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BSI Standards Publication

Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee PSE/17/-/9, Liquefied Natural Gas (LNG) installations and equipment.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface (ISO/TS 16901:2022)

Recommandations sur l'appréciation du risque dans la conception d'installations terrestres pour le GNL en incluant l'interface terre/navire (ISO/TS 16901:2022)

Leitfaden zur Durchführung von Risikobewertungen bei der Planung von LNG-Anlagen an Land, einschließlich der Schnittstelle zwischen Schiff und Land (ISO/TS 16901:2022)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 9, *Production, transport and storage facilities for cryogenic liquefied gases*.

This second edition cancels and replaces the first edition (ISO/TS 16901:2015), which has been technically revised.

The main changes are as follows:

— reference to IGF code added to the scope;

— references updated in Clause 2 and the bibliography;

— definitions added for HSE critical activity and HSE critical element.

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Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface

1 Scope

This document provides a common approach and guidance to those undertaking assessment of the major safety hazards as part of the planning, design, and operation of LNG facilities onshore and at shoreline using risk-based methods and standards, to enable a safe design and operation of LNG facilities. The environmental risks associated with an LNG release are not addressed in this document.

This document is applicable both to export and import terminals but can be applicable to other facilities such as satellite and peak shaving plants.

This document is applicable to all facilities inside the perimeter of the terminal and all hazardous materials including LNG and associated products: LPG, pressurized natural gas, odorizers, and other flammable or hazardous products handled within the terminal.

The navigation risks and LNG tanker intrinsic operation risks are recognised, but they are not in the scope of this document. Hazards arising from interfaces between port and facility and ship are addressed and requirements are normally given by port authorities. It is assumed that LNG carriers are designed according to the IGC code, and that LNG fuelled vessels receiving bunker fuel are designed according to IGF code.

Border between port operation and LNG facility is when the ship/shore link (SSL) is established.

This document is not intended to specify acceptable levels of risk; however, examples of tolerable levels of risk are referenced.

See IEC 31010 and ISO 17776 with regard to general risk assessment methods, while this document focuses on the specific needs scenarios and practices within the LNG industry.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO Guide 73, *Risk management — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO Guide 73 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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3.1
as low as reasonably practicable
ALARP
reducing a *risk* (3.28) to a level that represents the point, objectively assessed, at which the time, trouble, difficulty, and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained

3.2
boiling liquid expanding vapour explosion
BLEVE
sudden release of the content of a vessel containing a pressurized flammable liquid followed by a fireball

Note 1 to entry: This hazard is not applicable to atmospheric LNG tanks, but to pressurized forms of hydrocarbon storage.

[SOURCE: ISO/TS 18683, 3.1.2, modified — Note to entry added.]

3.3
bow-tie
pictorial representation of how a hazard can be hypothetically released and further developed into a number of *consequences* (3.6)

Note 1 to entry: The left-hand side of the diagram is constructed from the fault tree (causal) analysis and involves those threats associated with the hazard, the controls associated with each threat, and any factors that escalate likelihood. The right-hand side of the diagram is constructed from the hazard event tree (consequence) analysis and involves escalation factors and recovery preparedness measures. The centre of the bow-tie is commonly referred to as the "top event".

3.4
cost to avert a fatality
CAF
value calculated by dividing the costs to install and operate the protection/*mitigation* (3.20) by the reduction in *potential loss* (3.22) of life (PLL)

Note 1 to entry: It is a measure of effectiveness of the protection/mitigation.

3.5
computational fluid dynamics
CFD
numerical methods and algorithms to solve and analyse problems that involve fluid flows

3.6
consequence
outcome of an event

3.7
cost benefit analysis
CBA
means used to assess the relative cost and benefit of a number of *risk* (3.28) reduction alternatives

Note 1 to entry: The ranking of the risk reduction alternatives evaluated is usually shown graphically.

3.8
design accidental load
DAL
most severe accidental load that the function or system is able to withstand during a required period of time, in order to meet the defined *risk* (3.28) acceptance criteria

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3.9
explosion barrier
structural barrier installed to prevent explosion damage in adjacent areas

EXAMPLE A wall.

3.10
***F/N* curve**
FN
plot of cumulative frequency versus *N* or more persons that sustain a given level of harm from defined sources of hazards

3.11
failure mode and effect analysis
FMEA
analytically derived identification of the conceivable equipment failure modes and the potential adverse effects of those modes on the system and mission

Note 1 to entry: It is primarily used as a design tool for review of critical components.

