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Risk terminology—a platform for common understanding and better communication

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Abstract

The sciences analyzing and describing risks are relatively new and developing, and the associated terminologies are developing as well. This has led to ambiguity in the use of terms, both between different risk sciences and between the different parties involved in risk debates. Only recently, major vocabularies have been compiled by authoritative agencies. Some of these vocabularies are examined and explained based on a division into fundamental and action oriented risk terms. Fundamental terms are associated with description and characterization of the chemical, biological and physical processes leading from risk source(s) to possible consequences/effects. The approach to these terms is based on a cause–effect skeleton. The action oriented terms cover administrative, scientific, sociological, etc. processes associated with the work of identifying, characterizing, regulating and communicating risks in the society, and their internal connection and iterative character have been illustrated. Focus is laid on engineering and toxicological risks, but to some extent, the thoughts presented may be extrapolated to other areas. Differences in applied terminology probably cannot be eliminated, but they can be identified and clarified for better understanding. With the present paper, the authors hope to contribute to reducing the probability of derailing risk discussions from the risk issue itself.

Keywords: Risk terminology; Cause–effect; Risk management; Risk assessment; Risk analysis

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1. Introduction

Terminology is a source of ambiguity and at times even a source of controversy within many sciences. Terminology roots deeply in many scientists, and different views on the applied terms often derail a discussion from its core issue(s). The sciences analyzing and describing risks are relatively new and developing, and accordingly the terminology associated with identifying, estimating, regulating and communicating risk is no exception from this general rule. Ambiguity on risk terminology exists both between risk sciences and between different parties involved in the general risk debate. Only recently, major vocabularies have been compiled by authoritative agencies. Thus, several publications, institutions and regularly updated web-pages suggest terminology in different branches of risk sciences, a few of which are included in the reference list [1–18]. A closer study reveals minor and major deviations in the terms included and in the meaning of individual terms; not the least the definition of 'risk'. The aim of the present paper is not to introduce yet another suggestion for "the harmonized terminology". Rather, the authors have through their work with risk related issues found it relevant and needed to take a step back and try to understand and illustrate the underlying differences in perception of risk terms.

Consequently, the purpose of the paper is to discuss and to some extent explain different views and applications of terms used in risk associated sciences based on an understanding of the underlying physical (fundamental terms) and societal (action oriented terms) processes rather than taking a linguistic approach. The article can therefore be seen as complementary to a recent work prepared by WHO [2]. The present paper covers mainly terminology applied within engineering risk analysis and toxicological risk assessment for characterization and management of risks towards humans, the environment and physical installations caused by physical forces or chemical agents. However, the descriptions and thoughts presented may to some extent be extrapolated to other risk areas.

2. Method

Risk terms may basically be divided into two levels (as also done e.g. in the WHO work [2]):

- Fundamental terms.
- Action oriented terms.

The fundamental terms are used for description and characterization of chemical, physical and biological processes in the cause–effect relationship eventually leading from a risk source to the final characterization of risk(s). The cause–effect relationship shown in Fig. 1 and illustrated with a few examples is the 'theory-of-science' approach applied for dealing with these terms in this article. It is not the purpose of the present paper to introduce a new terminology. However, it turned out to be convenient to define a new set of terms for which different aspects of the cause–effect relationship are explained. Where relevant, these terms are compared with similar definitions in the core references included for comparison (references will be described later).

The action oriented terms cover the administrative, scientific, sociological, etc. processes/activities associated with the work of identifying, characterizing, regulating and

