



Guidelines for

**Developing
Quantitative
Safety Risk
Criteria**



GUIDELINES FOR DEVELOPING QUANTITATIVE SAFETY RISK CRITERIA

Center for Chemical Process Safety
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An AIChE Industry
Technology Alliance



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GUIDELINES FOR DEVELOPING QUANTITATIVE SAFETY RISK CRITERIA

This book is one in a series of process safety guideline and concept books published by the Center for Chemical Process Safety (CCPS). Please go to www.wiley.com/go/ccps for a full list of titles in this series.

PREFACE

The American Institute of Chemical Engineers (AIChE) has been involved with process safety and loss prevention in the chemical, petrochemical, hydrocarbon processing, and other process industries since its founding in 1908. As these industries increased in scale and economic importance in the years following World War II, AIChE's activities in this area expanded through specific programming activities and publications. AIChE's symposia, journals, and other publications have been important safety resources for chemical engineers, industrial chemists, and other technical professionals in these industries.

In 1985, following major chemical disasters in Mexico City, Mexico, and Bhopal, India, the Center for Chemical Process Safety (CCPS) was established as an AIChE Technology Alliance. The charter of CCPS is to develop and disseminate technical information for use in the prevention of major chemical accidents. CCPS is supported by more than 120 sponsors worldwide, including process industry companies, engineering consulting companies, and government entities. These sponsors provide funding, and, more importantly, technical knowledge, expertise, and professional guidance through participation in various CCPS project subcommittees. One important product of CCPS, in support of its charter, is a series of guidelines books which provide information on implementation of various aspects of a complete process safety management system.

Process hazard analysis, risk analysis, and risk management have been recognized as critical features of a process safety management program by CCPS from its inception in 1985. The first product of CCPS was the first edition of *Guidelines for Hazard Evaluation Procedures*, published in 1985, and now in its third edition (published in 2008). The second and third editions of this book include discussion of qualitative risk evaluation tools, which can be incorporated into process hazard studies. CCPS has also published several important books related to process risk analysis, including:

- *Guidelines for Chemical Process Quantitative Risk Analysis* (1989, 2nd Edition published in 2000) provides a complete methodology for quantitative process risk analysis.
- *Evaluating Process Safety in the Chemical Industry: A User's Guide to Quantitative Risk Analysis* (2000) is an overview of the use of quantitative risk analysis techniques in the process industries for engineers and managers.
- *Tools for Making Acute Risk Decisions with Chemical Process Safety Applications* (1995) describes how various decision analysis techniques can be applied to management decision making incorporating the results of risk analysis studies.
- *Layer of Protection Analysis: Simplified Process Risk Assessment* (2001) provides a description of a simplified technique for evaluating process safety risks.

This book, *Guidelines for Developing Quantitative Safety Risk Criteria*, provides additional guidance on the use of risk analysis studies for process risk management decisions. Over the last several decades, as quantitative risk analysis has been applied increasingly in the process industries, many government and industry organizations have begun to develop and apply risk criteria as tools for making process risk management decisions. This book surveys experience with the development and application of these criteria, and provides guidance on how an organization might use this experience to establish its own risk criteria. The book does not recommend criteria, or endorse specific criteria that have been used by various organizations. The focus is on understanding the meaning of the various criteria that have been used, their bases, how they are applied, and how this experience can be used by an organization that is considering similar approaches as a part of its own process risk management system. We hope that this book will help engineers and managers in the process industries better understand risk criteria, how they can be applied, how they can become one element of a comprehensive process risk management system, as well as understand the limitations and potential problems that might be associated with the use of risk criteria.

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ACRONYMS AND ABBREVIATIONS

ACDS	Advisory Committee on Dangerous Substances (UK)
ACMH	Advisory Committee on Major Hazards (UK)
AIChE	American Institute of Chemical Engineers
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
AQPP	Air Quality Permitting Program (New Jersey)
BLS	Bureau of Labor Statistics (US)
BRZO	Besluit Risico's Zware Ongevallen (Major Incident Risk Order, Netherlands)
CCPHI	Coordinating Committee on Land-Use Planning and Control Relating to Potentially Hazardous Installations (Hong Kong)
CCPS	Center for Chemical Process Safety
CETESB	Companhia de Tecnologia de Saneamento Ambiental (Brazil)
CHEM Services	Chemical Hazards and Emergency Management Services (Queensland, Australia)
COMAH	Control of Major Accident Hazards regulation (UK)
COVO	Commissie Veiligheid Omwonenden (commission for safety of inhabitants) of the Rijnmond Authority (Netherlands)
CPQRA	chemical process quantitative risk analysis
CSChE	Canadian Society for Chemical Engineering
DOD	Department of Defense (US)
DOE	Department of Energy (US)