3.12
fatal accident rate
FAR
number of fatalities per 100 million hours exposure for a certain activity

3.13
harm
physical injury or damage to the health of people or damage to property or the environment

3.14
hazard
potential source of *harm* (3.13)

3.15
hazard identification
HAZID
brainstorming exercise using checklists the hazards in a project are identified and gathered in a *risk register* (3.39) for follow up in the project

3.16
hazard and operability study
HAZOP
systematic approach by an interdisciplinary team to identify hazards and operability problems occurring as a result of deviations from the intended range of process conditions

Note 1 to entry: It consists of four steps: definition, preparation, documentation/follow up and examination to manage a hazard completely.

3.17
health, safety and environmental critical activity
HSE critical activity
activity or task that provides or maintains barriers

3.18
health, safety and environmental critical element
HSE critical element
component or system whose failure could cause or substantially contribute to the loss of integrity and safety of a system and whose purpose is to prevent or mitigate from the effects of hazards

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3.19
impact assessment
assessment of how *consequences* (3.6) (fires, explosions, etc.) do affect people, structures the environment, etc.

3.20
mitigation
limitation of any negative *consequence* (3.6) of a particular event

3.21
Monte Carlo simulation
simulation having many repeats, each time with a different starting value, to obtain distribution function

3.22
potential loss
product of frequency and *harm* (3.13) summed over all the outcomes of a number of top events

3.23
probability
extent to which an event is likely to occur

3.24
probit
inverse cumulative distribution function associated with the standard normal distribution

Note 1 to entry: Probit is used in QRA to describe the relation between exposure, e.g. to radiation or toxics, and fraction fatalities.

3.25
protective measure
means used to reduce risk

3.26
quantitative risk assessment
QRA
techniques that allow the *risk* (3.28) associated with a particular activity to be estimated in absolute quantitative terms rather than in relative terms such as high or low

Note 1 to entry: QRA may be used to determine all risk dimensions, including risk to personnel, risk to the environment, risk to the installation, and/or the assets and financial interests of the company. See ISO 17776:2016, B.12.

3.27
residual risk
risk (3.28) remaining after *protective measures* (3.25) have been taken

3.28
risk
combination of the *probability* (3.23) of occurrence of *harm* (3.13) and the severity of that harm

3.29
risk analysis
systematic use of information to identify sources and to estimate the *risk* (3.28)

3.30
risk assessment
overall process of *risk analysis* (3.29) and *risk evaluation* (3.33)

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3.31
risk contour
RC
two-dimensional representation of *risk* (3.28) on a map

Note 1 to entry: Also called individual risk contours (IRC) or location-specific risk (LSR).

3.32
risk criteria
terms of reference by which the significance of *risk* (3.28) is assessed

3.33
risk evaluation
procedure based on the *risk analysis* (3.29) to determine whether the *tolerable risk* (3.47) has been achieved

3.34
risk management
coordinated activities to direct and control an organization with regard to *risk* (3.28)

3.35
risk management system
set of elements of an organization's management system concerned with managing *risk* (3.28)

3.36
risk matrix
matrix portraying *risk* (3.28) as the product of *probability* (3.23) and *consequence* (3.6), used as the basis for risk determination

Note 1 to entry: Considerations for the assessment of probability are shown on the horizontal axis. Considerations for the assessment of consequence are shown on the vertical axis. Multiple consequence categories are included: impact on people, environment, assets, and reputation. Plotting the intersection of the two considerations on the matrix provides an estimate of the risk.

3.37
risk perception
way in which a *stakeholder* (3.46) views a *risk* (3.28) based on a set of values or concerns

3.38
risk ranking
outcome of a qualitative *risk analysis* (3.29) with a numerical annotation of *risk* (3.28)

Note 1 to entry: It allows accident scenarios and their risk to be ranked numerically so that the most severe risks are evident and can be addressed.

3.39
risk register
hazard management communication document that demonstrates that hazards have been identified, assessed, are being properly controlled, and that recovery preparedness measures are in place in the event control is ever lost

3.40
risk transect
RT
representation of *risk* (3.28) as a function of distance from the hazard

3.41
rollover
sudden mixing of two layers in a tank resulting to a massive vapour generation

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3.42
rapid phase transition
RPT
explosive change from liquid into vapour phase

Note 1 to entry: When two liquids at two different temperatures come into contact, explosive forces can occur, given certain circumstances. This phenomenon, called rapid phase transition (RPT), can occur when LNG and water come into contact. Although no combustion occurs, this phenomenon has all the other characteristics of an explosion. RPTs resulting from an LNG spill on water have been both rare and with relatively limited *consequences* (3.6).