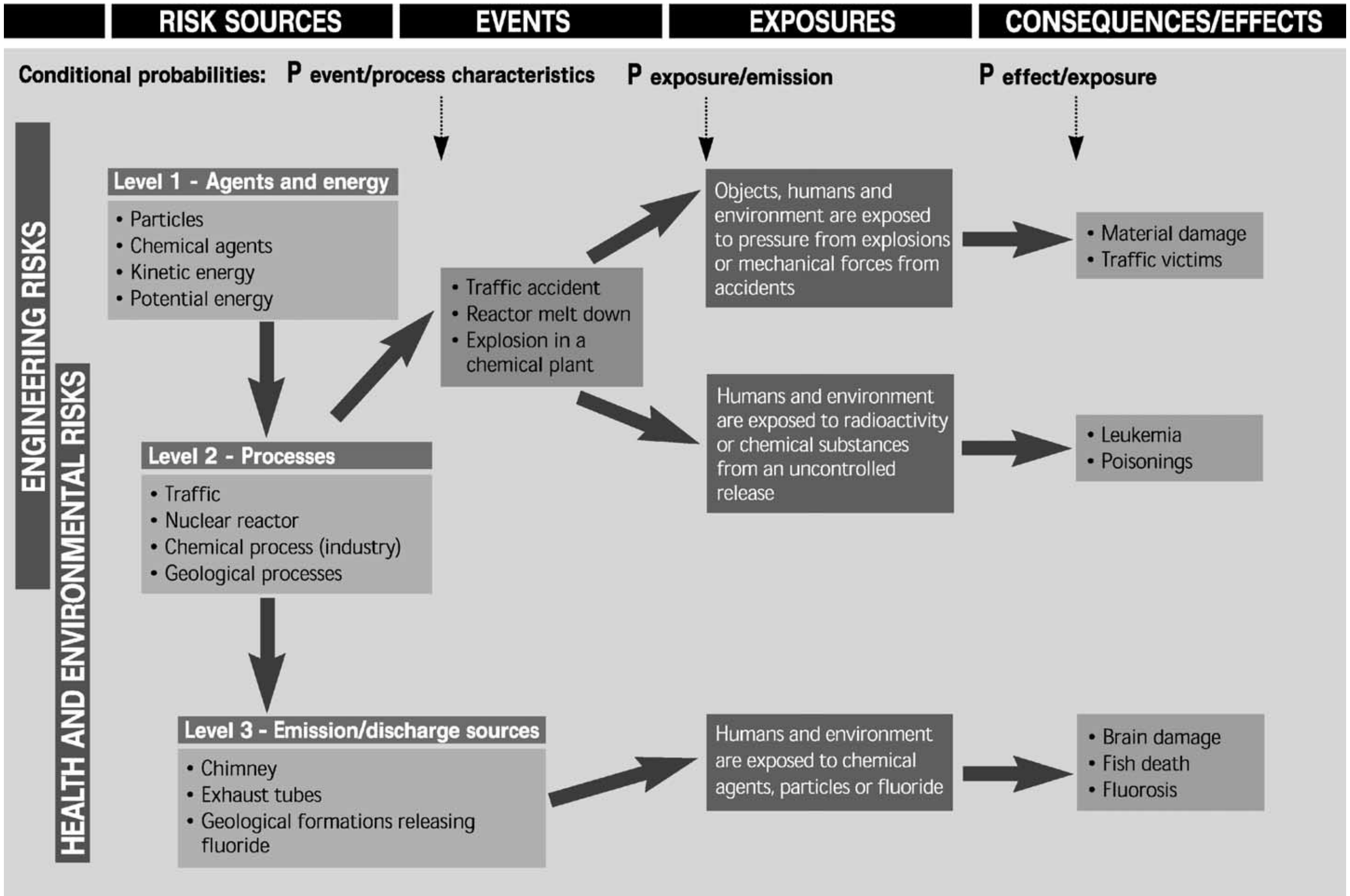

Fig. 1. Framework with examples on chemical, biological and physical cause–effect relationships leading from risk sources to possible consequences/effects. These relations are characterized when scientifically assessing/analyzing risks.

communicating risks in society. The core references use very different terms for the same processes/activities, but it seems that the central processes/activities are concordant. Therefore, focus is laid on a clarification of the practical interaction of these processes/activities by introducing a terminology for these activities that the authors find logical.

The following core references have been used for comparison and discussion in the approach taken in this article:

- EU, 2000 [1]. This report is a first attempt for harmonizing risk assessment methodologies, including terminology, in the European Union (EU). The reference is considered the most recent document from the EU Commission on risk terminology.
- UN/OECD, 1999 [2]. The project behind this article was prepared under the auspices of Interorganization Programme for the Sound Management of Chemicals (IOMC), which is an interdisciplinary program between several (mainly UN) organizations: UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD, which were all represented in the project steering committee. The article is the result of a digestion of terminology proposals from 200 international experts. The work was led by a terminologist and had a linguistic approach searching for consensus even though different applications and views on terminology are highly acknowledged. The article is considered the latest common terminology proposal from the involved UN-organizations even though it is still considered a draft as reflected in the title of the article.
- US-EPA, 1997 [3]. This report was prepared for the Congress by the Commission on risk assessment and risk management. The reference is considered the latest common publication from the American environmental authorities on the entire risk assessment/management process, including terminology.
- DS/INF 85, 1993 [4]. This document was prepared by a working group under the Danish Standards Organisation (DS). Although the reference is not very recent, it covers the terminology applied in engineering risk analysis in Denmark and abroad. The reference is in Danish but also includes the corresponding English terms. Where included in this article, explanations associated with the individual terms have been translated as consistent as possible.
- Seveso II-directive, 1996 [5]. This publication is included for historical reasons. Some people consider the directive and its precursor (Seveso I-directive) to be the first risk reduction initiatives within engineering risk analysis—as a result of the Seveso accident. Definitions from the directive have only been included under the definitions of 'hazard' and 'risk'.
- ISO, 2001 [6] (draft ISO guide 73) and ISO, 1999 [7] (ISO/IEC guide 51). These guidelines are intended for harmonization of the application of risk terms in ISO standards, guidelines and technical reports. Draft ISO guide 73 aims at a broader understanding of 'risk', e.g. the possible consequences of a risk may be positive as well as negative. By 'safety' assessments, where the possible outcomes are clearly negative, ISO/IEC guide 51 should be applied.

Any selection of core risk terminology references will be controversial. By selecting the above references it was intended to cover the state-of-the-art within human and environmental risk assessment as well as engineering risk analysis, and also to refer to national and international standardization organizations and authoritative opinion-formers within the risk area. The first three core references [1–3] are clearly related to the assessment of human and environmental risks from chemicals, the following two to engineering risk analysis [4,5], whereas the two ISO references [6,7] are more general.

3. Fundamental terms

3.1. Object

The exposed humans, environments and/or physical objects

Definitions in core references:
None.

3.2. Risk source

Activity, condition, energy or agent potentially causing unwanted consequences/effects

Definitions in core references:
EU, 2000 (*risk source*): agent, medium, commercial/industrial process, procedure or site with the potential to cause adverse effect(s)/event(s).
ISO, 2001 (*source*): item or activity having a potential for a consequence.

