A CCPS HANDBOOK

Handbook for Process Safety in Laboratories and Pilot Plants

A Risk-based Approach

WILEY

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Center for Chemical Process Safety
American Institute of Chemical Engineers
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Abbreviations and Acronyms

ACC	American Chemical Council
ACGIH	American Conference of Governmental Industrial Hygienists
ACH	Air Changes per Hour
ACS	American Chemical Society
AIChE	American Institute of Chemical Engineers
API	American Petroleum Institute
APIs	Active Pharmaceutical Ingredients
ASTM	American Society of Testing and Materials
CB	Control Banding
CCPS	Center for Chemical Process Safety
CFM	Cubic feet per minute
COO	Conduct of Operations
CPI	Chemical Process Industry
CSL	Chemical Safety Level
DOE	Department of Energy (US)
DOT	Department of Transportation (US)
EG	Exposure Guidelines
EHS	Environmental, Health, and (Occupational) Safety
ERPG	Emergency Response Planning Guideline
HEPA	High Efficiency Particulate Air [filter]
HHECB	Health Hazard Evaluation Control Band
HIRA	Hazards Identification and Risk Analysis
IDLH	Immediately Dangerous to Life and Health
IPL	Independent Protection Layer
ISO	International Organization for Standardization
LAPP	Laboratories and Pilot Plants
LC	Lethal Concentration
LFL	Lower Flammability Limit
LOPA	Layer of Protection Analysis
NASA	National Aeronautic and Space Administration (US)
NFPA	National Fire Protection Agency (US)
NIOSH	National Institute for Occupational Safety & Health (US)
NIST	National Institute of Science and Technology (US)
NOAA	National Oceanic and Atmospheric Administration (US)
OD	Operational Discipline

OEL	Occupational Exposure Limits (US OSHA)
P&ID	Piping and Instrumentation Diagram
PEL	Possible Exposure Limits (US OSHA)
PHA	Process Hazard Analysis
PI	Principal Investigator
PPE	Personal Protective Equipment
PTE	Permanent Total Enclosure
R&D	Research and Development
RBPS	CCPS Risk Based Process Safety
SDS	Safety Data Sheet
SME	Subject Matter Expert
SOP	Standard Operating Procedure
STEL	Short-Term Exposure Limit
TAM	Thermal Activity Monitor
TLV	Threshold Limit Value (for toxicity)
TWA	Time-Weighted Average
UFL	Upper Flammability Limit
US OSHA	US Occupational Safety and Health Administration
WPC	Work, Planning, and Control

Glossary

This Glossary contains Process Safety terms unique to this CCPS publication. The CCPS Process Safety terms in this publication are current at the time of issue. For other CCPS Process Safety terms and updates to these terms, please refer to the CCPS Process Safety Glossary [1].

Term	Definition
Acceptable Risk	The average rate of loss that is considered tolerable for a given activity.
Accident *(See Incident)*	An incident that results in a significant consequence involving: • human impact, • detrimental impact on the community or environment, • property damage, material loss, • disruption of a company's ability to continue doing business or achieve its business goals
Biosafety Level (BSL)	A biological risk management category used to identify the protective measures needed in a laboratory setting to protect workers, the environment, and the public.
Causal Factor	A major unplanned, unintended contributor to an incident (a negative event or undesirable condition), that if eliminated would have either prevented the occurrence of the incident, or reduced its severity or frequency.
Competent	Individual having the necessary ability, knowledge, or skill to do something successfully [2].
Consequence	The undesirable result of a loss event, usually measured in health and safety effects, environmental impacts, loss of property, and business interruption costs.
Exothermic	A physical or chemical change accompanied by the evolution of heat.
Exothermic Reaction	A reaction involving one or more chemicals resulting in one or more new chemical species and the evolution of heat.
Explosion	A release of energy that causes a pressure discontinuity or blast wave.
Explosion	The bursting or rupture of an enclosure or container due to the development of internal pressure from a deflagration.
Finding	A conclusion reached by an auditor or investigator based upon data collected and analyzed during an audit or investigation. Note: Findings can be positive or negative. Negative Findings describe a deficiency or gap between the current state and the expected state.
Fire	A combustion reaction accompanied by the evolution of heat, light, and flame.

Term	Definition
Fire Triangle	[A triangle diagram showing] the three basic conditions that are required for a fire to take place. These conditions are fuel, oxygen, and heat.
Flash Fire	A fire that spreads by means of a flame front rapidly through a diffuse fuel, such as a dust, gas, or the vapors of an ignitable liquid, without the production of damaging pressure.
Hazard	An inherent chemical or physical characteristic that has the potential for causing damage to people, property, or the environment.
Hazard Identification	Part of the Hazards Identification and Risk Analysis (HIRA) method in which the material and energy hazards of the process, along with the siting and layout of the facility, are identified so that a risk analysis can be performed on potential incident scenarios.
Hazard Identification and Risk Analysis (HIRA)	A collective term that encompasses all activities involved in identifying hazards and evaluating risk at facilities, throughout their life cycle, to make certain that risks to employees, the public, or the environment are consistently controlled within the organization's risk tolerance.
Health Hazard Exposure Control Band (HHECB)	A risk-based approach used to help manage inhalation risks when exposed to new substances that have little or no available hazards information.
Hierarchy of controls	A way of determining which actions will best control exposures [3].
Impact	A measure of the ultimate loss and harm of a loss event. Note: Impact may be expressed as the number of injuries and/or fatalities, the extent of the environmental damage, or the magnitude of the loss, such as property damage, material loss, production loss, market share loss, and recovery costs.
Incident *(See Accident)*	An event, or series of events, resulting in one or more undesirable consequences, such as harm to people, damage to the environment, or asset/business losses. Or An unusual, unplanned, or unexpected occurrence that either resulted in, or had the potential to result in harm to people, damage to the environment, asset/business losses, or loss of public trust or stakeholder confidence in a company’s reputation.
Kilo-prep lab	A lab used in scale-up between laboratory and pilot plant, with typical batch sizes of 2–3 kg. Often used to produce sufficient product for initial testing.

Term	Definition
Laboratory	A facility where the containers used for reactions, transfers and other handling of chemicals are designed to be easily and safely manipulated by one person. A laboratory is a workplace where chemicals are used or synthesized on a nonproduction basis [4].
Laboratory And Pilot Plant (LAPP)	A LAPP includes all laboratories, pilot plants, and research facilities that stand-alone or are a part of a commercial manufacturing site, government establishment, or academic institution.
Loss of Containment *(or Loss of Primary Containment)*	An unplanned or uncontrolled release of material from [primary] containment, including non-toxic and non-flammable materials *(e.g., steam, hot condensate, nitrogen, compressed CO2 or compressed air).*
Mitigative Safeguard	A [safeguard] designed to interrupt the chain of events after a loss event, given that there has been a loss of containment of a hazardous material or energy. Note: Specific to a hazards evaluation of an incident sequence, a mitigative [safeguard] is in between the loss of event (the loss of containment) and the scenario's impact, helping reduce the consequences of the incident scenario, and thus, helping reduce the scenario's risk.
Near-miss	An incident in which an adverse consequence could potentially have resulted if circumstances had been slightly different.
Observation	A conclusion reached by an auditor based upon data collected and analyzed during the audit. Observations can be positive or negative. Negative Observations may indicate opportunities for improvement.
Pilot Plant	An experimental assembly of equipment for exploring process variables or for producing semi-commercial quantities of materials [4].
Polariscope	A polariscope is composed of two polarized lenses and a light source mounted behind one lens. The glass item to be examined is placed between two lenses and viewed through the lens opposite the light source lens. Note: Polariscopes work based on the principle of stress induced birefringence, the phenomenon in which light passing through a homogenous material under stress exhibits two refractive indices.