3.43
safety
freedom from unacceptable *risk* (3.28)

3.44
SIMOPS
concatenation of simultaneous operations

Note 1 to entry: SIMOPS often refers to events such as maintenance or construction work in an existing plant when there are more personnel near a live operating plant and who are exposed to a higher level of *risk* (3.28) than normal.

3.45
showstopper
event or *consequence* (3.6) that produces an unacceptable level of *risk* (3.28) such that the project cannot proceed and where the level of risk cannot be mitigated to an acceptable level

3.46
stakeholder
individual, group, or organization that can affect, be affected by, or perceive itself to be affected by a *risk* (3.28)

3.47
tolerable risk
risk (3.28) that is accepted in a given context based on the current values of society

3.48
individual risk
probability of being killed (or harmed at certain level) on an annual basis from all *hazards* (3.13)

3.49
potential loss of life
expected value of the number of fatalities per year (or over the life time of a project)

4 Abbreviated terms

ALARP	as low as reasonably practicable
BLEVE	boiling liquid expanding vapour explosion
CAF	cost to avert a fatality
CFD	computational fluid dynamics
CBA	cost benefit analysis
DAL	design accidental load
EDP	emergency depressuring

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ERC	emergency release coupling
ESD	emergency shutdown
ETA	event tree analysis
FAR	fatal accident rate
FEED	front-end engineering design
FEM	finite element method
FN	frequency vs number (of affected individuals)
FMEA	failure mode and effect analysis
FMECA	failure, modes, effects, and criticality analysis
HAZID	hazard identification
HAZOP	hazard and operability study
HEMP	hazards and effects management process
HSE	health, safety and environmental
IR	individual risk contour
LSR	location-specific risk
LOPA	layers of protection analysis
MTTF	mean time to failure
MTTR	mean time to repair
OBE	operating basis earthquake
PERC	power emergency release coupler
P&IDs	process and instrument diagrams
PIMS	pipeline integrity management system
PLL	potential loss of life
QRA	quantitative risk assessment
RC	risk contour
RPT	rapid phase transition
RT	risk transect
SIL	safety integrity level
SMS	safety management system
SSE	safe shutdown earthquake
SSL	ship/shore link

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5 Safety risk management

5.1 Decision support framework for risk management

Safety risk management is integrated in the project development and decision-making processes and need as consistent support for decisions in all phases of an LNG development but does not include the full operational lifecycle.

The approach to risk management should address the project-specific requirements as agreed between the different parties and stakeholders and also establish an agreed format to communicate risk and ensure that decisions are made in a consistent and agreed format through the life of the project.

The acceptance criteria including the format should be defined in conformity with company standards. The format of the acceptance criteria prescribes thereby the approach as discussed below.

There is a wide range of tools and approaches that can be used to support decisions related to risk management. UK Offshore Operators Association (UKOOA) presented a framework for decision support reflecting the significance of the decision as well decision context. The framework as shown for information in Figure 1 illustrates the balancing between use of codes and standards, QRA, and decision processes reflecting company and societal values.