DOP	Department of Planning (New South Wales, Australia)
EIA	environmental impact assessment
EIAO	Environmental Impact Assessment Ordinance (Hong Kong)
EPA	Environmental Protection Agency (US)
EPD	Environmental Protection Department (Hong Kong)
FAR	fatal accident rate
FDA	Food and Drug Administration (US)
FEEMA	Fundação Estadual de Engenharia do Meio Ambiente (Brazil)
FEPAM	Fundação Estadual de Proteção Ambiental (Brazil)
FMEA	failure modes and effects analysis
F-N	frequency-number (curve)
FSA	formal safety assessment
HAZID	hazard identification
HAZOP	hazard and operability analysis
HID	Hazardous Installations Directorate (UK)
HSE	Health and Safety Executive (UK)
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
IDLH	immediately dangerous to life or health
IMO	International Maritime Organization
IPEEE	Individual Plant Examination of External Events
IPL	independent protection layer
IPS	instrumented protective system
LFL	lower flammable limit
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LOPA	layer of protection analysis
MHF	Major Hazard Facilities Regulation (Victoria, Australia)
MHIDAS	Major Hazard Incident Data Service database (EU)
MI	mechanical integrity
MIACC	Major Industrial Accidents Council of Canada
NASA	National Aeronautics and Space Administration (US)
NJDEP	New Jersey Department of Environmental Protection
NRC	Nuclear Regulatory Commission (US)

NSC	National Safety Council (US)
NSW	New South Wales, Australia
OSHA	Occupational Safety and Health Administration (US)
PADHI	Planning Advice for Developments Near Hazardous Installations (UK)
PCD	Pollution Control Department (Singapore)
PHA	process hazard analysis
PHI	potentially hazardous installation
PLL	potential loss of life
PPRT	Technological Risks Prevention Plan (France)
PRA	probabilistic risk assessment
QRA	quantitative risk assessment
RBPS	risk-based process safety
RSSG	Royal Society Study Group (UK)
SFAIRP	So Far As Is Reasonably Practicable
SIS	safety instrumented system
TOR	tolerability of risk
TQ	threshold quantity
V&W	Ministerie van Verkeer en Waterstaat (Ministry of Transport, Public Works, and Water Management, Netherlands)
VCE	vapor cloud explosion
VROM	Volkshuisvesting, Ruimtelijke Ordening en Milieu (Ministry of Housing, Spatial Planning, and the Environment, Netherlands)

GLOSSARY

Aggregate risk: Societal risk for on-site workers in occupied buildings (uniquely applied to facility siting studies, as described in [CCPS 1996] and [API 2003]).

Anchor point: A single F-N pair which, along with the slope, defines an F-N risk criterion curve.

Apportionment: The subdividing of a risk criterion among a number of risk sources (for example, among all process units at an operating site). The concept of risk apportionment can apply to both individual and societal risk, but at different levels in the enterprise.

As Low As Reasonably Achievable (ALARA): A concept equivalent to *As Low As Reasonably Practicable*.

As Low As Reasonably Practicable (ALARP): The concept that efforts to reduce risk should be continued until the incremental sacrifice (in terms of time, effort, cost, or other expenditure of resources) is grossly disproportionate to the value of the incremental risk reduction achieved.

Average individual risk (exposed hours/worked hours): The individual risk for an activity, calculated for the duration of the activity, or averaged over the working day.

Average individual risk (exposed population): The individual risk averaged over the population which is exposed to risk from the facility.

Average individual risk (total population): The individual risk averaged over a predetermined population, without regard to whether or not all people in that population are actually exposed to the risk.

Average rate of death: A measure of societal risk expressed as the average number of fatalities that might be expected per unit time from all possible incidents.

Canvey Island Study: An early (1978) quantitative risk assessment which evaluated the risks associated with an integrated chemical/petrochemical processing complex in the UK.

Checklist analysis: A hazard evaluation procedure using one or more pre-prepared lists of process safety considerations to prompt team discussions of whether the existing safeguards are adequate.

Consequence: The undesirable result of an incident, usually measured in health and safety effects, environmental impacts, loss of property, and business interruption costs.

Consequence modeling: Development of numerical estimates of the expected effects of incident outcome cases independent of frequency or probability.

De minimis risk: A level of risk that would be perceived by most to be broadly acceptable, and not requiring further reduction.

Establishment: In the context of the EU Seveso Directive (Seveso 2), the whole area under the control of an operator where dangerous substances are present in one or more installations, including common or related infrastructures or activities.

Event tree: A logic model that graphically portrays the combinations of events and circumstances in an accident sequence.