Term	Definition
Preventive safeguard	A [safeguard] designed to interrupt the chain of events leading up to a loss event, given that an initiating event has occurred. Note: Specific to the hazards evaluation of an incident sequence, a preventive [safeguard] is in between the initiating event (the cause) and a loss event, helping reduce the frequency of the incident scenario, and thus, helping reduce the scenario's risk.
Process Hazard Analysis (PHA)	An organized effort to identify and evaluate hazards associated with processes and operations to enable their control. This review normally involves the use of qualitative techniques to identify and assess the significance of hazards. Conclusions and appropriate recommendations are developed. Occasionally, quantitative methods are used to help prioritized risk reduction.
Protection Layer	A concept whereby a device, system, or human action is provided to reduce the likelihood and/or severity of a specific loss event.
Qualitative Risk Analysis	An analysis method based primarily on description and comparison using historical experience and engineering judgment, with little quantification of the hazards, consequences, likelihood, or level of risk.
Quantitative Risk Analysis (QRA)	The systematic development of numerical estimates of the expected frequency and severity of potential incidents associated with a facility or operation based on engineering evaluation and mathematical techniques.
Recommendation	A proposed action intended to correct a deficiency that resulted in a Finding.
Risk	A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the injury or loss. Note: A simplified version of this relationship expresses risk as the product of the Frequency and the Consequence of an incident (i.e., Risk = Frequency times Consequence).
Risk Analysis	The estimation of scenario, process, facility and/or organizational risk by identifying potential incident scenarios, then evaluating and combining the expected frequency and impact of each scenario having a consequence of concern, then summing the scenario risks if necessary to obtain the total risk estimate for the level at which the risk analysis is being performed.

Term	Definition
Risk Analysis	The estimation of scenario, process, facility, and/or organizational risk by identifying potential incident scenarios, then evaluating and combining the expected frequency and impact of each scenario having a consequence of concern, then summing the scenario risks to obtain the total risk estimate.
Risk Assessment	The process by which the results of a risk analysis (i.e., risk estimates) are used to make decisions, either through relative ranking of risk reduction strategies or through comparison with risk targets.
Risk Assessment	The process by which the results of a risk analysis (i.e., risk estimates) are used to make decisions, either through relative ranking of risk reduction strategies or through comparison with risk targets. Note: The decision-making protocol may conclude: 1. The Risk is tolerable, no further action is needed 2. Additional safeguards or protection layers should be considered 3. The Risk is unacceptable, the activity as is should be discontinued
Risk Based Process Safety (RBPS)	The Center for Chemical Process Safety's (CCPS) process safety management system approach that uses risk-based strategies and implementation tactics that are commensurate with the risk-based need for process safety activities, availability of resources, and existing process safety culture to design, correct, and improve process safety management activities.
Risk Management	The systematic application of management policies, procedures, and practices to the tasks of analyzing, assessing, and controlling risk in order to protect employees, the general public, the environment, and company assets, while avoiding business interruptions. Includes decisions to use suitable engineering and administrative controls for reducing risk.
Risk Management	The management systems, such as the those described in the CCPS RBPS program, that are integrated for use in managing operations, maintenance, and changes for the life of the process.

Term	Definition
Risk Matrix	A [graphical approach to present the organization's] risk tolerance criteria, typically involving graduated scales of incident likelihood on the [ordinate] and incident consequences on the [abscissa]. Each cell in the [graph] (at intersecting values of incident likelihood and incident consequences) represents a particular risk level. Note: The *ordinate* refers to the (y) coordinate and the *abscissa* refers to the (x) coordinate of a standard two-dimensional graph.
Risk Matrix	A graphical presentation of the risk tolerance criteria, with the incident's likelihood plotted versus the incident's consequence. Note: Each intersecting cell represents the LAPP's tolerance criteria, ranging from acceptable risk to unacceptable risk. An example Risk Matrix is shown in Figure 4-1.
Risk Reduction	Development, comparison, and selection of options to reduce risk to a target level, if needed, or as needed.
Risk Tolerance	The maximum level of risk of a particular technical process or activity that an individual or organization accepts to acquire the benefits of the process or activity.
Risk Tolerance Criteria	A predetermined measure of risk used to aid decisions about whether further efforts to reduce the risk are warranted.
Risk-based Approach	A quantitative risk assessment methodology used for building siting evaluation that takes into consideration numerical values for both the consequences and frequencies of explosion, fire, or toxic material release.
	The use of systematic methods to identify and control risks, … initiated at the earliest stages of work proposal and remains in effect through all subsequent phases of work [5].
Root Cause	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.
Safeguard	Any device, system, or action that interrupts the chain of events following an initiating event or that mitigates the consequences.
Scenario	A detailed description of an unplanned event or incident sequence that results in a loss event and its associated impacts, including the success or failure of safeguards involved in the incident sequence.

Term	Definition
Toxic Hazard	A measure of the danger posed to living organisms by a toxic agent, determined not only by the toxicity of the agent itself, but also by the means by which it may be introduced into the subject organisms under prevailing conditions.
Toxicity	The quality, state, or degree to which a substance is poisonous and/or may chemically produce an injurious or deadly effect upon introduction into a living organism.
Worker	Any laboratory or pilot plant personnel who uses materials or procedures in their LAPP, including principle investigators, supervisors, students, lab technicians, pilot plant operators, staff, etc.,

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Although the peer reviewers provided comments and suggestions, they were not asked to endorse this handbook and did not review the final manuscript before its release.

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Dedication

CCPS Handbook for Process Safety in Laboratories and Pilot Plants

Is dedicated to

Jerry Forest

Jerry's focus and passion for Process Safety shines in his work and life. He is an indispensable contributor to CCPS's mission and he truly lives its tenets. His contributions on the leadership of the CCPS Planning Board have been and continue to be invaluable, as well.

Jerry's focus on practical applications shows through his activities. To Jerry, 'walk the line' is not a country song or movie, but a process safety initiative he led as Senior Director of Process Safety at Celanese and that he shared with the rest of the industry. Clear and concise communications are at the focus of this initiative. Eliminating errors by improving the conduct of operations is Jerry's belief—the operators must know with 100% certainty where energy will flow each time a processing unit change is made.

Jerry has been on many CCPS project committees, contributing his expertise to the CCPS body of knowledge. When the COVID-19 pandemic affected the process industry, Jerry was a key contributor on a CCPS panel on managing Risk Based Process Safety (RBPS) during disruptive times. More recently, Jerry served as committee chair for the book *Introduction to Process Safety for Engineers, 2nd Edition*. Jerry maintains his status as a CCPS Certified Process Safety Professional (CCPSC).

Jerry is a passionate believer in teaching and giving future engineers process safety knowledge. Currently, he teaches a course on process safety at the Louisiana State University, his Chemical Engineering alma mater.

CCPS is delighted to dedicate this book to Jerry in recognition for his past, present and continuing support of CCPS and the global process safety community.

Anil Gokhale and Jennifer Bitz

Online Materials Accompanying this Handbook

CCPS invites readers to contribute to the incident data by providing laboratory and pilot plant incident summaries.