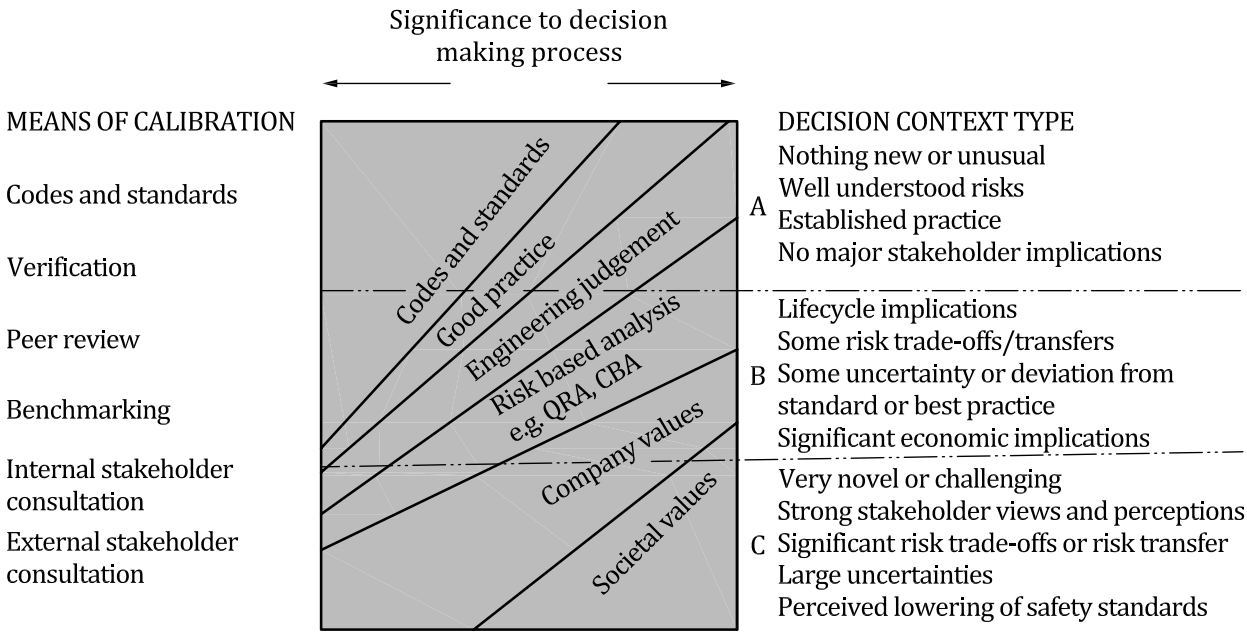

Figure 1 — Decision support framework for risk management

5.2 Prescriptive safety or risk performance

Both prescriptive and risk-based approaches are used in the planning, design, and operation of LNG facilities.

Prescriptive approaches represent industry experience and practices.

The main advantages with prescriptive approaches are predictability and effective decision processes in the design.

The main objections to the use of prescriptive approaches are that they do not accommodate new solutions and thereby can limit novel development and improvement. Further, when the requirements are met, the prescriptive approaches do not encourage a continued effort for further improvements.

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Risk-based approaches have developed in the nuclear and offshore industries. Risk-based approaches are used in many parts of the world and are gaining a wider usage.

In essence, risk-based approaches start from first principles aiming at demonstration that the risk acceptance criteria are met with a proper selection of design and operational measures. In principle, no "prescribed solutions" should be given as a starting point (but in reality, good industry experience, practices and standards are adopted as the starting point).

The main advantage of a risk-based approach is that it stimulates new and improved solutions; it encourages continuous focus on improved safety, and it focuses efforts on the key areas as formulated in the risk acceptance criteria.

Normally, a risk-based approach starts early and focuses the attention on the key issues that should be addressed in the different project phases. In most cases, a risk-based approach ensures that the correct decisions are made at the right time and thereby avoids costly revisions and adjustments. Further, the site-specific conditions and particular stakeholder views are better reflected.

The main criticism to risk-based approaches focuses on the complexity of the process, and the line of responsibility can become unclear. It is essential that risk acceptance criteria are established and derived from owner's requirements. National and international regulations can apply.

It is often found that a risk-based design does not enable all engineering design disciplines to proceed on a firm design basis until the results from the risk analysis is available. This can have a schedule impact.

Further, the uncertainty involved due to, e.g. lack of relevant failure data, model assumptions can make it difficult to relate to the results. A situation where detailed results from sophisticated computational models can generate false confidence in the results can lead to the wrong conclusion. The uncertainty is a particular concern when a risk-based approach is used to demonstrate that sensible safety measures are not needed.

Risk analyses shall not be used to deviate from good engineering practice.

Finally, it is often claimed that the lack of predictability leads to increased cost. But the savings earned by adopting novel solutions can be significant but difficult to quantify.

Successful use of a risk-based approach normally requires an iterative process where the first layouts and decision are based on experience and industry practice (i.e. prescriptive guidelines, standards for process design, etc.) and that this first estimate is qualified and improved using risk-based techniques.

Risk analyses also enable areas and causes of higher risk to be identified so that mitigation measures can be applied in a cost-effective manner.

5.3 Risk assessment in relation to project development

Risk assessment is used for decision support.

The decisions being made in the different phases of a project development vary, and the need for decision support accordingly.

The available information and level of detail as input to any risk assessment increase as the planning progresses. As a result, the requirements to risk assessment techniques and results vary over the project phases, and this can represent a challenge in the communication of the results.

In the early phase of the planning where the key issue is to select business model and technical concept, the main risk activities are to establish risk criteria and safety targets, as well as to demonstrate absence of showstoppers. This requires qualitative approaches.

At this stage of project development, quantitative risk analyses have limited value as no detailed information to describe the facilities are available as input.

