integral part of overall business management and act accordingly.

Incident investigation is an essential element of every process safety management program. This book presents underlying principles, man-
agement system considerations, investigation tools, and specific methodologies for investigating incidents in a way that will support implementation of a rigorous process safety program at any facility.

A team of incident investigation experts from the chemical industry drafted the chapters for this guideline and provided real-world examples to illustrate some of the tools and methods used in their profession. The subcommittee members reviewed the content extensively and industry peers evaluated this book to help ensure it represents a factual accounting of industry best practices. This second edition of the guideline provides updated information on many facets of the investigative process as well as additional details on important considerations such as human factors, forensics, legalities surrounding incident investigation, and near miss reporting.
Acknowledgments

The American Institute of Chemical Engineers wishes to thank the Center for Chemical Process Safety (CCPS) and those involved in its operation, including its many sponsors whose funding made this project possible; the members of its Technical Steering Committee who conceived of and supported this Guidelines project; and the members of its Incident Investigation Subcommittee. The Incident Investigation Subcommittee of the Center for Chemical Process Safety authored this second edition of the Guidelines for Investigating Chemical Process Incidents.

The members of the CCPS Incident Investigation Subcommittee were:

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The members of the CCPS Incident Investigation Subcommittee wish to thank their employers for allowing them to participate in this project and lastly, we wish to thank Scott Berger and Les Wittenberg of the CCPS staff for their support and guidance.
Acronyms and Abbreviations

ACC  American Chemistry Council
AIChe  American Institute of Chemical Engineers
ALARP  As Low as Reasonably Practicable
ANSI  American National Standards Institute
API  American Petroleum Institute
ARIP  Accidental Release Information Program
ASME  American Society of Mechanical Engineers
B.P.  Boiling Point
BI  Business Interruption
BLEVE  Boiling Liquid Expanding Vapor Explosion
BPCS  Basic Process Control System
C  Consequence factor, related to magnitude of severity
CCF  Common Cause Failure
CCPS  Center for Chemical Process Safety,
CEA  Change Evaluation/Analysis
CEI  Dow Chemical Exposure Index
CELD  Cause and Effect Logic Diagram
CIRC  Chemical Incidents Report Center
CLC  Comprehensive List of Causes
CPQRA  Chemical Process Quantitative Risk Assessment
CSB  Chemical Safety and Hazards Investigation Board (US)
CTM  Causal Tree Method
CW  Cooling Water
D  Number of times a component or system is challenged

DIERS  Design Institute for Emergency Relief Systems,
DOT  Department of Transportation
E&CF  Events & Causal Factor Charting
EBV  Emergency Block Valve
Guidelines for Investigating Chemical Process Incidents

EPA  United States Environmental Protection Agency
ERPG  Emergency Response Planning Guideline
ETA  Event Tree Analysis
F  Failure Rate (hr\(^{-1}\) or year\(^{-1}\))
f  Frequency (hr\(^{-1}\) or year\(^{-1}\))
F&EI  Dow Fire and Explosion Index
F/N  Fatality Frequency versus Cumulative Number
FCE  Final Control Element
FMEA  Failure Modes and Effect Analysis
FTA  Fault Tree Analysis
HAZMAT  Hazardous Materials
HAZOP  Hazard and Operability Study
HAZWOPER  Hazardous Waste Operations and Emergency Response
HBT  Hazard−Barrier−Target
HE  Hazard Evaluation
HRA  Human Reliability Analysis
IChemE  Institution of Chemical Engineers
IEC  International Electrotechnical Commission
IEEE  Institute of Electrical and Electronic Engineers
IPL  Independent Protection Layer
ISA  The Instrumentation, Systems, and Automation Society
(Jointly with the Instrument Society of America)
JSA  Job Safety Analysis
LAH  Level Alarm—High
LEL  Lower Explosive Limit
LFL  Lower Flammability Limit
LI  Level Indicator
LIC  Level Indicator—Control
LNG  Liquefied Natural Gas
LOPA  Layer of Protection Analysis
LOTO  Lockout/Tagout
LT  Level Transmitter
MARS  Major Accident Reporting System
MAWP  Maximum Allowable Working Pressure
MCII  Multiple-Cause, Systems-Oriented Incident Investigation
MES  Multilinear Event Sequencing
MHIDAS  Major Hazard Incident Data System
MOC  Management of Change
MORT  Management Oversight Risk Tree
MSDS  Material Safety Data Sheet
N\(_2\)  Nitrogen
NTSB  National Transportation Safety Board
OREDA  The Offshore Reliability Data Project
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Introduction

1.1. Building on the Past

Flixborough, Bhopal, Piper Alpha—All three are now synonyms for catastrophe. These names are inextricably linked with images of death and disastrous loss tied to the production of chemicals or oil. An objective review of the world’s industrial history reveals a story punctuated with infrequent yet similarly tragic incidents. Invariably, in the wake of such tragedy, companies, industries, and governments work to learn the causes. Their ultimate goal is that the knowledge acquired through diligent investigation can help prevent recurrence.