CCPS Member companies are encouraged to enter these incident cases into the CCPS Process Safety Incident Database (PSID). The PSID submittal procedure may be downloaded from the CCPS webpage [6].

Lessons shared from previous incidents can be used, in part, to improve process safety performance in Laboratories and Pilot Plants (LAPPs). This book presents cases throughout the chapters to illustrate relevant concepts. Appendix A of this handbook contains details of the case studies that are referenced briefly within the chapters.

Each incident is noted in the format shown in Appendix A . The typical incident descriptions provide a brief overview of where, when, and what happened. Since process safety and risk management system deficiencies are often the root causes of the incident, the authors end each case with a summary table of the management system(s) based on the Risk Based Process Safety (RBPS) Elements model, listed in Table 1-2 [7]. The table of root causes at the end of each incident case shows the most relevant management systems that could have helped prevent or mitigate the consequences of the incident.

Appendix A should be used only as a tool to identify incidents with applicable learnings. Since these examples are not from an exhaustive literature search, ***they are not to be used for statistical or trending information.***

An electronic version of the incidents are available for downloading and searching capability. Please download the file from the CCPS website at:

www.aiche.org/ccps/LAPP-incidents

When opening the file, enter the password:

CCPSLAPP

Preface

The Center for Chemical Process Safety (CCPS) has been the world leader in developing and disseminating information on process safety management and technology since 1985. The CCPS, an industry technology alliance of the American Institute of Chemical Engineers (AIChE), has published over 100 books in its process safety guidelines and process safety concepts series, and over a hundred courses, including 33 training modules through its Safety in Chemical Engineering Education (SAChE) series. CCPS is supported by the contributions and voluntary participation of more than 225 companies globally.

The acronym LAPP is used throughout for Laboratories and Pilot Plants for better readability. The reader should recognize that it covers the entire scope of research activities and operations from a gas chromatograph to a pilot plant, or from a simple mixing operation inside a hood to a major processing step. Many process safety-related issues are applicable to LAPPs, including: hazards identification and risk analysis; the handling and storage of hazardous materials; locating equipment; designing piping; and maintaining adequate emergency response.

Laboratory, pilot plant, and research applications occupy a unique niche within the chemical process industries. Their research activities are intended to develop process information – chemical, safety, operability, and maintainability – to advance the general chemistry understanding, find viable commercial applications or solutions, and ensure safe design and operation of a commercial process. LAPPs often handle similar hazardous materials and energies as a manufacturing plant, yet in smaller quantities and smaller equipment. The unknowns and uncertainties that accompany these activities significantly increases the potential risks. If the hazards are not properly understood and their associated risks not properly mitigated, personnel may be harmed when an incident occurs.

This book grew out a recognition that researchers could benefit from a dedicated CCPS handbook on process safety for LAPPs. This handbook is intended to help the reader identify process safety hazards and risks in a laboratory, pilot plant, or research environment. It offers practical hazard identification and risk analysis guidance to help prevent or reduce the consequences of incidents. Readers will be able to learn from LAPP-related incidents, as well, reducing the likelihood that they will learn by having a similar incident. This handbook provides examples of typical process safety-related practices, procedures, and systems, as well as references for more information, as needed.

Part 1 – Introduction and Overview

The purpose of this part of the book is to:

- present key points about why taking a risk-based approach to safety is important
- propose some ways to begin the discussion and present the risk-based approach to colleagues and leaders
- provide an introduction to hazards and their controls
- present the Risk Based Process Safety elements in a way that labs, pilot plants, and other research facilities can implement
- provide some resources and examples to help implement a risk-based management system for safety

1 Purpose and Scope

1.1 Purpose

The purpose of this book is to help organizations better control hazards and risks in Laboratories and Pilot Plants (LAPPs). Hazards control starts with hazards identification, consequence evaluation, likelihood estimation and then risk analysis and assessment. This book provides methods for determining the controls needed to manage the risk in a LAPP. For example, when designing, operating, maintaining, and changing experimental and testing equipment, the CCPS Risk Based Process Safety (RBPS) concepts and related good management practices can be applied to help reduce the LAPP's risk. In particular, this book shows how to prevent LAPP incidents and helps LAPP staff identify the specific engineered and administrative controls that are needed to prevent the loss of control of hazardous materials and stored energies. Since the overall risk includes the impact of the release, this book also identifies the controls can be used to help reduce the impact of a release if it occurs.

This book is intended to supplement available information and guidance for identifying the hazards, controlling the risks, and managing process safety in LAPPs. It describes the proven risk management systems and approaches that have evolved at industrial facilities over since the 1980's. These industrial practices help eliminate or reduce many of the causes and impact of process safety incidents. The factors that were weak or missing altogether, identified as contributors to severe incidents in LAPPs include:

- Having a sense of vulnerability to the hazards and their associated risks
- Understanding the potential severity of an incident
- Using established design practices
- Having robust engineered and administrative safeguards
- Having robust operating and maintenance procedures
- Having robust training for operations and maintenance personnel
- Adhering to procedures (e.g., strong operational discipline; recognizing and preventing normalization deviance)
- Having robust change management practices
- Planning and preparing for emergencies
- Evaluating and addressing human factors issues

The CCPS RBPS practices described in this book will help eliminate or reduce the inherent factors in laboratories and pilot plants that may contribute to incidents in a LAPP. When applied effectively, these practices will help prevent the loss of control of hazardous materials or energies, will help significantly reduce the impact of the consequences if the loss of control does occur, and reduce the potential for injuries, fatalities, equipment damage, and program delays.

1.2 Scope of Book and Target Audience

When people work with hazardous materials and energies in a laboratory or pilot plant, their experimental designs from benchtop to full-scale manufacturing should include equipment and methods that help prevent the loss of control of their hazards. This handbook identifies four broad hazard categories in LAPPs as: 1) Chemical; 2) Physical; 3) Biological, and 4) Ionizing radiation. The primary scope of this book is on how LAPP staff manage the material's chemical and physical hazards. Biological and ionizing radiation management practices are outside this handbook's scope.

However, it is worth noting that this handbook does include summaries of incidents that resulted in the loss of control of biological or ionizing radiation hazards. In addition, a description of a biological hazard management control approach, Biosafety Control Banding, is included as Appendix C .

All LAPP staff will work with some level of chemical and physical hazards. This handbook presents approaches that can be used to help manage the risks associated with these hazards. This handbook will show how process safety practices and systems can help prevent the loss of control of hazardous materials and energies in LAPPs. They are based on the experience of researchers around the world and can be applied to the following activities:

<u>Chemical and biochemical transformations</u>

- catalytic and non-catalytic chemical synthesis reactions
- bio-transformations involving viable cells or immobilized enzymes;
- thermal or catalytic cracking or decomposition
- smelting of mineral ores
- electrochemical reactions
- partial or complete oxidation
- neutralization reactions
- chemical precipitation
- chemical vapor deposition

<u>Changes in physical state, concentration, or form</u>

- dissolving
- evaporation
- drying
- size reduction of solids
- agglomeration of solids or pelletizing
- solids melting and solidification
- encapsulation of particles or fluids
- coating of films, parts, or components
- thermal forming or extrusion of polymers

Physical mixing

- gases
- vapors
- solids
- liquids

Physical separation and purification

- phase changes
- distillation
- drying
- absorption
- ion exchange
- size selective or affinity type chromatography
- size selective membranes
- crystallization
- precipitation
- solvent extraction

In addition, this handbook addresses the storage and handling of the hazardous materials associated with these activities, and presents some of the physical and chemical analytical techniques that help verify and validate the effectiveness of the safety management system.