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In the next phase, the risk assessment should provide quantitative risk information related to the land planning in support of the permitting process.

In later project phases where key issues are the design of mitigation measures, more detailed analyses are appropriate to provide a proper basis for project decisions.

In some jurisdictions, the planning process makes it difficult to modify proposals once they have been submitted to the planning authorities. This makes it difficult to modify the design to reduce risk as detailed engineering develops. This aspect should be considered in project planning.

The requirements, recommendations, and advice given in this document reflect this need. Risk assessment and risk results shall always reflect the following:

a) the type of decision that shall be made;

b) effective utilization of available information.

Actions arising from reviews such as HAZID, risk matrix, HAZOP, etc., which are not closed out after the review, should be recorded in a tracking system (for example, a risk register). This should answer that items requiring action at later project stages (i.e. items for operating manuals, etc.) should not be overlooked or forgotten.

This varying level of details in the risk assessment process is illustrated in Table 1 which also is relevant to a wide range of different types of industrial risk assessment.

Table 1 should be used instead of IEC 31010:2019, Table A.1 to identify risk assessment methods. Further description is given in Clause 7.

Table 1 — Typical requirements to risk-related information in different project phases

Project phase	Needed risk related information	Key decisions based on risk assessment	Method of risk assessment within this guideline
Pre-FEED (i.e. Concept selection and business case development)	— Identify stakeholders — Input to the permitting process (demonstrate absence of showstoppers) — Risk criteria — First estimate of the risk level (when required by regulators) — Basic design options — Go-ahead for the development	— Select site — Select concept — Identify and decide risk criteria — Select design criteria — Select design options — Approve continued development	— HAZID — Consequence analyses of major accident scenarios — Prepare risk criteria — Risk communication to legislation and stakeholders

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Table 1 *(continued)*

Project phase	Needed risk related information	Key decisions based on risk assessment	Method of risk assessment within this guideline
FEED Development of basic design	— Focus areas for the design process, i.e. results from HAZID and Consequence analysis — Estimate of the risk level of design options — Basis for selection of an optimized basic design	— Optimisation of the design in terms of safety by comparison of options — Select main technologies — Performance standards for safety system — Confirm concept selection — Authority permit — Decide to start detail design	— Qualitative analysis (risk matrix) — HAZOPs and determination of SIL requirements — QRA — Determine DALs — Detailed consequence assessment — Fire/explosion analysis — Risk communication to legislation and stakeholders
Detail design	— Performance standards for components and systems — Issues to be addressed in the design identified in HAZOP findings incl. SIL requirements — Specifications for buildings and equipment	— Selection of equipment, solutions and operational procedures — Detailed design	— Detailed QRA — Detailed HAZOPs — SIL assessment — Vendor HAZOPs — Evacuation analysis
Commissioning and start-up	— Final results from risk assessment — Confirmation of acceptance according to regulations	— Approve the design — Approve decision to start up	— Completion of risk studies and verification schemes — Commissioning of safety systems — Risk communication to legislation and stakeholders

6 Risk

6.1 What is risk

To be able to express the risk, the consequences shall be defined and the associated probability determined.

Risk is also often referred to as potential loss. The loss or consequence can be loss of life, damage to the environment, assets, or reputation. The probability term is usually expressed as a frequency. In QRAs, the potential loss in general is not calculated from the product of one event and one consequence, but the sum of a large number of frequency and consequence probability combinations.

Risk or potential loss, combination of the probability of an event, and the consequences of the event cannot be readily used as an indicator to decide the tolerability of the risk. It can be used to compare options when all things different between the two options have been evaluated in terms of probability and consequence and included in the assessment.

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To be able to use risk in workable concepts, a number of risk indicators have been developed to express risk. These risk indicators are discussed in 6.5.

6.2 Safety philosophy and risk criteria

LNG developments are often organized as project organizations (e.g. JV) with international participation. It is therefore important for LNG projects to formulate a safety philosophy and risk criteria based on recognized guidelines/standards in their risk management process (national statutory minimum requirements can apply). This aids the project team in gaining a common terminology, understanding of risk, risk philosophy, and ultimately a common risk management system.

The safety philosophy and risk criteria for the project can address the following categories:

— risk to the population and third-party activities. This has significant impact on the land use and is normally defined by national regulations;

— risk to personnel in the plant. This is normally defined by the company philosophy but can be subject to national regulation;

— risk with respect to material damage and loss of production. The criteria should be defined by the company and are often based on a cost benefit assessment;

— limitations on third-party activity due to hazards arising from the facility.