However, these investigations have revealed something of more significance—the key to preventing disaster first lies in recognizing the leading indicators. These leading indicators exist in incidents that are less than catastrophic. They can even be seen in so-called near misses that may have no discernable impact on routine operation. By examining lower-consequence, higher-frequency occurrences, companies may avoid those rare incidents that cause major consequences. The two most significant roles incident investigations can play in comprehensive process safety programs are:

1. Preventing disasters by consistently examining and learning from near misses and
2. Preventing disasters by consistently examining and learning from major consequence accidents.

The Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) recognized the role of incident investigation when it published the original Guidelines for Investigating Chemical
Process Incidents in 1992. The first edition provided a timely treatment of incident investigation including:

- a detailed examination of incident investigation's role in a process safety management system,
- guidance on implementing an incident investigation system, and
- in-depth information on conducting incident investigations, including the tools and techniques most useful in understanding the underlying causes.

This second edition builds on the first text's solid foundation. The goal is to retain the knowledge base provided in the original book while simultaneously updating and expanding upon it to reflect the latest thinking. This edition presents techniques used by the world's leading practitioners in the science of process safety incident investigation.

Successful investigations are dependent on preplanning and appropriate training. Preplanning allows organizations to respond properly and promptly. The first step in conducting a successful incident investigation is to recognize when an incident has occurred so that it can be investigated appropriately. To enhance effective recognition and communication during an investigation, the following definitions for key terms will apply throughout this book. Some investigators may define the terms presented below slightly differently or use other descriptive terms that mean the same things. The heart of the issue is that members of an operating investigation team all share a common language that supports their investigation objectives efficiently and accurately.

**Incident**—an unusual or unexpected occurrence, which either resulted in, or had the potential to result in:

- serious injury to personnel,
- significant damage to property,
- adverse environmental impact, or
- a major interruption of process operations.

This definition implies three categories of incidents:

1. Accidents
2. Near misses
3. Operational interruptions

An **accident** is an occurrence in which property damage, material loss, detrimental environmental impact, or human loss (either injury or death) occurs.

A **near miss** is an occurrence in which an accident (that is, property damage, material loss, environmental impact, or human loss) or an operational interruption could have plausibly resulted if circumstances had been slightly different.
An operational interruption is an occurrence in which production rates or product quality is seriously impacted.

The second step in conducting a thorough investigation is to assemble a qualified team to determine and analyze the facts of the incident. This team’s charter, using appropriate investigative techniques and methodologies, is to reveal the true underlying root causes. The terms causal factor and root cause help investigators analyze the facts and communicate with each other during the investigation phase.

A causal factor, also known as a critical factor or contributing cause, is a major unplanned, unintended contributor to the incident (a negative occurrence or undesirable condition), that if eliminated would have either prevented the occurrence, or reduced its severity or frequency.

A root cause is a fundamental, underlying, system-related reason why an incident occurred that identifies a correctable failure(s) in management systems. There is typically more than one root cause for every process safety incident.

The third step in incident investigation is to generate a report detailing facts, findings, and recommendations. Typically, recommendations are written to reduce risk by:

- improving the process technology,
- upgrading the operating or maintenance procedures or practices, and
- upgrading the management systems. (When indicated in a recommendation, this is often the most critical area.)

After the investigation is completed and the findings and recommendations are issued in the report, a system must be in place to implement those recommendations. This is not part of the investigation itself, but rather the follow-up related to it. It is not enough to put a technological, procedural, or administrative response into effect. The action should be monitored periodically for effectiveness and, where appropriate, modified to meet the intent of the original recommendation.

These four steps will result in the greatest positive effect when they are performed in an atmosphere of openness and trust. Management must demonstrate by both word and deed that the primary objective is not to assign blame, but to understand what happened for the sake of preventing future incidents. This book helps organizations define and refine their incident investigation systems to achieve positive results effectively and efficiently.
1.2. Who Should Read This Book?

This book assists three target groups:

1. Incident investigation team leaders
2. Incident investigation team members
3. Corporate and site process safety managers and coordinators

For anyone directly involved in leading or participating on incident investigation teams, the book provides a valuable reference tool. It presents knowledge, techniques, and examples to support successful investigations. For persons in technical and management roles responsible for implementing the incident investigation element of an integrated process safety system, it offers a model for success in building or upgrading their program.