Comments/discussion:

There is good concordance between the definitions used in the core references and the definition used in this article, although the latter may also cover natural risk sources. It is important to distinguish between levels of risk sources (cf. Fig. 1). Level 1 is the chemical, physical or biological agent or energy, the inherent properties of which may potentially result in consequences/effects. Level 2 is the process (natural or man-made) in which the agent/energy is involved or generated and from which it may be released to the surroundings as the result of an event (defined below) or via a (controlled) emission. Level 3 is the actual (controlled) emission/release source of an agent, e.g. a chimney. Core differences between releases from an event and a (controlled) emission source are that the former is typically short-term and less controlled in time and space than the latter.

Examples:

Health and environment		
Level 1	Level 2	Level 3
Organic solvent	Cleaning process	Surface from which the solvent evaporates
Ultraviolet light	Physical–chemical processes on the sun	Radiation (emission of UV-light from the sun)
Radioactive material	Nuclear reactor	May be released by an event (see later)
Particles from diesel exhaust	Traffic (diesel engines)	Exhaust tubes on vehicles
Antifouling paints	Application of paints	Release of toxic paint components to the environment
Fluoride minerals	Natural processes	Release from geological formations

Engineering		
Level 1	Level 2	Level 3
Kinetic energy in flowing fluid	Fluid transport in tube systems	May be released by events (see later)
Potential energy in uranium	Processes in a nuclear reactor	May be released by events (see later)
Kinetic energy in traffic	Traffic	May be released by events (see later)
Potential energy in the earth	Volcanic processes	May be released by events (see later)

3.3. Event

Isolated incident or a number of interrelated circumstances/incidents resulting in release of agents and/or energy

Note:

An event may result in an accident. Events/accidents are typically related to engineering risks. An event is typically acute/short-term whereas the exposure and the consequences/effects may be acute or chronic (cf. Fig. 1).

Definitions in core references:

ISO, 2001 (*event*): occurrence of a particular set of circumstances.

ISO, 2001 (*harmful event*): occurrence in which a hazardous situation results in harm.

Comments/discussion:

The definition used in this article as well as ISO (2001) operates with the possibility of a number (or a set of) circumstances. ISO (1999) defines specifically an event as harmful, which is also the approach taken in this article. The extent and severity (defined later) of the consequences/effects of the event/accident will depend on where, when and under which other circumstances, the event/accident takes place. As can be seen in Fig. 1, health and environmental risk assessment and engineering risk analysis overlap in situations, where toxic material is released due to an accident.

Examples:

- A tube rupture is an event, where kinetic energy and potentially toxic substances are released.
- Melt-down of a nuclear reactor is an event where radioactive material as well as radiation and heat energy are released. This event is typically the result of an array of incidents.
- Traffic accidents convey the kinetic energy to objects and may therefore cause material damage, injuries or death.
- A volcanic eruption is an event releasing heat and physical material.

3.4. Hazard

The inherent property/properties of a risk source potentially causing consequences/ effects

Definitions in core references:

EU, 2000 (*hazard*): the potential of a risk source to cause an adverse effect(s)/event(s).
UN/OECD, 1999 (*hazard*): inherent property of an agent or situation capable of having adverse effects on something. Hence, the substance, agent, source of energy or situation having that property.
US-EPA, 1997 (*hazard*): a source of possible damage or injury.
DS/INF 85, 1993 (*hazard*): situations or conditions, which may cause damage.
Seveso II-directive, 1996 (*hazard*): hazard shall mean the intrinsic property of a dangerous substance or physical situation, with a potential for creating damage to human health and/or the environment.
ISO, 1999 (*hazard*): potential source of harm.

Comments/discussion:

All definitions deal with the possibility or potential of (adverse) consequences/effects. Note that hazard does not include the probability of an (adverse) outcome, which is a core difference from the risk term. Mixing the terms 'hazard' and 'risk' is a common source of misunderstanding and poor communication. US-EPA (1997) and ISO (1999) do not distinguish between risk source and hazard, whereas the remaining definitions define hazard as an (inherent) property of the risk source(s).

Examples:

- Hazard is associated with UV-light, as it may cause sun burn, skin cancer and cataract.
- Hazard is associated with nuclear reactors, as they may melt-down, release radioactivity and thereby cause damage and health effects.
- Hazard is associated with traffic, because accidents and exhaust may cause material damage, death and health effects.
- Hazard is associated with antifouling paints, because they contain substances potentially affecting aquatic organisms.
- Hazard is associated with a cleaning process, as organic solvents may evaporate and potentially affect the workers.
- Hazard is associated with a volcano as it may erupt and thereby cause damage.

3.5. Exposure

The extent to which an agent or energy reaches an object (or objects)

Definitions in core references:

EU, 2000 (*exposure*): refers to UN/OECD, 1999 (see later) and WHO/IPCS, 1989 [18]. The amount of an environmental agent that has reached the individual (external dose) or has been absorbed into the individual (internal dose, absorbed dose).

UN/OECD, 1999 (*exposure*): concentration, amount or intensity of a particular agent that reaches a target system. It is usually expressed in terms of substance concentration, duration, frequency and intensity.