Examples of the risk criteria required by different authorities are discussed in Clause A.7 and examples of project-specific criteria in Clause A.8.

6.3 Risk control strategy

A widely accepted risk control strategy is the following:

a) adopt inherently safe design;

b) prevent – consider measures that will avoid the hazard;

c) reduce probability of occurrence trough design, inspection, maintenance, and working practices;

d) mitigate consequences – minimize the outcome of an unwanted event;

e) emergency response – enable returning to a controlled situation.

This can be formalized in the bow-tie methodology as described in 7.2.4. The bow-tie is a model that represents how a hazard can be released, escalate, and how it is controlled.

6.4 ALARP

A common approach is to divide risks into three bands:

a) an upper band where the level of risk is regarded as intolerable whatever benefits the activity can bring, and risk treatment is essential whatever its cost;

b) a middle band (or “grey” area) where costs and benefits are taken into account and opportunities balanced against potential consequences;

c) a lower band where the level of risk is regarded as negligible or so small that no risk treatment measures are needed.

The “as low as reasonably practicable” or “ALARP” criteria system follows this approach and is illustrated in Figure 2.

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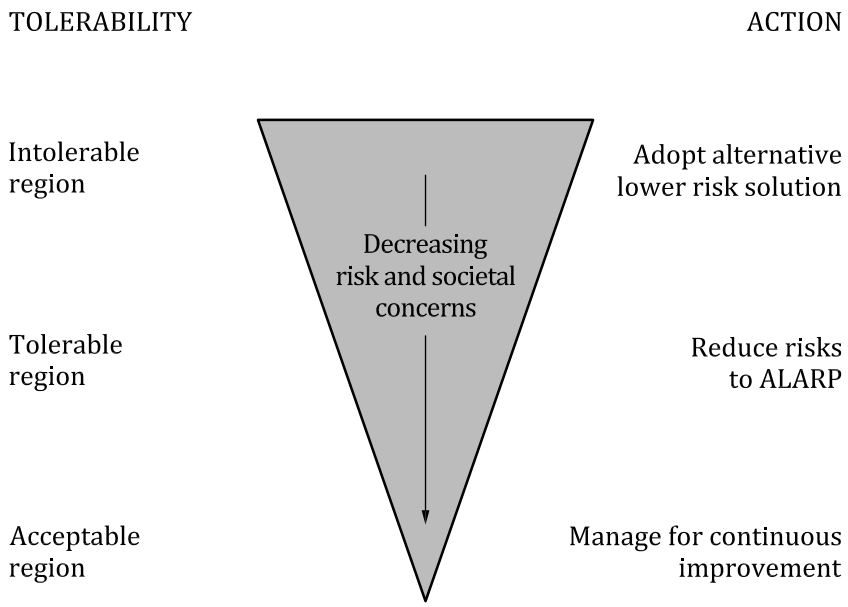

Figure 2 — Risk reduction triangle

ALARP is the process in which all identified options to reduce the risk have been evaluated. A major part of the ALARP process is the documentation of which options have been evaluated and why they have been included in the design or why they have been discarded. The documentation can be consulted when the circumstances change or when the design is challenged in the future. In general, full documentation is only required for high risks and complicated medium risk as it is not reasonable to insist on full documentation for low risk.

The assessment of risk is not an exact science and the techniques used and the experience of the analyst has been shown to produce widely varying result as discussed in studies on uncertainties in chemical risk assessment using a benchmark exercise in 1992 and a 2002 Risø study[3] about uncertainties in risk analysis of chemical establishments.

The results are evaluated against company or regulatory criteria and there is often a tendency to stop the improvement process when the criteria apparently are satisfied to minimize further capital and manpower expenditure.

The ALARP approach is a conceptual model and there are no boundaries between the three regions. The factors that ultimately decide how a risk is categorized (intolerable, tolerable, or acceptable) are dynamic in nature.

The addition/deletion or modification of mitigation features to just meet the acceptance criteria is strongly discouraged due to the accuracy of the process.

The ALARP process should be continued until the optimum design without incurring excessive cost is achieved. At the conceptual stage, it is often found that risk can be reduced at very low cost.

It is therefore important to start the risk assessment early in the project.

6.5 Ways to express risk to people

6.5.1 General

Risks should be expressed in understandable terms, and the units in which the level of risk is expressed should be clear (see IEC 31010) and reflect the safety criteria as defined by legislation and operator. An example of ways to express risk to people is given in A.8.

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