Event tree analysis: A method used for modeling the propagation of an initiating event through the sequence of possible incident outcomes. The event is represented graphically by a tree with branches from the initiating cause through the success or failure of independent protection layers.

Experience-based criteria: Risk criteria that are calibrated/validated against established consensus as reflected in historical precedents/decisions about tolerance of major hazard risks, particularly those subjected to broad public discussion or scrutiny.

External safety: A term used in the Netherlands to refer to “risks to the surrounding area in handling hazardous materials, in the use, storage, and transport of those materials.” [VROM 2005]

Failure modes and effects analysis (FMEA): A hazard evaluation procedure in which all known failure modes of components or features of a system are considered in turn and undesired outcomes are noted to guide discussions of whether the existing safeguards are adequate.

Fatal accident rate: A measure of individual risk expressed as the estimated number of fatalities per 10^8 exposure hours (roughly 1000 employee working lifetimes).

Fault tree analysis: A method used to analyze graphically the failure logic of a given event, to identify various failure scenarios (called cut-sets), and to support the probabilistic estimation of the frequency of the event.

F-N curve: A plot of cumulative frequency versus consequences (typically expressed as number of fatalities).

Frequency modeling: Development of numerical estimates of the likelihood of an event occurring.

Hazard and operability analysis (HAZOP): A scenario-based hazard evaluation procedure in which a team uses a series of guide words to identify possible deviations from the intended design or operation of a process, then examines the potential consequences of the deviations and the adequacy of existing safeguards.

HSE Risk Interval: A single-value measure of societal risk that can be calculated from the data used to develop an *F-N curve*, or can be estimated based upon an assumed shape for the F-N curve and information on a proposed “worst case” scenario.

Hypothetical individual: A modeling construct that allows the risk estimate to reflect variations in exposure durations or patterns, diverse forms of protection available to different population groups, variations in individual characteristics that might affect susceptibility to harm (e.g., age, gender, abilities or disabilities), and so forth. Multiple risk calculations may be required to determine the hypothetical individual at greatest risk at a particular location.

Immediately dangerous to life or health: An atmospheric concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual’s ability to escape from a dangerous atmosphere.

Incident: 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. Such events include fires, explosions, releases of toxic or otherwise harmful substances, and so forth.

Independent protection layer (IPL): A device, system, or action that is capable of preventing a postulated accident sequence from proceeding to a defined, undesirable endpoint. An IPL is (1) independent of the event that initiated the accident sequence and (2) independent of any other IPLs. IPLs are normally identified during layer of protection analyses.

Individual risk: The risk to a person in the vicinity of a hazard. This includes the nature of the injury to the individual, the likelihood of the injury occurring, and the time period over which the injury might occur.

Installation: In the context of the EU Seveso Directive (Seveso 2), a technical unit within an establishment in which dangerous substances are produced, used, handled, or stored. It includes all the equipment, structures, pipework, machinery, tools, private railway sidings, docks, unloading quays serving the installation, jetties, warehouses or similar structures, floating or otherwise, necessary for the operation of the installation.

Instrumented protective system (IPS): A safety system composed of a separate and independent combination of sensors, logic solvers, final elements, and support systems that are designed and managed to achieve a specified risk reduction.

Involuntary risk: Risk that is imposed on someone who does not directly benefit from the activity that poses the risk.

Land use planning: The control of developments around hazardous installations based upon consideration of the risks posed by the installations, and the nature of the developments and the populations they might contain.

Layer of protection analysis (LOPA): An approach that analyzes one incident scenario (cause/consequence pair) at a time, using predefined values for the initiating cause frequency, independent protection layer failure probabilities, and consequence severity, in order to compare an order-of-magnitude scenario risk estimate to tolerable risk goals for determining where additional risk reduction or more detailed analysis is needed. Scenarios are identified elsewhere, typically using a scenario-based hazard evaluation procedure such as a HAZOP study.

Less vulnerable object: In the Dutch regulatory context, an off-site population characterized by a lower population density of generally more fit and/or more easily evacuated persons, as contrasted with a *vulnerable object*.

Likelihood: A measure of the expected frequency with which an event occurs. This may be expressed as a frequency (e.g., events per year), a probability of occurrence during a time interval (e.g., annual probability), or a conditional probability (e.g., probability of occurrence, given that a precursor event has occurred).

Location risk: Individual risk calculated for a particular geographical location, independent of the nature of the population, or whether anyone is likely to be present at a particular location. The calculation assumes a receptor present 24 hours per day, 365 days per year, out of doors, with no protection.

Maximum individual risk: The individual risk to the person(s) exposed to the highest risk in an exposed population.

Off-site population: Persons located outside of the site property line that may be impacted by an on-site incident.