Comments/discussion:

Exposure is only defined in two of the core references—both associated with health and environment. These definitions only focus on living organisms, whereas the definition used in this article also covers physical objects. As can be seen from EU (2000), it is important to specify whether the exposure is internal or external, when living organisms are exposed. When quantifying exposure, it is important to consider the intensity of the exposure (e.g. the concentration of a substance), the frequency of exposure and the duration per exposure event and to state to which extent an exposure is integrated over time.

Examples:

- Sun bathing results in exposure to UV-light.
- Staying in an area close to a nuclear reactor, which has melted down causes exposure to radioactivity and heat.
- Antifouling paint is designed to leach toxic compounds thereby causing exposure of aquatic organisms.
- Objects in the traffic are exposed to exhaust and potentially to mechanical forces.

3.6. Consequence/effect

Result of a realized hazard that may be caused by exposure to an agent or energy

Note:

Consequence and effect are considered synonyms, although consequence is usually applied within engineering risk analysis, whereas effect is usually applied in health and environmental risk assessments. In engineering risk analysis, both terms may be applied, for instance, consequence is the size of the radioactive cloud after a reactor melt-down, whereas the effect is the resulting 'consequences', e.g. on humans.

In toxicological sciences, 'response' is often applied in association with describing the potential outcome of an exposure. Although it is sometimes applied synonymously with 'effect', there is usually a distinction between the two. 'Effect' is mainly used to describe inherent characteristics of risk sources qualitatively, whereas 'response' is mainly used in association with expressing the (potential) number or fraction of objects affected after a given exposure. The outcome of a toxicological experiment is often shown as a 'dose–response curve'.

Definitions in core references:

EU, 2000 (*effect*): refers to WHO/IPCS, 1989 [18]. A biological change in an organism, organ or tissue.

EU, 2000 (*adverse effect*): refers to WHO, 1994 [15]. Change in morphology, physiology, growth, development or life span of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences.

UN/OECD, 1999 (*effect*): change in the state or dynamics of a system in relation to the action of an agent.

UN/OECD, 1999 (*adverse effect*): change in morphology, physiology, growth, development or life span of an organism, which results in impairment of functional capacity or impairment of capacity, an impairment of the capacity to compensate for additional stress, or an increase in susceptibility to the harmful effects of other environmental influences. Decisions on whether or not any effect is adverse require expert judgment.
DS/INF 85, 1993 (*consequence*): the result of an unwanted event, e.g. damage to health, life, material values and/or the environment.
ISO, 2001 (*consequence*): outcome of an event.
ISO, 1999 (*harm*): physical injury or damage to the health of people, or damage to property or the environment.

Comments/discussion:

In the core references, it is seen that for health and environmental risk assessment there is a distinction between 'effect' and 'adverse effect', and the latter is further defined. The definition used in this article and the other core references—with the exception of ISO (2001)—inherently consider a consequence/effect as adverse, because focus is laid on a possible negative outcome associated to risk sources. ISO (2001) explicitly states that it covers broader, e.g. the risk associated with stock exchange activities may result in a positive (appreciation) or a negative (depreciation) outcome.

Examples:

- Sun burn, skin cancer and cataract are possible adverse consequences/effects of exposure to UV-light.
- The consequence/effect of exposure to radioactive radiation could be leukaemia.
- One possible consequence/effect of exposure to traffic exhaust is the impairment of lung function.
- Possible consequences/effects of volcanic eruption are material damage, burns and death.

3.7. Cause–effect relationship

Established connection between a cause and the coupled consequence/effect

Note:

The cause–effect relationship is the bridge between the cause complex on one side and the consequence/effect complex on the other. Without an established cause–effect relationship, the analysis/assessment of a risk is pure speculation. The documentation of a cause–effect relationship may range from hypothetical to well documented and can be interpreted as an empirical connection (an association) as one extreme, and a theoretical connection (a causality) as the other extreme—in practice often a combination.

Definitions in core references:

None.

Comments/discussion:

Cause–effect is not defined in the core references but is included to illustrate that cause–effect is the skeleton of a scientifically-based approach to description and understanding of the term risk. Fig. 1 illustrates a number of cause–effect relationships leading from risk sources to possible consequences/effects.

Examples:

- There is a cause–effect relationship between exposure to UV-light and damage on human skin.
- There is an empirically understood cause–effect relationship between traffic exhaust and effects on the pulmonary function.
- Antifouling paints release toxic substance to the environment, which cause effects on aquatic organisms.
- There is a clear deterministic cause–effect relationship between the release of radioactive material from a nuclear reactor that has melted down and physical damage, death and human health effects.

3.8. Severity

Expression of the weight allocated to a consequence/effect based on type and degree

Definitions in core references:
None.

Comments/discussion:

The core references do not define severity, even if the term in some of the references is used for the definition of risk. The reason may be that severity is assumed to be self-explanatory. However, confusion may arise by mixing 'severity' with 'extent' (defined below). Further, severity may be a very subjective assessment, and therefore it is often for the risk manager and not for the scientific advisor conducting the risk analysis/assessment to decide. See further discussion under the definition of 'risk'. As will be evident from the examples, severity may logically be categorized in 'type' and 'degree':

1. Consequence/effect *type*—there is difference in severity *between* effects/consequences.
2. *Degree* of a consequence/effect—there is difference in severity *within* the individual effect/consequence.

Examples (*type*):

- Human death/mutilation will usually be weighted higher than material damage in a traffic accident.
- Intoxication is typically regarded as more severe than irritation.