The target audience for this book is any LAPP staff working with or managing hazardous materials. In particular, for staff in either on-site chemical processing facility laboratories or off-site product Research and Development (R&D) laboratories. Other types of laboratories include other industry laboratories (e.g., electronics, agriculture, food, etc.), government laboratories (e.g., energy, agriculture, food production, etc.) and university laboratories (i.e., chemistry, chemical engineering, and material science departments). LAPP engineering and scientific professionals, LAPP technical support staff and LAPP managers will benefit from the approaches described in this handbook, as well.

Managing the risks of any laboratory or pilot plant requires diligent attention to how changes in experiments and experimental set-ups can (and do) change the risk. The authors hope that the "Where to Start" discussion, presented in Section 2.3, will help the reader apply the CCPS the Risk Based Process Safety (RBPS) Management approach to their LAPP, either reinforcing the systems already in place or provide a proven approach for reducing their risks.

1.3 Terms for Laboratories and Pilot Plants

The following terminology will be used throughout this book:

LAPP: Describes all Laboratories And Pilot Plants. Thus, "LAPP" includes all laboratories, pilot plants, and research facilities that stand-alone or are a part of a commercial manufacturing site, government establishment, or academic institution.

Worker: any laboratory or pilot plant worker including principle investigators, supervisors, students, lab technicians, pilot plant operators, staff, etc.

Incident [8]**:** an unusual, unplanned, or unexpected occurrence that either resulted in, or had the potential to result in harm to people, damage to the environment, or asset/business losses, or loss of public trust or stakeholder confidence in a company's reputation

Accident [8]**:** an incident that results in a significant consequence involving:

- human impact,
- detrimental impact on the community or environment,
- property damage, material loss,
- disruption of a company's ability to continue doing business or achieve its business goals

Near-miss [8]**:** an incident in which an adverse consequence could potentially have resulted if circumstances had been slightly different.

This book includes many examples of actual incidents that have occurred in laboratories and pilot plants. The book will use the term "incident" when describing these events. Thus, all incidents described will include all LAPP "incidents."

Because distinctions are often made between laboratories and pilot plants, including definitions in regulations or consensus standards, selected terms and definitions are provided. Regardless of whether specific process equipment or systems are considered "lab scale" or "pilot plant scale", the practices described in this book should apply to both types of operations.

Multiple terms have been used to describe laboratories and pilot plants and to distinguish between the two types of facilities or activities. Definitions include amount of hazardous materials in use and the scale of chemical process equipment and apparatus. In this book, the acronym "LAPP" (Laboratories and Pilot Plants) will refer to all types of laboratories and pilot plants. The terms "staff" or "worker" are used throughout the book to refer to lab technicians, researchers, pilot plant workers, and other LAPP personnel who operate the equipment.

NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals [4], used for design of laboratory facilities, draws a distinction between laboratories and pilot plants. NFPA 45 applies to laboratory buildings, laboratory units, and laboratory work areas in which chemicals, as defined, are handled or stored. The standard covers laboratory unit hazard classification, design, and construction; fire and explosion hazard protection; ventilating systems and chemical fume hoods; chemical storage, handling, and waste disposal; flammable and combustible liquids; compressed and liquefied gases; operations; and hazard identification.

The research laboratory has an ever-changing environment, with research experiments changing frequently and may involve different hazards, such as chemical, physical, or biological. In NFPA 45 standard, laboratories and pilot plants are defined as follows:

- A laboratory is a facility where the containers used for reactions, transfers and other handling of chemicals are designed to be easily and safely manipulated by one person. A laboratory is a workplace where chemicals are used or synthesized on a nonproduction basis.
- A pilot plant is an experimental assembly of equipment for exploring process variables or for producing semi-commercial quantities of materials [4].

NFPA 45, referenced throughout this book, classifies laboratories based on the quantities of flammable and combustible materials within the laboratory. Examples of engineered controls recommended under this standard are described in Part 4 and its laboratory fire hazard rating system is discussed in Section C.1.

1.4 Distinctions between Laboratories and Pilot Plants

Some commonly used terms used to describe the relative scale of experimental and testing facilities include lab-scale, bench-scale, bench-top, micro-scale, rack-mounted, skid-mounted, lab, pilot plant, prototype plant, semi-works plant, and demonstration plant. More information on data needs during scale-up are covered in Section 9.4.

Considering the broad scope of Research and Development (R&D) activities across the Chemical Processing Industry (CPI), lab scale and pilot plant scale activities differ significantly in the types, sizes, and throughput capacity of equipment. The size and throughput rates of equipment used by different CPI sectors in their LAPPs can vary by orders of magnitude. Even within a CPI sector such as polymers production, the sizes and throughput rates may vary in pilot plants depending on many factors (batch versus continuous flow process or a large production volume commodity material versus a very high value specialty polymer).

Many continuous-flow pilot plants use vessels that are much smaller in volume than those in a batch process pilot plant. Despite the smaller volume vessels, the total daily throughput may be much greater for the continuous-flow pilot plant and thus require relatively large raw material and product storage compared to those for a batch process pilot plant (e.g. ones used to produce batches of high value specialty chemicals, potent drug substances, or electronics industry specialty materials).

Pilot plants can be located within:

- a bench-top chemical fume hood
- a floor mounted or walk in chemical fume hood
- an individual “laboratory area” on a skid
- a dedicated space, bay, or room inside a laboratory building or research facility

- a dedicated pilot plant building or outside pilot plant area at an R&D site
- a CPI manufacturing site inside a building or outside near larger units

The descriptions in the next few sections include some types of laboratory and pilot plant operations within the CPI.

1.4.1 Laboratory-scale, bench-top pilot plants, and micro-units:

Pilot plants that fit on a bench top or inside a small laboratory hood typically occupy surface space in the range of 0.5 to 1.0 m^2 (~ 5.5 to 11 ft^2) and use small diameter tubing from ~1.5 to 6 mm (~1/16 to 1/4 inch) for transport of fluids into or out of equipment items. They often involve testing of a single step or unit operation or process such as synthesis or a product separation / purification. Many such units have been operated with limited automation and have been continuously attended but in recent decades more heavily automated units designed to run continuously, with minimal technician control, have become more common, with many running unattended.

1.4.2 Integrated process R&D scale pilot plants

These units often will not fit in a bench top, floor mount, or small walk in hood. These units may vary in size from several frames or skids covering several square meters of floor space to a large room with multi-level platforms for larger equipment and columns. Fluids transport typically uses small diameter tubing (6 to 25 mm or 1/4 to 1 inch) and/or small diameter pipe (6 to 50 mm or 1/4 to 2 inch). Such units usually are automated and may be designed for unattended operation.

1.4.3 Demonstration units, semi-works units or prototype units

These are units designed to operate at or near the lower end of commercial plant scale. They are often in a separate building or work area dedicated to "pilot plant" work (at times in manufacturing facilities where necessary utilities are available as well as feedstock and solvents) and have a foot print that could measure in the tens to hundreds of square meters (hundreds to thousands of square feet) or more. They typically use smaller commercial pipe sizes, typically in the range of 2.5 to 20 cm (1 to 8 inches). They often closely resemble a commercial operating unit with similar automation and operating practices.

