A CCPS HANDBOOK

Handbook for Process Safety in Laboratories and Pilot Plants

A Risk-based Approach

WILEY

Handbook for Process Safety in Laboratories and Pilot Plants

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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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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

surface of a glass vessel wall). Rapid changes from hot to cold can be more harmful for brittle materials with surface defects because it generates tensile stresses on the rapidly cooled surface that may activate pre-existing micro-cracks and lead to wall failure as the cracks propagate.

Thicker glass is more prone to damage/failure as a result of rapid temperature changes because glass is such a poor thermal conductor. Jacketed glass vessels will often fail due to thermal stress at the junction of the two vessels (outer jacket and inner vessel). This is not where jacketed glass will fail due to pressure. Joint failures are due to several issues, and may be the single greatest source of containment failure in a glass system.

The Process Hazard Analysis (PHA) or safety review team should identify actions with laboratory glass equipment that could lead to thermal shock condition. This can be done by asking questions about the heating and cooling steps in the procedures. If these steps are done incorrectly or skipped entirely, thermal shock could result.

Connections to glass equipment involving materials with different thermal expansion coefficients can (and do) fail. When metal tubing or pipe is used for connections to glass equipment, differences in thermal expansion can induce stresses at the connection points. Thermal expansion of metal piping or tubing may be several times as much as that of borosilicate glass. As a result, lateral or perpendicular pipe and supports induce more shear and tensile stress on the glassware (already not good under stress), inducing cracks. Metal clamps and metal bolts used on glass joint connections will also expand more than the glass at a given temperature, effectively loosening connections, and thus allowing vapors to be released and bottom fittings to leak and drip. Heating and cooling of pressure joints need to be controlled, and the fittings tightened or loosened in stages to assure containment and to avoid over-stressing the glass at the connection. Polariscopes again could be used to detect such stress points in glass. This is difficult and unreliable even for the most experienced users.

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