Like the previous edition, the book remains focused primarily on investigating process-related incidents that present realized or potential catastrophic consequences (that is, accidents as well as near misses). However, readers will find that the methodologies, tools, and techniques described in the following chapters may also be applied when investigating other types of occurrences such as reliability, quality, and occupational health and safety incidents.

1.3. The Guideline's Objectives

Readers should be able to achieve the following objectives.

- Describe the basic principles behind successful incident investigations.
- Identify the essential features of a management system designed to foster and support high quality incident investigations.
- List detailed information for planning and conducting incident investigations including investigative tools, techniques, and methodologies for determining causes.
- Use the findings of an investigation to make effective recommendations that can reduce the likelihood of recurrence or mitigate the consequences of similar incidents (or even dissimilar incidents with common root causes).
- Plan an effective system for documenting, communicating, and resolving investigation findings and recommendations including a method to track closure of incident recommendations.
1 Introduction

The summaries below provide an overview of the content and organization of the book chapter-by-chapter and assist in quickly locating a particular area of interest.

Chapter 2—Designing an Incident Investigation Management System
This chapter provides an overview of a management system for investigating process safety incidents. It opens with a review of management responsibilities and presents the important features that a management system must address to be effective. It examines systematic approaches that help implement incident investigation teams, root cause determinations, recommendations, follow-up, and documentation.

Chapter 3—An Overview of Incident Causation Theories
This section discusses the basics of determining incident causation and describes the general categories of incidents—from near miss to major catastrophe. It examines the anatomy of process incidents as related to theoretical models of incident causation.

Chapter 4—An Overview of Incident Investigation Tools and Methodologies
This chapter provides a brief overview of investigation tools in simple, generic terms, and demonstrates the benefits of using a more structured approach. It describes both public and proprietary methodologies.

Chapter 5—Reporting and Investigating Near Misses
Many major process safety incidents were preceded by precursor occurrences. These occurrences were unrecognized or ignored because “nothing bad” actually happened. The lessons learned from such occurrences, typically referred to as near misses, can be extremely valuable in averting disaster. However, this benefit is only realized when they are recognized, reported, and investigation techniques are properly applied. This chapter describes near misses, discusses their importance, and presents the latest methods for helping ensure appropriate near misses are reported.

Chapter 6—The Impact of Human Factors
This chapter describes human factor considerations in incident causation. It provides insight and tools to identify and address applicable human factors issues during an investigation.

Chapter 7—Building and Leading an Investigation Team
Personnel with proper training, skills, and experience are critical to the successful outcome of an incident investigation. This chapter describes team composition as a function of incident type, complexity, and severity as well as suggested training topics. It also provides team leaders with a high-level overview of the basic team activities typically required in the course of conducting an investigation.
Chapter 8—Gathering and Analyzing Evidence
Facts are the fuel an investigation needs to reach a successful conclusion. This chapter addresses the practical considerations of data-gathering activities. It describes types of data, sources of data, data-gathering tools, and techniques.

Chapter 9—Determining Root Causes—Structured Approaches
This chapter addresses methods and tools used successfully to identify multiple root causes. Process safety incidents are usually the result of more than one root cause. This chapter provides a structured approach for determining root causes. It details some powerful, widely used tools and techniques available to incident investigation teams including timelines, logic trees, predefined trees, checklists, and fact/hypothesis. Examples are included to demonstrate how they apply to the types of incidents readers are likely to encounter.

Chapter 10—Developing Effective Recommendations
Once the likely causes of an incident have been identified, investigation teams evaluate what can be done to help prevent recurrence. The incident investigation recommendations are the product of this evaluation. This chapter addresses types of recommendations, some attributes of good recommendations, methods to document and present recommendations, and management’s responsibilities.

Chapter 11—Communication Issues and Preparing the Final Report
In the case of incident investigation, a major milestone is completed when the final incident investigation report is submitted. The incident report documents the investigation team’s findings, conclusions, and recommendations. This chapter describes practical considerations for writing formal incident reports, a discussion of the attributes of quality reports, and the issue of communicating the report findings to affected persons, both internally and externally.

Chapter 12—Considering Legal Issues
The work products of incident investigations are subject to the legal process of discovery. The incident investigation team must keep two purposes in mind. First, the ultimate purpose of the incident investigation is to determine what happened, why it happened, and how to prevent future occurrences. Second, there are important legal issues associated with the conduct, documentation, and follow-up of incident investigations. This chapter provides insight into legal issues and is written for a lay audience.

Chapter 13—Implementing the Team's Recommendations
The recommendations generated from an incident investigation should be properly implemented in a timely fashion to decrease the probability of