Classification by size is useful for assessing the pilot plant's costs, scale and requirements. The intended purpose, types of hazards, and technologies are more useful when assessing risks. More information on data needs during scale-up are covered in Section 9.4.

1.5 Organization of This Handbook

The framework for the parts in this Handbook is shown in Table 1-1. This framework uses the structure of the CCPS Risk Based Process Safety, with its four Pillars and twenty Elements [7].

Table 1-1 Framework for this Handbook

Section	**Subject**
Part 1	Introduction and Overview
Part 2	Committing to Process Safety
Part 3	Understanding Hazards and Risks
Part 4	Managing Risk: Engineered Controls
Part 5	Managing Risk: Administrative Controls
Part 6	Managing Risk: RBPS Management Systems
Part 7	Learning from Experience
Part 8	Conclusion
Appendix A	Case Reports
0	Examples and Tools
Appendix C	Control Banding Strategies
Appendix D	Glass Equipment Design

The framework for the CCPS Risk Based Process Safety (RBPS) management system was developed to help companies manage their process safety risks [7]. It includes the four Pillars and twenty Elements that are listed in Table 1-2. The LAPP Handbook Chapter pertaining to each applicable RBPS Element is also listed in this table. Keep in mind that this handbook is written to provide insights for each of these twenty elements on how they can apply to laboratory and pilot plant risk reduction efforts. The reader is not expected to apply all twenty at once, as it is not practical or feasible to do so. As was noted earlier in this chapter, a good starting point for tailoring and implementing an RBPS management program is discussed in Section 2.3 on “Where to Start” with its development.

Table 1-2 The CCPS Risk Based Process Safety (RBPS) Management System

RBPS Pillar	CCPS RBPS Element	LAPP Handbook Chapter
I. Commit to Risk Based Process Safety	1) Process Safety Culture	Chapter 5
	2) Compliance with Standards	Chapter 6
	3) Process Safety Competency	Chapter 7, Section 7.1
	4) Workforce Involvement	Chapter 8, Section 8.1
	5) Stakeholder Outreach	Chapter 8, Section 8.2
II. Understand Hazards and Risks	6) Process Knowledge Management	Chapter 9
	7) Hazard Identification and Risk Analysis	Chapter 11
III. Manage Risk	8) Operating Procedures	Chapter 20, Section 20.1
	9) Safe Work Practices	Chapter 21, Section 21.1
	10) Asset Integrity and Reliability	Chapter 22
	11) Contractor Management	Chapter 21, Section 21.2
	12) Training and Performance Assurance	Chapter 7, Section 7.2
	13) Management of Change	Chapter 23, Section 23.1
	14) Operational Readiness	Chapter 23, Section 23.2
	15) Conduct of Operations	Chapter 20, Section 20.2
	16) Emergency Management	Chapter 24
IV. Learn from Experience and Continuous Improvement	17) Incident Investigation	Chapter 25
	18) Measurement and Metrics	Chapter 1, Section 26.1
	19) Auditing	Chapter 1, Section 26.2
	20) Management Review	Chapter 1, Section 26.3

Summaries for LAPP incidents used in this book are noted with the format shown in Figure 1-1. The case reports on the incident are detailed in Appendix A : Case year-# (organized by year), incident title, where and when the incident happened, its location, date that the incident occurred, the organization (if identified), a background on the organization (academic, industrial, governmental), the activities at the site (research, product development, testing), what happened (toxic release, uncontrolled reaction, fire, or explosion), how it happened (from investigation), why it happened (from investigation), and relevant CCPS RBPS Elements (inadequate or missing process safety system). The purpose of providing these case reports is to share prior incidents such that weak or missing CCPS RPBS Elements can be identified and its learnings applied to the reader's LAPP, if applicable. Applying shared learnings without have to experience the incident will help reduce the likelihood for or consequences of a similar incident.

Summary from **Case yyyy-#: Title of Incident**

Text from Case yyyy-#

(full Case Report located in Appendix A)

Figure 1-1 Format for Case Summaries in Chapter

2 Managing Risk to Prevent Incidents

2.1 Some LAPP Characteristics

Although the operating characteristics of LAPPs differ from those in the CPI (Chemical Process Industry), process safety risk reduction in a LAPP is essential due to frequent changes. The changes must be addressed with a change management system to ensure the safety of the staff performing the work. For example, frequent changes may occur in LAPP:

- programs and their projects
- equipment and their service
- equipment operating conditions
- chemical syntheses
- staffing
- operating schedules

Staff turnover, for example, occurs relatively often in an academic laboratory. Laboratories may operate experiments with minimal or no staff once the experiment is running. Some work may occur overnight or over the weekend with minimal staff.

2.1.1 Frequent changes to programs and equipment

Many new project activities in LAPPs represent the first time an organization has worked with certain chemicals under specific operating conditions or in new equipment. Implementing hazard identification protocols and formal safety reviews offers the opportunity to analyze and control new hazards and reduce the risks.

The relatively short duration of many projects conducted in LAPPs, or the short lifetime of specially designed equipment or systems also often presents significant challenges for safety and risk management. Duration of use for equipment, systems, and facilities may span only weeks or months with many experimental apparatus' or systems seldom used more than a few years, as compared to decades for many CPI manufacturing facilities. Some small-scale experimental or laboratory production systems are temporary and are intended only to demonstrate technical feasibility or to produce a few test lots of materials for product evaluations. In such situations, test units may be run only several times at given operating conditions, or intermittently, sharing equipment with unrelated processes. In such a rapidly changing work environment, an appropriate and practical balance for allocation of resources should be established. The Risk Based Process Safety approach offers practical guidance for prioritizing these resources.

In other situations, equipment is used by different project teams in succession. The equipment may be idle for extended periods. Thus, previously used or older equipment present asset integrity challenges over the lifetime of the equipment. As new personnel use the equipment, the hazards should be identified and any associated risk mitigated. Changes should be managed, as well, if the equipment is used in new ways. Equipment design, chemical compatibility, and operating conditions should be considered.

Because of the frequent changes that occur in LAPPs, they may require additional formal operating and maintenance procedures. Train workers in new technologies and equipment, and communicate safety information on the hazards to reduce operational risks. LAPP personnel should expect and plan for loss of containment or loss of control events, and include measures to mitigate the consequences and their impacts. Examples of techniques to mitigate consequences of loss of control events include conducting experiments in test cells or chambers designed to contain fires and overpressure events and controlling the equipment remotely to limit worker exposures. Examples of such techniques are described in Parts 4 and 5 of this handbook and in cases presented in the chapters.

2.1.2 Unattended or Minimally Staffed Experimental Runs

Many LAPPs are not staffed routinely for 24 hours a day. In some cases, increased automation has led to a single person running several pieces of equipment or units simultaneously. Experiments that run overnight may be unattended or minimally staffed. These unattended areas need to have reliable safeguards in place to help prevent incidents or mitigate their consequences. LAPP personnel working alone should be able to manage a loss of containment event; these emergency plans should be developed before initiating the work. Examples of techniques for control of unattended experimental or testing systems are described in cases and in Section 24.7.1.

2.1.3 Developing and Maintaining a Sense of Vulnerability—Remembering the Past

One method for LAPP management and workers to increase the sense of vulnerability to hazards and risks in LAPPs is to periodically review and discuss the severe incidents that have occurred globally in LAPPs.