Examples (*degree*):

- The degree of a burn is characterized as first, second or third.
- The degree of an irritation effect can e.g. be characterized on a scale of small, medium and severe.

3.9. Extent of a consequence/effect

Measure of the spread of the consequence/effect

Definitions in core references:
None.

Comments/discussion:

As for severity, extent is not defined in the core references even if used in some of the risk definitions. Extent may cover:

1. The *number of objects* on which a consequence/effect is manifested. The extent increases, if the number of exposed objects increases.
2. The *spread* of a consequence/effect on the *individual* object.

Examples (*number*):

- The number of damaged animals in a population living in the vicinity of a sewage outlet.
- The number of buildings damaged by an explosion.

Examples (*individual spread*):

- Skin area burned.
- The size of the hole in the ground caused by an explosion.

3.10. Frequency

An expression for the number of outcomes per time unit

Definitions in core references:

DS/INF 85, 1993 (*frequency*): frequency of an event, e.g. the average number of events per year.

DS/INF 85, 1993 (*error-frequency*): the expected number of errors per time unit provided the functionality of the unit at the beginning of the time interval.

Comments/discussion:

Frequency is only defined in one core reference—DS/INF 85 (1993). This is probably not a coincidence, as engineering risk analysis typically focus on estimation/characterization of the event/accident frequency of a given phenomenon.

Examples:

- The number of traffic accidents per day.
- The number of tube ruptures in a year.
- The number of sun bathing days in July.

3.11. Probability

Probability can be defined in two ways:

1. The probability is an expected frequency (see previous frequency definition).
2. The probability is the expected fraction of a specific outcome in a population.

Note:

In both definitions, probability is a measure of an expected outcome of a future observation. The unit of the first definition is ‘per time unit’, whereas the second is without unit (a fraction).

Definitions in core references:

ISO, 2001 (*probability*): extent to which an event is likely to occur.

Comments/discussion:

It can be seen that probability is interpreted as self-explanatory in most references. This is unfortunate, because confusion is frequently caused by lack of clarity as to which of the two definitions are used and confusion due to lack of indication of unit. Too often the unit—which may be ‘no unit’ or ‘time^{-1}’ (e.g. per day, per year or lifetime^{-1})—is incorrectly considered tacit information, especially in expert communities.

Examples (*first definition*):

- The probability of nuclear reactors having melt-down (in the course of 1 year).
- The probability of being involved in a traffic accident (per week).

Examples (*second definition*):

- The probability of obtaining ‘six’ when throwing a die.
- The probability that three out of a million develop allergy after a given exposure.
- The probability of acute death following ingestion of 10 mg arsenic.

3.12. Risk

There are two fundamentally different understandings of the term ‘risk’:

1. Risk expresses a combination of:
   - probability of consequence/effect on the considered object(s);
   - severity;
   - extent of the consequence/effect

   under given specified circumstances.
2. Risk expresses:
   - probability of a given consequence/effect of a given severity and extent under given specified circumstances.

Note:

As will be evident from the discussion below ‘under given circumstances’ is very important. Which system (including space and time) is in focus when expressing risk should be very carefully described. The second risk definition can be understood as a ‘specified risk’.

Definitions in core references:

EU, 2000 (*risk*): the probability and severity of an adverse effect/event occurring to man or the environment following exposure, under defined conditions, to a risk source(s).

UN/OECD, 1999 (*risk*): the probability of adverse effects caused under specified circumstances by an agent in an organism, a population or an ecological system.

US-EPA, 1997 (*risk*): the probability of a specific outcome, generally adverse, given a particular set of conditions.

DS/INF 85, 1993 (*risk*): expresses a combination of frequency of an unwanted event and the extent of the consequences.

DS/INF 85, 1993 (*individual risk*): the risk, which an individual is incurred to. The risk will among others depend on the distance from the risk source. Often calculated as the average individual risk for a person in the most incurred sub-population.

Seveso II-directive, 1996 (*risk*): risk shall mean the likelihood of a specific effect occurring within a specified period or in specified circumstances.
ISO, 2001 (*risk*): combination of the probability of an event and its consequence.
ISO, 1999 (*risk*): combination of the probability of occurrence of harm and the severity of that harm.

Comments/discussion:

Clearly, there are disagreements and different understandings associated to this core term. UN/OECD (1999), US-EPA (1997) and Seveso II-directive (1996) are close to the second definition suggested in this article, whereas the definitions in the other core references are more or less in concordance with the first definition, although they use either 'severity' or 'extent'.

In practice, the scientist conducting a health and environmental risk assessment often understands risk and probability as synonyms. The scientist estimates/characterizes the probability of a given extent and severity of a given effect to a given object(s) under given circumstances. The broader perspective where a weight (based on severity) is allocated to an effect, is often employed by the persons conducting the risk management, i.e. the risk manager, for instance when prioritizing between possible risk reduction efforts. In contrast, an engineer will intuitively associate an engineering risk with the combination of frequency as one component and severity and/or extent as the other component(s).

Severity and extent

The definition in EU (2000) and ISO (1999) can be understood in different ways. Either that 'severity' covers severity as well as extent or that the risk definitions are specified on extent, e.g. to estimate the probability that the pulmonary function will be reduced by 10% after a given dust exposure. For some types of effect, it is not relevant to talk about individual extent of the effect, e.g. acute death. The definition in DS/INF 85 (1993) may also cover both severity and extent or may be specified on the severity.