Maintaining a sense of vulnerability means that everyone in the plant:

- is aware of the hazards of processes and materials
- looks for symptoms of weaknesses that might foreshadow more serious events, including near misses
- avoids complacency regardless of good past performance and a good safety record

Adapted from: [9]

This book contains examples that can be used as shared learnings. The incidents in this book occurred in industry, government and university operated LAPPs. Some resulted in severe consequences while others had only minor impacts but could have been more severe under different circumstances. These cases are provided to help illustrate that incidents occurred due to deficiencies in specific management system practices. Example B - 2 lists example questions to ask to maintain a sense of vulnerability.

2.1.4 Statistical Incident Information Available Globally for LAPPs

LAPPs are workplaces for several million individuals globally. In 2011 in the United States (US), the number of individuals working in laboratories was estimated to be over 500,000 [10]. In 2016, according to the US Bureau of Labor Statistics, employment in medical and clinical laboratories alone in the US was above 150,000.

Despite the large numbers of workers in LAPPs, statistical data worldwide for this workforce group on occupational injuries, illnesses and fatalities are limited. Such data are not reported separately for LAPPs in most countries. Thus, there is no comprehensive global databases of fatal incidents and other severe incidents (e.g. major fires) in industrial, university and government LAPPs. Furthermore, many of the individuals working in labs at universities are students and not employees of the institution. Therefore, an injured student may not be covered by occupational injury and illness reporting requirements.

Because of the discrepancy in reporting requirements between LAPPs and CPI, it is not possible to make direct comparisons of occupational injury and illness rates and fatality rates for those working in LAPPs versus those working in other occupations such as in chemical manufacturing facilities. The tables in Section 2.1.5 lists some incidents resulting in fatality.

2.1.5 Fatal Incidents in LAPPs

Severe incidents involving permanent disabling injuries, fatalities, extensive property damage, and research and scheduling interruption have occurred in LAPPs.

LAPP-related process safety incidents have occurred in industrial, university, and governmental supported LAPPs worldwide. Many of these incidents involved chemical use or storage and subsequent loss of control or containment of the hazardous chemicals or energies. The chemicals were flammable, combustible, pyrophoric, toxic, corrosive, thermally unstable, or shock sensitive. The release of stored energy and exposures to asphyxiant gases, biohazards, and radioactive materials contributed to this list, as well. Some of these incidents are discussed in detail in subsequent sections and are presented in Appendix A [11] [12].

More than 225 laboratory incidents are listed in the *Memorial Wall* [11]; almost half of them were due to explosions and a quarter of them were due to toxic exposures. Radiation-related fatalities surpassed fire-related fatalities over the period due to the early years of radioactive isotope research, when radiation hazards were not well-understood (1902-1960). The following tables provide a list of some of the LAPP incidents that resulted in fatalities:

- Table 2-1 Fatal Incidents in LAPPs Resulting from Fires and Explosions
- Table 2-2 Fatal Incidents in LAPPs Resulting from Exposure to Toxic Chemicals
- Table 2-3 Fatal Incidents in LAPPs Resulting from Exposure to Biological Agents
- Table 2-4 Fatal Incidents in LAPPs Resulting from Other Causes

Table 2-1 Fatal Incidents in LAPPs Resulting from Fires and Explosions

2020—A mechanical engineer and materials scientist who was a client of Innovative Test Solutions, Inc. in Schenectady NY USA was fatally injured when pressurized equipment in a testing lab at the company used for processing avocados exploded while he was observing an experiment. Two other individuals were injured. 2020—An explosion and fire involving a metal alkyl powder fatally injured a researcher and injured two others at an LG Chemical company lab in Seosan, South Korea.
2019— A Professor Emeritus was fatally injured in an explosion at his lab in the Department of Materials Science and Engineering at the Technion in Haifa Israel while conducting experiments involving hydrogen.
2018—One contract worker was fatally injured and another was seriously injured while taking samples of an explosive material that exploded and caused a fire at the High Energy Material Research Laboratory (HEMRL) of the Defense Research and Development Organization (DRDO), at Pashan in Pune, India 2018— One researcher was fatally injured and three were seriously injured when a gas cylinder exploded at the Laboratory for Hypersonic and Shock Wave Research of the Indian Institute of Science in Bengaluru, India. 2018—Three graduate students were fatally injured in a lab explosion and fires within the environmental engineering department at Jiaotong University in Beijing, China.
2017—A laboratory technician at a clinical laboratory in Zimbabwe was conducting a bacterial staining test for tuberculosis involving an open flame and a flammable solvent. His lab coat ignited and he was fatally injured due to burns.
2016—A chemist at Leeden National Oxygen in Singapore was fatally injured in an explosion caused by a faulty valve on a gas cylinder.
2015—Fires and explosions in an industrial lab in Singapore used for mixing and analyzing industrial gas mixtures fatally injured a chemist and injured seven others including four members of the emergency response team. 2015—A postdoctoral researcher was fatally injured in a chemistry lab explosion that occurred during an experiment using hydrogen at Tsinghua University in Beijing, China 2015—A gas explosion fatally injured one graduate student and injured four others in a chemistry lab at the China University of Mining and Technology located in the eastern Chinese city of Xuzhou.
2014—A laboratory worker was fatally injured in an explosion at a university petroleum engineering lab in Qatar.
2011—A worker was fatally injured following an explosion at a US Army lab in the United States. 2011—A laboratory worker was fatally injured and a colleague injured in an explosion at an industrial lab using membrane separations process technology development and testing in the United States. (**Case 2011-1**)
2010—An inventor was fatally injured in a hydrogen explosion at a small company's laboratory that conducted fuels research in the United States.
2008—A research assistant at a research lab in the United States was fatally injured when pyrophoric t-butyl lithium sprayed on them during a chemical synthesis experiment. (**Case 2008-1**)

Table 2 1 continued

2007—Six were fatally injured in a chemical engineering department pilot plant performing hexane extraction at a university in Argentina as a result of explosion and fire (**Case 2007-5**)
2006—An explosion at a university chemistry department lab in France fatally injured a professor. 2006—A technician was fatally injured at the Khan Research Laboratory for nuclear materials in Pakistan in an explosion involving conventional explosives.
2003—An explosion in an industrial lab in in the United States resulted in the fatality of a lab worker.
2002—A chemist suffered burns over 85% of their body from an explosion and fire during classified tests on explosive compounds at a government military research facility in the UK.
1996—Acetylene leaked and ignited in a petroleum research lab in the United States and a worker was fatally injured from burns. 1996—An industrial pilot plant worker in France poured samples and residues from a polymer batch into a drum and closed it for disposal. Minutes later the drum exploded and a fireball fatally burned the worker. (**Case 1996-1**)
1993**—**A worker was fatally injured at an industrial lab in the United States after moving a shield in order to remove a flask containing a reactive chemical from a rotary evaporator. The material exploded and glass fragments cut his throat.
1992—A laboratory technician was fatally injured and three others were injured when hydrogen leaked and ignited a flash fire at a laboratory in the United States involved with hydrogenation of animal and vegetable oils. (**Case 1992-1**) 1992—An electrochemist at a contract R&D institute in the United States was fatally injured and two others injured in a hydrogen-oxygen explosion during a cold fusion experiment. 1992—A graduate student at a public university in the United States was fatally injured in a hydrogen explosion in a fume hood while drying acetonitrile with a hydride.
1991—A silane cylinder exploded when nitrous oxide back flowed into the cylinder at an Osaka University lab in Japan fatally injuring two graduate students and injuring six others.
1988**—**An explosion fatally injured four at an industrial explosives lab in Canada.
1987**—**An explosion occurred in an industrial gas supplier's analytical lab in the United States. Silane instead of acetylene was hooked to an atomic absorption instrument. Three were fatally injured and one seriously injured.