Frequency and probability

The definition in DS/INF 85 (1993) is focusing on the frequency of an (unwanted) event. This is due to the scientific approach of engineering risk analysis focusing on the expected frequency of events/accidents. The definition does not explicitly contain the probability of given consequences. It is implicitly assumed that there are always consequences related to events/accidents. The probability that specific consequences will occur after the event/accident is covered by the determination of the 'extent of the consequences'.

In a health and environmental risk assessment, the frequency of emission and exposure is implicitly covered by 'under given circumstances', whereas probability in the definitions cover the probability of effect given these circumstances (and thereby the exposure). See also Fig. 1, which illustrates some of the frequencies and probabilities in the cause–effect chain from risk source to possible consequence/effect. Note that the probabilities are conditional; the probability (or expected frequency) of an event given certain process characteristics, the probability of exposure given a certain emission and the probability of effect given a certain exposure. Altogether, it is highly recommended to explicitly state the conditional frequency or probability included in a given risk statement, specifying the given set of conditions.

Number of objects and scenarios

EU (2000) and US-EPA (1997) mention one effect in one object under given circumstances. UN/OECD (1999) mentions several effects but still on one object (understood as one organism, one population or one ecosystem). DS/INF 85 (1993) considers one event but all possible effects/consequences. One explanation of these differences is that engineering risk analysis regards the event as the starting point of the analysis, whereas the starting point of health and environmental risk assessments is often found in the critical effects (i.e. the effect occurring at the lowest exposure level) or the effect regarded as the most severe (e.g. carcinogenicity). In a risk characterization, it is therefore recommended to explicitly specify risk for whom?

Altogether, it can be concluded that it is beneficial to always specify the characterization of risks:

- Which scenario(s) are considered?
- Which and how many objects?
- Which frequencies and probabilities are considered?
- Etc.

Examples (first definition):

The risk of UV-light is a combination of:

1. The extent of sunburn, skin cancer and cataract
2. The severity allocated to these effects
3. The probability that these effects will occur

under given specified circumstances, including frequency, duration and intensity of exposure on given objects.

The risk of traffic is a combination of:

1. The extent of health effects, death/mutilation and material damage
2. The severity allocated to these consequences/effects
3. The probability that these effects will occur

under given specified circumstances, including specification of traffic situation, frequency of accidents and frequency, duration and intensity of exposure (how often and under which behavioral patterns does a person stay in the traffic).

Examples (second definition):

- The risk/probability of leukemia under given circumstances, including frequency, duration and intensity of radiation exposure
- The probability of an irreversible brain damage after 20 years operating of a cleaning process with organic solvent
- The probability that the fertility of an aquatic organism is severely affected after given exposures to substances in antifouling paints

3.13. Uncertainty

Imperfect knowledge about the individual aspects of a system as well as the overall inaccuracy of the output determined by the system

Definitions in core references:

UN/OECD, *1999* (*uncertainty*): imperfect knowledge concerning the present or future state of a system under consideration.

Comments/discussion:

The term is considered self-explanatory in most references. To distinguish uncertainty from probability (defined earlier) and to elaborate 'uncertainty', uncertainty is included in the definitions suggested in this article. The concept of 'uncertainty' and not the least the associated terminology is just as controversial as the concept and terminology of 'risk'.

Uncertainty can be divided into:

1. Model/structure uncertainty.
2. Data/parameter uncertainty.
3. Variability.
4. Outcome uncertainty.

Ad 1: Reflects the limited ability of a model to accurately represent the real world. Limited knowledge results in erroneous mathematical formulations or even omissions of important processes. Omissions can be deliberate or be the consequence of ignorance. Acquiring more knowledge by education or research can reduce ignorance except, e.g. chaotic systems, such as weather phenomena, where long-term prediction by definition is impossible. The latter can be termed indeterminacy.

Examples:

- There is model uncertainty associated with a model applied to estimate the frequency of tube failure.
- There is model uncertainty associated with a model applied to predict degradation and spread of chemical substances in the environment (i.e. the environmental fate).

Ad 2: Data/parameter uncertainty is both attributable to sampling errors and measuring errors (accuracy and precision) and to statistical uncertainties arising in erroneous estimation of model parameters.

Examples:

- Estimation of exposure to sunshine.
- Estimation of vaporous organic solvent concentration in the breathing zone of a worker (both subject to sampling and measurement error).

Ad 3: Variability is an inherent variation associated with an input to the model. An important variability feature is that it is true and cannot be reduced. However, increased sampling and measurement accuracy and precision may decrease the (parameter) uncertainty associated with description of the variability.

Examples:

- Diurnal, seasonal and random variation of sunshine.
- Variability among experimental animals in susceptibility towards chemical substances.
- Variability in age, weight and sex distribution in a population.

Ad 4: Outcome uncertainty is associated with the resulting prediction achieved by a model. The three first categories in combination express themselves as a resulting uncertainty associated with the result of the calculation.

Examples:

- Uncertainty of prediction of resulting skin cancer from exposure to sunshine under specified conditions.
- Uncertainty of prediction of cancer in a population due to exposure to a chemical.
- Uncertainty of estimation of fish kill due to an accidental oil spill.