Table 2-2 Fatal Incidents in LAPPs Resulting from Exposure to Toxic Chemicals

2018— A scientist was fatally injured from exposure to potassium cyanide in a laboratory in Exton, PA USA.
2012—A lab worker in Germany was fatally injured from accidental exposure to trimethylsilyldiazomethane. (inhalation exposure)
2004—A worker in a laboratory building at a Chinese research institute in Fuzhou, Fujian Province, was fatally injured from exposure from an accidental exposure to phosgene. Hundreds of others on the site sought medical evaluations after exposure.
2008—A research scientist at an R&D laboratory was fatally injured after exposure to the toxic chemical trimethylsilyldiazomethane. (**Case 2008-2)** (inhalation exposure) 2008—A chemist was fatally injured after being exposed to trimethylsilyldiazomethane at an industrial lab in the United States. (inhalation exposure)
1999—An employee at an industrial testing lab in Canada was opening a chamber used to clean drill core samples with toluene. Once the chamber was opened, the employee was exposed to a high concentration of toluene and was fatally injured. (inhalation exposure)
1996—Fatal exposure to a University professor in US during work with toxic dimethyl mercury. (**Case 1996-3)**
1995— Two bottles of reagents were accidentally overturned in a university lab in Hong Kong releasing 96% acryloyl chloride and 94% methacrylic anhydride. One of four individuals exposed to the toxic vapors was fatally injured within a day of the event. (**Case 1995-1)** (inhalation exposure)
1994—A lab technician at an industrial mineral resources lab in Western Australia was fatally injured when he spilled concentrated hydrofluoric acid on himself. (**Case 1994-1**) (dermal exposure-primary)
1985—A lab worker at a university operated government funded R&D lab in the United States was using arsine. An undetected leak developed and he was fatally injured from the exposure. (inhalation exposure)
1981—Following an HF tank leak at an industrial R&D facility in the United States, a clean-up crew went in without proper respirators and two workers were fatally injured. (inhalation exposure)

Table 2-3 Fatal Incidents in LAPPs Resulting from Exposure to Biological Agents

2012—A researcher working in the United States at the San Francisco Veterans Affairs Medical Center was fatally injured from exposure to a strain of bacterium that can cause meningitis.
2010—A researcher at the French National Research Institute for Agriculture, Food and Environment (INRAE) Molecular Virology and Immunology Lab injured her left thumb through two layers of latex glove while cleaning a cryostat that had been used on mice prion-infected brain samples. Exposure to meat from Bovine spongiform encephalopathy (BSE) diseased animals has been linked to a variant of Creutzfeldt-Jakob disease (vCJD) in humans. Average incubation period is typically less than 10 years after exposure. The fatality occured in 2019, nine years after the lab incident. Testing found evidence of vCJD. Because the vCJD virtually disappeared in Europe decades before, the chance that she could contract vCJD from food sources was considered “negligible” and therefore most likely related to the lab exposure.
2009—A research geneticist at the University of Chicago in the United States was fatally injured after becoming infected with a weakened strain of *Yersinia pestis*, the bacterium causing the plague. It was not expected that the bacterium could infect healthy adults.
2004—A scientist conducting vaccine research at a former Russian biological weapons research lab in Siberia was fatally injured after accidentally sticking herself with a syringe needle containing Ebola virus.
1978—A medical photographer at a medical school in England was fatally injured from accidental exposure to a strain of smallpox virus released in a research laboratory on the floor below her workplace. It was alleged by investigators that the virus likely spread through building air ducting.
1958- An electrician was fatally injured after contracting pulmonary anthrax at a US Army Laboratory at Ft. Detrick Maryland.
1951—A microbiologist was fatally injured after contracting anthrax at a US Army Laboratory at Ft. Detrick Maryland.

Table 2-4 Fatal Incidents in LAPPs Resulting from Other Causes

2015—A maintenance technician at a US university was fatally injured during a line opening task on a pressurized cooling water line. The line had been isolated two weeks earlier. However, the closed valve leaked and re-pressurized the line during the two-weeks before the incident (**Case 2015-2**).
2014—A technician in the United States was fatally injured from blunt-force injuries to the chest while doing maintenance in an engine combustion research laboratory to clean "optical window" used in photographing fuel spray patterns in a pressurized chamber.
2001—A microbiologist was fatally injured of suffocation at an animal disease research laboratory in Australia because of a liquid nitrogen leak.
2000—A lab worker was fatally injured and five were injured at a medical school MRI laboratory in the United States when liquid nitrogen leaked.
1999—A hospital lab worker was fatally injured in Scotland from nitrogen inhalation from vaporization of seven hundred liters of liquid nitrogen.
1991—Three people were fatally injured in laboratory incidents at a university in Germany.
1945 and 1946—Two fatalities occurred within a year at the Los Alamos Scientific Laboratory in, New Mexico in the United States during development of the first atomic bombs. Radiation bursts were released during hand assembly. Remote-control assembly of such components replaced, hand-manipulations after the second event.

Adapted from [11] and [12].

2.1.6 Fire Losses in LAPPs

Fires may cause minor to significant injuries and large property losses. They might also result in major scheduling interruption and delays in R&D projects.

Table 2-5 lists examples of structural fires in laboratory buildings. Hundreds of such fires were reported annually in the US. The NFPA report for the period 2009 to 2014 listed on average five such structural fires a week. Property damage from these cases averaged between $40,000 and $50,000 (USD) per event [13] [14].

Table 2-5 Fire Losses in Laboratory Buildings

Sprinklers Control Fire in Lab in New Hampshire (2008): The fire occurred in a detached single-story laboratory of a US Department of Defense contractor that was located on site with other buildings. Either the thermocouple or process controller failed for a furnace used in the heating and growing of crystals and the development of new compounds. The furnace exploded and ignited a nearby cardboard box and small plastic storage drawers. As the fire grew, the sprinklers activated and minimized the impact of the fire. The sprinkler flow triggered a water flow alarm that summoned the fire department. Losses associated with damage to the furnace and contents of the room damaged by fire or water totaled less than $50,000. There were no injuries.
Large-Loss Laboratory Fire in California (2000): A two-story laboratory building was unoccupied during the night and early morning hours when the when the fire occurred. The cause and origin of the fire were not reported. Arriving firefighters found the structure on fire, and initiated interior firefighting procedures until the roof failed, forcing them to the exterior. The fire spread to an adjacent property. The fire caused $10 million in structural damage and $5 million in damage to contents.
$3 Million Loss from Fire at Pennsylvania Research Facility (1992): Defense department research project work was being done in a single-story laboratory building of ordinary construction, 76 meters (250 feet) long by 15 meters (50 feet) wide. The building was not protected by an automatic sprinkler system. Employees were conducting an experiment in a laboratory when a laser or a chemical reaction ignited a combustible shower curtain attached to a hood. Workers tried to put out the fire using several small extinguishers, but their efforts were ineffective. The fire burned through a suspended ceiling into the ceiling void area, where it spread laterally throughout the structure in about 20 minutes. Fire department notification was delayed because of employees' unsuccessful efforts to fight the fire themselves. Smoke detectors provided only a localized evacuation warning. Damage to the building was estimated at $800,000. The loss of a significant amount of electronic and computer equipment was estimated at $2.2 million.
R&D Laboratory Building Fire in Massachusetts (1986): A chemical explosion and resulting fire occurred in a one story 2790 sq meter (30,000 sq. ft.) research and development building associated with the military. The incident occurred in a glovebox being used for an experiment. It contained cylinders that were being filled with aluminum alkyl (pyrophoric) under nitrogen. One minute after the explosion, an employee called the fire department. The facility was equipped with a wet-pipe sprinkler system that did not cover the room of origin and did not activate. Two employees were severely burned and admitted to burn centers. Damage was estimated at $110,000, against a value of $3,000,000.