4. Action oriented terms

Recall that the action oriented terms are associated with the administrative, political, scientific, sociological, etc. processes around risk management. For these terms, there is even more ambiguity about the terminology than for the fundamental terms. However, as can be seen from Tables 1–5 there seem to be consensus about which processes/activities are of importance; they are just termed differently.

There are four basically different types of processes/activities. Focus will be laid on terminology for these and further subdivision is left out. The four kinds of activities will be briefly described along with a terminology logical to the authors, including a fifth superior/unifying term covering the four activities (cf. Table 6). It is also tried to illustrate the interrelation and iterative character of the processes/activities in practice (cf. Fig. 2).

Table 1
Hierarchical presentation of action oriented terms in UN/OECD (1999)

Risk analysis		
	Risk assessment	
		Hazard identification
		Dose-response assessment
		Exposure assessment
		Risk characterization
	Risk management	
		Risk evaluation
		'emission and exposure control' [a]
		Risk monitoring
	Risk communication	

[a] Not explicitly defined but described in the text

Table 2
Hierarchical presentation of action oriented terms in US-EPA (1997)

No overall term		
	Risk assessment	
		Hazard identification
		Dose-response assessment
		Exposure assessment
		Risk characterization
	Risk management	
		'analyse and select actions to reduce risk' [a]
		'implementation' [a]
		'evaluate actions taken' [a]
	No term covering risk communication	

[a] Not explicitly defined but described in the text

Table 3
Hierarchical presentation of action oriented terms in EU (2000)

Risk analysis		
	Risk assessment	
		Hazard identification
		Hazard characterization (incl. dose-response assessment)
		Exposure assessment
		Risk characterization
	Risk management	
		'weighting and select alternatives' [a]
		'implementation' [a]
		'monitoring' [a]
	Risk communication	

[a] Not explicitly defined but described in the text

Table 4
Hierarchical presentation of action oriented terms in DS/INF 85

No overall term		
	Risk analysis	
		Hazard analysis
		'determination of risks' [a]
	Risk assessment/ risk evaluation	
	Risk management	
		'administrative routines' [a]
		'control of risks' [a]
	No term covering risk communication	

[a] Not explicitly defined but described in the text

Table 5
Hierarchical presentation of action oriented terms in ISO (2001)

Risk management			
	Risk assessment		
		Risk analysis	
			Source identification
			Risk estimation
		Risk evaluation	
	Risk treatment		
		Risk avoidance	
		Risk optimization	
		Risk reduction	
		Risk transfer	
		Risk retention	
	Risk acceptance		
	Risk communication		

Table 6
Hierarchical presentation of the main action oriented terms, as suggested by the authors

Risk management	
	Risk assessment/analysis
	Risk evaluation
	Risk regulation/control
	Risk communication

4.1. Risk management

Risk management is suggested to be the superior term, as societal risk activities/processes occur or are initiated with the aim of managing an existing or a potential risk. EU (2000) and UN/OECD (1999) suggest risk analysis as the superior term. Risk analysis is found misleading as an analysis is: "study of sth.[1] by examining its parts and their relationship..." [19]. The authors find risk analysis much more appropriate for the activities related to the scientific investigations, where it is also applied.

4.2. Risk assessment/risk analysis

The scientific estimation/characterization of risk is the output of this activity. Risk analysis is generally applied when studying engineering risks, whereas both 'analysis' and 'assessment' are encountered for health and environmental risks with a tendency of preferring 'assessment' (cf. also Tables 1–3). In this article, the authors find no need to communicate, whether one of these terms should be preferred to the other or to differentiate between these terms. Risk analysis and risk assessment will therefore be considered synonymous in the following. Note, that ISO (2001) suggests 'risk assessment' as a superior term for the two processes 'risk analysis' (understood as the scientific risk characterization) and 'risk evaluation'.

4.3. Risk evaluation

As can be seen from Fig. 2, risk evaluation can be conducted several times during the management of an existing or potential risk and is basically an evaluation of all available information, when a decision on the further strategy in the risk management process is necessary. Four different types of decisions can be made:

1. There is a need for a (better) scientific characterization of the risk and a risk assessment/analysis should therefore be conducted. Although it seems evident, historical experience has shown that it is advisable to clearly specify what this assessment/analysis should characterize.

[1] Abbreviation for 'something' as applied by the referred dictionary.

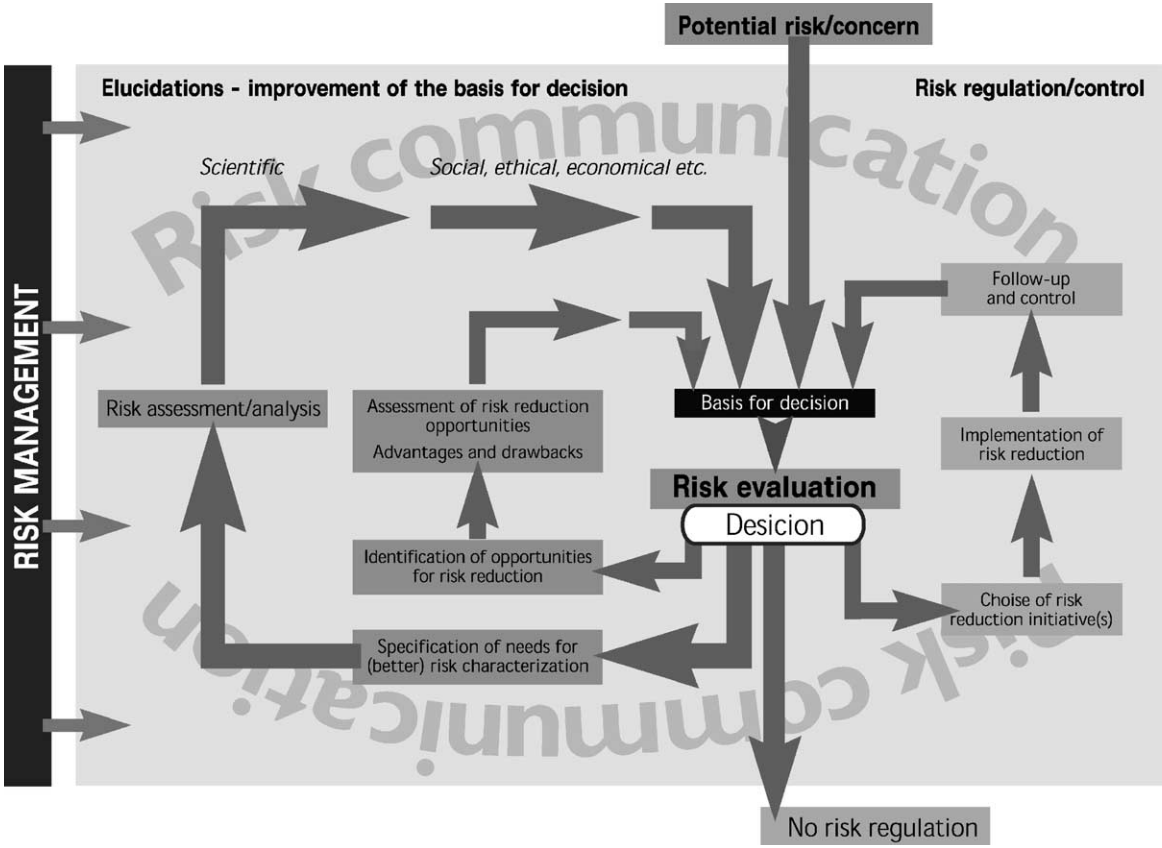

Fig. 2. Dynamic relations between the action oriented risk terms and the associated activities. See text for details.

2. There is a need for identification and/or assessment of advantages and drawbacks (or costs and benefits) of proposed risk reduction possibilities as compared to the reference situation without risk reduction. Such an assessment may range from a pure quantitative monetary assessment to a broader perspective, where ethical and other social aspects are included in a more or less quantitative fashion.
3. No risk reduction should be conducted. This may be the decision, if the scientific analyses/assessments show that there is no or only negligible risks or if it is overall assessed that there are more drawbacks than advantages associated with risk reduction.
4. Risk reduction is necessary and the initiatives to be taken and how to implement them are decided.

The basis for decision may vary dependent on point in time of the overall risk management process and on size, character and resources available for investigating the particular risk in question. For instance, when a 'new' potential risk has been discovered, relatively limited knowledge is usually available. In some of these situations, it may be necessary to simultaneously make several of the above types of decisions. If, for instance, the possible consequences of a 'new' potential risk seem acutely threatening, it may be decided to simultaneously implement risk reduction initiatives and to conduct a risk assessment/analysis. Based on the results of the risk assessment/analysis, a new risk evaluation may lead to adjustment of the risk reduction initiatives.

4.4. *Risk regulation/control*

Risk regulation/control covers the activities associated with risk reduction. When the risk reduction initiatives have been chosen, they should be implemented and a follow-up should secure that the initiatives are actually functioning and that feedback to the 'basis for decision' for a possible adjustment of the regulation/control is carried through (cf. Fig. 2). It is again chosen to present two terms with risk regulation being merely associated with activities at the societal level and risk control being associated with the activities in a (production) facility.

4.5. *Risk communication*

This term illustrates the communication of risk information, risk accept, risk behavior and risk perception within and between all relevant parties, such as: decision-takers, risk advisors, consumers, media, NGOs and the general public. 'Communication' should be understood in the meaning of 'dialogue' and should be an integral part of the risk management process (cf. Fig. 2). Risk communication with stakeholders should start as early as possible, because it is essential to ensure the right framing of the issue. Stakeholder opinions should be accounted for when making risk evaluations and subsequent decisions, because the final decision based on evaluation is essentially political and not scientific.

5. Conclusion

This article introduces a platform for understanding the basis for the terms applied when describing, characterizing, analyzing/assessing, evaluating, managing and communicating hazards and risks. The approach to the fundamental terms associated with description and characterization of chemical, biological and physical processes leading from a risk source to a possible consequence/effect has been based on cause–effect relationships (cf. Fig. 1). The approach to the action oriented terms (cf. Table 6 and Fig. 2) has been to overall consider these activities/processes as part of the societal risk management process, which is initiated with the aim of managing risks in the best possible way in society. The iterative character and interconnectivity of the risk management have been described and illustrated (cf. Fig. 2). It has not been the intention to introduce a new terminology to be followed by everyone but to present a common platform for understanding different views and applications of risk terminology. The authors hope that this article will contribute in improving the understanding and facilitate qualification of risk debates, which at present often end up in discussing terminology rather than the risks themselves.

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