Table 2-5 continued

University pilot plant in Argentina: Safeguards were inadequate for the magnitude of the hazards and potential consequences of loss of control. This incident occurred in a pilot plant operated at the University of Rio Cuarto in Argentina and resulted in six fatalities. Drums of hexane were in storage and use inside the facility that was staffed by research assistants, graduate student researchers, and postdoctoral researchers. R&D work at the pilot plant facility included renewable fuels from biomass-derived materials such as biodiesel produced from vegetable oils extracted from oil seed crops. Although the building housing the Pilot Plant had been designed initially for only experimental R&D work, a section of the building was subsequently converted to classroom and office uses. (Case 2007-5)
National Chemical Laboratory in India: India's Council of Scientific and Industrial Research (CSIR) oversees the operation of dozens of scientific and engineering laboratories for R&D across India. A destructive fire occurred in CSIR's National Chemical Laboratory (CSIR-NCL). The chemical process pilot plant facility was inaugurated just 13 months before this fire. It was established to help India's fine and specialty chemicals industry develop process technologies that are cleaner, greener, safer, compact, scalable and economical. The fire destroyed most of the Pilot Plant III building within an hour. There were no casualties, but the physical damage was estimated at close to one million US dollars (at the exchange rate at the time) and the R&D activities were interrupted for an extended period.

Adapted from examples presented in [15].

A few images of laboratories after a fire or an explosion follow:

Figure 2-1 Laboratory Explosion and Fire Damage. This explosion and fire completely destroyed the laboratory, including all of the research, lab notes, and other work by the research professor and their students. An adjacent lab was also damaged, and the three-alarm blaze took firefighters more than an hour to extinguish [16].

Figure 2-2 Laboratory Fire and Water Damage. Although the flames were confined to a small section of the building, thousands of gallons of water used to extinguish the fire caused significant damage to the building. Around 100 researchers — chemists, virologists, microbiologists, and others—worked in the building [17].

Figure 2-3 Laboratory Hood Fire Damage. The unattended vacuum pump is believed to have started this fire that damage the hood and caused the evacuation of six researchers [18].

Figure 2-1 Laboratory Explosion and Fire Damage

Figure 2-2 Laboratory Fire and Water Damage

Figure 2-3 Laboratory Hood Fire Damage

2.2 Safety in Laboratories and Pilot Plants

Although the effects of a LAPP incident typically do not extend outside the laboratory or immediate vicinity of the pilot plant, LAPP incidents can result in major impacts to personnel and facilities.

Severe LAPPs incidents have occurred and continue to occur globally over the past several decades. The fatal incidents in LAPPs listed in Table 2-1 through Table 2-4 and major fire losses described in Table 2-5 summarize some examples. Many of these incidents were bona fide “process safety incidents” involving loss of control and containment of hazardous materials and energies. Appendix A contains over 60 cases from industry, government and academic LAPPs worldwide.

When reviewing information the LAPP incident cases in Appendix A , the reader should remember these key observations that these incidents had in common:

- They were all preventable.
- Each organization involved had one or more management system deficiencies:
- Safety Culture
- Hazard identification and understanding (competency issues)
- Risk analysis and risk-based decision making to select and implement appropriate hazard controls
- Maintaining and assuring the effectiveness of the hazard controls adopted to manage the risks
- Managing changes

2.3 Where to Start with a Risk-based Approach in the LAPP

Whether staff in a LAPP is starting to develop a risk management program, has some risk management systems in place, or has years of risk management system experience, it's often the "next step" that needs a clear scope. This section is designed to help staff in a LAPP begin their process safety journey from an environment that has little or no process safety system experience. By initially developing and implementing just a few of the key management systems, LAPP staff will be well on their way to effectively reducing and managing their risks.

The risk reduction approach this handbook takes follows the framework of the CCPS Risk Based Process Safety (RBPS) management system, introduced in Table 1-2 [7]. The six elements recommended for developing, implementing, or updating in the beginning are :

1. **Hazard Identification and Risk Analysis (HIRA)** –The HIRA helps staff identify the hazards, analyze the risks, and select the risk reduction controls needed to operate the LAPP safely. By analyzing potential incident scenarios and estimating their risks, staff can prioritize their risk reduction efforts. The HIRA approach, Element 7, is discussed in Chapter 11.
2. **Process Knowledge Management** – The hazards information, the process technologies, and the risk evaluations, must be accurate, complete, understood, and documented. This process safety information is required input for HIRAs, MOCs and Asset Integrity programs. Managing process technology information, Element 6, is discussed in Chapter 9.
3. **Operating Procedures** –The written work instructions and procedures help ensure that practices are in place and used to perform the LAPP tasks safety. This element supports training as well, and helps maintain consistency, especially in high turnover research or training LAPPS. such as those in academia. Operating Procedures, Element 8, is discussed in Chapter 20.
4. **Training and Performance Assurance** – Effective training helps maintain a high level of human performance, reducing the likelihood for and the consequences of mistakes. Humans are involved in all stages of the experimental life cycle, from conceptual design to decommissioning of the LAPP. This Element, Element 12, is discussed in Chapter 7.

5. **Management of Change (MOC)** – An MOC program is important to LAPPs due to constant research program or pilot plant production-related changes. An effective MOC program helps identify and manage equipment, process, and procedural changes. The MOC system, Element 13, is discussed in Chapter 23.
6. **Incident Investigation** – Learning from effectively performed incident investigations helps LAPP staff implement controls that should prevent a similar incident from occurring in the future. These investigations identify root causes and recommend actions that will correct current deficiencies. Incident Investigation approaches, Element 17, is discussed in Chapter 25.

Many of the RBPS Elements correlate to activities that workers in LAPPs already do. Table 2-6 provides examples of these activities relative to the RBPS Elements. If the six key RBPS Elements just discussed are refined with the current LAPP activities, the risk reduction program will begin with documenting the location of process safety information, ensuring that standards and reference materials are available, that risk reduction measures are implemented, and that proposed changes are formally identified, reviewed, approved, and documented. Along with these program development and implementation efforts, staff in the LAPP must be able to recognize and investigate near misses and unexpected events, such as a loss of containment of a hazardous material or energy.

Table 2-6 Comparison of LAPP Activities to the RBPS Elements

LAPP Activity	**Corresponding RBPS Element**	
Program manager, principal investigator, project advisor support for safety efforts in each LAPP	1	Process Safety Culture
Written plans for hazardous chemical storage and handling in LAPPs (Note 1)	2	Compliance with Standards
Programs to ensure skills-based ability to use systems and perform tasks safely	3	Process Safety Competency
Assignment of responsibilities for managing safety	4	Workforce Involvement
Established communication protocols to program or project administrators	5	Stakeholder Outreach
Location and availability of standards and reference materials	6	Process Knowledge Management